SPIRE/QMW/M/0036.10

Minutes of 2nd SPIRE Bolometer Array Group Meeting Saclay, 28, 29 May 1998

Matt Griffin
June 4 1998

Note: These minutes should be read in conjunction with the viewgraph package from the meeting, which contains much additional information.

1 Review of SPIRE status and aims of meeting

Matt Griffin presented some introductory viewgraphs summarising

(a) The aims of the meeting:

(i) to review progress on array development since October meeting;

(ii) to establish the detailed instrument design for each option;

(iii) to identify aspects of the design which DON'T depend on the array technology finally selected;

(iv) to plan the testing and evaluation programme consistent with the schedule;

(v) to identify the special requirements of each option (thermal, mechanical, electronics, EMI, array control, etc.);

(vi) to review on-board data processing and data compression requirements for filled array options.

(b) The FSEC recommendations concerning SPIRE
(c) The conclusions of the October 1997 Detector Array Group meeting at QMW
(d) The array selection criteria agreed at the QMW meeting

2 The SPIRE schedule

Ken King presented an outline of what is foreseen as the most likely schedule for FIRST instrument development and delivery to ESA, which is expected to include a launch date of mid-2006. It incorporates some assumptions about what ESA will announce, and so should be seen as tentative. Although the EQM delivery is very late in this schedule (mid.2003), it will still be necessary for us manufacture and test it before FM manufacture. For the purposes of array technology selection, the latest date at which the decision on array technology can be made is determined by the need to have the SPIRE CDR at the end of Q1 2000 so that we can start building the EQM immediately afterwards. Even with detector array selection at the start of 2000, the schedule will be very tight. The instrument PDR is in mid-1999, before the formal array selection date, underlining the need to have a clear picture of the implications for system design of the various array options.

In discussion it was agreed that:

(i) With a launch date of mid-2006, the latest possible date for array selection is January 2000.

(ii) Some negotiation and clarification with ESA is needed on the functions of the EQM and the EM. It is not clear whether the EM is actually necessary at all if it is to be delivered at around the same time as the EQM.

3 Review of progress on array development since October meeting

Presentations were made by Louis Rodriguez (CEA), Harvey Moseley and Kent Irwin (Goddard/NIST) and Jamie Bock (JPL/Caltech). Some of the main points are summarised below - see the viewgraphs for full details.

3.1 CEA arrays

- Chemical effects have caused corrosion of the lead-out parts of the absorber grid metalisation.
- Reflectivity measurements on prototype absorbers have been done, and the results are consistent with model predictions.
- The temperature dependence of the thermal conductivity of the Si legs has been measured and found to be more or less s expected.
- Implanted sensors in the recent batch of prototypes have higher than desired resistance (~ 10^{12} Ω instead of ~ 10^{10} Ω). It is planned to implement a mesa thermometer configuration to correct this.
- The thermal conductivity of the indium bumps has been measured and found to vary as T^3 rather than T as expected. This implies a much greater heat load on the ^{3}He fridge (20-25 μW) than planned. An alternative thermal interface using Al bridge connections will be implemented for future arrays, but this will not be done for the evaluation arrays, which will be ready by the end of 1998.
- To reduce the capacitance I order to meet the SPIRE speed of response requirement, the $\lambda/4$ reflector will be designed as a metal grid.
- The envisaged 20-Hz speed of response of the CEA detectors is somewhat slower than the current specification for the FTS – this may require that the mirror scan speed be reduced.

3.2 Goddard/NIST

- Harvey Moseley said that it is expected that the US proposal to NASA for participation in SPIRE will be accepted (this covers all of the US groups involved in detector development).
- Progress has been made in combining PUD and TES technologies
- SQUID multiplexing at 1 MHz with 8 channels has been demonstrated and the design for a high-speed feedback system has been produced
- A second-generation MUX system (multiplexer plus control electronics) is being designed for SPIRE with a 3.2 MHz pixel rate
- For SPIRE, the PUD + SQUID option will involve having the SQUID multiplexer on the 2-K stage.

3.3 JPL/Caltech

- Electromagnetic modelling of the feed-horn/detector cavity coupling of the BOLOCAM style pixel indicates that high absorption efficiency (~ 90%) and low crosstalk (~4% total leakage per pixel) can be achieved, and that the performance is not highly sensitive to the manufacturing tolerances, absorber dimensions or absorber surface impedance. Bandwidth has not yet been modelled, but is expected to be around 25%.

- Currently achieved NTD Ge bolometer performance (BOOMERANG) implies that the SPIRE requirement (in terms of the NEP$\tau^{0.5}$ product) can be met, and that the overall NEP will be very much dominated by photon noise.

- A dry etch and release technique is being developed to increase the pixel yield for BOLOCAM.

- Tests on a spider web bolometers using a titanium-film TES sensor have been done. Excess 1/f noise was measured, corresponding to an electrical NEP of around 8 x 10^{-17} W Hz$^{-1/2}$. It is expected that the noise performance will be better with Al/Ag bi-layers.

4 Review of comparison of filled arrays and feed-horn arrays

Matt Griffin summarised the conclusions of the analysis of the relative performance (in principle) of filled arrays (0.5Fλ) pixels and feed-horn arrays (2.0Fλ pixels), as presented in the note TBD. Although this analysis was based on an unsophisticated model, it showed that the advantages of filled arrays over 2.0Fλ pixels corresponded to a factor of 2 - 2.5 in mapping speed for a realistic detector NEP of 3 x 10^{-17} W Hz$^{-1/2}$. In discussion, the following points were agreed.

(i) The superiority of the feed-horn arrays over the filled array for a point source on-axis (a factor of 2 in speed) was questioned – on general grounds, one would predict that, in principle, the speed should be the same. The difference is partly due to the fact that the simple analysis merely combined the signals and noise contributions from the pixels to be co-added with no weighting. Jamie Bock said that he had done a refined calculation with appropriate pixel weighting and that the difference was smaller.

(ii) Further analysis was necessary to evaluate the performance of the various options for deep mapping of confusion-limited fields. Walter Gear will co-ordinate this activity (which will also involve Laurent Vigroux, Jamie Bock, Matt Griffin, Bill Duncan and others as appropriate) and produce a report for the next Array Group meeting in September.

5 Implications for instrument design (Bruce Swinyard)

Bruce Swinyard outlined the aspects of the instrument design which must be studied to determine how they are affected by the array technology choice. After discussion the following conclusions were drawn.

5.1 Optical design

A single design is probably possible. Stray light rejection levels would have to be consistent with bare arrays, so baffling would need to be included to accommodate the needs of bare arrays, being changeable or removable if necessary if a horn option is chosen. The position of the focus will be different for the different options and the implications of this must be studied. It is essential to have a detailed model for the beam clipping and stray light within the instrument.

5.2 Interfaces to the 2-K and 0.3-K stages

It is highly desirable to have common interfaces for the various options if possible, to avoid having to have several designs being developed in parallel. Some details may need to be different and can be left open. The essential requirements are:

- All options will have the main mechanical interface to the 2-K structure and will receive 0.3-K cooling via a thermal strap of common design.
- All cabling to the rest of SPIRE will be at 2 K
- The volume envelope will be fixed and agreed
- Limits will be set for the mass, and the total power (dissipation, conduction and radiation) at the 2-K and 0.3-K levels
- The positions of the connectors and the constraints on cable runs will be defined
- Alignment and fixation methods will be specified
- The interface to the filters at the 2-K and 0.3-K levels will be common

5.3 Signal processing and electronics

- The array readout and multiplexing schemes, clock speeds, and signal conditioning requirements are very different for the SQUID and CEA options. It will not be possible to have a common array controller

- A common specification of the control signals relating to array readout and chopper or FTS position will be defined.

- A common command set is feasible.

- Implementing the array electronics with an ASIC may be impossible – the development timescale (~ 1 year) is too long. An FPGA implementation will therefore be essential.

- A uniform policy on grounding (star point at cold end or at warm end) would be desirable. It was not clear which option was to be preferred. It may be better to assume for now that the FPU is to be isolated from the cryostat structure – they can easily be shorted together if required.

- The EMC sensitivity and RF filtering requirements of the different options may be very different. This will need to be studied by building up an EMC model in collaboration with ESA.

5.4 Summary of impact on design of other subsystems

FTS	Unaffected except for mirror speed (slower for CEA option) and baffling
Structure	Largely unaffected. But focal plane mass will have some impact.
^{3}He system	Different cooling power requirements – can it be designed for the maximum case. Temperature stability requirements need to be specified
Chopper	Two-axis motion is required for feed-horn arrays. This should be incorporated in case it is needed.
SPU	Hardware unaffected; software different
DPU	Unaffected
JFET box	Major difference between back-up option and SQUID or CEA options
Cryoharness	Big differences in number and types of wires. Two detailed cryoharness definitions will need to be produced. There may be strong pressure from ESA to define a single option so that their industrial contractors can study it.

6 Detailed description of the SPIRE instrument design for the different array options

6.1 CEA

Louis Rodriguez said that there were no updates over the description presented in the SPIRE proposal.

6.2 SPUDs and SQUID arrays

Harvey Moseley presented a block diagram showing the envisaged configuration of the SQUID readout electronics. Kent Irwin also provided a draft document (attached for information only) summarising some aspects of the system design for the SQUID/TES sensor options.

- Only column multiplexing is proposed for the TES/SPUD arrays, so a fairly large number of connections to the focal plane will be required. As a baseline, around 100 address lines, 100 bias, 100 flux feedback (~ 400 wires in all) will be needed for the five arrays. It may also be appropriate to common some of the bias lines also (e.g., 32 biases for the 32 x 32 array).

- The current levels in the wires depend on the crosstalk spec. – the more stringent the crosstalk spec. the higher the current. Levels of a few mA per line are envisaged (this could perhaps be reduced if the voltage regulation could be improved).

- A specification on the required properties and parameters of the cryoharness is needed for the SQUID-based options. For the SPIRE cryoharness, it is unlikely that the actual resistances of the warm-cold wires will be known to a high accuracy (within, say, 30%) until quite late (after manufacture of the QM harness by the spacecraft contractor).

- The high readout rate proposed will allow the use of 12-bit ADCs in the warm array readout electronics.

6.3 JPL/Caltech (BOLOCAM-type) arrays

Jamie Bock summarised the configuration for the BOLOCAM-type arrays.

- For the photometer, 1.0Fλ feeds are the base-line. For the FTS, it may be that 2.0Fλ are optimum (this depends on whether the main application of the FTS will be in observing known point sources or in mapping).

- The SQUID-based readout electronics would be essentially identical to the 0.5Fλ SPUD array option (but with fewer detectors).

- The BOLOCAM array size would need to be reduced by a factor of around six. The mechanical tolerances would be tight. (~ 25 μm).

- The location of the SQUIDs (on the 0.3-K stage or at 2 K) is still open.

- Mechanical mounting of back-up option and the 1.0Fλ option would be very similar

6.4 Back-up option

Colin Cunningham presented the essential features of the back-up option: SCUBA-type feed-horn fed bolometer arrays using spider web bolometers with NTD Ge thermistors. Important issues to be resolved were:

- Feed-horn design and manufacture (e.g., conical horns or diagonal horns)
- Design and accommodation of the JFET box
- Design of cables and connectors
- Definition of the cryoharness and warm readout electronics
- Definition of the observing modes

7 On-board data processing requirements and algorithms

This item was deleted from the agenda. A note by Peter Hamilton on the requirements for on-board processing of the FTS data was considered at the FTS technical meeting on May 29th.

8 On-board calibration sources for SPIRE

Harvey Moseley presented a brief summary of the characteristics of IR calibration sources being developed at Goddard for the WIRE and SIRTF projects. Three source types could be considered:

(i) Micromachined polysilicon filaments ($T \sim 800$ K; $\tau \sim 10$ ms; $P \sim 1.5$ mW). Prototype devices of this kind have been delivered to QMW for testing at submillimetre wavelengths)

(ii) Reverse bolometers ($T \sim 10$ K; $\tau \sim 1$ ms; $P \sim 1$ µW). operating at around 10 K

(iii) Reverse hot-electron bolometers (T up to 50 K; $\tau \sim$ µs; $P \sim 1$ µW).

9 Review of conclusions from day 1

See summary of conclusions of meeting under item 13 below.

10 QMW array test facility - BACUS

Bruno Maffei presented a summary of the design and capabilities of the QMW array evaluation facility which will be built at QMW, and the schedule for its construction and commissioning. For full details, see the viewgraphs.

10.1 Facility design

In discussion, the following points were agreed:

(i) The essential capabilities of the facility are adequate to characterise the arrays, but the ability to measure linearity and dynamic range should be included.

(ii) The schedule as presented was agreed as essential in order to complete the array evaluation programme in time.

(iii) It will not be possible to measure VIs for the CEA detectors, and the VIs for TES sensors are very different to those for semiconductor bolometers.

(iv) The pixel sizes of the CEA and Goddard arrays were close to (but not exactly matched to) the design parameters of 350 μm wavelength, F/5 optics, and 0.5F pixel size. However, the differences were not regarded as a problem.

(v) To test fully equipped CEA arrays, 64 pins per array rather than 41 will be needed. To accommodate this requirement, a different connector type may be needed, which may not be available in the first instance. However, the 41-pin connectors will be adequate for single-pixel and limited-area tests which are expected to be more important in the early stages.

(vi) A redesign of the system to create more space behind the array mount for readout electronics boards will probably be needed.

(vii) The mechanical interface for the Goddard arrays will be at 2 K, with a thermal strap to the 0.3 K level.

(viii) The Goddard evaluation array would probably be 3 x N or 4 x N in size.

(ix) If possible, the facility should be able to test arrays over their full active area, although this may not be necessary in the first instance.

(x) For the BOLOCAM-type arrays, it may be possible to use the same JFET module as is used for BOLOCAM itself.

(xi) The capability to illuminate the arrays with X-rays should be retained as it is potentially very useful for electrical crosstalk measurement.

(xii) Incorporating a reverse HEB source would allow the optical speed of response measurements to be made using the internal source.

10.2 Test campaigns

There was a discussion on the question of where the array evaluation tests should be carried out – centralised at QMW or distributed: in the laboratories of the array groups.

(i) In the case of the CEA arrays, it was in any case anticipated that the main tests would be done at QMW.

(ii) For the JPL/Caltech and Goddard options, the logistical problems associated with installation and operation of the arrays and associated cold and warm electronics and data acquisition systems could make testing at QMW problematical In particular, operation of the SQUID multiplexer at QMW would be very difficult.

(iii) Matt Griffin summarised a number of reasons why, from the SPIRE project point of view, centralised testing at QMW was to be preferred:

- QMW is the best equipped and most suitable laboratory for photometric systems testing
- QMW will be responsible for delivering the fully-tested EQM arrays only two years after the evaluation phase ends. It is therefore essential that the group becomes fully familiar and expert in the relevant technologies.
- Given the short time between evaluation and production of flight hardware, portability will be regarded as an indicator of technical maturity.
- Having the critical tests performed at QMW (a "neutral" location) would be in the interests of a visibly fair selection process.
- QMW were willing (and regarded it as essential) to provide manpower effort in the form of visits by PDRAs or students to other participating laboratories to become familiar with the technology (especially read-out electronics and data acquisition) and to assist with in-house tests prior to tests at QMW.

Various alternatives or modifications to the test plan were discussed, including replication of the test facility at other locations. The following points were agreed:

(i) Only one BACUS-type facility would be built, to be located at QMW. If it were absolutely necessary to carry out testing at another laboratory, then BACUS would need to be transported to that laboratory (but this would not be desirable).

(ii) Standardised portable modules capable of providing uniform, calibrated illumination to an array in the array group's laboratory would be provided by QMW for basic array evaluation prior to final evaluation in the QMW system.

(iii) For TES/SQUID detectors, tests at the single pixel level (no multiplexer required) could be done at QMW in the interim. This would enable the basic TES device performance to be tested, the facility operation to be verified and de-bugged, and for the QMW staff to gain experience with the detector and readout technology.

(iv) The success of the evaluation programme would require close collaboration between QMW and the array-providing laboratories, including regular visits and exchanges of personnel.

Note: Following the Saclay meeting, further discussions between Harvey Moseley and the QMW team on June 1 on the issue of testing resulted in a modified agreement – see the appendix below.

11 Development, test, and evaluation schedule

11.1 CEA

Louis Rodriguez presented the CEA array development plan.

- Some parameters of the evaluation arrays have already been defined and some are still to be decided.
- The first 16 x 16 arrays should be ready for QMW facility tests early in 1999.
- A thermal/mechanical mock-up could be provided earlier to check the interfaces in the BACUS system.

11.2 JPL/Caltech

Jamie Bock presented the JPL/Caltech schedule, which is based on the BOLOCAM project plan.

- Tests will be done on individual TES bolometers in mid-1998.
- Both a multiplexed TES array and an NTD SPIRE array will be tested during 1999.

11.3 SPUDs/TES

Harvey Moseley outlined the development schedule.

- Electrical tests of TES detectors with SQUID amplifiers and multiplexers will be done in Autumn 1998.
- Electrical characterisation of TES thermistors is in progress. Optical measurements will be done in Autumn 1999.
- Testing of a representative prototype focal plane assembly will commence in summer 1999.

12 List of actions

1.	Provide template document describing common 2-K interface and circulate to the array groups for completion. [*June 30*]	Swinyard
2.	Provide detailed description of cryoharness for SQUID/TES options (level of detail required as in the IID-B). [*June 30 – needed in time for SPIRE Systems Group meeting in early July*]	Moseley, Bock
3.	Co-ordinate further study of capabilities of filled and feed-horn arrays, especially for point source extraction. [*Report to be presented at next meeting*]	Gear
4.	Define power and mass budgets for warm electronics and produce base-line functional description. [*June 30 – needed in time for SPIRE Systems Group meeting in early July*]	Rodriguez, Moseley, Bock
5.	Define all the mechanical, electrical and thermal interfaces for BACUS. [*July TBD*]	Maffei, Hargrave, array providers
6.	Define detailed test plan for technology evaluation. [*First draft plan to be presented at next meeting*]	Maffei, Hargrave, array providers
7.	Send to Kent Irwin the details of the temperatures of the SPIRE interfaces with the FIRST cryostat. [*June TBD*]	Griffin
8.	Specify ^{3}He cold stage temperature requirements for SPIRE and BACUS. [*July TBD*]	Rodriguez, Moseley, Bock
9.	Specify which FPGA is being considered for the Goddard array control and readout electronics. [*June 30*]	Moseley
10.	Define how and by whom the back-up option will be developed in the US (using BOLOCAM and Planck design concepts where possible). [*By next meeting*]	Moseley
11.	Define a draft schedule for future Array Group meetings, including formal selection meeting. [*To be presented for discussion and agreement at the next meeting*]	Griffin
12.	Define the quantitative performance requirements and the make-up of the array selection team. [*To be presented for discussion and agreement at the next meeting*]	Griffin

13. Provide monthly reports on progress on the array to Matt Griffin, copied to Ken King *[Deadline for first report: June 30]*	CEA (Rodriguez) development programme Goddard/NIST (Moseley) JPL/Caltech (Bock) QMW (Hargrave)

13 Main conclusions of the meeting

1. The array evaluation schedule has been clarified.

2. The essential design of the BACUS test facility have been agreed.

3. The detailed test plan still needs to be clarified: in particular, a much more detailed plan is needed for the delivery of devices for testing at QMW.

4. Some details of the instrument hardware configuration for the different options are now more clear, but a great deal more needs to be done to specify the options adequately.

5. It is possible to have an essentially common 2-K interface for the different options. This will greatly simplify the focal plane unit design.

6. There are substantial differences in the cryoharness implementation and the warm electronics for the different options.

7. The design of SPIRE will assume the "worst case" combination of parameters corresponding to the various possible array types.

8. The back up option needs to be defined more precisely.

9. The aims and schedule of the array evaluation programme are very ambitious and challenging. To meet them, it will be essential that the array group works very closely and meets more frequently than before. Group meetings will take place around every three months from now. In addition, brief monthly progress reports will be provided by the participating groups: QMW [Hargrave], Caltech [Bock], Goddard [Moseley], NIST [Irwin], CEA [Rodriguez].

14 Date and venue of next meeting

The next Array Group meeting will be held at NASA Goddard on September 17 and 18, 1998.

Appendix: Revised array test facility plan

A meeting between Harvey Moseley and the QMW group on June 1 to discuss the test and evaluation programme for the TES/SQUID options resulted in a modified plan for the implementation of the test programme.

1. The final array evaluation tests for all the US options shall be done at QMW, as agreed at Saclay, using the BACUS optical module, and will be supported appropriately by staff from the US groups.
2. Evaluation of the SQUID multiplexer and the 1.0Fλ detector and optical performance can be done separately. Essentially, if the operation and performance of the multiplexer is proven in the course of SPUD array testing, this will be taken as a demonstration that it will work for the TES detectors in the 1.0Fλ option.
3. To evaluate and compare the 1.0Fλ and 2.0Fλ options, JPL/Caltech will use the same array chip interfaced to a 1.0Fλ horn plate (using all pixels) and a 2.0Fλ horn plate (using ¼ of the pixels). The relative efficiency can be tested using semiconductor thermometers.
4. For the SPUD evaluation, the size of the evaluation array shall be at least 4 x 8 pixels.
5. Three identical cryostats (including Chase ^{3}He systems) shall be used. One will be based at QMW, as already proposed, one at Goddard and one at Caltech.
6. The test plan for the CEA detectors is unchanged: the QMW cryostat will be set up for these tests.
7. Preliminary array testing will be done by the US groups using their own dewars to commission the test arrays and their associated cold electronics. For this purpose, QMW will provide a simple calibration module (also as agreed at Saclay).
8. For testing with BACUS at QMW, the dewars (complete with ^{3}He systems, detector arrays, cold electronics and wiring harnesses to the external connectors) will be brought to QMW. The BACUS optics module will be installed so that complete testing can be done.

   The rationale for this approach is that all of the trouble-shooting and optimisation of the cold electronics and wiring can be done in the home laboratories, precluding the need for lengthy and risky disassembly and reassembly and re-commissioning at QMW.
9. If possible, all cryostats will use 64-pin connectors from the start rather than 41.
10. The cost of the additional cryostats and ^{3}He refrigerators will be borne by the USA.
11. A common design for the cryogenics must be worked out and agreed soon if the schedule for the test facility is to be met. The plan will only be workable if
    - (i) the cryostat design can be defined;
    - (ii) the dewars can be procured on schedule;
    - (ii) the additional ^{3}He fridges can also be procured on schedule.
12. To accommodate the extra design work, the BACUS schedule as presented at Saclay will need to be delayed by two weeks.

Action: Bruno Maffei and Peter Hargrave will work with the Goddard (Harvey Moseley) and JPL/Caltech (Jamie Bock) to define the common interfaces for the systems and verify that the cryostats and ^{3}He systems can be procured in time. ***Deadline: June 30: A report on feasibility of this approach should be included in the QMW progress report for June.***

Bolometer Array Technology Meeting, Saclay 28, 29 May 1998

Agenda 28th May   Morning: Chair = Vigroux

0	Agree agenda; meeting logistics etc.		
1	Review of SPIRE status and aims of this meeting	Griffin	09.30
2	SPIRE development schedule and its implications for array technology choice	King	10.00
	Coffee		10.15
3	Review of progress on array development since October meeting (around 20 minutes each)		10.30
	- CEA arrays	Rodriguez	
	- SPUDs	Moseley	
	- BOLOCAM-type arrays	Bock	
	- TES sensors/SQUIDS	Irwin	
4	Review of comparison between filled arrays and back-up option	Griffin	12.00
	- Advantages & disadvantages of filled arrays		
	- Performance requirements		
	Discussion and conclusions from morning session		12.30
	Lunch		13.00

Afternoon: Chair = Swinyard

5	Implications for instrument design	Swinyard	14.00
	- Cold and warm electronics		
	- Thermal/mechanical		
	- Optical design		
6	Detailed description of SPIRE instrument design for the different options (30 min. each)		14.15
	- CEA arrays	Rodriguez	
	- SPUD + TES	Moseley	
	Coffee		15.15
	- BOLOCAM + TES	Bock	
	- Backup (BOLOCAM + NTD Ge)	Cunningham	
7	On-board data processing requirements and algorithms	Swinyard	16.15
	- Deglitching (different requirements for the different options?)		
	- FTS data processing		
	- Photometer data processing		
8	Short presentation: on-board calibrators	Moseley	16.45
9	Review of conclusions from Day 1	Swinyard	17.00

May 29th Agenda   Morning: Chair = Griffin

10	QMW array test facility	Maffei	09.30
	- Design and capabilities		
	- Schedule for its commissioning and operation		
	Discussion of test facility plans		09.50
	Coffee		10.15
11	Development, test and evaluation schedule for selection late 1999/early 2000 (20 min. each)		10.30
	- CEA	Rodriguez	
	- SPUDs	Moseley	
	- BOLOCAM	Bock	
	- Backup	Bock	
12	Discussion and definition of detailed plan and schedule for final review and selection		12.00
13	Conclusions and review of actions	Swinyard	13.00
14	Date of next meeting		
	Detector Array meeting ends 13.30		

SPIRE FTS Group Meeting, Saclay, 29 May 1998

Chair = Swinyard

Start: 14.30
End : 17.30

1	Introduction and aims of meeting	Swinyard
2	Discussion of FSEC recommendations to reduce spectral resolution, mass, data rate	All
3	Revised estimates of on-board data processing requirements	Swinyard
4	Discussion of options for redesigning the FTS	All

- Reduce on-board processing
  - Reduce field of view
    - Reduce physical size of arrays (e.g., 1 x 1 arcmin.)
    - Different operating modes (e.g., transmit only 1 x 1 arcmin as optional mode)
- Reduce mass and power dissipation
  - Smaller mirrors (implies smaller field)
  - Lighter mechanism
  - Light-weighting of mirrors, structure, etc.
- Simpler drive (e.g. linear rather than arc)
- Other ideas

5	Conclusions, actions, and plans for June 12 FTS meeting	Swinyard

1

Review of SPIRE status and aims of this meeting

Matt Griffin

Aims of this meeting

1. **Review progress on array development since October meeting**
2. **Establish the DETAILED instrument design for each option**
3. **Identify aspects of the design which DON'T depend on the array technology finally selected**
4. **Plan the testing and evaluation programme consistent with the schedule**
5. **Identify the special requirements of each option (thermal, mechanical, electronics, EMI, array control, etc.)**
6. **Review on-board data processing and data compression requirements for filled array options**

We need a comprehensive description of each option to provide as complete a picture as possible of the instrument design and how it differs from one case to another.

Summary of FSEC recommendations concerning SPIRE

- They approve of the SPIRE photometer capabilities and design.
- Low resolution (R ~ 20-100) spectrophotometry is essential for SED measurement - higher resolving power is not essential.

  Not a design driver but we will implement R > 100 if it means little extra cost or complexity.

- Martin-Puplett design good for broad wavelength coverage, but we are urged to improve efficiency by recovering lost light at input.

  We will be looking at this.

- We are encouraged to see if we can incorporate the spectrometer into the photometer.

  We have considered this. It is a bad idea.

- We are advised to study in detail the relative merits of full sampling of the diffraction spot (filled arrays) vs. feed-horn fed arrays.

  We are doing this.

- On-board data processing is seen as a problem for all FIRST instruments – FSEC recommends that convincing and detailed plans be drawn up at an early stage.

  We will do this.

- Minimum acceptable SPIRE capabilities:
  - Photometer with fall-back arrays
  - Spectrometer: whole wavelength range but R = 100
  - Separate photometer and spectrometer not a scientific requirement

  OK – but this should not be taken as a justification for de-scoping the instrument.

Focal plane arrays

- Dimensions
- Mass
- Electrical/mechanical/thermal interfaces, etc.
- Cold wiring and connectors
- Full description of cryo-harnesses from arrays to cold readout and multiplexing electronics and from there to the to warm electronics
- Anything else that affects instrument design

Array readout scheme

- Cold readout electronics and multiplexing
- Grounding scheme
- Buffer amplifier requirements
- Readout control signals and timing
- Frame rate
- Integration of detector signals between samples
- Synchronisation with chopper and FTS drive
- Electrical filtering?
- Anything else that affects instrument design

Warm electronics description

- Array control
- Data acquisition and front-end processing
- EMC considerations
- Anything else that affects instrument design

Conclusions of October '97 meeting at QMW

- "Base-line" = 0.5Fλ filled arrays – CEA
  0.5Fλ filled arrays – SPUDs
  1.0Fλ spider-webs with TES sensors

  "Back-up" = 2.0Fλ feed-horns with NTD Ge sensors

- Filled arrays chosen as base-line for two reasons:

  (i) to promote their development and allow them to be chosen if they are proven in time;

  (ii) to make sure instrument design/spacecraft resources are appropriate.

  - On-board electronics and software will be designed to be compatible
  - Optical design and stray-light requirements will be compatible
  - ^{3}He cooler performance will be compatible

- "Back-up" option must still be developed and designed: it is the only option that is known to work.

- Selection process must choose the best out of all four options.

- Technical challenges associated with filled arrays option

  - Developing and demonstrating a workable and proven filled array option in time for FIRST
  - Achieving lower detector NEP by a factor of 2 than for feed-horn option
  - Elimination of stray light within the instrument
  - Coping with the greatly increased data rate and on-board processing requirements

Array selection criteria agreed at QMW meeting

1. Filled array options must be better than 2.0Fλ feed-horn option in mapping speed by a factor of ~ 2
2. CEA option will be chosen if equivalent or nearly equivalent in mapping speed
3. A US option, if chosen, shall be fully funded by NASA
4. Readout electronics and/or warm analogue electronics will be built by CEA for whatever option is chosen
5. Credible space qualification process and schedule for qualification shall already be identified at selection
6. Array prototypes shall have (at the very least) undergone full testing in the laboratory to determine performance parameters
7. Selection will be based on
    - Experimental evaluation of:
        - Sensitivity (optical NEP); speed of response
        - Yield
        - Uniformity
        - Crosstalk
        - Ionising radiation susceptibility
        - Etc.
    - Conformance to the operating and performance requirements:
        - Power dissipation
        - Operating temperature = 300 mK
        - Telemetry rate
        - Instrument optical/thermal/mechanical modeling
        - Redundancy
        - Accurate estimates of electronics and spacecraft requirements
    - Credible schedule, consistent with overall project schedule, and cost estimates for QM and FM manufacture and delivery, including readout electronics

2

SPIRE development schedule and its implications for array technology choice

Ken King

DEVELOPMENT

Array development
System Design
Interface Definition
Instrument Preliminary Design Review

DESIGN

Detailed Design
Array Selection
Instrument Critical Design Review

PROTOTYPE

EM Manufacture and Test
EQM Manufacture and Test
Qualification Model Delivery Review

BUILD

PFM Manufacture and Test
FS Build/Refurbishment
Flight Model Delivery Review

LAUNCH AND OPERATIONS

DEVELOPMENT

Array development

- Prototyping and testing of arrays
- Development of Interface Specifications for each technology

System Design

- Electrical design
- Mechanical design
- Thermal design
- Optical design
- Scientific Requirements
- Instrument Engineering Requirements
- User Requirements on DPU and SPU s/w

Interface Definition

- Freezing of Interfaces and Budgets
- Definition of Interface Control Plan

Instrument Preliminary Design Review

Duration: Approximately 12 months

DESIGN

Detailed Design

- Subsystem design, including options for different array technologies
- Software Specification for DPU and SPU s/w

Array Selection

- Select Arrays
- Consolidation of design for chosen arrays

Instrument Critical Design Review

EM and EQM release for manufacture

Duration: Approximately 9 months

PROTOTYPE

EM Manufacture and Test

- Manufacture (12 months)
- AIV (3 months)
- Instrument Users Manual (Draft)

EQM Manufacture and Test

- Manufacture (18 months)
- AIV (6 months), including preliminary calibration
- Instrument Users Manual (Issue 1)

Qualification Model Delivery Review

Note: EQM System Tests (Compatibility Test) is carried out after this review

Duration: Approximately 24 months

BUILD

PFM Manufacture and Test

- Manufacture (18 months)
- AIV (9 months), including calibration
- Instrument User's Manual (Issue 2)

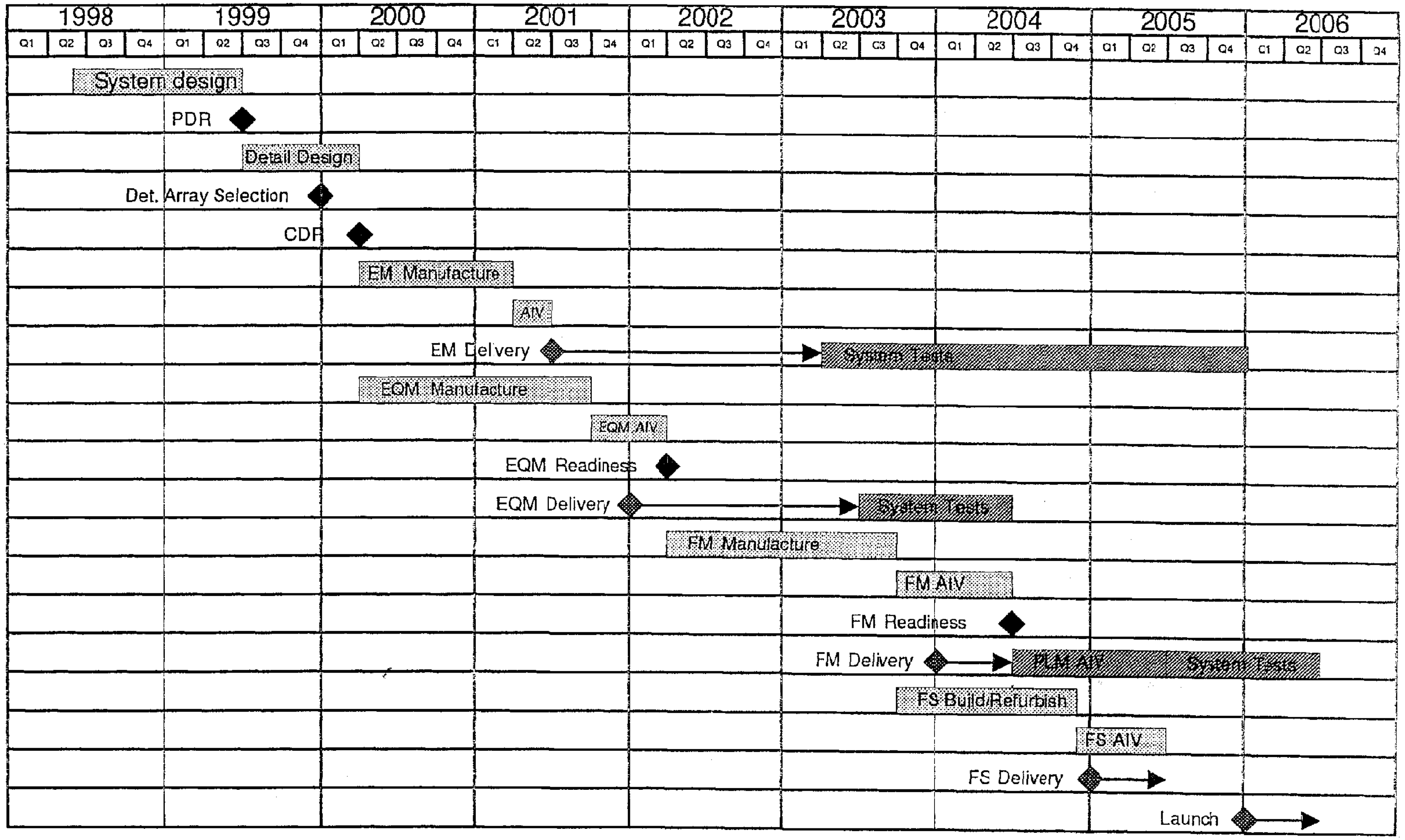
FS Build/Refurbishment

- Manufacture of some subsystems
- Refurbishment of others?
- AIV (7 months), including calibration?

Flight Model Delivery Review

Duration: Approximately 39 months

SPIRE Instrument Development Schedule



28 May 1998

3

Review of progress on array development since October meeting

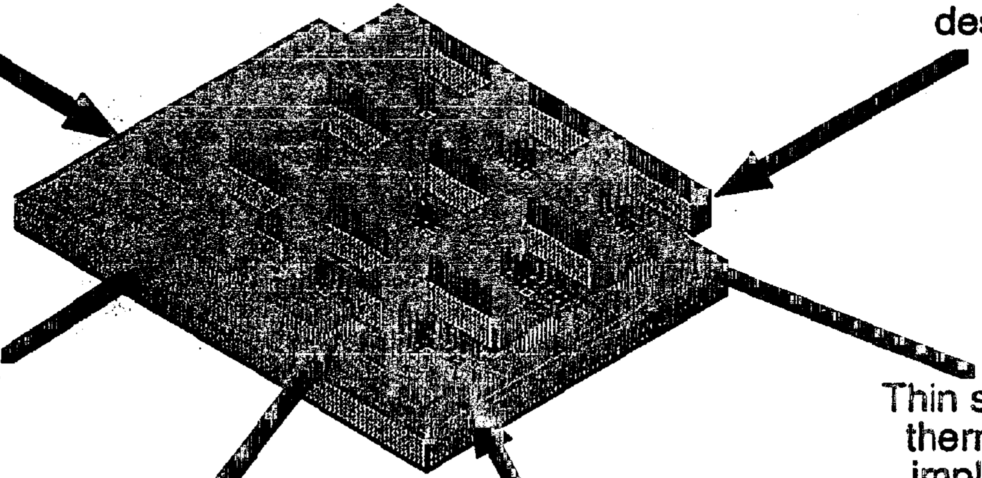
CEA arrays	Louis Rodriguez
SPUDs/SQUID MUX	Harvey Moseley
	Kent Irwin
BOLOCAM-type arrays	Jamie Bock

SPIRE:
CEA ARRAY
DETECTOR STATUS

L. RODRIGUEZ
E-MAIL:LRODRIGUEZ CEA.FR

BOLOMETER DEVELOPMENT STATUS

Summary



Cold Read out circuit

Thermal &
mechanical interface
design

Metal e-m absorption
efficiency

Thin silicon film
thermometer
implantation

silicon beams
thermal conduction

Indium bumps
thermal conduction

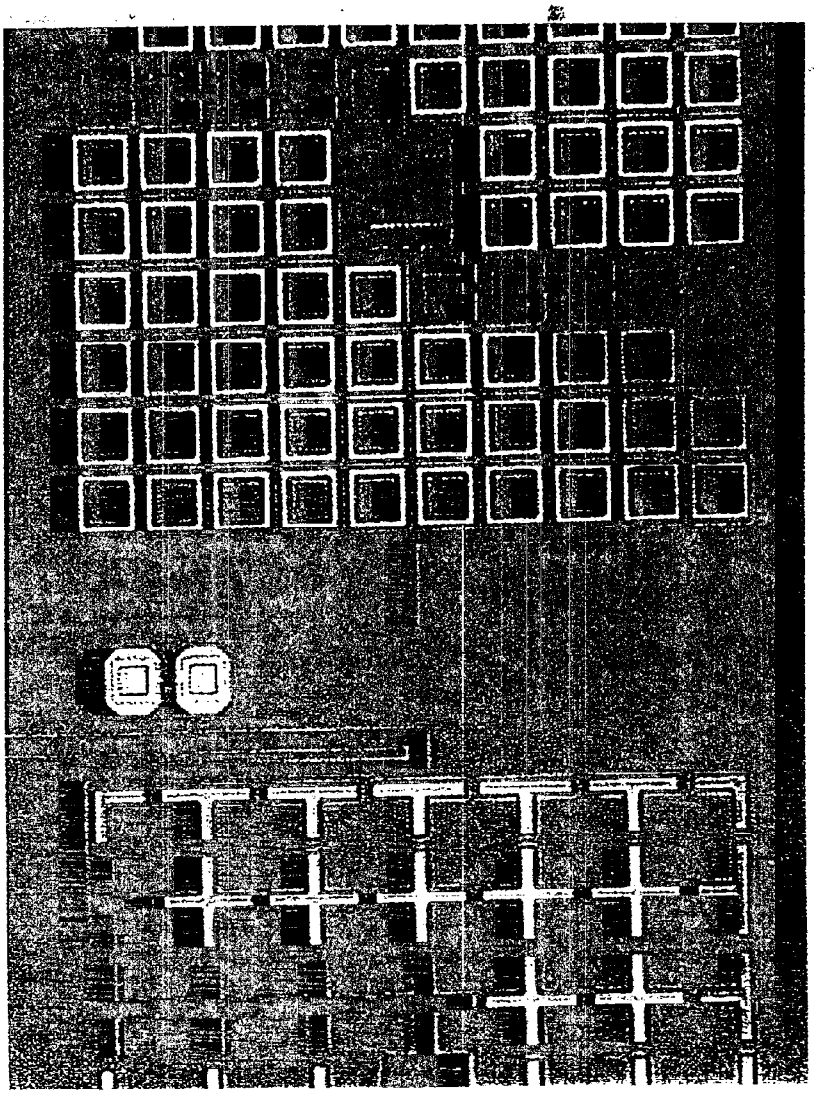
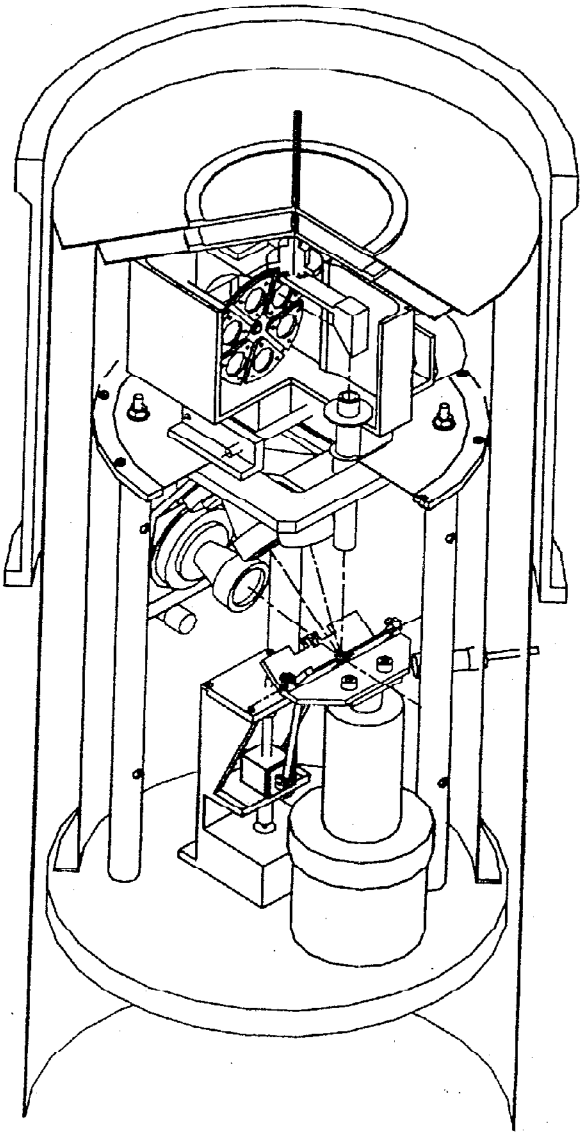


Photo d'ensemble d'un bolomètre montrant que les pistes WN connectées aux plots TiNiAu d'hybridation se sont oxydées (bleuissement) alors que les motifs WN (carrés ou croix) utilisés comme absorbeur n'ont visiblement pas évolué.



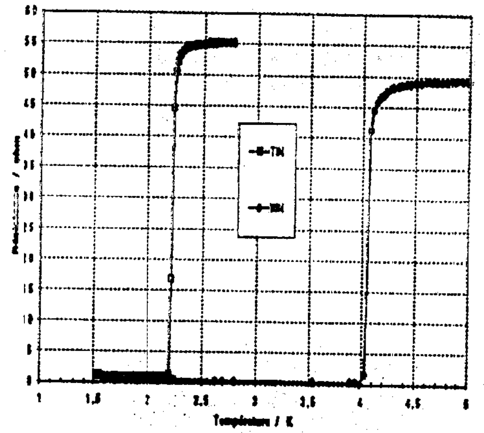
ABSORBING METAL EVALUATION (I)

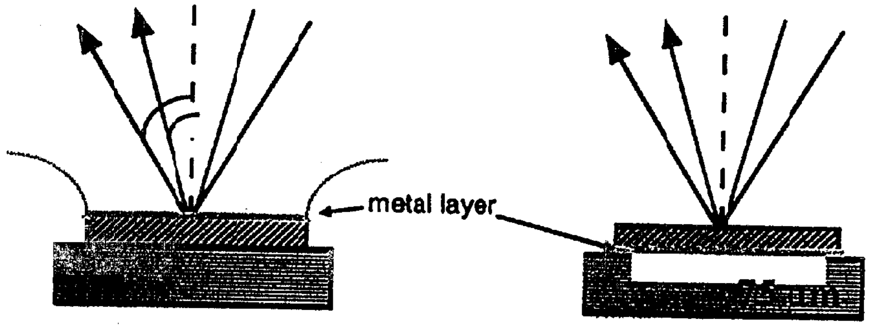
Two metallic layers were evaluated: TiN & WN. They were choosen for compatibility purpose with silicon sensor technology.

We measured:
- DC conductivity,
- sub-mm reflectivity in 3 λ bands (50-170 / 170-285 / >285)

For
- Plain metal layers 54 Ohm/sq.
- Metallic loops 377 Ohm/sq.

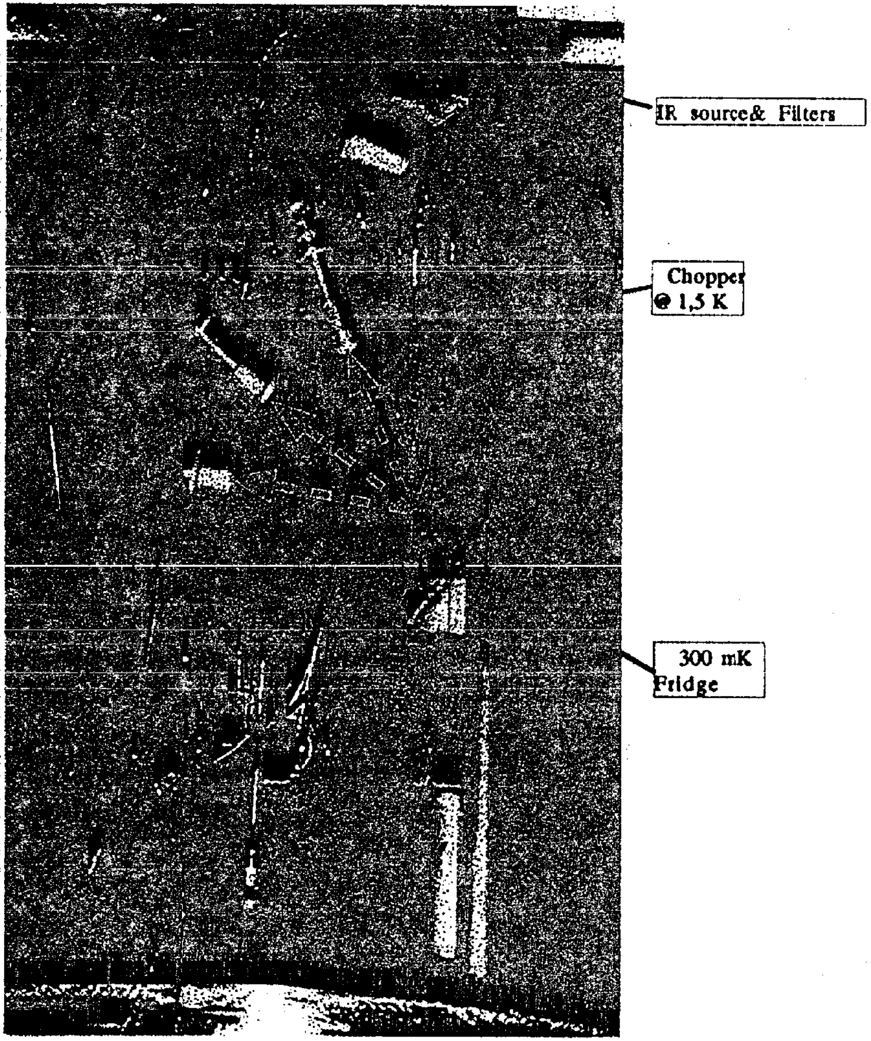
on thick silicon substrate with or without cavity @ different incidence angles (15 & 30°).



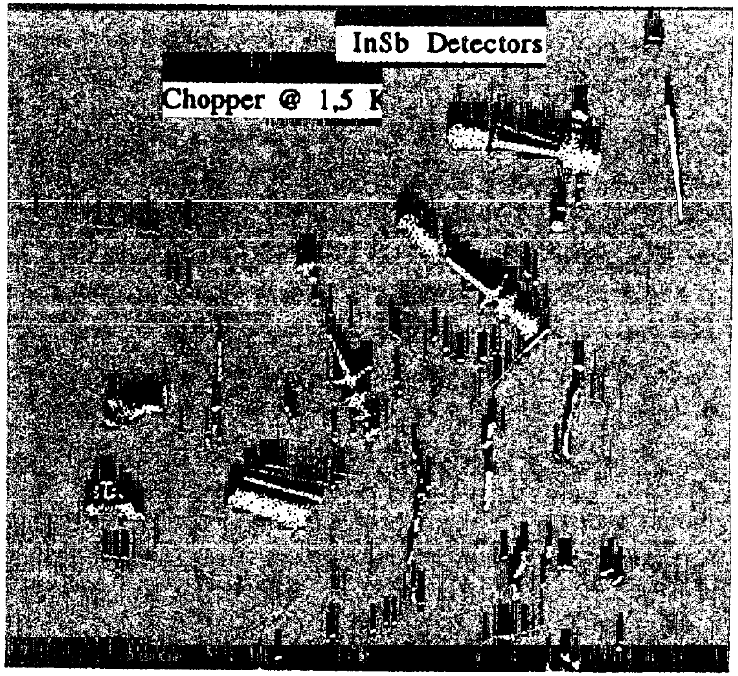


DC & Sub mm measurement

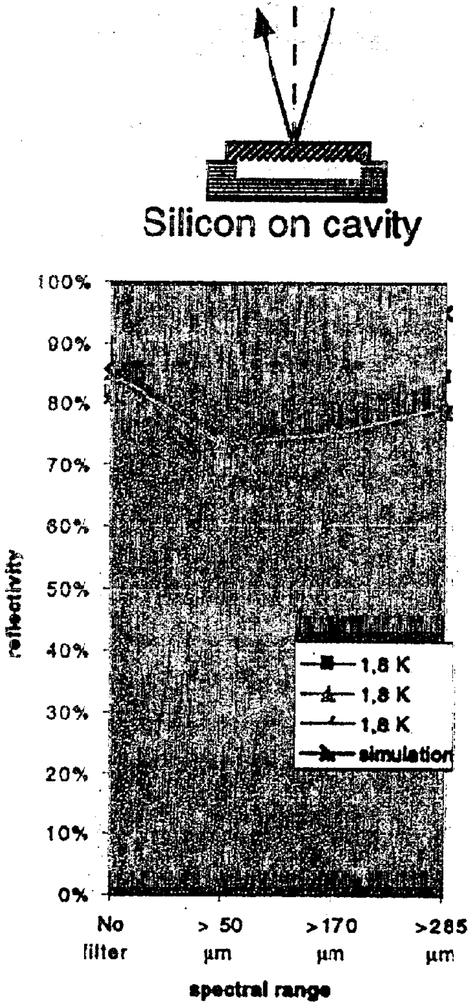
ABSORBING METAL EVALUATION (II)

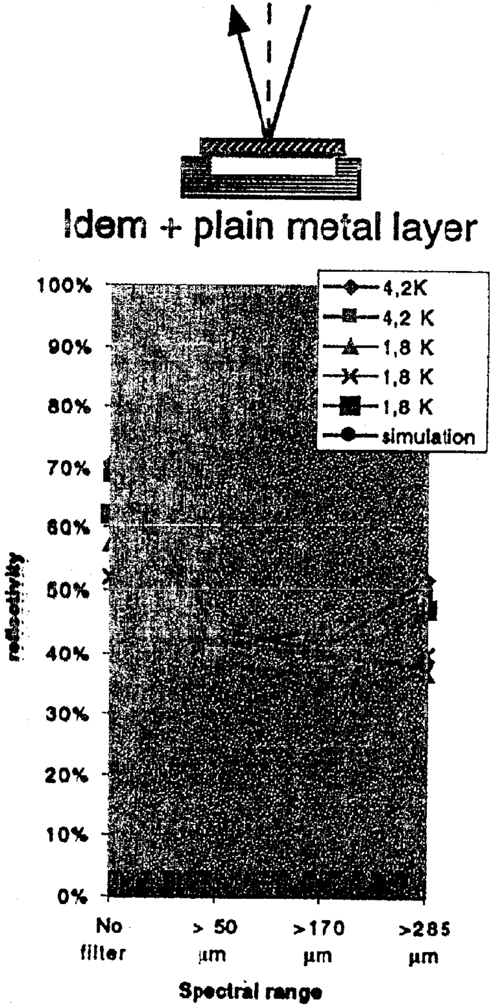


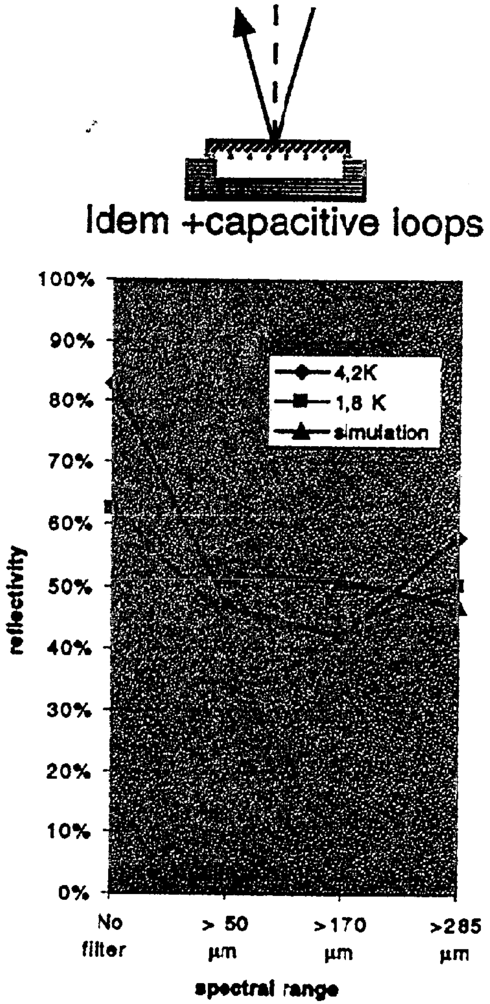
Optical test bench



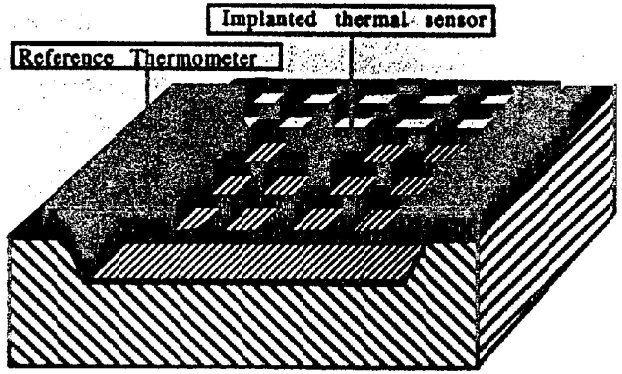
ABSORBING METAL EVALUATION (III)


Silicon on cavity


Idem + plain metal layer


Idem +capacitive loops

IMPLANTED THERMOMETER

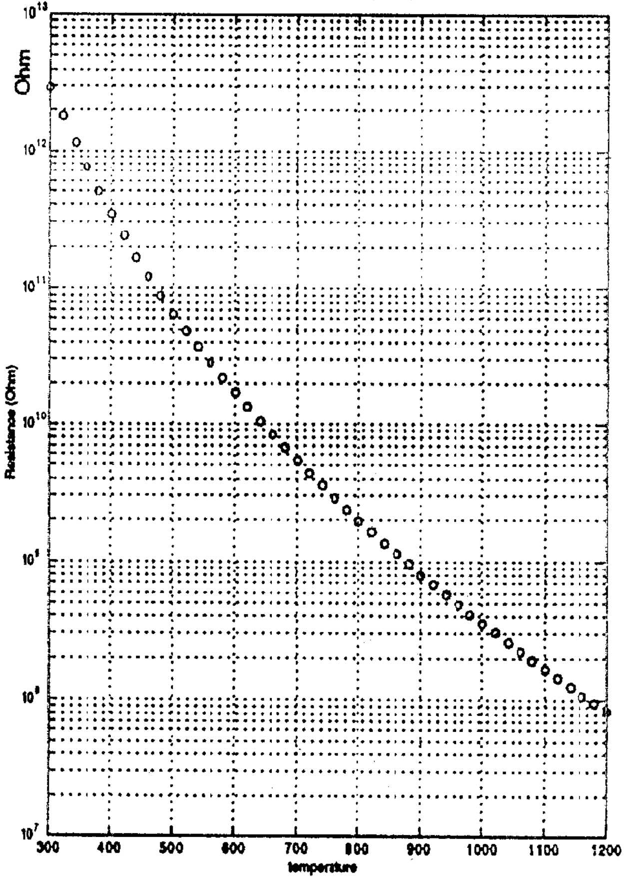


References I(V) Curves at different fridge temperature(300->900 mK*) permit to determine the resistive thermometer dependence.

This dependence was measured for the reference thermometers over a whole row. The dispersion is found to be in the order of few percent.

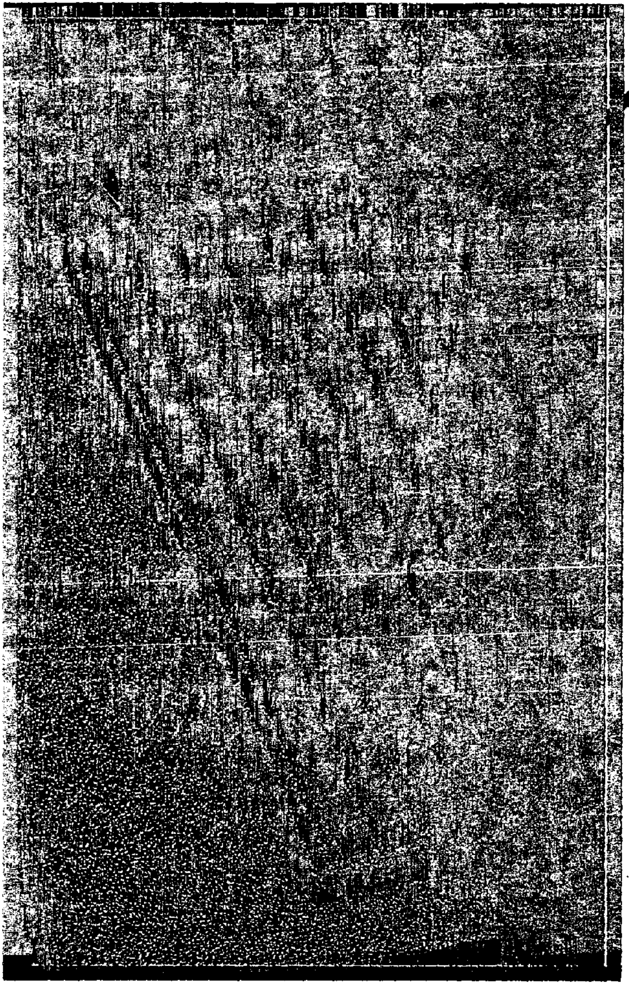
The I(V,T) dependence was then used as a calibration for bolometer thermometers.

Resistance dependence with T



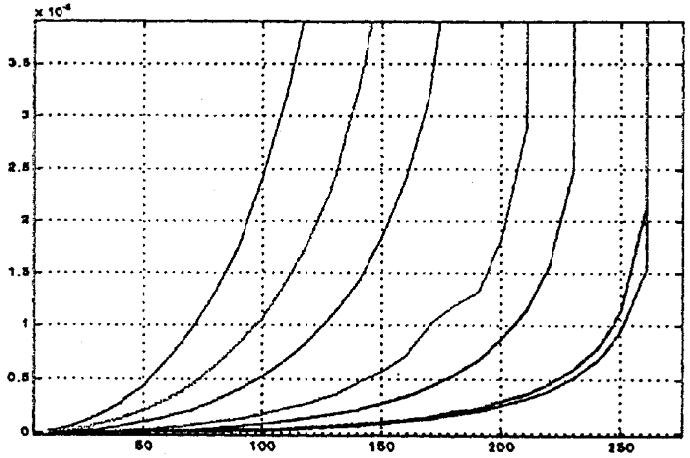
Bias 100 mV

SILICON BEAM THERMAL CONDUCTIVITY (I)



Thermal conductance to the substrate and fridge

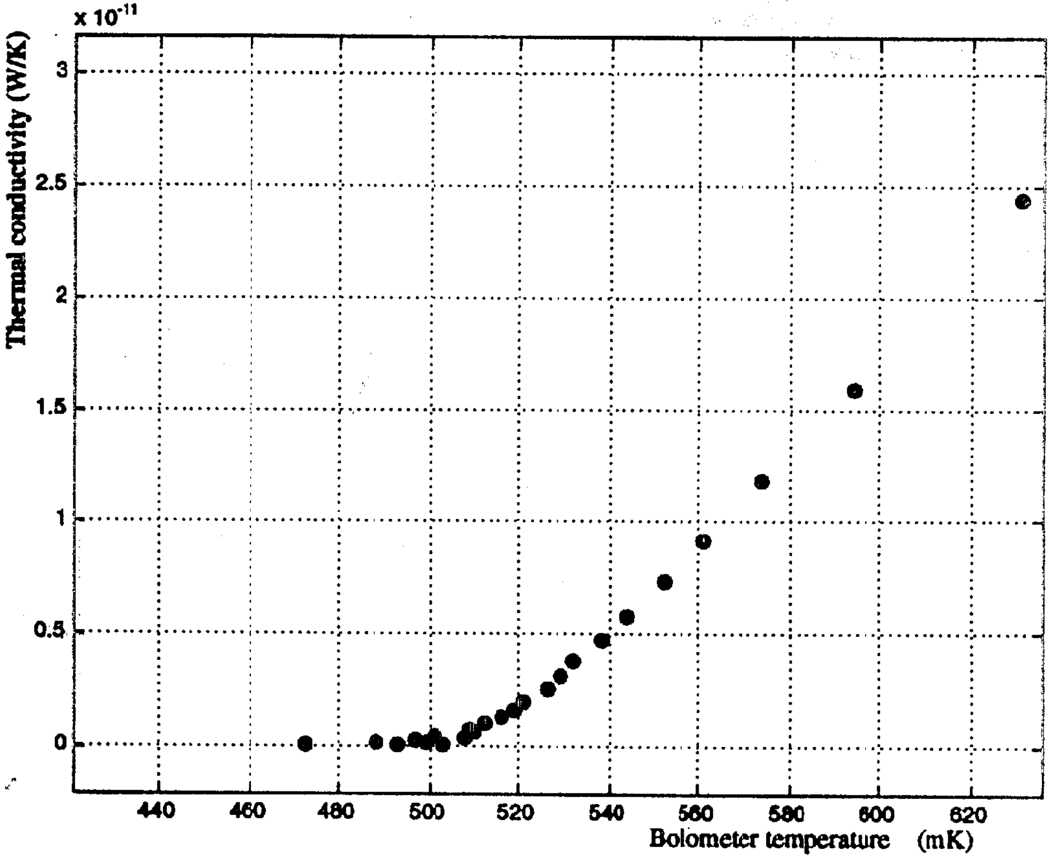
The thermal conductance was deduced from the I(V) curves of thermometers on bolometers
$P_{electrical}$ and T_{bolo} are known from the curve.



SILICON BEAM THERMAL CONDUCTIVITY (II)

We obtained the thermal conductivity for the 2µm x 5µm x700 µm x 4 beams. The deduced numbers are compatible with the expected values.

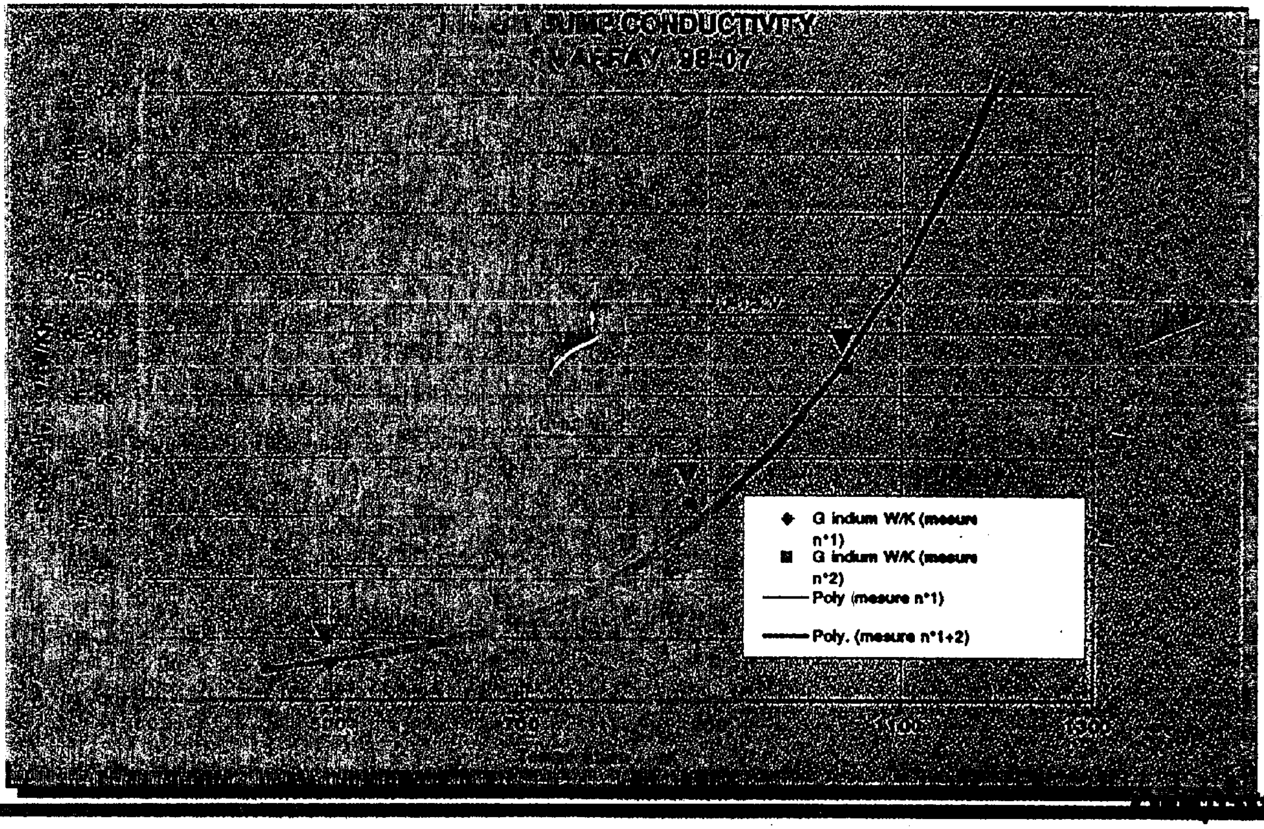
A student is currently working in Grenoble on the influence of beam geometry (bends-saw teeth) on the thermal conductance



INDIUM BUMPS THERMAL CONDUCTIVITY

Using high power dissipation on bolometers and measuring substrate (reference) temperature, we deduced the thermal conductivity of the indium bumps. They were supposed to isolate the cold read out circuit at 1,8 K from the 300 mK stage .

We measured a conductivity variation with T^3 in place of T, incompatible with admitted thermal load on the ^{3}He fridge.

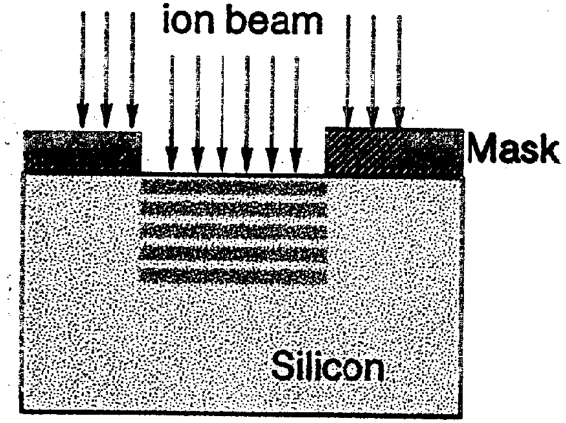


BOLOMETER DEVELOPMENT STATUS
WORK IN PROGRESS (I)

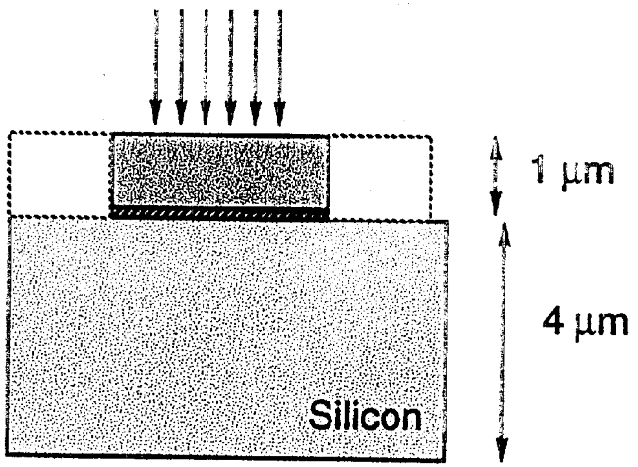
Detector Resistance

The Resistance deduced from measurements is currently too high to couple the thermometer to the cold read out folower circuit. Only the "low resitance" splits can be used. Measured implantation profile is not as homogeneous as desired.
Implantation was made in a new device (different from those used in 1996 on thick silicon substrate).
To improve the density control we split the 98 process to have:
- same process (with better control expected!)
- Mesa type thermometer:

Deep channel



Mesa



BOLOMETER DEVELOPMENT STATUS
WORK IN PROGRESS (II)

Read out circuit

-Cold R/O circuit is currently manufactured to be mounted on 16 x16 arrays. It includes the cold MUX.

- The λ/4 cavity mirror on the Interconnection circuit will be made of a small step grid to minimize the capacitance of the electrical leads to the read out circuit.

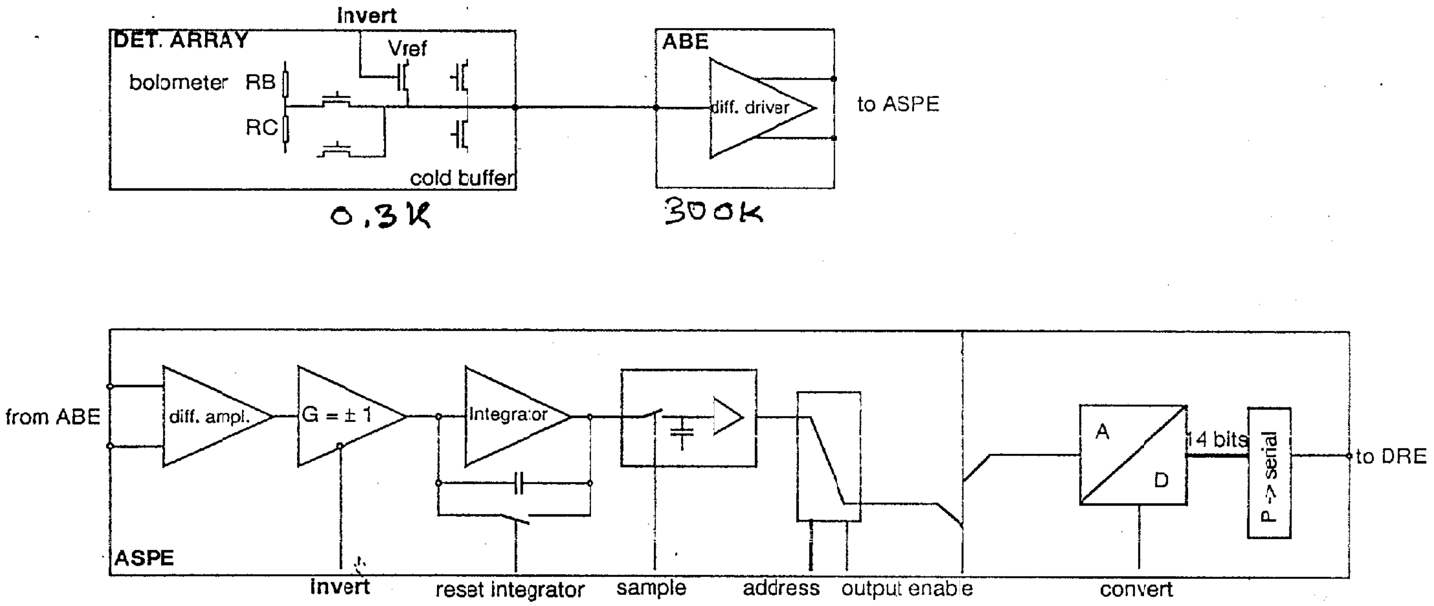
-Warm R/O circuit prototype have been manufactured and tested. It needs to be coupled to a real bolometer.

Mechanical & thermal interface

-The evaluation arrays are under process to be ready by end 98. They will be representative in optical performances to final arrays but not for the heat load to the 300mK stage. The thermal and mechanical interface is currently re-designed to take account of the bad thermal resistivity measured of the indium bumps.

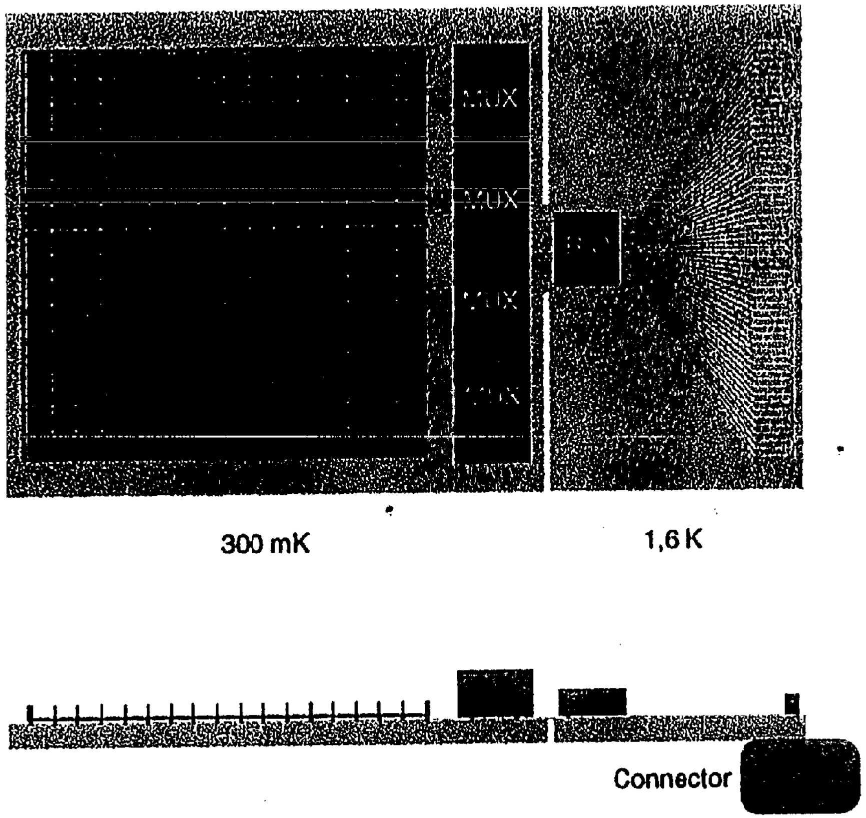
Modelisation

-All the data obtained from measurements is included in a Simulink model. A student in Saclay is in charge to develop the realistic electro-thermal analog model.



differential analog input
range 0 -> 1 V

Analog Signal Chain


MUX
MUX
MUX
MUX
300 mK
1,6 K
Connector

SPUDS /SQUID MUX

HARVEY MOSELEY
KENT IRWIN

PUD Progress

- Mechanical Concept for 12 x 32 array (with JFETs for SOFIA)
- Successful operation of XRS focal plane in “bare pixel” configuration + EMI tests
- Demonstration of granular Al superconducting interconnects on PUD leads at NIST
- Have begun to add staff for this year’s development both at NIST and GSFC

Proposal

PUD Progress

- Process Integration:
  - Shadow mask TES deposited on GSFC PUD at NIST (high thermal conductance model)
  - PUD etched from SOI wafer at NIST
  - Complete microfabrication process for TES on nitride working at NIST

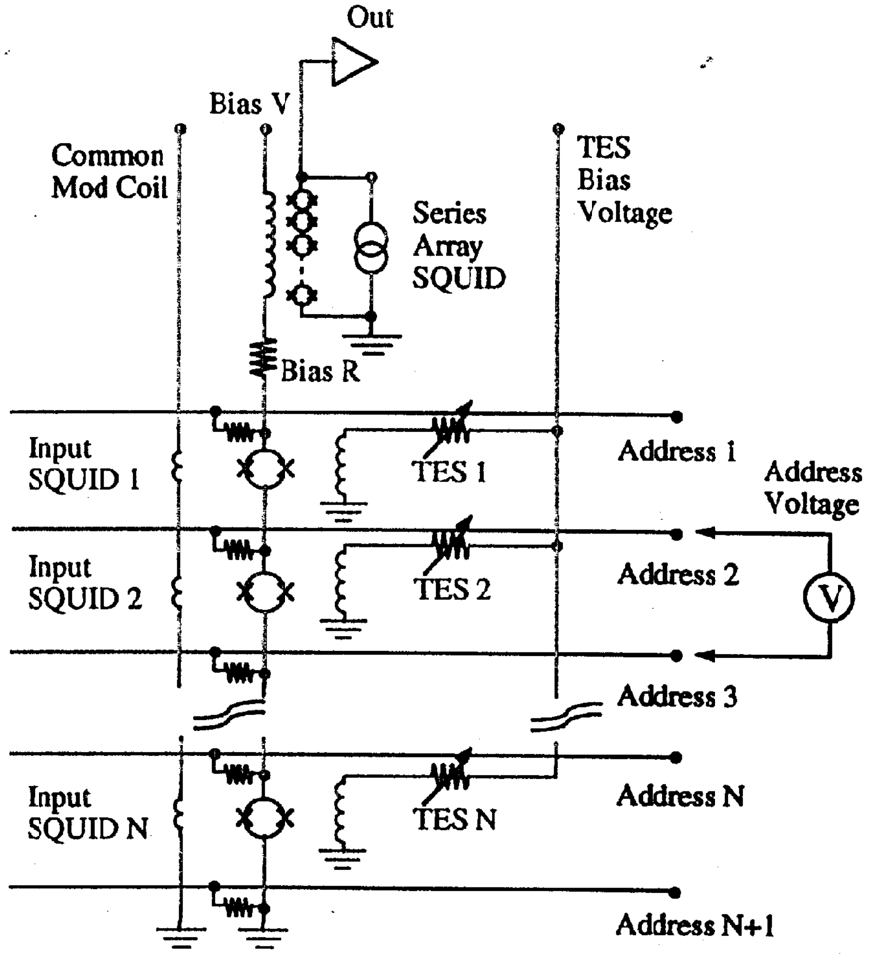
MUX Progress

- Have advanced from 40 kHz multiplexing of two distinct SQUIDs to 1 MHz multiplexing of an 8 channel monolithic mux chip.
- Successful demo of first gen computer control for mux
- Concept for Gen II high speed feedback system developed.

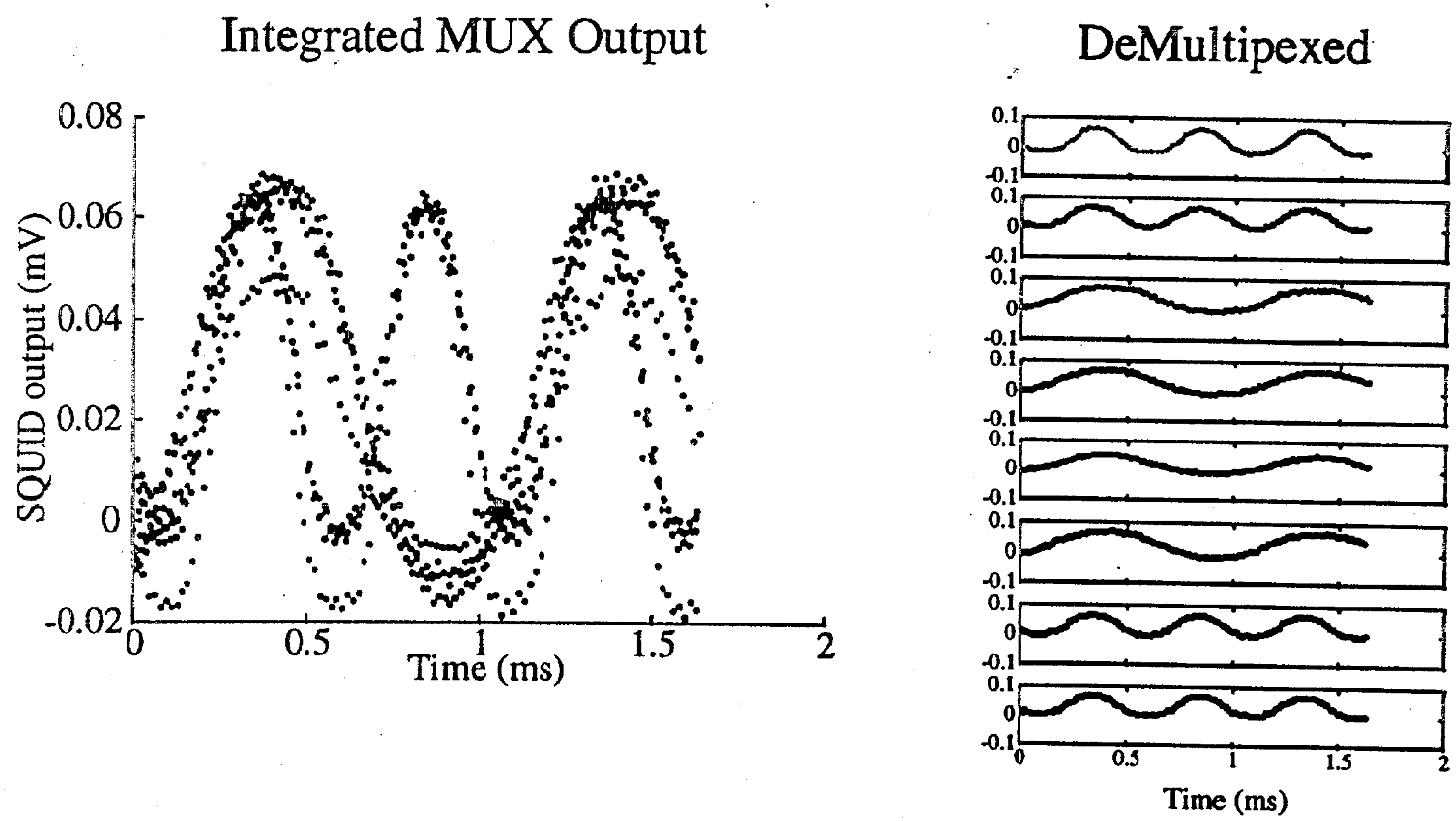
Future Developments

- Second Generation control electronics
  - 3.2 MHz pixel rate, design goal for SPIRE
- Second Generation Mux chip
  - Coupling to series array optimized by reducing coupling turns from 10 to 3.
  - Separate band limiting inductance from SQUID input coil for added design flexibility
  - Evaluate enhanced design using extra SQUID input stage.

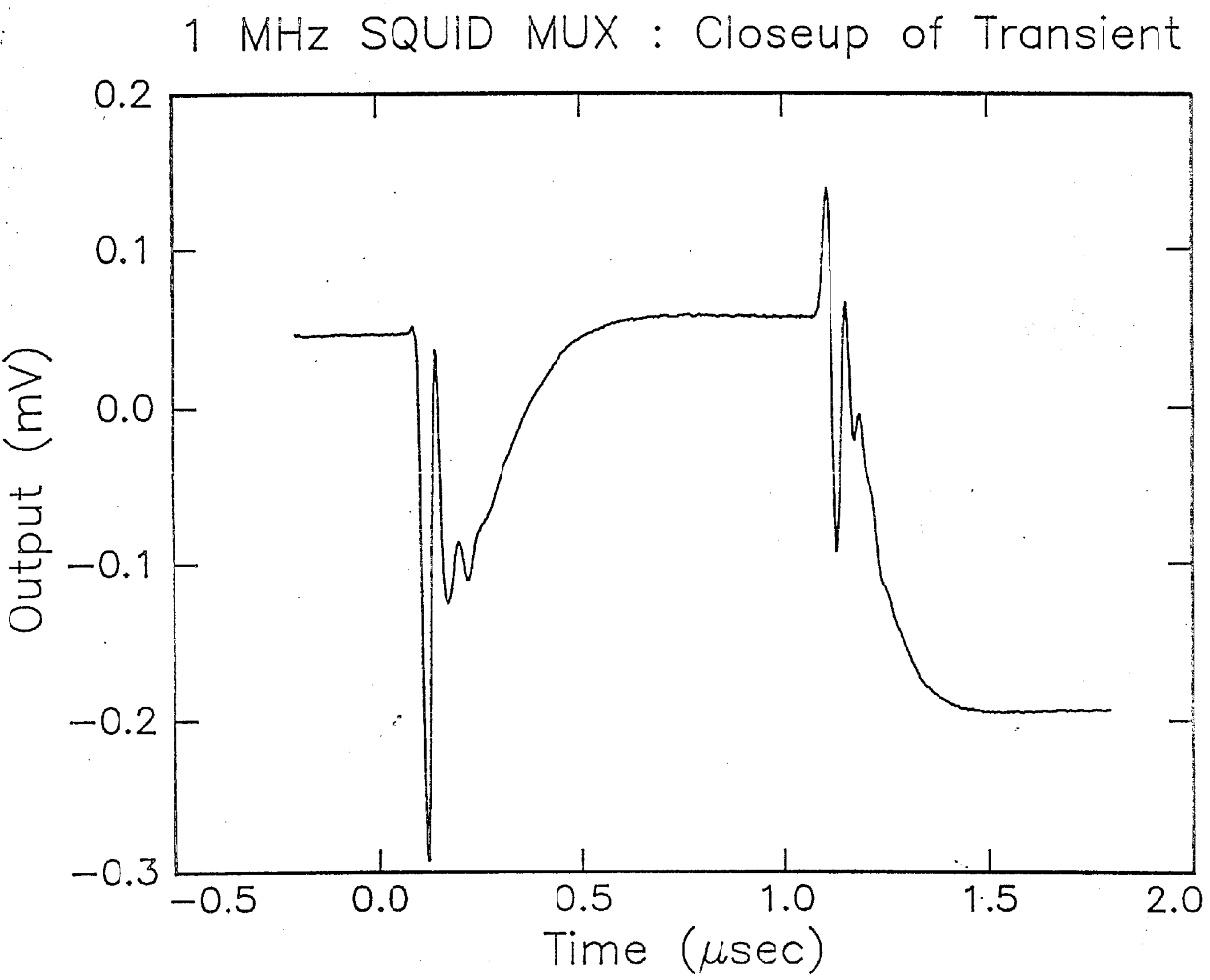
N x 1 Array of TES Bolometers With SQUID Multiplexer



1 x 8 SQUID MUX at 500 kHz



Eight sinusoids; different periods, amplitudes, offsets


1 MHz SQUID MUX : Closeup of Transient
0.2
0.1
0.0
−0.1
−0.2
−0.3
Output (mV)
−0.5
0.0
0.5
1.0
1.5
2.0
Time (μsec)

PROGRESS TO DATE

JPL / CALTECH ARRAY OPTION

28 MAY 1998

SACLAY BOLOMETER MEETING

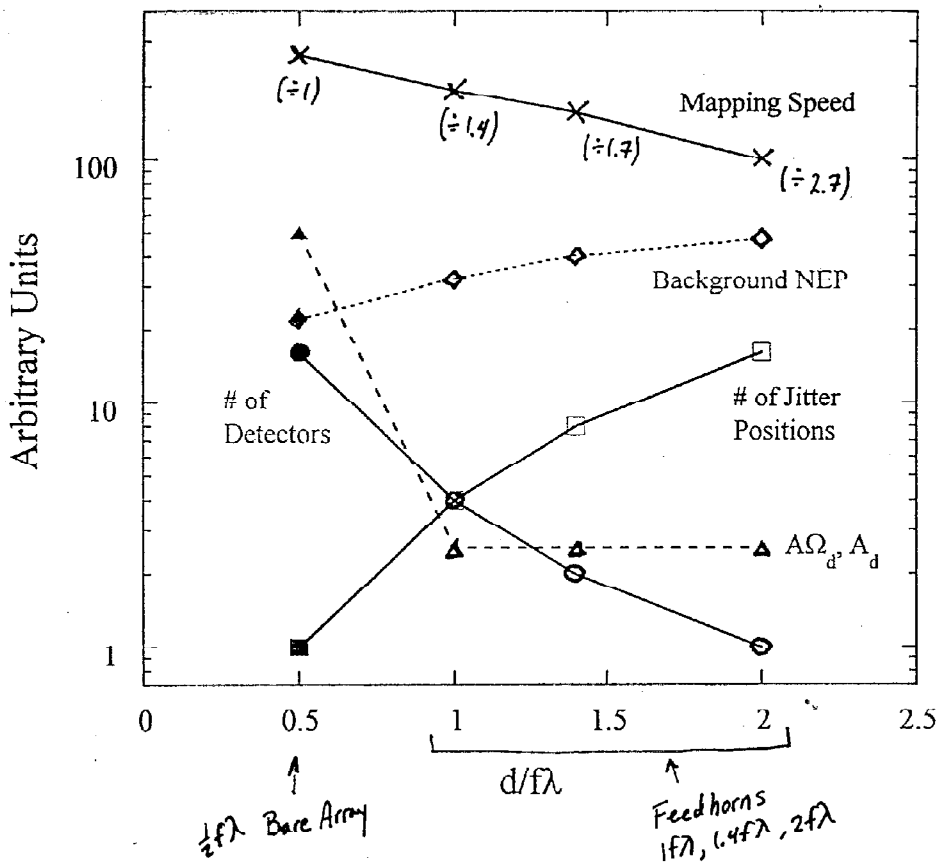
I. OPTICAL COUPLING OF FEEDHORNS
   - ULTIMATE SENSITIVITY
   - OPTICAL EFFICIENCY

II. FABRICATION
   - NTD BOLOMETERS AT 300mK
   - DRY ETCH AND RELEASE

III. BOLOCAM
   - FIELD TEST OF BACKUP READOUT, COUPLING
   - HARDWARE TESTED
   - ARRAYS IN FABRICATION

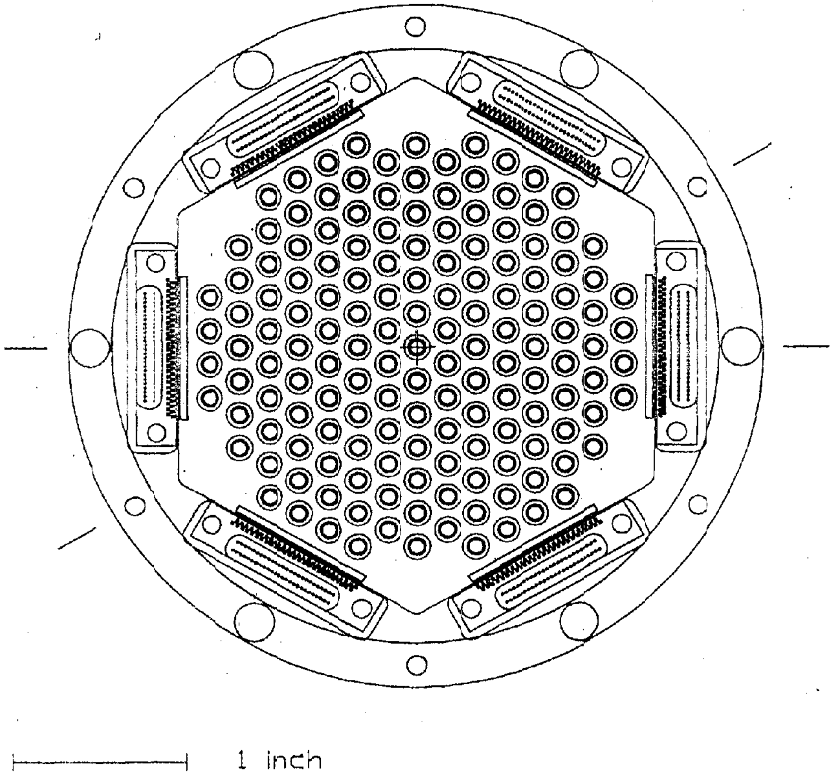
IV. TES BOLOMETERS
   - Ti/Nb RESULTS
   - Ag/Al/Ag/Nb FILMS TESTED, IN FABRICATION

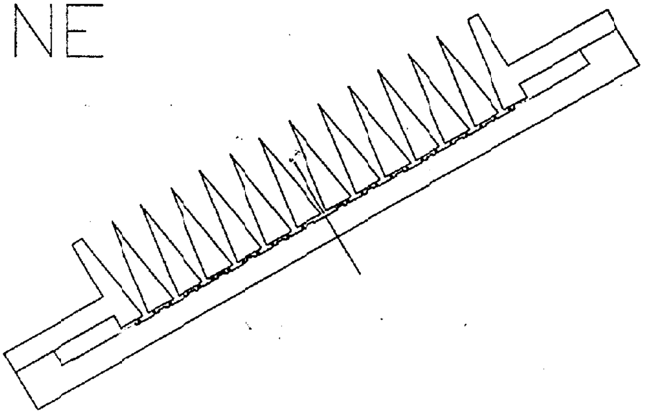
Tradeoffs in a Mapping Observation

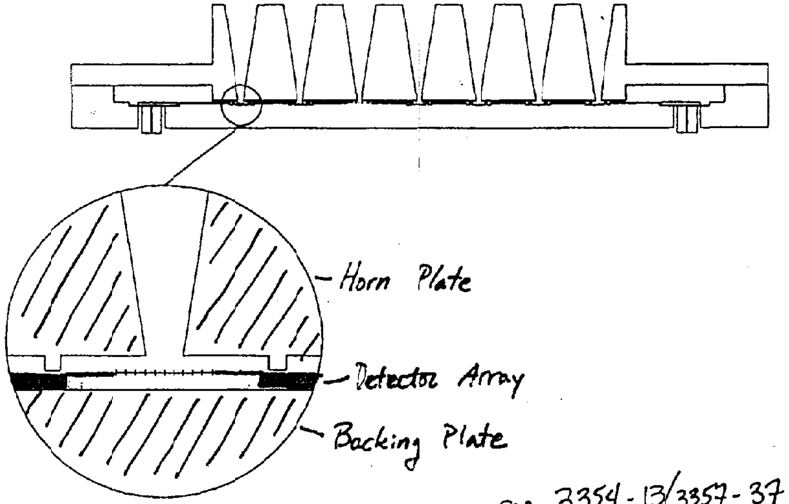


- Background-limited case
- f/5

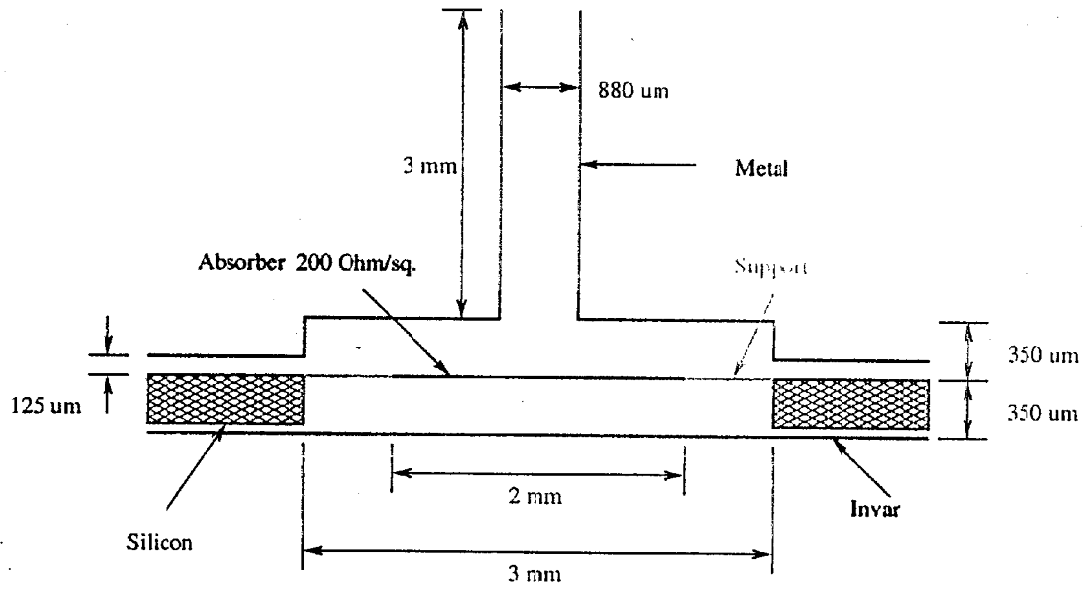
BOLOCAM FOCAL PLANE





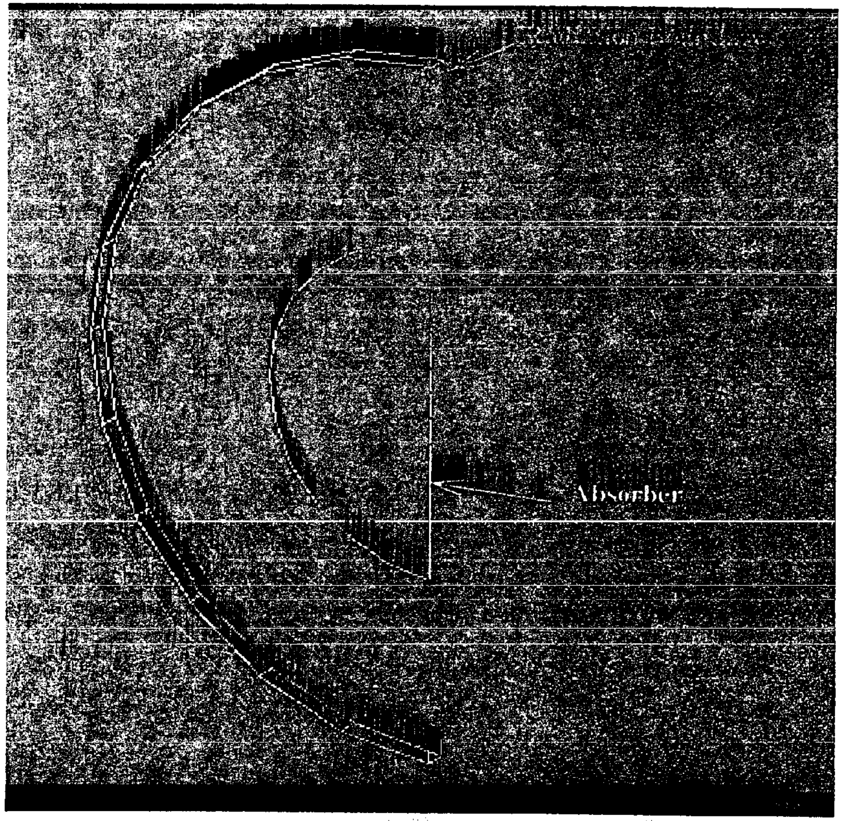


see 3354-13/3357-37



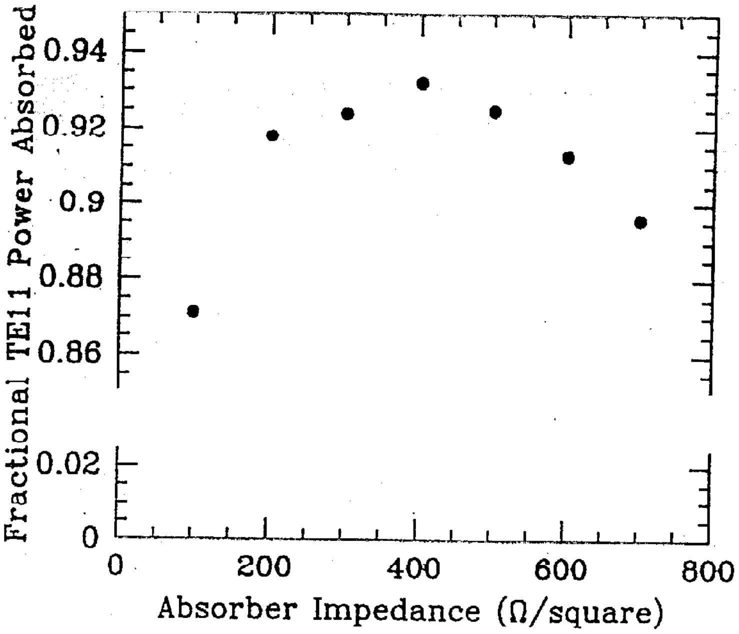
Cavity Resonator Details for 214 GHz.

For 143 GHz, change the waveguide dia to 1.317 mm.



HFSS DRAWING

Preliminary BOLOCAM HFSS Results



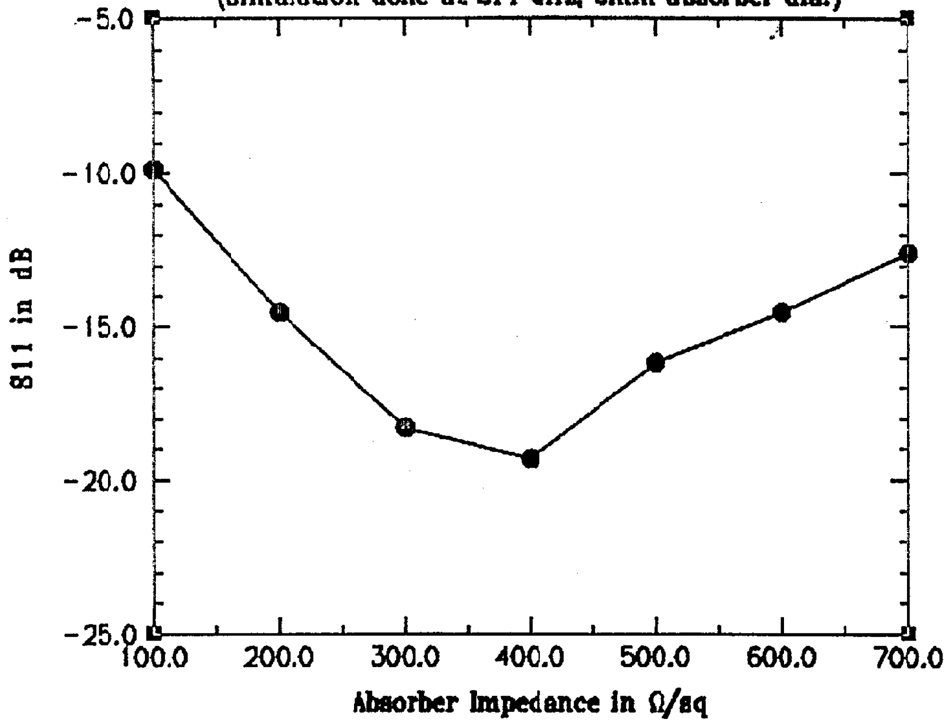
Cavity front and backshorts	Efficiency
$\lambda/4$	0.93
$\lambda/2$	0.35

Crosstalk: $< 4\%$ TE_{11} radiation leak out of the cavity

Caltech

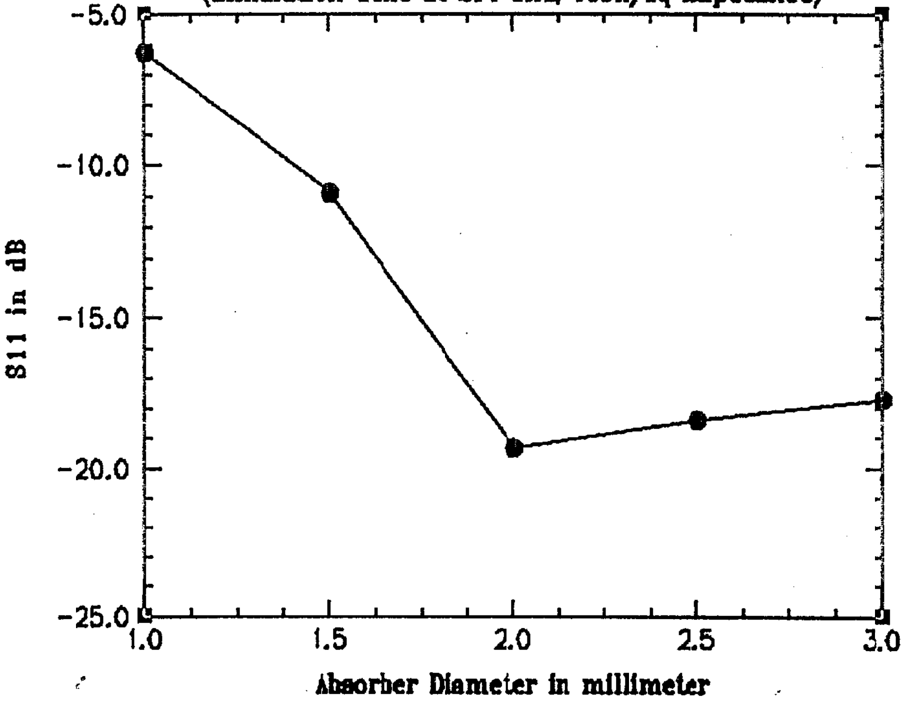
Return Loss Vs. Absorber Impedance

(Simulation done at 214 GHz, 2mm absorber dia.)



Return Loss Vs. Absorber Dia.

(Simulation done at 214 GHz, 400Ω/sq impedance)



Required Detector Performance for SPIRE

	Wavelength [μm]	NEP$_{Phot}$ [x10^{-17} W/√Hz]	τ [ms]	NEP$_{Bolo}\sqrt{\tau}$ [x 10^{-17} J]	NEP$^{a}_{Tot}$ / NEP$_{Phot}$
Photometer (1 fλ feeds)	250	8	30	0.7	1.04
	350	6	30	0.5	1.08
	500	5	30	0.4	1.12
Spectrometer (2 fλ feeds)	200 - 300	8	10^{b}	0.4	1.12
	300 - 670	5	10	0.3	1.25
Measured Bolometer (NTD Ge at 300 mK)	1000 - 1800^{c}	1.2	100	0.4	

[a] $NEP^2_{Tot} = NEP^2_{Johnson} + NEP^2_{Phonon} + NEP^2_{Amp} + NEP^2_{Photon}$.

[b] Optical time constant of absorber measured ≤ 4 ms.

[c] 2.5 mm absorber diameter with 200 μm grid spacing.

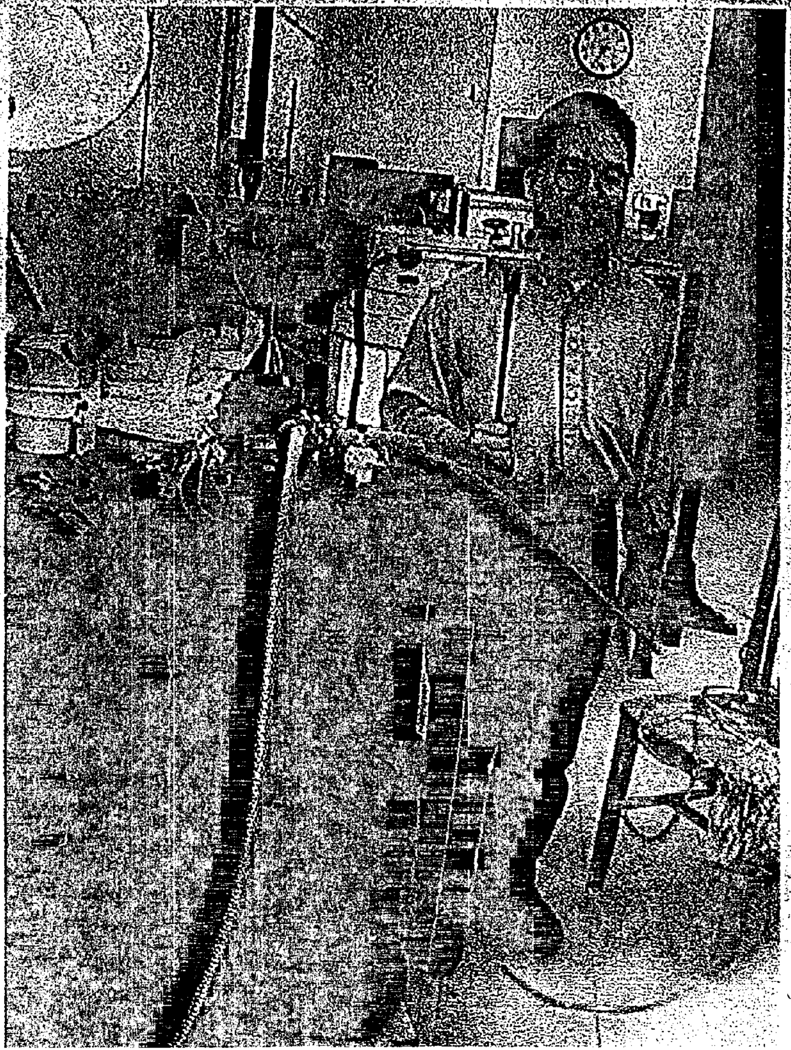
Current detector technology meets performance specifications

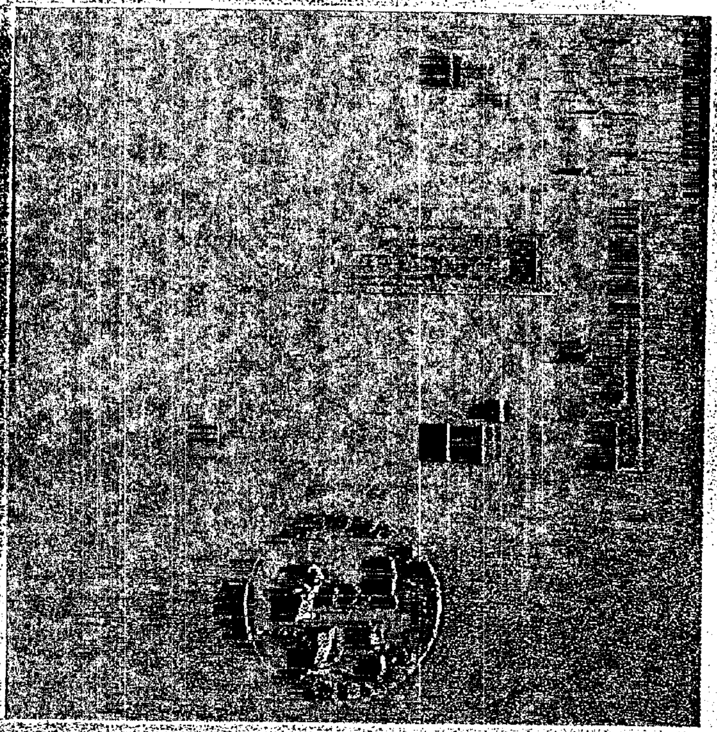
BOOMERANG SOUTH POLE BOLOMETERS (5/98)

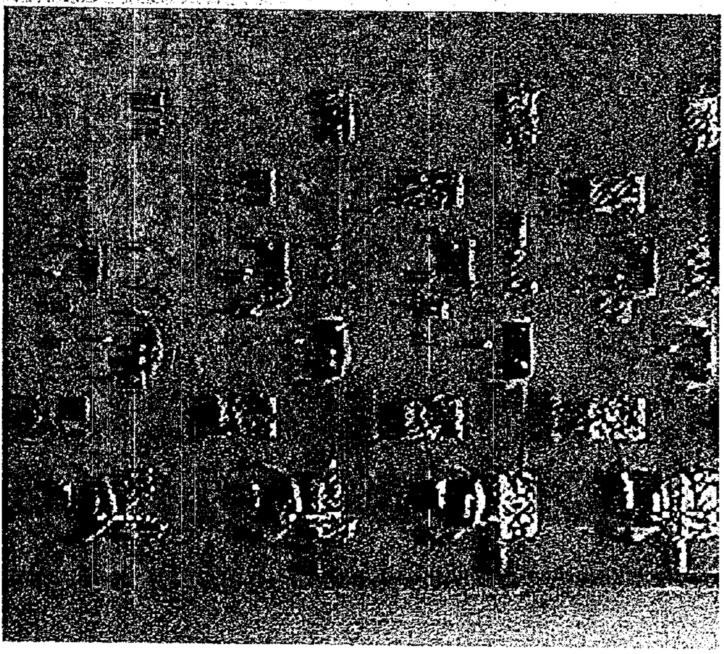
$\lambda = 750\,\mu m - 3.3\,mm$

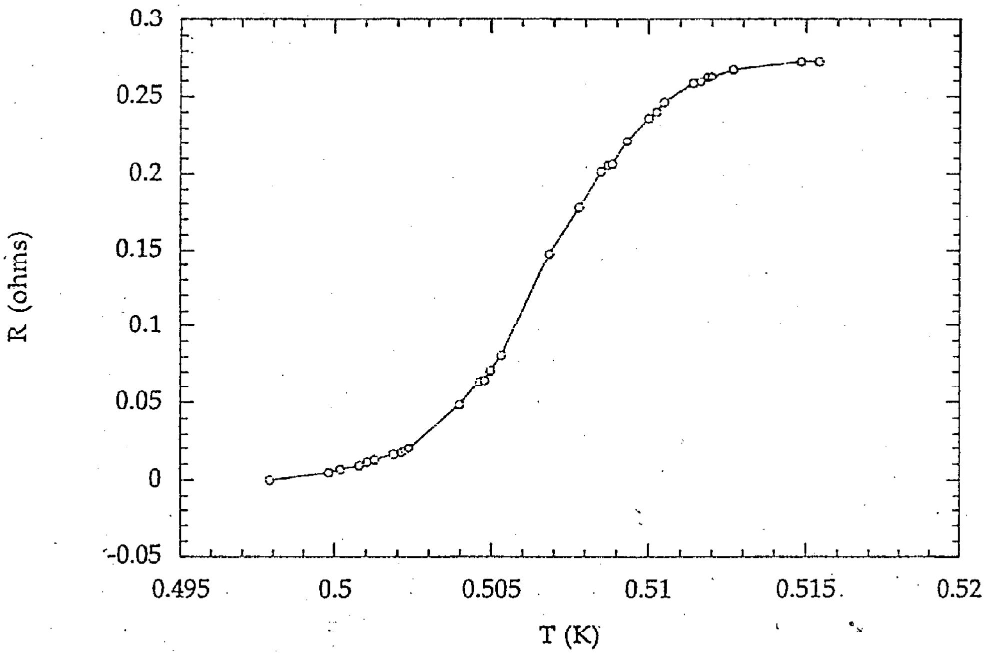
$NEP\sqrt{\tau} \leq 0.4 \times 10^{-17}\,J$

$\tau = (2 - 20)\,ms$ [optical]



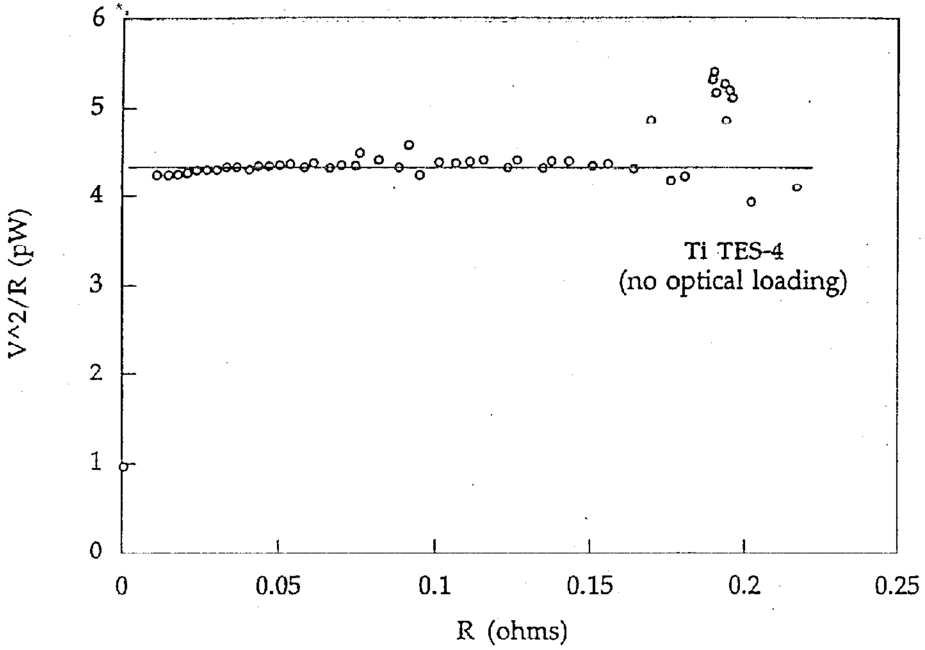






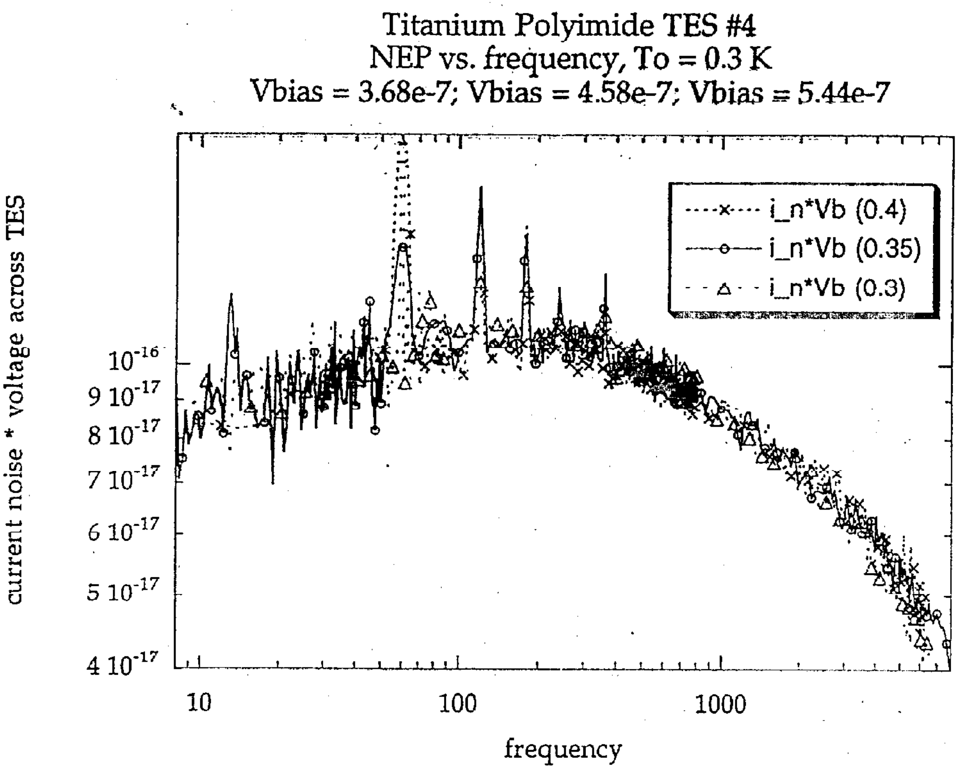
Polyimide TES #1
Resistance vs. temperature

Titanium Transition Edge Sensor:
Electrical heating power through the superconducting transition
(TES theory predicts a constant heating power)



$$G \sim \frac{P_E}{\Delta T} = 20\ pW/K$$

$$NEP_p = \sqrt{4kT^2 G} = 1.7 \times 10^{-17}\ W/\sqrt{Hz}$$



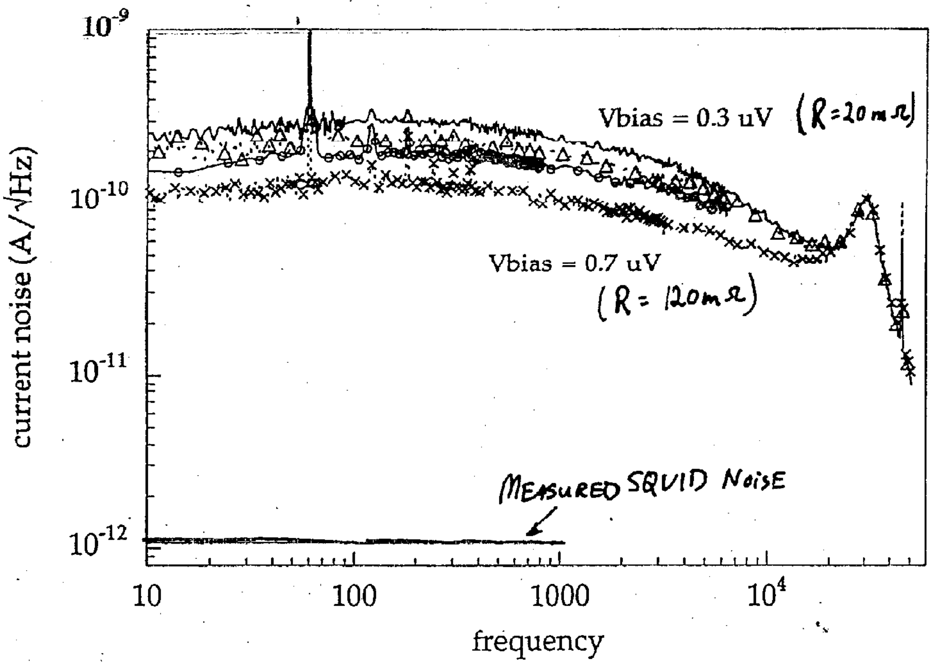
Titanium Polyimide TES #4
NEP vs. frequency, To = 0.3 K
Vbias = 3.68e-7; Vbias = 4.58e-7; Vbias = 5.44e-7

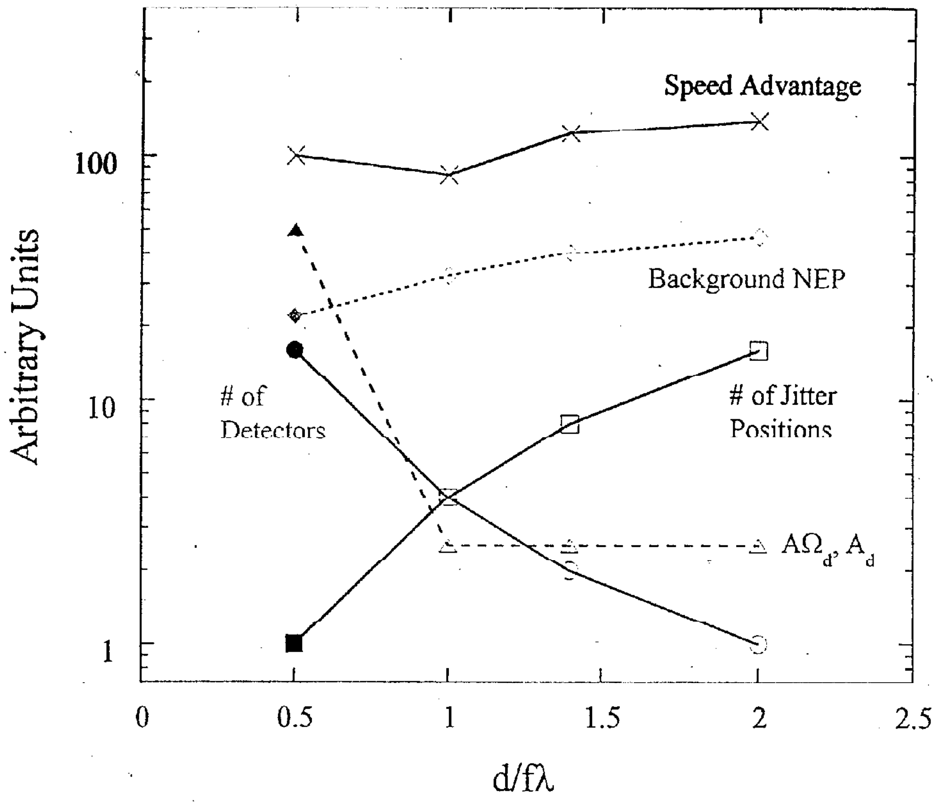
RECALL :

$$i_n^2 V_b^2 = \gamma 4 k T^2 G \left(\frac{\mathcal{L}}{1+i\omega\tau_0+\mathcal{L}}\right)^2 + \frac{V_b^2}{(1+\mathcal{L})^2}\left(\frac{4kT}{R}\right)$$

where $\mathcal{L} = \frac{P_b \alpha}{GT}$

Titanium Polyimide TES #4
Current noise vs. frequency





Tradeoffs in a Pointed Observation

4

Review of comparison between filled arrays and back-up option

Matt Griffin

Point source on-axis; no jiggle; background limited

S/N achieved for given integration time	2.0Fλ	1
	1.0Fλ	0.69
	0.5Fλ	0.70
Mapping speed [∝ (S/N)^2]	2.0Fλ	1
	1.0Fλ	0.48
	0.5Fλ	0.49

Point source on-axis; 7-point jiggle; background limited

		250 µm	500 µm
S/N achieved for given integration time	2.0Fλ	1	1
	0.5Fλ	1.03	0.77
Mapping speed [∝ (S/N)^2]	2.0Fλ	1	1
	0.5Fλ	1.05	0.60

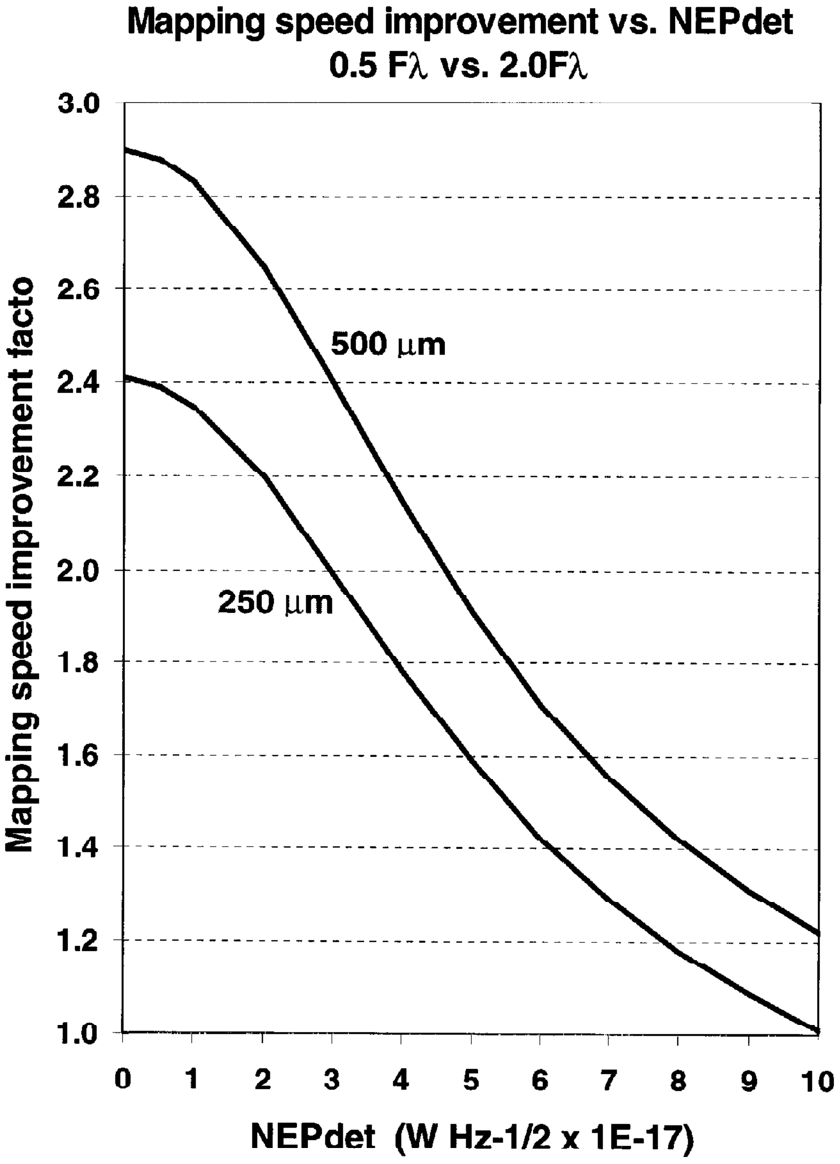
Extraction of a point source from a fully-sampled map

- Neighbouring pixels are co-added to improve S/N
- PSF is fully sampled in each case
- 64-pt jiggle map needed for 2.0Fλ
- 16-pt jiggle map needed for 1.0Fλ
- Background limited (detector NEP negligible)

		250 µm	500 µm
S/N achieved for given integration time	2.0Fλ	1	1
	1.0Fλ	1.25	1.28
	0.5Fλ	1.56	1.70
Mapping speed [∝ (S/N)^2]	2.0Fλ	1	1
	1.0Fλ	1.54	1.64
	0.5Fλ	2.42	2.92

As above, but detector NEP = 3 x 10^{-17} W $^{\mathrm{Hz}-1/2}$

		250 µm	500 µm
S/N achieved for given integration time	2.0Fλ	1	1
	1.0Fλ	1.22	1.25
	0.5Fλ	1.41	1.55
Mapping speed [∝ (S/N)^2]	2.0Fλ	1	1
	1.0Fλ	1.48	1.57
	0.5Fλ	1.99	2.40



	NEP$_{ph}$ (W Hz$^{-1/2}$ x 10^{-17}	
	250 μm	500 μm
2.0Fλ	11.1	6.2
1.0Fλ	8.3	4.6
0.5Fλ	5.5	3.1

5

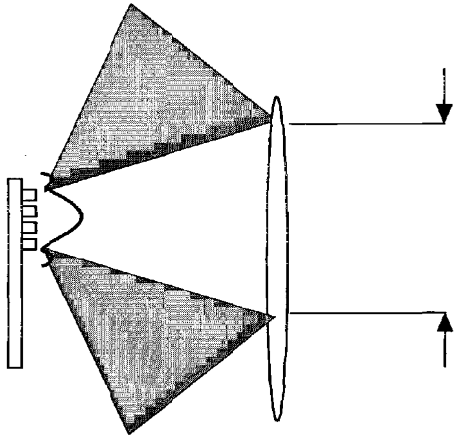
Implications for instrument design

Bruce Swinyard

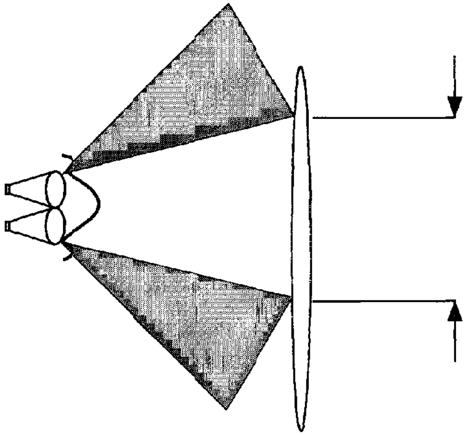
Implications for System Design

i) Optical design

0.5Fλ - baffles;
under sized pupil stop;
oversized mirrors;
severe straylight control constraints



Fλ - baffles;
under sized pupil stop (not quite so?);
oversized mirrors;

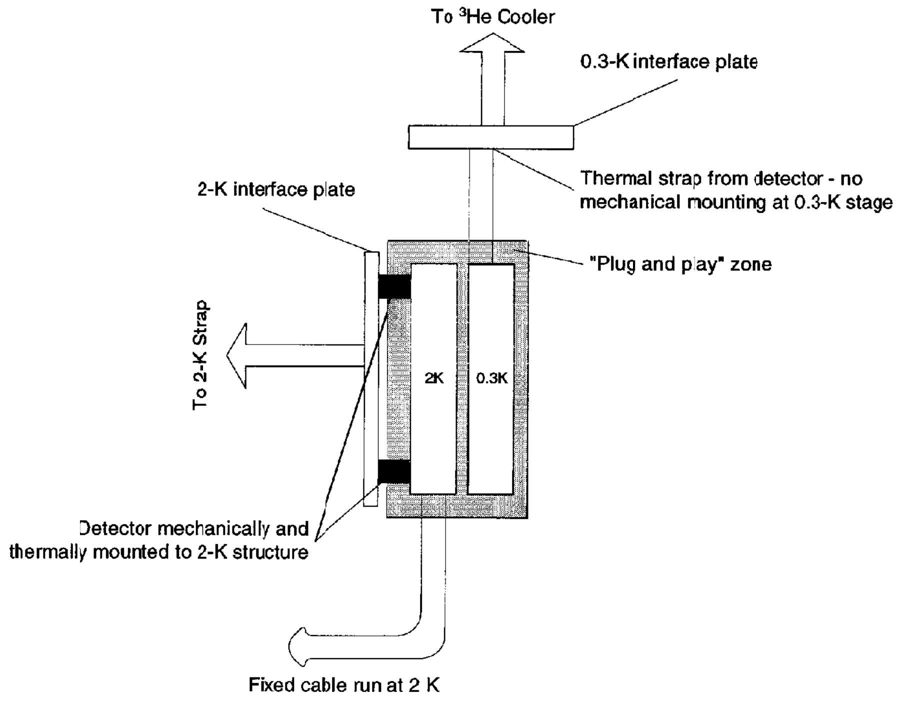


Implications for System Design

ii) Focal Plane mechanical/thermal design:

All options interface differently to 0.3 and 2-K stages.
All options have different power inputs to ^{3}He cooler.
All options have different numbers of wires to outside world.
The Fλ and 2Fλ horns have different focal plane mass compared to the filled arrays.

> common interface – is this possible



Implications for System Design

iii) Signal Processing and Control Electronics

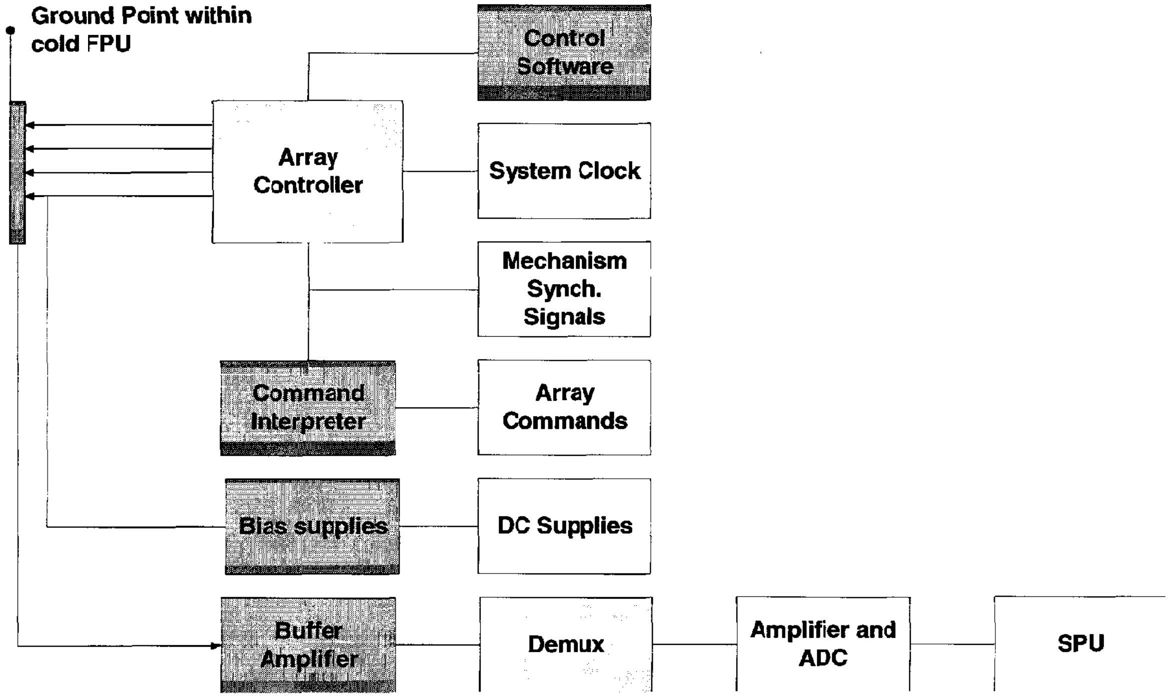
Here be dragons!

Issues are:

1. **Array controller – can we have same FPGA or ASIC with array specific software?**
2. **Grounding – desirable to specify single star point as early as possible; ESA will want this information, well, now!**
3. **Signal conditioning: filled arrays and Fλ have single ended read outs (?). CEA have a requirement for a buffer amplifier. What about JFET amplifiers?**
4. **Clock speeds/multiplexing – CEA ~ 30 kHz; SQUIDS? – both multiplexed at cold end – can the same demux scheme be used at the warm end? JFETs no multiplexers?**
5. **Interface to other hardware – can the array controller accept a single control signal from the chopper and FTS mechanisms to facilitate synchronisation.**
6. **Commanding – is it possible to agree a common commanding protocol – e.g. “on”, “off”, “observe” etc. to be used by all array types.**
7. **DC supplies – cannot support a plethora of different DC levels, especially if they need to have large currents.**

Implications for System Design

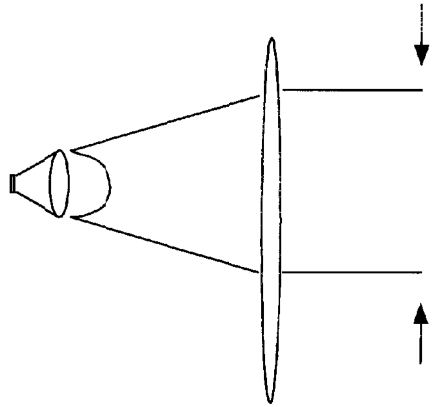
Signal processing ctd...



Implications for System Design

Optics Design Ctd....

$2F\lambda$ - over sized pupil stop; over sized mirrors.



Can we have a single optical design?

> probably except for the sizing of the pupil stop.

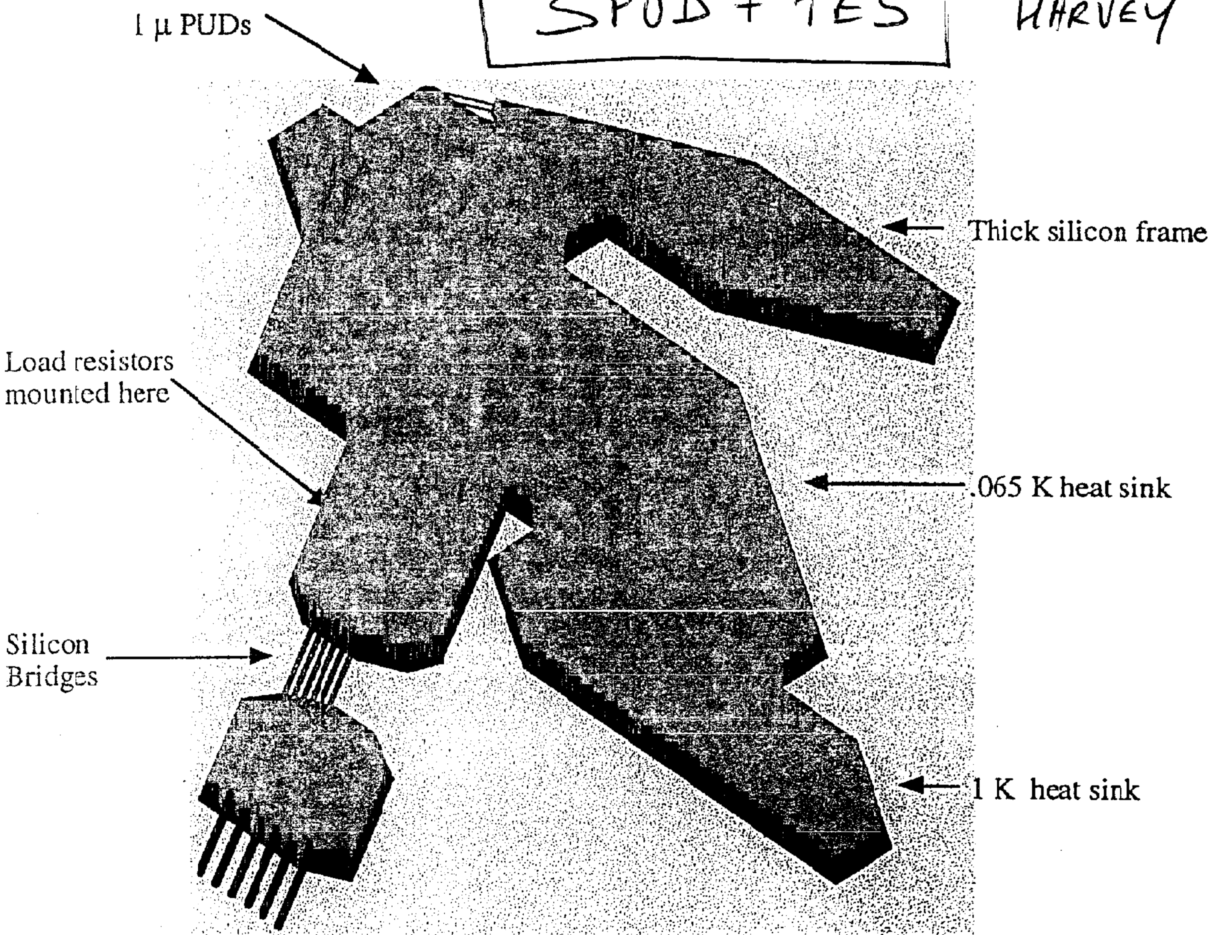
6

Detailed description of SPIRE instrument design for the different options

SPUD + TES	Harvey Moseley
BOLOCAM + TES	Jamie Bock
Backup	Colin Cunningham

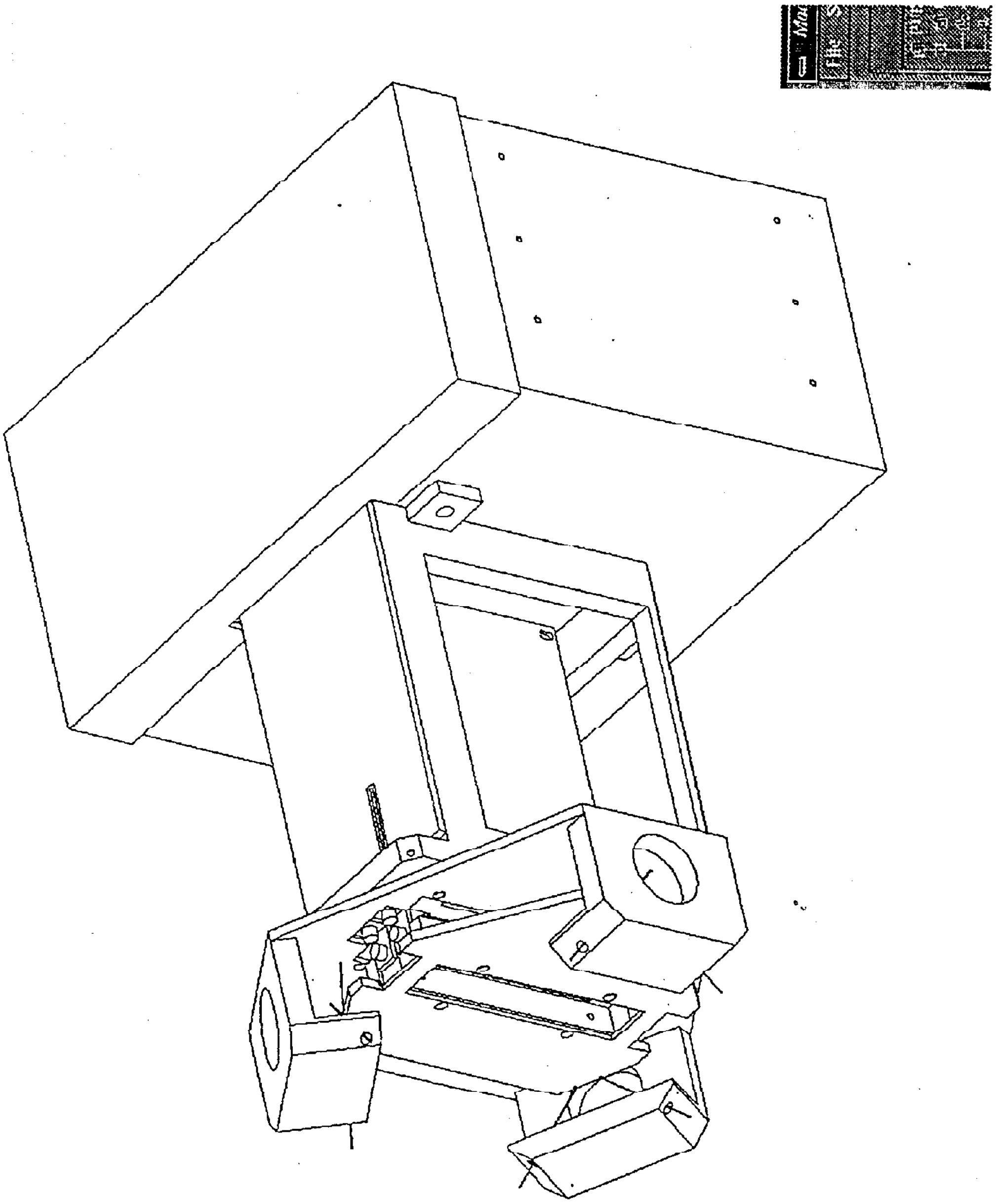
SPUD + TES

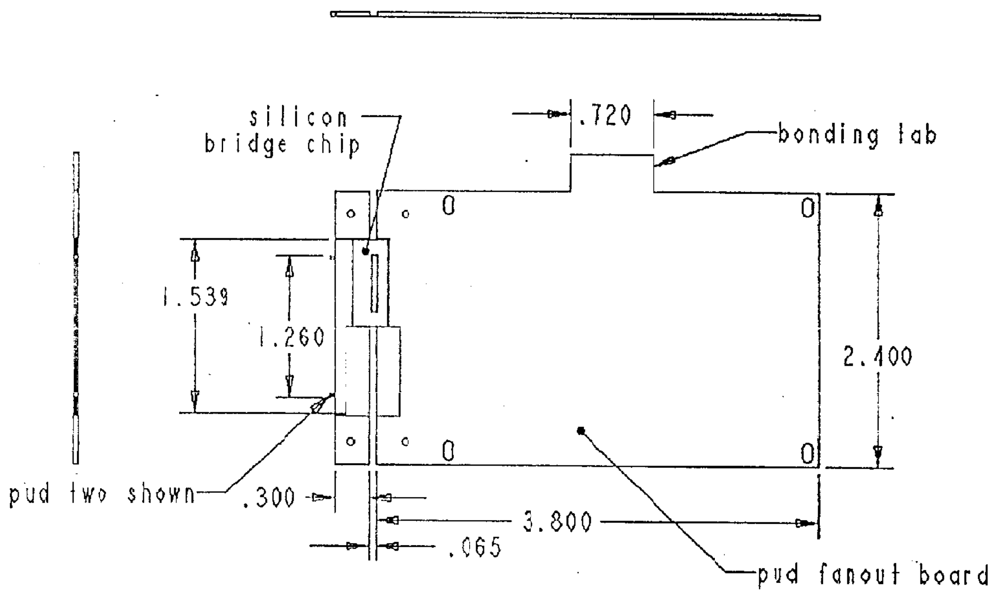
HARVEY MOSELEY



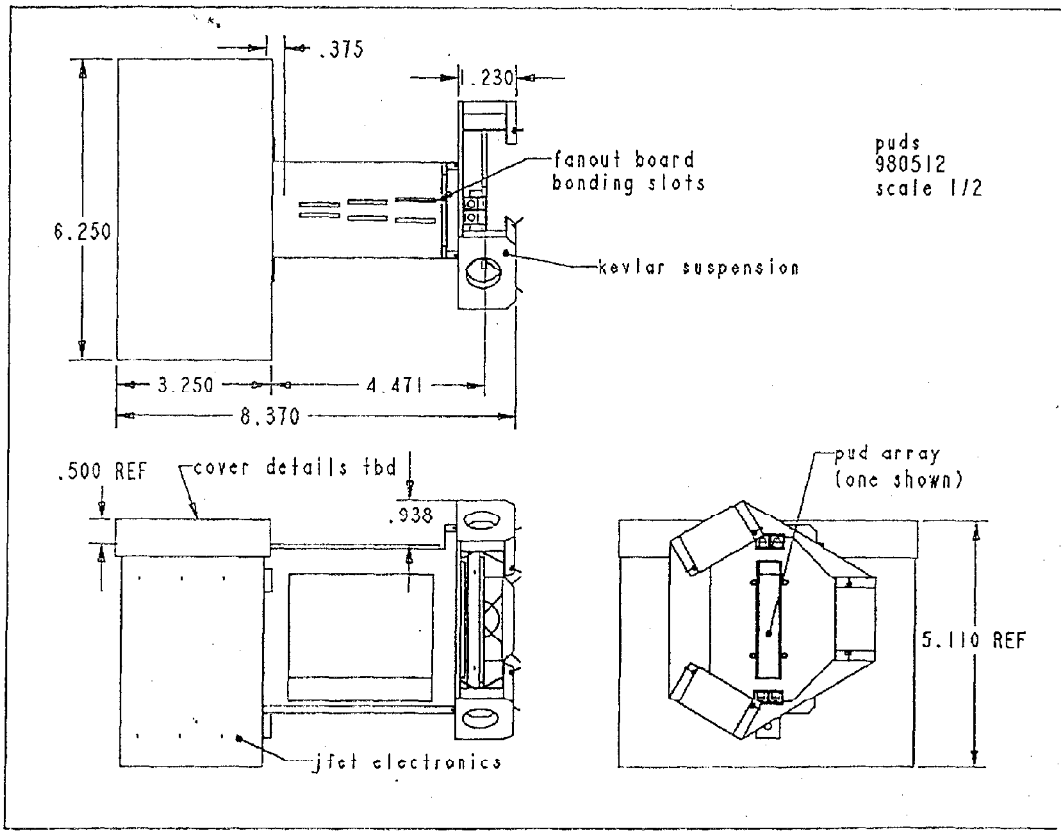
Artist's conceptual drawing of the PUD FOLDING PROCESS.

The 1 µm PUD support legs are bent to 90° to allow the thick portions of the supporting frame to be attached to heat-sink bars, which are, in turn, attached to cryogenic buss-bars with heat straps to the .065 K stage. The silicon bridges provide low thermal conductance electrical connection from the PUD array, to the JFET pre-amps located below the 1K stage.


File



SCALE : 1.000 TYPE : ASSEM NAME : PUD-2 SIZE : A



SCALE : 0.500 TYPE : ASSEM NAME : PUD-1 SIZE : A

Notes on Squid Electronics Block Diagram   5/1998   RGB

FPGA's could be XILINX or ALTERA SRAM based (reconfigurable)

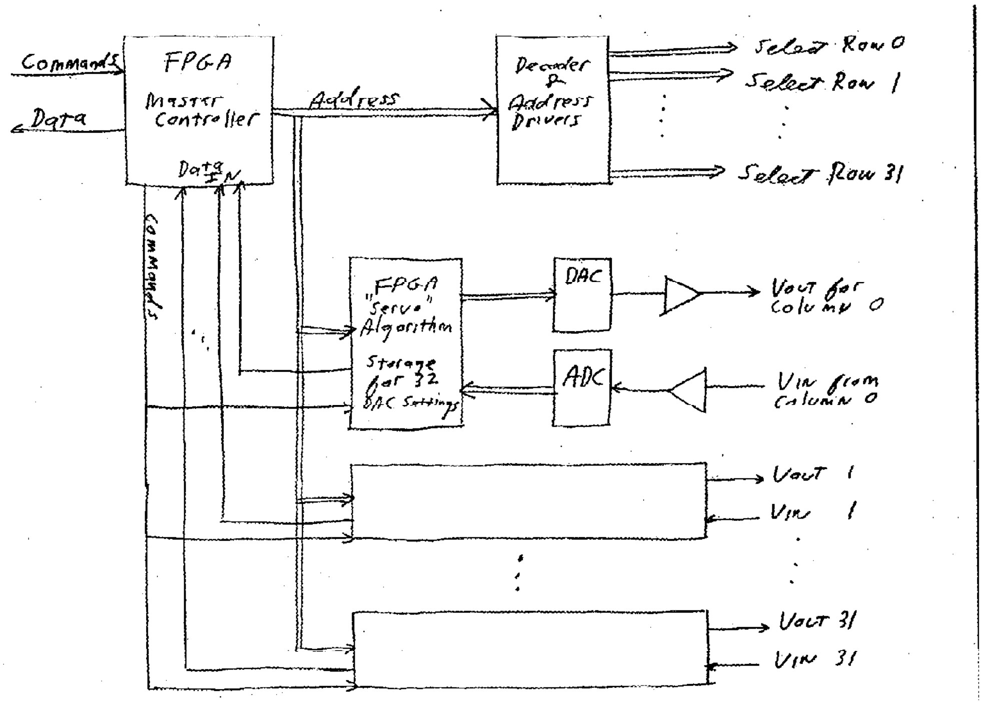
DAC could be AD568, 12-bit, settle in 35 nsec, 550 mW.

ADC could be AD9220, 12-bit 10 MSPS, 250 mW.

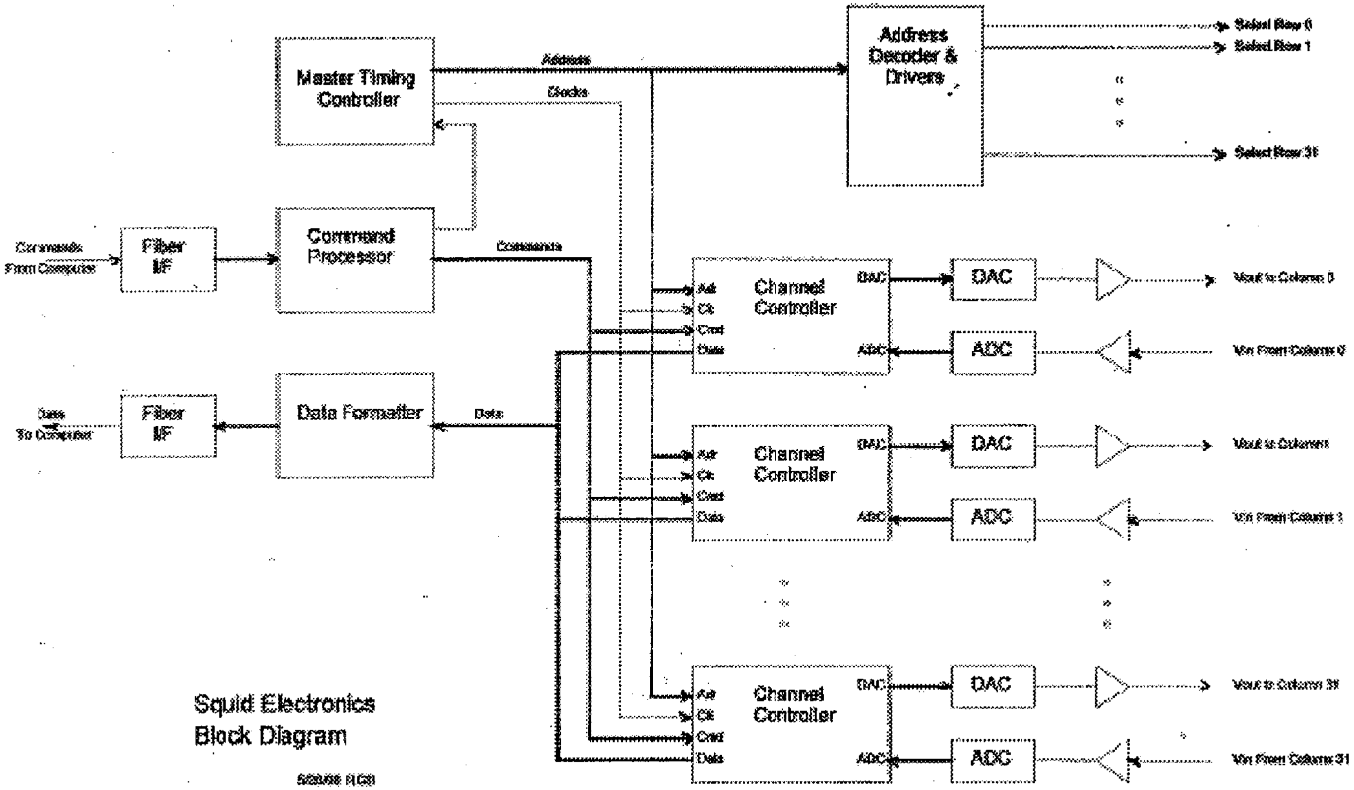
Buffer op-amps could be AD8041, 160 MHz, 25 mW.

Electronics would contain 32 ADC's/DAC's/FPGA's plus "Master" controller that generates the address and collects, formats and transmits the data (using fiber-optic interface??). The controller would also receive and distribute commands.

Data rate may be 16 bits X 1024 detectors X 100 KHz/detector = 1.64 Gbits/sec.



SQUID Electronics Block Diagram 5/1998 RGB



Squid Electronics
Block Diagram

5/29/98 RCS

DETAILED DESCRIPTION

JPL / CALTECH ARRAY OPTION

28 MAY 1998

SACLAY BOLOMETER MEETING

PHOTOMETER ARRAYS 1fλ (÷1.4 in mapping)

SPECTROMETER ARRAYS ~2fλ (÷1 in pointing
÷2.7 in mapping)

MECHANICAL DESIGN

COMPOSITE STRUCTURES: ARRAY, BACKPLANE, MUXES, FEEDS

PLANAR ASSEMBLY OF READOUT

MONOLITHIC ARRAY

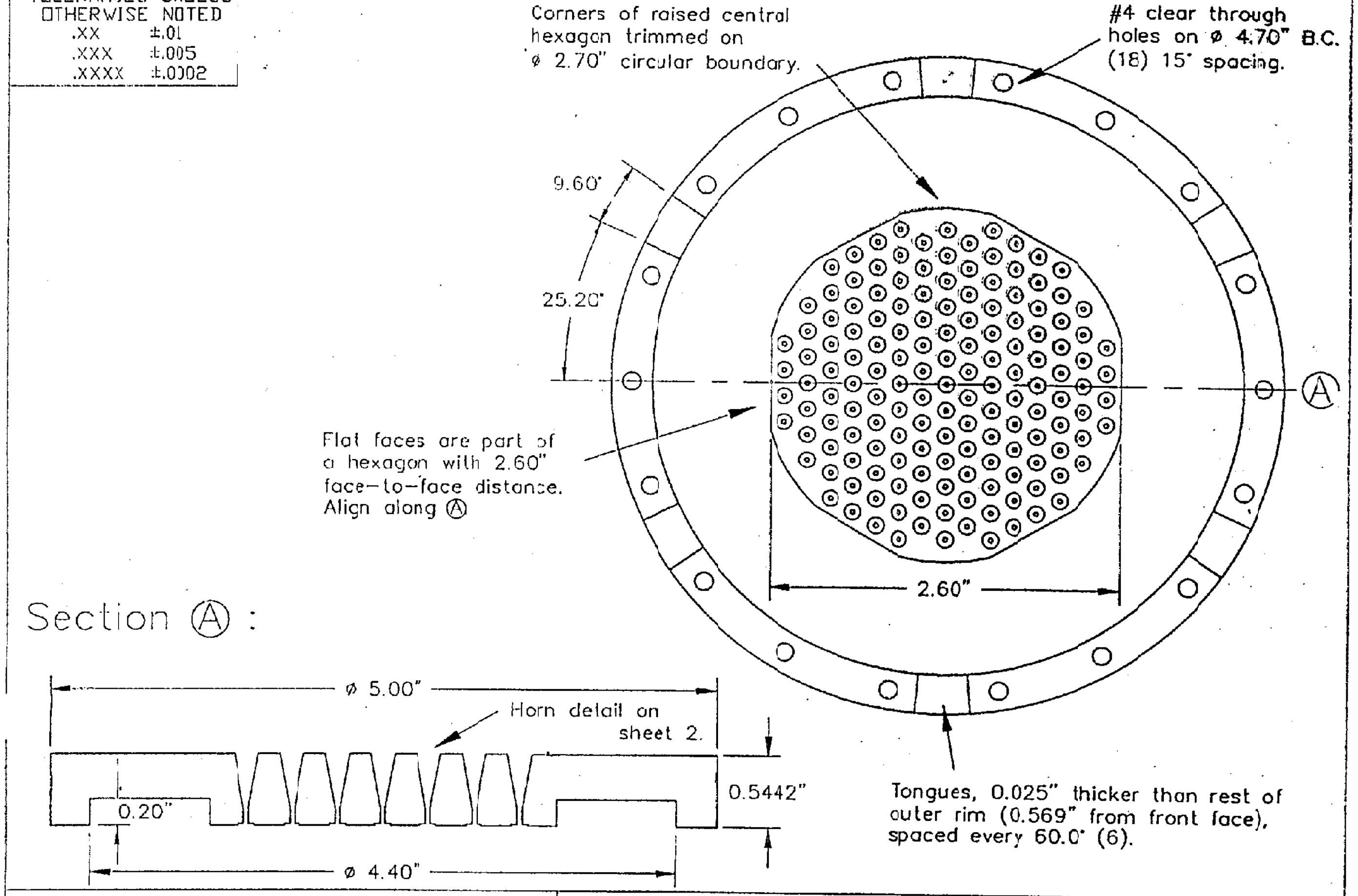
- → MECHANICAL / THERMAL SIMPLICITY
- ⇒ VERY TIGHT MECHANICAL TOLERACES (~25μm = 0.001")
- → REQ'S HIGH YIELD

* PLACEMENT OF FIRST STAGE SQUIDS *

ELECTRICAL DESIGN

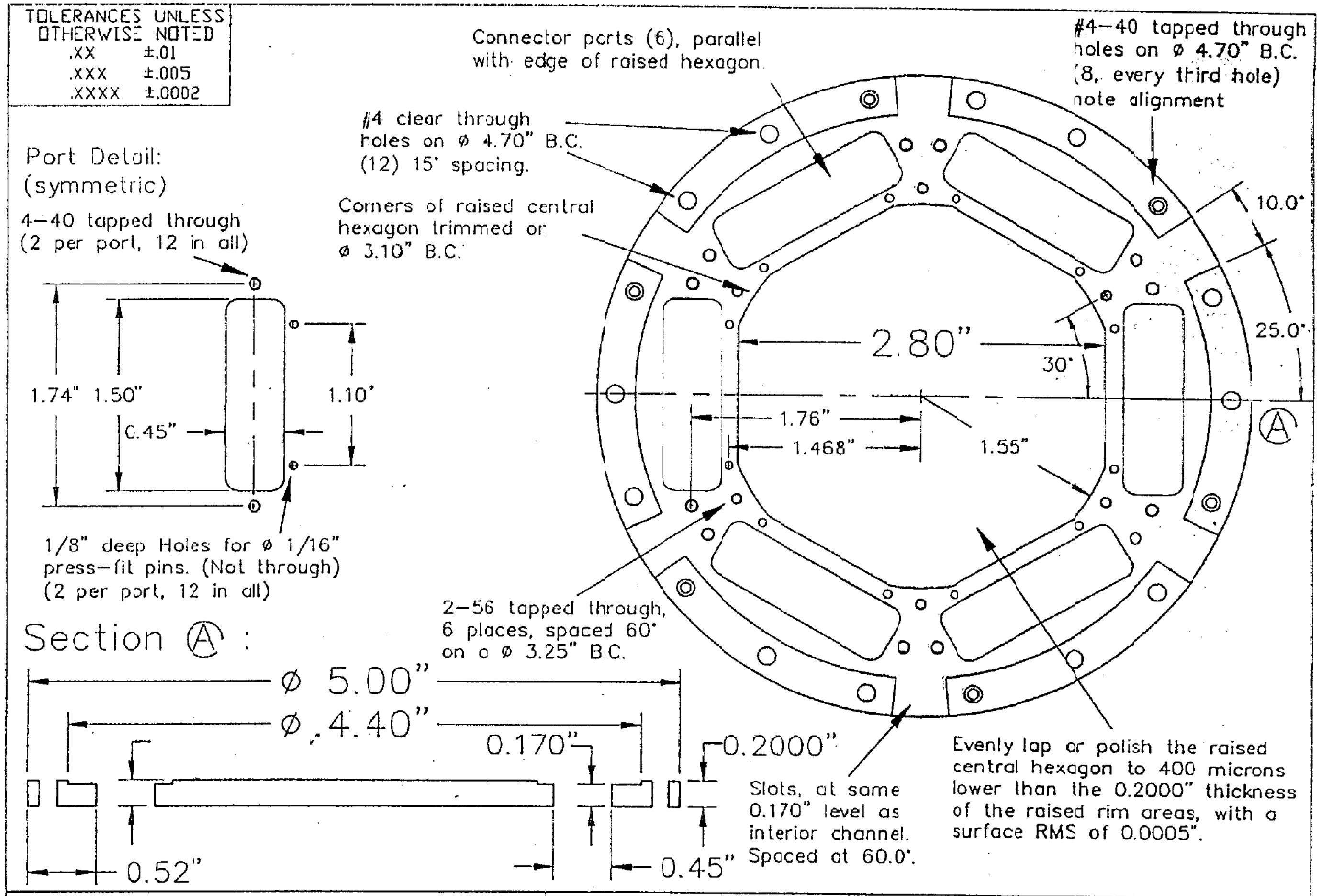
IDENTICAL TO SPUDs WITH 4x FEWER DETECTORS

TOLERANCES UNLESS
OTHERWISE NOTED
.XX ±.01
.XXX ±.005
.XXXX ±.0002



NOTES Material: Aluminum 6061
Align raised area and holes
on outer rim along Ⓐ

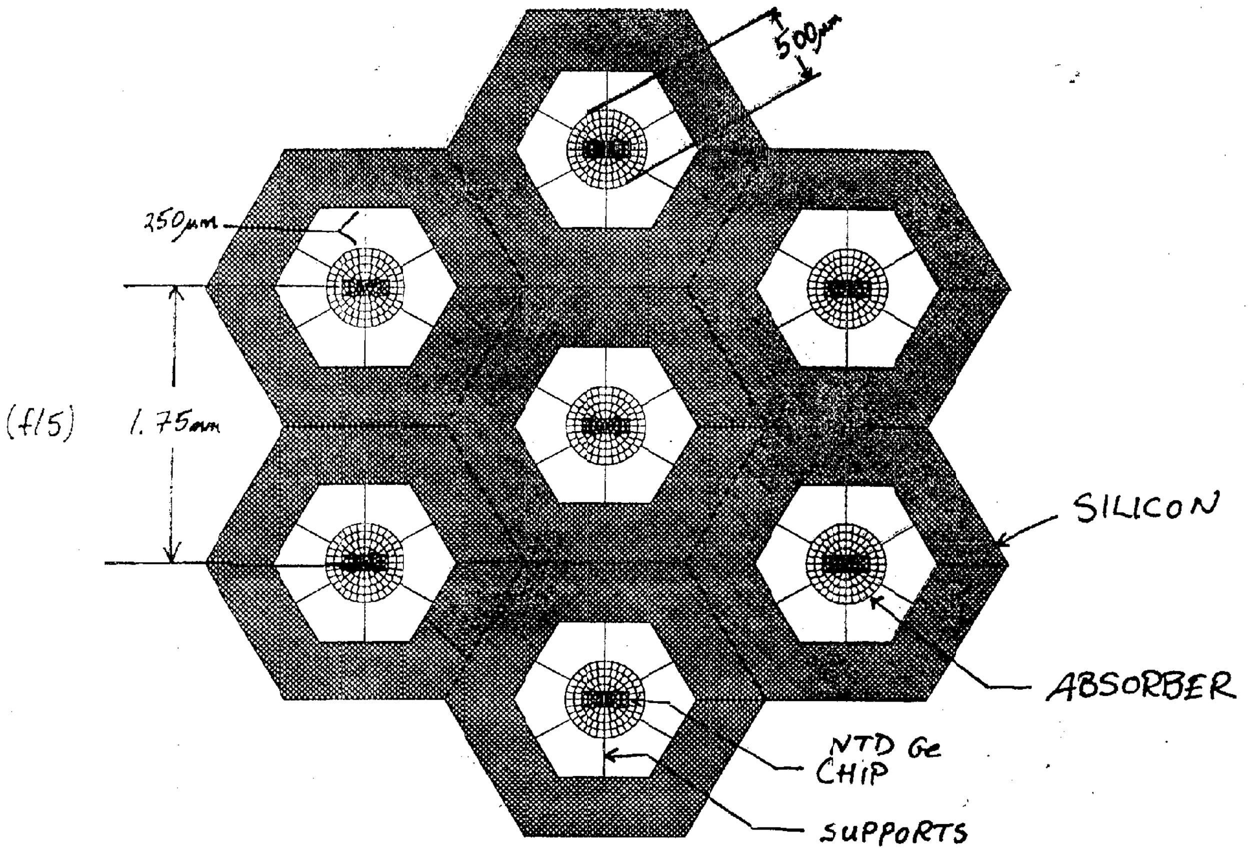
FCRAD FIVE COLLEGE RADIO ASTRONOMY OBSERVATORY
UNIVERSITY OF MASSACHUSETTS AT AMHERST
TITLE: Feedhorn Array (back) DWG: mntrtnr2 REV 2



NOTES Material: Invar 36 Alloy
Align raised area, port and holes on outer rim along Ⓐ.

FCRAO FIVE COLLEGE RADIO ASTRONOMY OBSERVATORY
UNIVERSITY OF MASSACHUSETTS AT AMHERST
TITLE: Wafer Mounting Ring | DWG: mntrtnr2 | REV 6

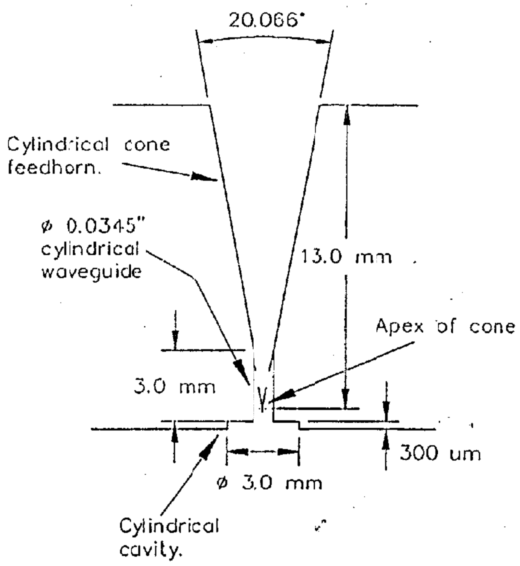
FIRST 350μm ARRAY LAYOUT



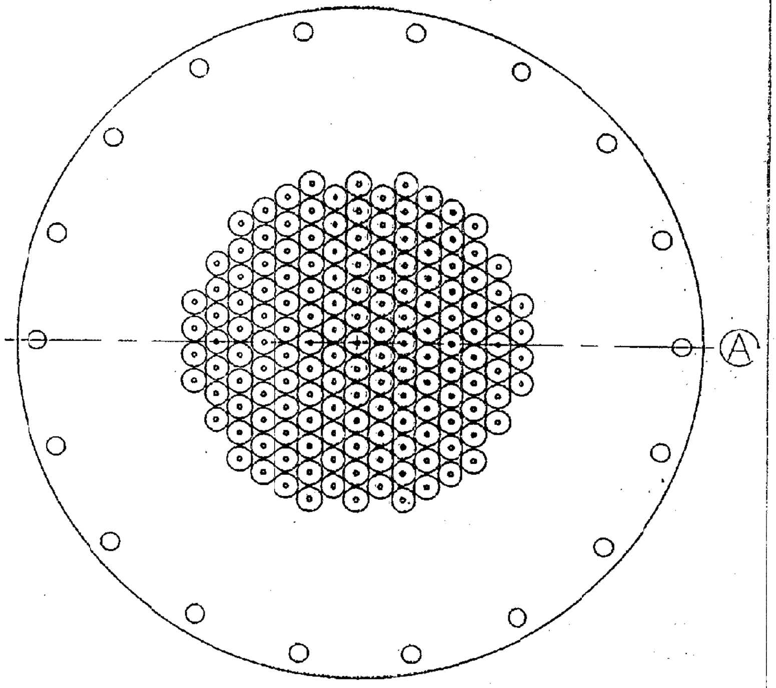
TOLERANCES UNLESS OTHERWISE NOTED

.XX	±.01
.XXX	±.005
.XXXX	±.0002

Horn Detail:



Front Face:



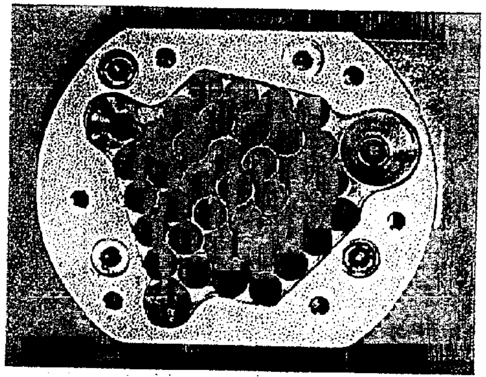
NOTES
Material: Aluminum 6061
Sheet 1 has general dimensions.

FCRAO FIVE COLLEGE RADIO ASTRONOMY OBSERVATORY
UNIVERSITY OF MASSACHUSETTS AT AMHERST

TITLE: Feedhorn Array (front)	DWG: mntrtnr2	REV 1

FIRST SPIRE
Back-up Option

COLIN CUNNINGHAM



- We need a back-up in case the filled arrays are not developed in time
- It will be based on a combination of proven technology from SCUBA and new developments from BOLOCAM:
    - Conical horns of $2F\lambda$ or $F\lambda$ aperture
    - Spider web & NTD Germanium bolometers
    - JFET amplifiers

Photometer arrays specification

- 3 hexagonally close-packed arrays, at F/5
- Single-mode horns of aperture 2Fλ for maximum aperture efficiency
- Bolometer speed: 3db frequency > 3Hz, target 5Hz
- Operating temperature must be no less than 300 mK

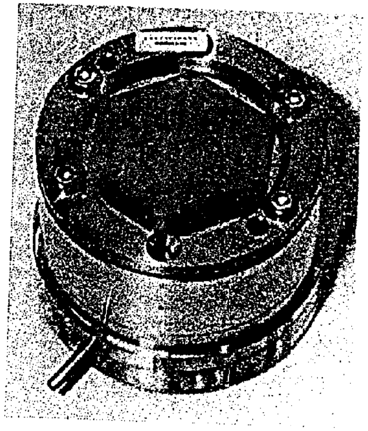
Wavelength (μm)	NEP x 10^{-17} (W $Hz^{-1/2}$)	Number of detectors	Max array dimension		
			(pixels)	(arcmin)	(mm)
250	12	61	9	4.7	22.5
350	9	37	7	5.1	24.5
500	7	19	5	5.2	25.0

FTS arrays specification

- 2 hexagonally close-packed arrays, at F/5
- Winston cones of aperture 2Fλ at centre frequency of band
- Bolometer speed: 3db frequency > 15Hz, target 20Hz
- Operating temperature must be no less than 300 mK

Wavelength (μm)	Optimised wavelength (μm)	NEP x 10^{-17} (W $Hz^{-1/2}$)	Number of detectors	Max array dimension		
				(pixels)	(arcmin)	(mm)
200-300	250	8 ??	37	7	~~5.1~~ 3.6	~~22.5~~ 17.5
300-670	350	5	19	5	~~5.2~~ 3.6	~~24.5~~ 17.5

FIRST SPIRE
Back-up Option

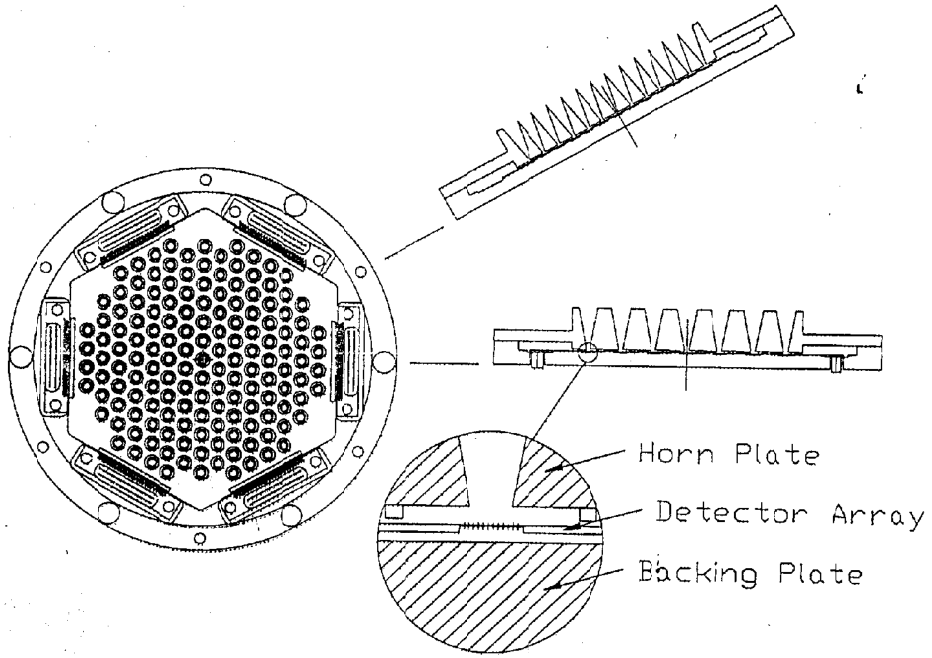


- Photometer arrays specification
- FTS arrays specification
- Focal plane layout
- Alternative Horns
- Read-out electronics
- Thermal model
- Observing modes
- Development & Risks

ROYAL OBSERVATORY EDINBURGH

UK Astronomy Technology Centre

Focal plane layout



ROYAL OBSERVATORY EDINBURGH

UK Astronomy Technology Centre

Alternative Horns

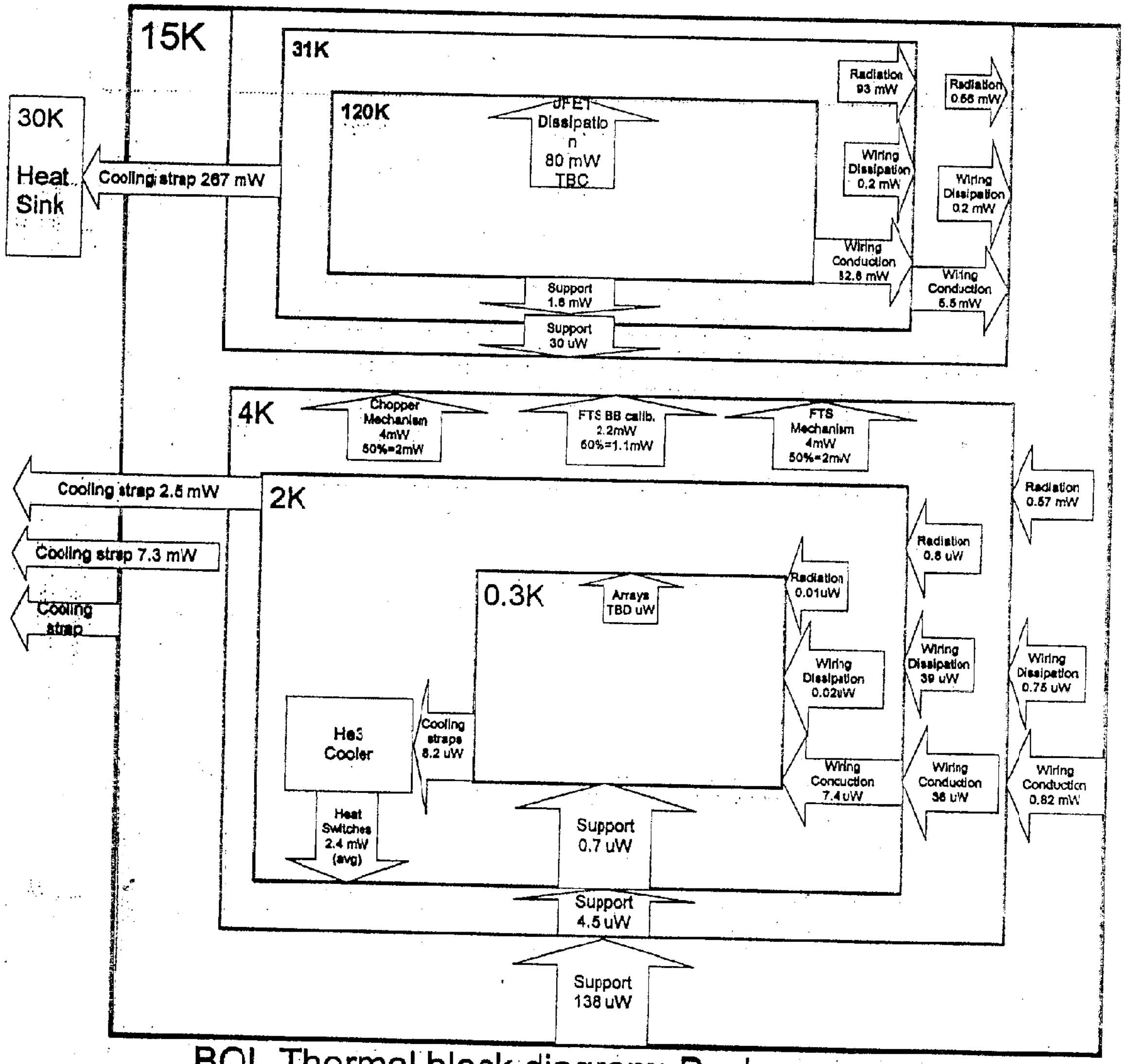
- BOLOCAM uses Fλ horns: we need to consider trade-offs here. Problem would be number of bolometers, wires and FETs

- Diagonal horns may be worth considering: they may be easier to manufacture & could have reasonable beams

Horn Manufacture

- Machined from one piece as in Bolocam- can this be done in aluminium for 250 µm array?
- Diagonal horns - probably need to be square array
- Electroformed as in SCUBA - but mass a problem
- Silicon Micro-machined

Thermal model



BOL Thermal block diagram: Back-up V1.0 Date: 29/12/97

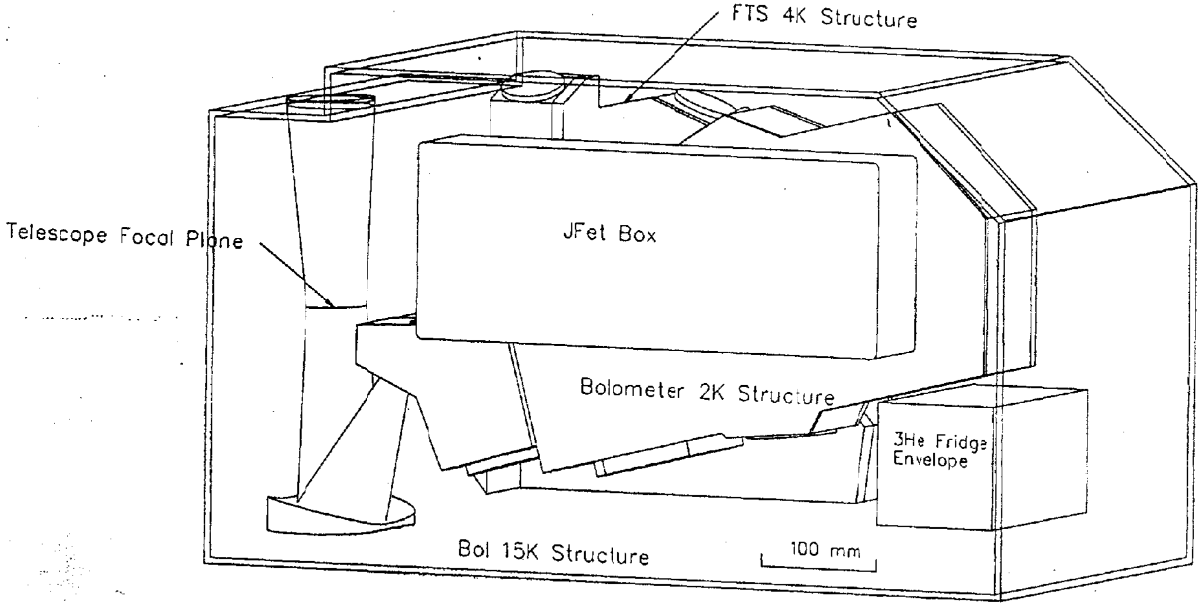
Read-out electronics

- Differential amplifiers with DC biased bolometers, and warm pre-amplifiers and multiplexers

Or:

- Bolocam technique of AC bias at about 1kHz
  - Both options require a pair of JFETs per bolometer, at about 100K
  - Cables must go from 0.3K to 100K, via 2K, 4K and 15K heat-sinks, then back to 15K to output connectors
  - Careful thermal & electrical design needed to minimise EMI, Microphonics & Cross-talk

JFET amplifier box



Observing modes

- Photometry: Fine pointing correction
  - The telescope Airy pattern is not fully sampled, so photometry of point sources will need either small jiggled images, or fine adjustments of the telescope pointing to maximise photon collection
  - Alignment of 3 arrays is critical
- imaging
  - Take a set of observations with different telescope pointing offset

    or:
  - Jiggle the image on the arrays by small increments of the 2-axis chopping mirror

Development & Risks

Some development specific to the back-up option is needed:

- Focal plane design: Light-weighting, horn manufacture, array alignment, coupling to bolometer & telescope
- Cable, heat-sinks and connector design
- Heat strap to 30K, and light-tight thermal feed-throughs
- Load resistors
- RF filters
- FET box thermal & mechanical design - more added mass
- Bolometer speed for FTS arrays
- Temperature stability for Ge bolometers compared with TES

Development & Risks

In two areas there is considerable advantage to the horn design over filled arrays:

- Data rate: Total pixel count for the back up is 160 compared with 2368 for filled arrays
  - Need for data compression much reduced
  - Signal processing unit will require considerably less computing power and memory

- Stray light: not quantified, but much easier to control with gaussian beam rather than 2π steradian illumination; but note need for more wiring & thermal feed-throughs

CONCLUSION

Don't underestimate development & design work needed for the back-up option

If it is to be a real back-up, it must be ready for us to pick it up when the filled array options are finally evaluated

7

On-board data processing requirements and algorithms

This item was deleted and partly covered in the FTS Group meeting on May 29

8

On-board calibrators

Harvey Moseley

IR Sources

Functions:

1) Absolute flux calibration
   e.g. FIRAS, Voyager IRIS

2) Relative flux standard
   IRAS, DIRBE, ...

3) Temporal response/phase monitor
   Proposed for ASTRO-F IRIS

Source Characteristics

1) Input Power
2) Response Time
3) Output Power
   Attenuation needs
4) Stability

Candidate Sources

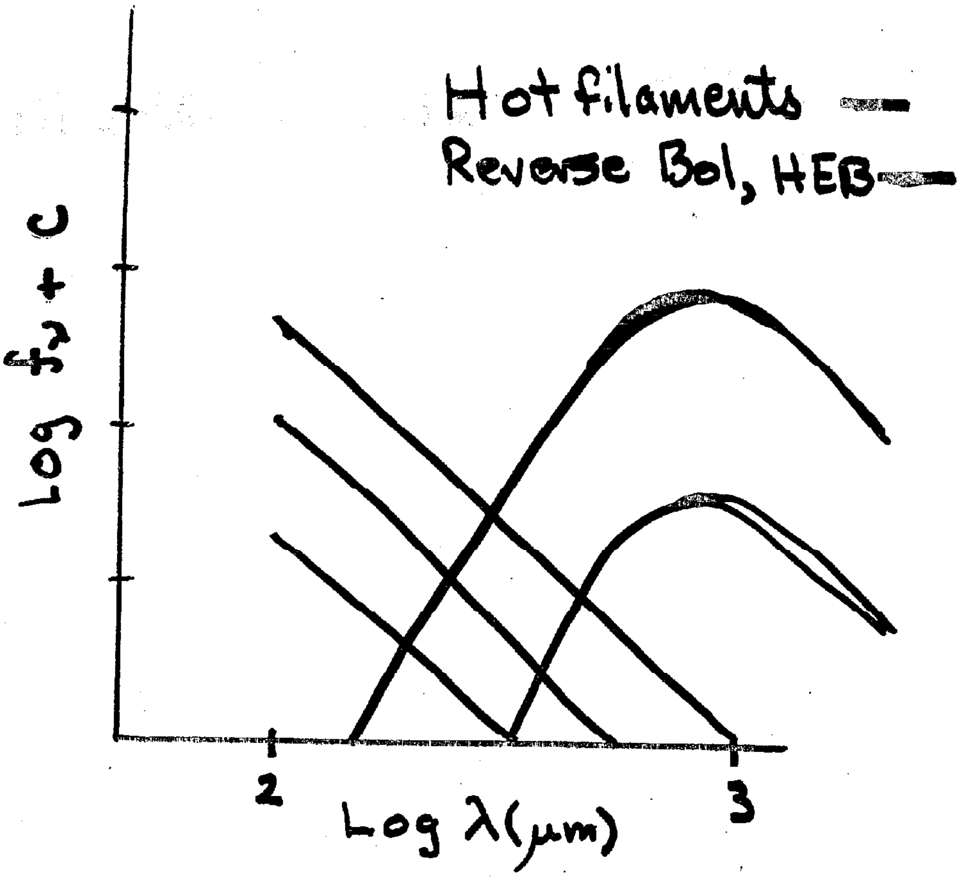
1) Micromachined Polysilicon filament
for $T \sim 800\,K$, $p \sim 1.5\,mW$,
$\tau \sim 10\,ms$? (based on earlier design)

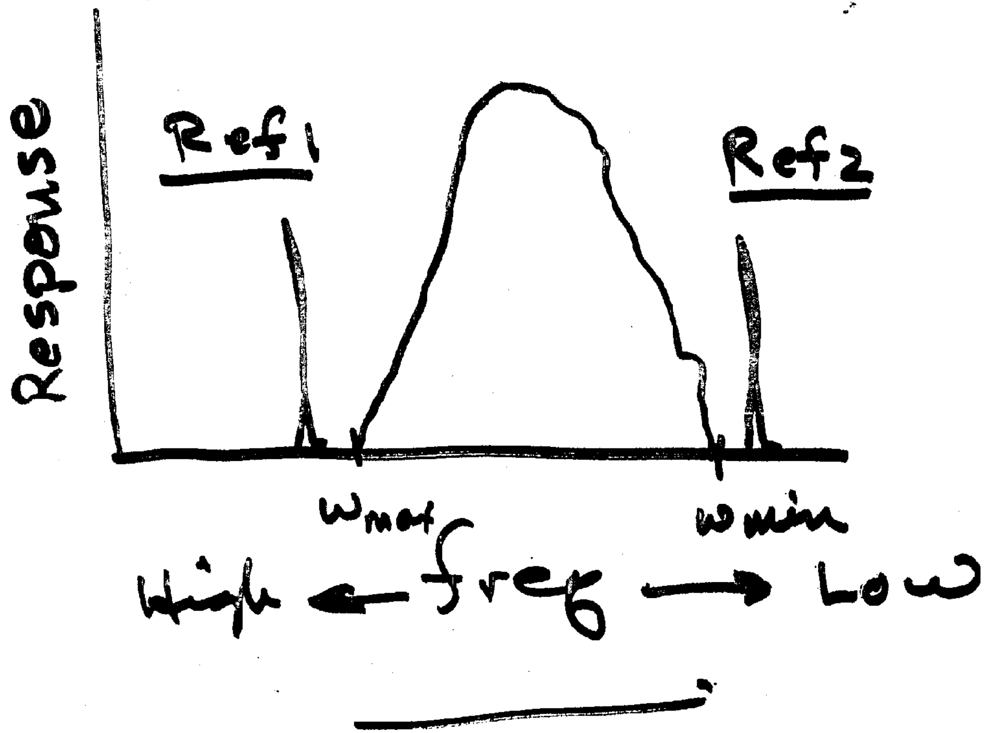
2) Reverse Bolometer
for $T \sim 10\,K$, $p \sim 10^{-6}\,W$,
$\tau \sim 1\,ms$? Large range of parameters possible

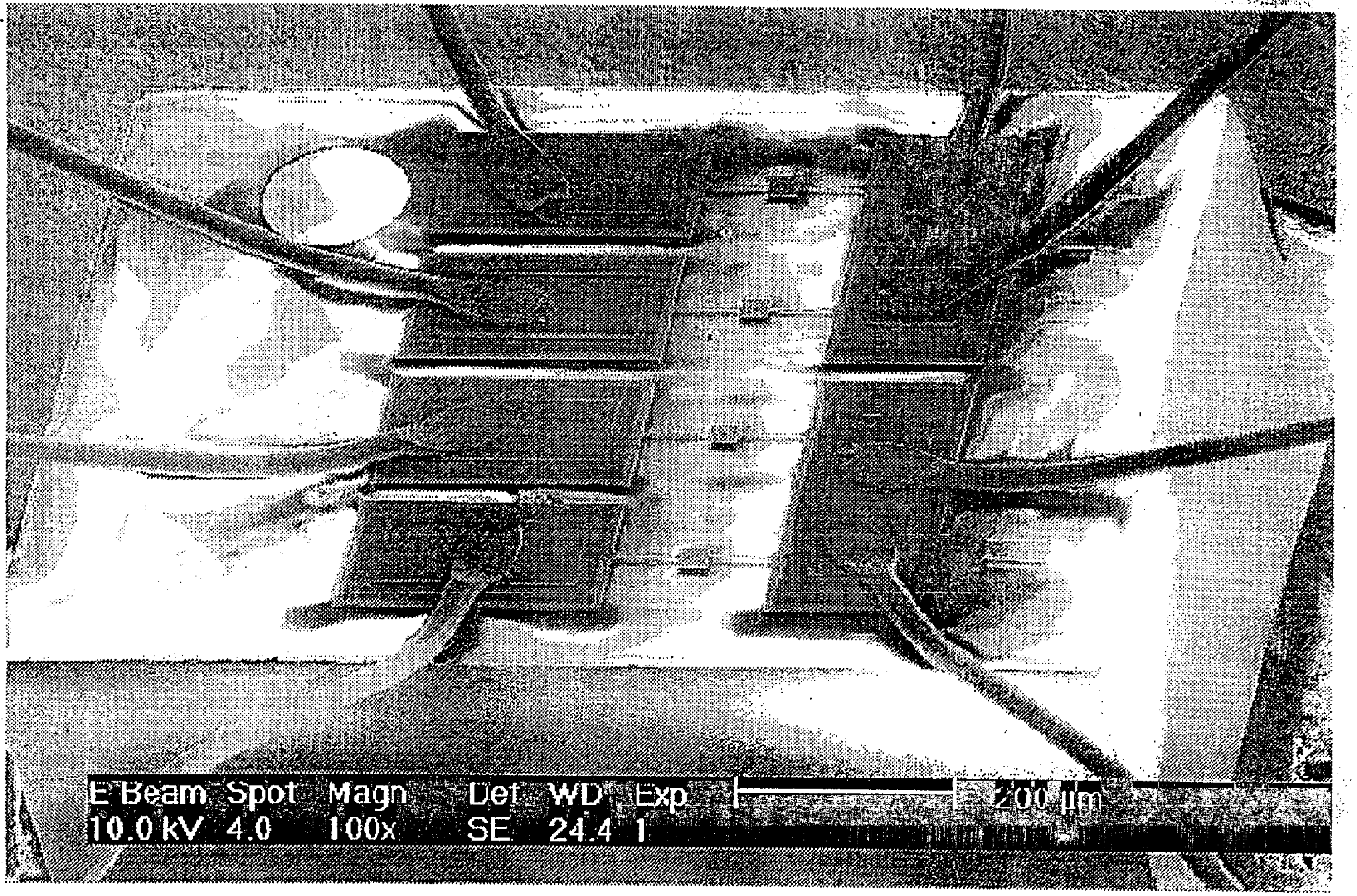
3) Reverse Hot Electron Bolometer
$4K \leq T \leq 50K$ $\tau \ll 1\mu s$, $P \leq 10^{-6}\,W$

Temporal modulation for flux control, linearity measurement, and phase monitoring.

Spanning SPIRE's Spectrum




Response
Ref1
Ref2
ω_{max}
ω_{min}
High ← freq → Low


E Beam Spot Magn Det WD Exp
10.0 kV 4.0 100x SE 24.4 1
200 µm

9

Conclusions from first day

See final conclusions

10

QMW array test facility

Bruno Maffei

BACUS

(**B**olometer **A**rray **C**alibration **U**nit for **SPIRE**)

B. Maffei, P. Hargrave, M. Griffin, P. Ade

Description of the calibration and evaluation facility to compare the bolometer arrays for SPIRE

I Specifications - Requirements
II Capabilities
III Description
IV Interfaces - Questions
V Schedule
VI Documentation
VII Conclusions

Specifications - Requirements

- Operating temperature of detectors : 300 mK
  (320 mK for GSFC and CalTech ?)

- Temperature stability : ? TBD

- Wavelength of operation : 350 µm
  (R = 3, 300 µm to 420 µm bandpass)

- Background level
  - Closed : < 10 pW (same as SPIRE)
  - With window : add NDF to reduce to same level

- Array
  - Size (pixels only) : 25x25 mm
  - Ultimately 24x24 pixels but for evaluation :
    Number of pixels to be tested ?

Description

Calibration sources

- Illuminator able to be modulated (up to 10 Hz)
  5x5 array of thermal sources + Neutral density filter
  + Edge filter to work in the R-J regime
- Uniform source: plate with variable temperature (up to 30 K)
- Window to the outside (for QMW purpose only)

Optics

Offner relay to illuminate uniformly the array with F/5 beam

Cryogenics

- Dewar with LN and L^4He tanks (space av. : 200 mm diam, 210mm high)
- Optics at 1.5 K (pumped L^4He bath)
- Detectors at 300 mK on extension isolated by Kevlar and linked to an ^3He fridge

Electrical connections

- 3x 41 pins connectors + probably one 19 pins connector
- 41 pins connector for illuminator and JFETs
- 19 pins connector for thermometry + drives
- 41 pins connector for each read out syst. (CEA - GSFC/CalTech)

Data acquisition

P90 using windows NT and Labview.

Capabilities - Tests to perform

System closed (no optical input from outside)

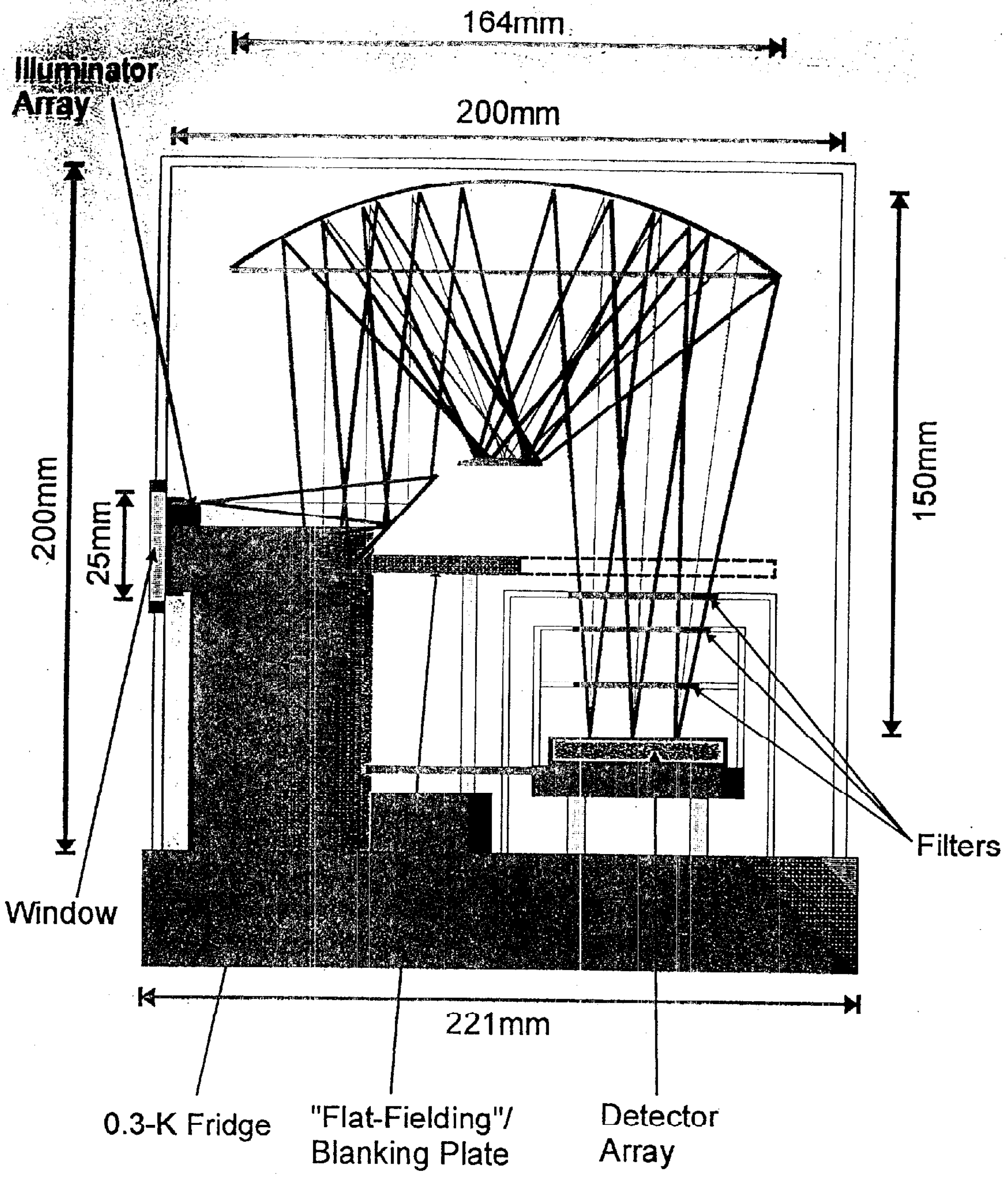
- V-Is with arrays fully blanked off or with uniform background
- Speed of response : illuminator modulation and/or γ-ray source
  X ray
- Flat fielding with blanking plate
- Cross-talk between bolometers
- Optical NEP: - Noise measurement
  - Responsivity: * dV/dQ for detector
    * Quantum efficiency

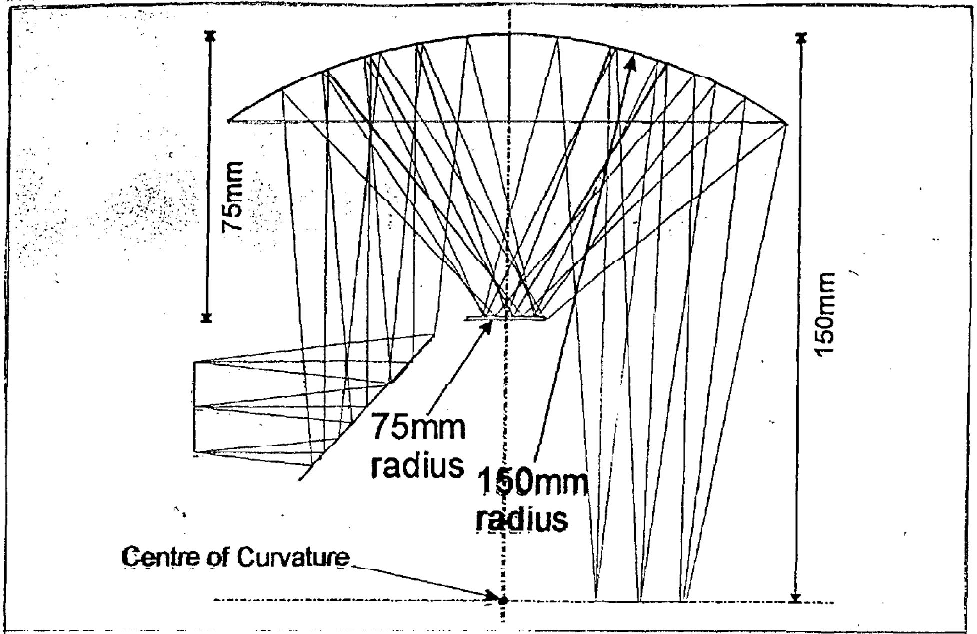
Optical input from outside (QMW only)

- Spectral response
- Fringing between optical elements
- Calibration of detector responsivity (ext. black body)
- Calibration of illuminators in the facility
- Detector speed of response
- Connection to telescope simulator

Other

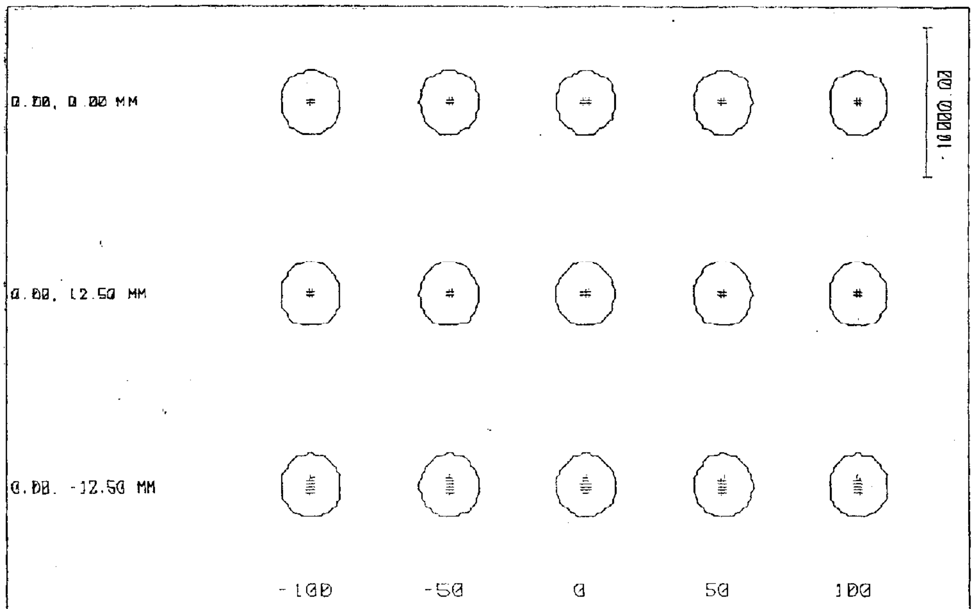
Conceptual Drawing for BACUS





3D LAYOUT

F5 OFFNER RELAY FOR BACUS - OPTIMISED 25X25MM
TUE MAY 26 1998



SURFACE: IMA

THROUGH FOCUS SPOT DIAGRAM

F5 OFFNER RELAY FOR BACUS - OPTIMISED 25X25MM
TUE MAY 26 1998 SPOT SIZE UNITS ARE MICRONS.

FIELD	:	1	2	3
RMS RADIUS	:	79.305	95.821	273.424
GEO RADIUS	:	142.294	142.793	488.675

AIRY DIAM : 4293 REFERENCE : CHIEF RAY

Description-Interfaces-Questions

(Not exhaustive list - To be answered as soon as possible !)

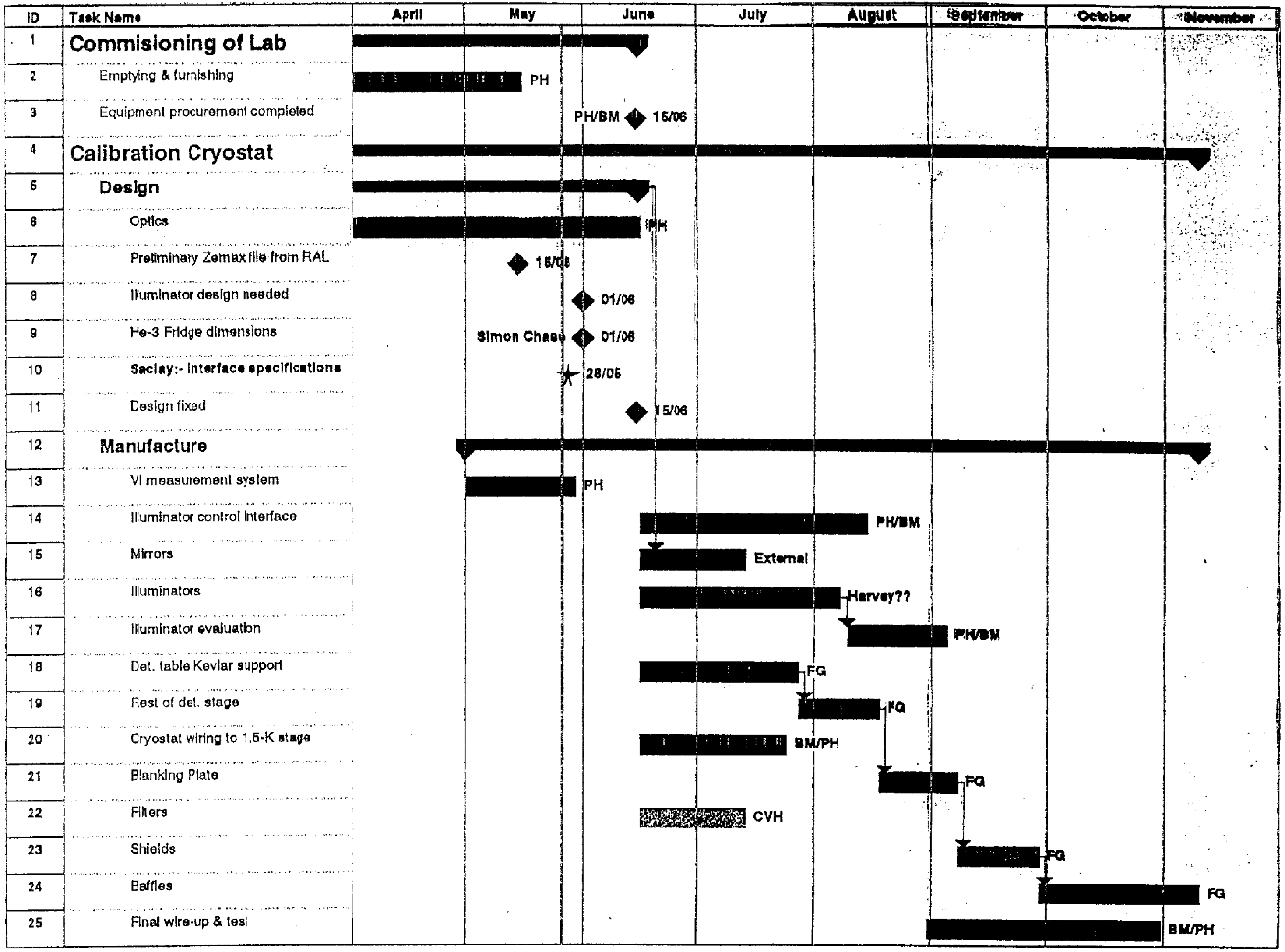
Electronics

- Cold and warm electronics for read out **systems will be provided by detector teams**
- The space available for the cold electronics will be approx. **25x25x50 mm (1.5 K)**
  Is that OK, could it be smaller ?
- **QMW will provide the wiring up to 1.5 K stage:** 41 pins **micro conn. for each syst.**
  How many bolometers can work with 41 wires ?
- **Detector teams will provide wiring from 1.5 K stage to cold electronics and array**
  Kind of wires to be used ? Max length / number of wires between array
  and cold electronics ? Wiring scheme ?

Mechanics **(space available at 300 mK ~ 60x60 mm)**

- We need precise description of interfaces between array and 300mK and 2 K stages
- Location of SQUIDs/CMOS/Multiplexers ?
- Apart from the array, is there something else which has to be at 300 mK ?
- Will the array team provide a baffling around the array (CEA) ?
- Size, weight of the devices
- Power dissipation ?
- Compatibility between different techniques ?

Schedule


ID
Task Name
April
May
June
July
August
September
October
November
1 Commisioning of Lab
2 Emptying & furnishing
PH
3 Equipment procurement completed
PH/BM
15/06
4 Calibration Cryostat
5 Design
6 Optics
PH
7 Preliminary Zemax file from RAL
16/05
8 Iluminator design needed
01/06
9 He-3 Fridge dimensions
Simon Chase
01/06
10 Saclay:- Interface specifications
28/05
11 Design fixed
15/06
12 Manufacture
13 VI measurement system
PH
14 Iluminator control interface
PH/BM
15 Mirrors
External
16 Iluminators
Harvey??
17 Iluminator evaluation
PH/BM
18 Det. table Kevlar support
FG
19 Rest of det. stage
FG
20 Cryostat wiring to 1.5-K stage
BM/PH
21 Blanking Plate
FG
22 Filters
CVH
23 Shields
FG
24 Baffles
FG
25 Final wire-up & test
BM/PH

Documentation

Draw up of detailed document (extension of **existing draft**)

- Performance requirements for arrays for SPIRE
- Evaluation criteria
- Description of test facility
- Description of all the tests to be done
- List of agreed/required inputs:
    - * Array hardware and read out
    - * External electronics
    - * Data acquisition requirements
    - * Manpower for test campaigns
- Schedule

Conclusions

- The facility design is basically OK but **many questions still need answers**
- Can we have essential information on its **detailed design** as soon as **possible**
  (contact needed over/within ~ 1 month)
- The schedule for the facility is achievable **if we get essential design information.**
  What is the schedule for prototype array production ?
- Support of tests/installation at QMW: **will be probably be essential:**
  Could the array teams provide such support ?

11

Development, test and evaluation schedule for selection in early 2000

CEA	Louis Rodriguez
SPUDs	Harvey Moseley
BOLOCAM/Backup	Jamie Bock

DEVELOPMENT PLAN OF CEA ARRAYS BEFORE SELECTION

L. RODRIGUEZ

LR.

98 BOLOMETER ARRAY PROCESS

STARTED MARCH 98

Fixed characteristics:

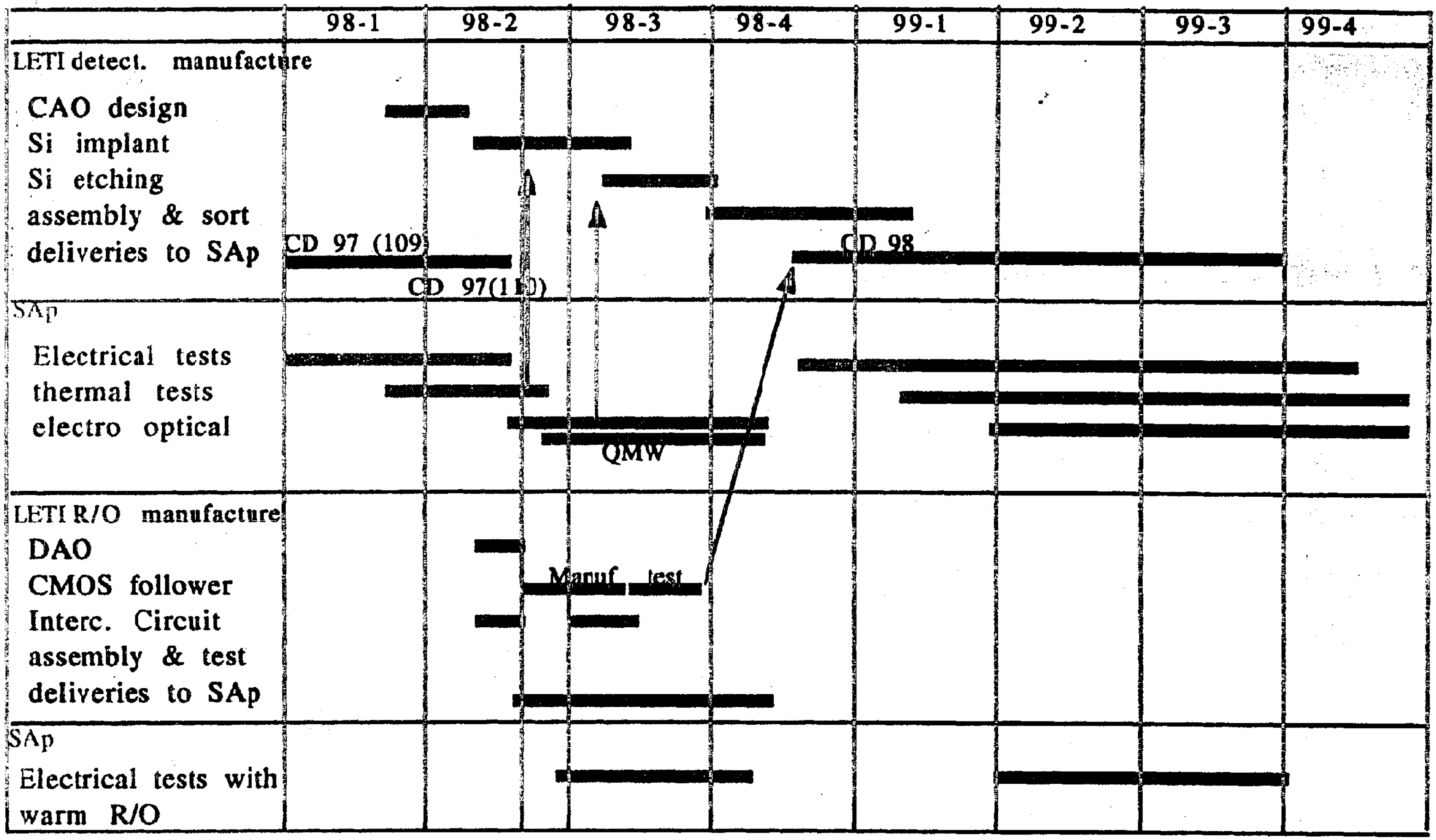
Complexity: 16 x16 pixels
Central wavelenght: 350µm
pixel size: 750 µm
filling factor: 87%
array size: 13 mm
thermometer type : P B(50%)
thermometer geometry: deep implant. channel and mesa
Interconnection circuit size : 19 mm
read out: MUX & cold follower hybridized by In bumps.

To Be Fixed :

absorber: TiN & WN (with passivation) (loops,'+',grid)
silicon grid filling factor: 70 % ----->40 %
quarter wave cavity mirror pattern size: effect on shorter wavelenght
silicon support beams characteristics: thermal time constant
mechanical interface: intermediate plate to 300 mK
R/O C thermal interface to 1.5 K: gold back surface & gold bondings.
300 mK shield and filter mount to install on BACUS

98 BOLOMETER ARRAY PROCESS

BOLOMETERS & READOUT ELECTRONICS



Technology Demo Phase:

Squid Amplifiers and Multiplexers:

WITHOUT DETECTORS

- **GAIN**
- **CROSSTALK**
- **NOISE (NECESSARY BUT NOT SUFFICIENT)**
- **SWITCHING CHARACTERISTICS**

→ **POWER DISSIPATION**

WITH DETECTORS

Fall 98

GAIN
CROSSTALK
NOISE
SWITCHING CHARACTERISTICS
INTERACTION WITH THE DETECTOR

Bolometers

TES

→ **Tc control**
→ **Transition quality**
in progress **Noise (phase slip lines, etc.)**

Pop-Up detector element

Summer 98 — **Thermal conductance**
Fall 98 — **Mechanical Properties**
Optical properties

Spr. 99.

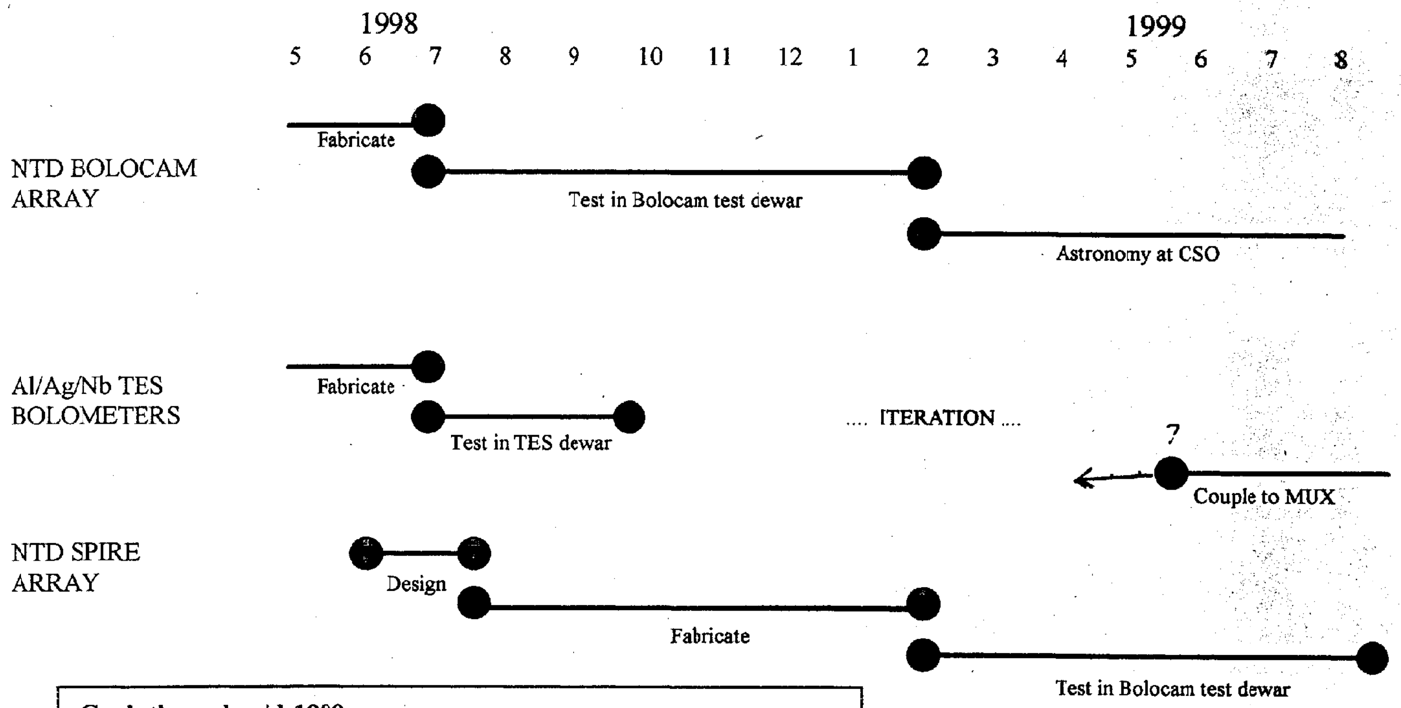
Absorption in free space vs Freq. (warm and cold)
Absorption in resonant structure vs. Freq. (warm and cold)
Temporal stability under storage conditions
Accelerated aging tests

Overall Focal Plane Assembly (some done at single row level)

Begin Summer '99

Sensitivity
Linearity
Frequency response (vs modulation freq)
Saturation behavior
Sensitivity vs wavelength
Crosstalk (focused beam response)
Optical and electrical

SPIRE DETECTOR DEVELOPMENT SCHEDULE -- BOLOCAM-STYLE BOLOMETER ARRAYS

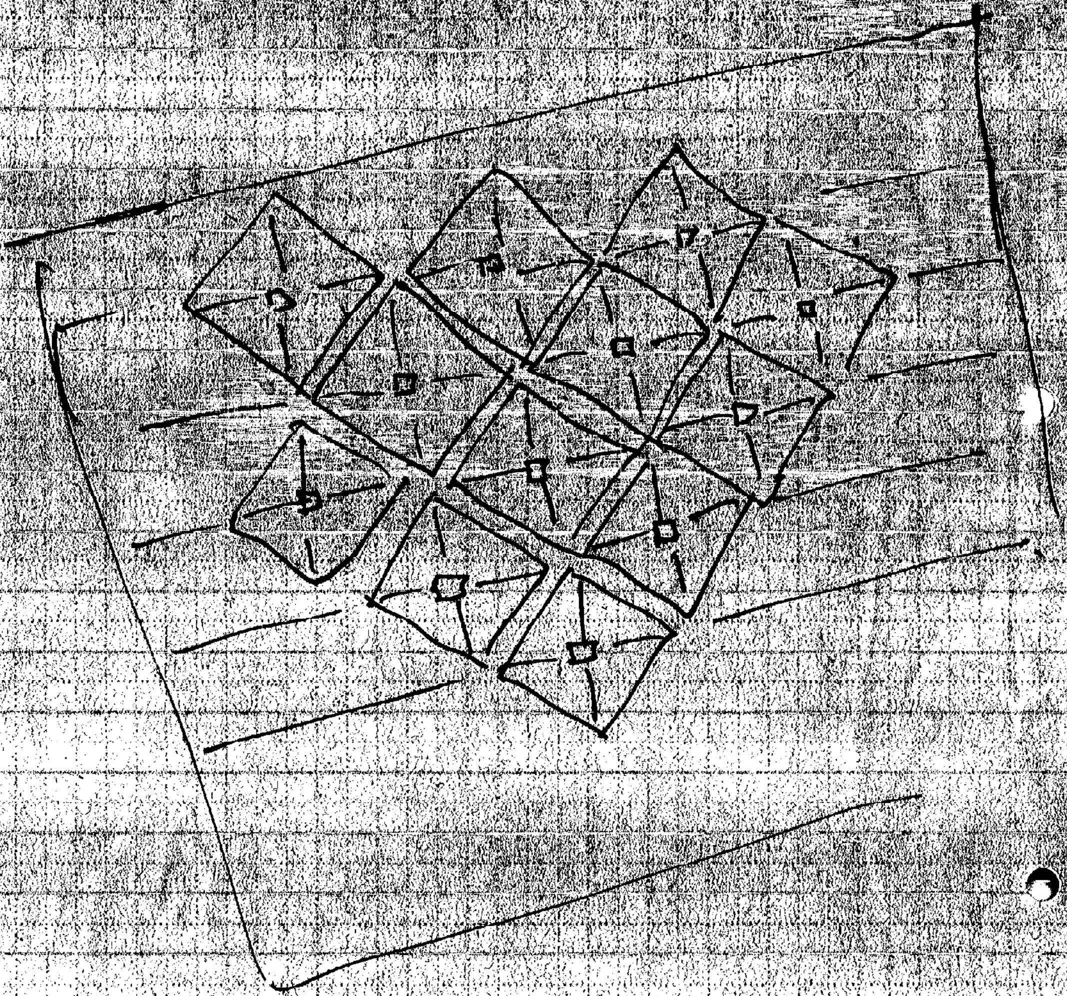


Goals through mid-1999:
- **Measure optical properties of FIR SPIRE arrays**
- **Operate millimeter array in a demanding science application**
- **Demonstrate single-element TES bolometers**

12a

Diagonal horn option for feed-horn arrays

William Duncan



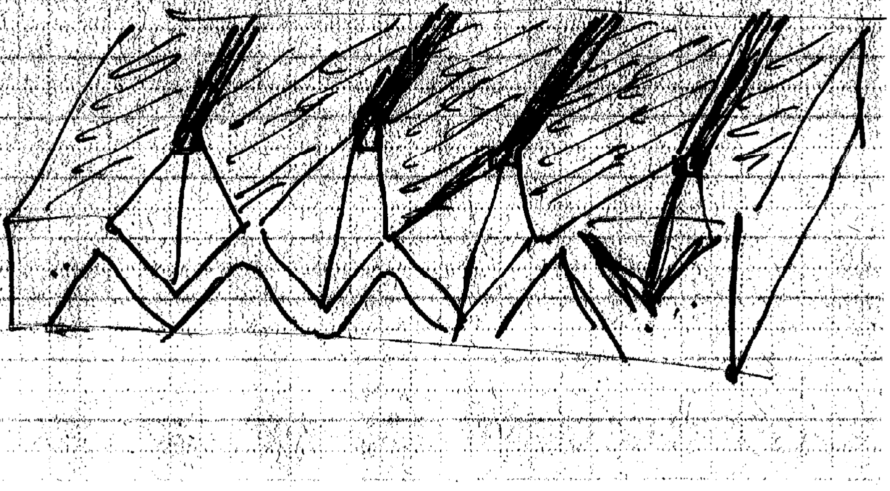


TABLE 1 A Gaussicity comparison between different feed types.

Feed Type	Gaussicity [%]	Co-Pol Content [%]	Matching w/a
Corrugated Horn	98.1	100	0.644
Potter Horn	96.3	98.6	0.590
Conical Horn	86.7	95.9	0.768
Diagonal Horn	84.3	90.5	0.863
Hard Horn	81.5	100	0.892
TSA	≈ 75	≈ 80	—[a]

---

[a] Matching w/a N/A

TABLE 2 An Airicity comparison between different feed types.

Feed Type	Airicity [%]	Co-Pol Content [%]	Matching $\frac{4a}{\lambda/\pi}$
Corrugated Horn	83.7	100	4.67
Potter Horn	81.4	98.6	5.02
Conical Horn	74.8	95.9	3.97
Diagonal Horn	72.7	90.5	3.54
Hard Horn	71.7	100	3.51
TSA	≈ 55	≈ 80	$\leq \approx 2.5$

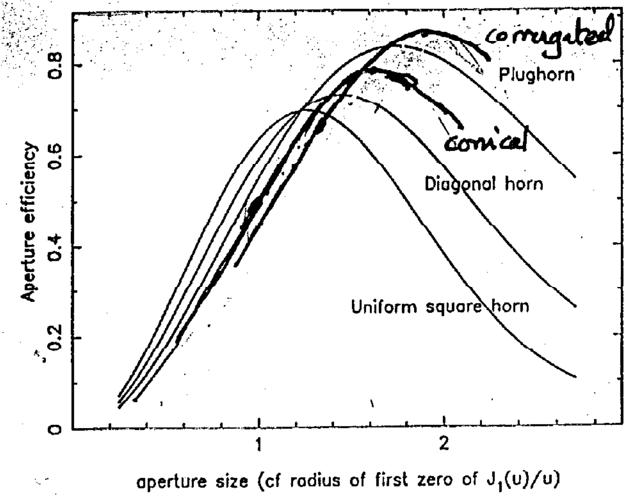


FIGURE 5 Aperture efficiency of a diagonal plughorn compared with that of a simple diagonal horn and a square horn with uniform aperture fields, as a function of size normalized to the radius of the focal-plane Airy pattern.

13

Conclusions and review of actions

Matt Griffin

CONCLUSIONS FROM YESTERDAY

① 2-K INTERFACE WILL BE DEFINED

- VOLUME ENVELOPE
- MASS LIMIT
- MAX POWER {CONDUCTION / DISSIPATION < 0·3K / 2K
- ^{3}HE STRAP FIXATION
- INTERFACES FOR MOUNTING FILTERS, BAFFLES
- POSITIONS OF CONNECTORS
- CONSTRAINTS ON CABLE RUNS
- ETC

BMS + MJG WILL COMPILE TEMPLATE DOCUMENT

② CRYOHARNESS TO BE DEFINED FOR SQUID/TES OPTIONS [JJB; KI]

③ FURTHER STUDY OF FILLED ARRAYS VS. FEEDHORN ARRAYS [WKG + --]

④ DEFINE POWER/MASS BUDGETS FOR WARM ELECTRONICS [LR; HM] + PRODUCE BASE-LINE FUNCTIONAL DESCRIPTION

⑤ SPECIFY ^{3}HE COLD STAGE TEMP. STABILITY REQUIREMENT [LR; JJB]

⑥ SPECIFY WHICH FPGA IS PROPOSED FOR ARRAY CONTROL/READOUT ELECTRONICS

CONCLUSIONS

- OVERALL SCHEDULE HAS BEEN CLARIFIED

- AGREEMENT ON DESIGN OF TEST FACILITY

- MORE DETAIL NOW AVAILABLE ON H/W CONFIGURATION FOR EACH OPTION (BUT MUCH MORE NEEDED SOON)

- COMMON 2-K INTERFACE POSSIBLE
- COMMON OPTICAL DESIGN IS POSSIBLE
- SUBSTANTIAL DIFFERENCES IN WARM ELECTRONICS / HARNESS FOR THE DIFFERENT OPTIONS
- INTERNAL INST. DESIGN WORK WILL ASSUME WORST CASES
- CLOSE COORDINATION OF EVALUATION PROGRAMME IS IMPORTANT

  ⟹ MORE MEETINGS

- FINAL OPTICS FOR BACKUP OPTION NEEDS WORK

- DEVELOPMENT OF BACKUP OPTION NEEDS TO BE BETTER DEFINED

EVALUATION PLAN

- DEFINE QUANTITATIVE PERFORMANCE REQUIREMENTS
- DEFINE SCHEDULE OF ARRAY GROUP MEETINGS AND FORMAL SELECTION MEETING
- DEFINE MAKE-UP OF SELECTION TEAM
- QMW TO LIAISE WITH EACH GROUP TO DRAW UP JOINT TEST PLANS AND [illegible] VISITS ETC.
- MONTHLY PROGRESS REPORTS