

**SPIRE Bolometer Array Technology Meeting  
QMW January 21, 22 1999**

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# B

## List of attendees

Peter	Ade	QMW
Patrick	Agnese	LETI
Jamie	Bock	JPL
Terry	Cafferty	JPL
James	Caldwell	GSFC
Christophe	Cara	CEA
Colin	Cunningham	UKATC
William	Duncan	UKATC
Fred	Gannaway	QMW
Walter	Gear	MSSL
Bill	Gray	JPL
Matt	Griffin	QMW
Peter	Hargrave	QMW
Paul	Harvey	U. Texas
Raul	Hermoso	QMW
Kent	Irwin	NIST
Ken	King	RAL
Ernst	Kreysa	MPIfR, Bonn
Yannic	Le Pennec	CEA
Bruno	Maffei	QMW
Harvey	Moseley	GSFC
Hien	Nguyen	JPL
Seb	Oliver	IC
Louis	Rodriguez	CEA
Juan	Roman	GSFC
Bruce	Swinyard	RAL
Neal	Todd	IC
Sarah	Unger	IC
Laurent	Vigroux	CEA
Adam	Woodcraft	QMW

**C**

**MINUTES**

# Draft minutes of 4th SPIRE Bolometer Array Group Meeting QMW, London, 21, 22 January 1999

Matt Griffin  
February 26 1999

## Note:

1. These minutes should be read in conjunction with the viewgraph package from the meeting, which contains most of the information - this will be made available shortly.
2. The topics are ordered here as on the original agenda, not necessarily as actually presented at the meeting.
3. Actions are tabulated in Section 13.

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Louis	Rodrigucz	CEA
Juan	Roman	GSFC
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Neal	Todd	IC
Sarah	Unger	IC
Laurent	Vigroux	CEA
Adam	Woodcraft	QMW

## 1 Introduction and aims of the meeting

Matt Griffin presented some introductory viewgraphs on the aims of the meeting and the current status of FIRST and SPIRE – see viewgraphs.

## 2 Schedule

Ken King presented the current schedule for the detector development programme and the SPIRE instrument, which is driven by the delivery date for the PFM (mid. 2004). Recent discussion between ESA and the instrument teams on the detailed spacecraft-level AIV plan have not revealed anything grossly unreasonable in ESA's AIV planning. There may be scope for shortening the AIV campaign, but certainly not by 9-12 months. It should therefore be regarded as unlikely that ESA will be willing to accept a significantly later PFM delivery date unless the launch date also slips (which nobody wants). So we must still plan for a SPIRE PDR (or something nearly equivalent to the) in the middle of 1999, before detector selection.

A list of detector development milestones was annotated in real time to indicate those that have been met, revealing how some slips in the schedule have already occurred.

Monthly reports from ALL SPIRE institutes will be mandatory from now on as we have to report to ESA every month.

## 3 Instrument design status

Bruce Swinyard presented an update on the SPIRE instrument design. The following points are important:

The photometer optical design is under review, and the outcome may depend on what happens with the redefinition of how PACS, SPIRE and HIFI share the FIRST focal plane. Kjetil Dohlen has produced a new design which solves the problems of pupil imaging, Strehl ratio and field of view, but has a slightly anamorphic final image. The impact of this on science is TBD.

The intensity beam divider FTS option is looking promising based on preliminary results from the breadboard model that Peter Ade has made. An optical design based on this scheme for SPIRE is now needed.

For the feedhorn option, the FTS detector array baseline is to have a 200-300  $\mu\text{m}$  band and a 300 – 670  $\mu\text{m}$  band. For the latter,  $2F\lambda$  350  $\mu\text{m}$  feedhorns are baselined, but multimoded at the short wavelength to allow propagation of 670  $\mu\text{m}$ . The efficiency of such horns and the number that can be accommodated need to be studied. The option of having an extra dichroic is not ruled out.

The need for a shutter to eliminate excess background from the cryostat during ground testing is being studied. The advantages are viewed as significant. A first-draft specification will be drawn up and given to Gary Davis (Canadian Associate Scientist) as part of an industrial study phase in Canada with a view to this item being provided by Canada.

The issue of stray light control and baffle design and implementation will need to be carefully addressed in the opto-mechanical system design. The question of who actually delivers the baffles is still TBD.

The telescope design is still not fixed – the latest JPL design has a larger secondary. Terry Cafferty pointed out that the possibility of having a larger focal ratio for the FIRST primary was being examined at JPL (maybe even up to  $f/1$  instead of the present  $f/0.5$ ). SPIRE must design for the current value, but a slower primary would reduce field curvature and make it easier to optimise the imaging optics. A decision on this is envisaged on a timescale of 3-6 months.

The SPIRE opto-mechanical system design has still to be properly addressed. Work is now underway to examine the basic concept suggested by Bruce in October.

Mass at 2 K may be a problem. It may be feasible and useful to mount the  $^3\text{He}$  cooler at 4 K rather than 2 K. Bruce is looking into this with Lionel Duband.

The available volume for the detector array modules may be problematic – it would help the array providers greatly if a 3-D CAD model were available for them to use as a design aid.

The nominal budget for warm electronics power is low for some of the array options. The extent to which this is a problem will need to be examined with ESA.

Matt Griffin said that for this issue, and many others, what is required is that the array groups fill out the system design document following the template already given. This should contain a baseline design with options and questions so that cost/benefit analysis can be done and ESA can provide industry with appropriate information and ask the right questions (e.g., about the impact on lifetime, on-board power consumption, etc. of anything we might want to propose).

#### **4 Status of actions from the Goddard meeting**

Ken King reviewed the open actions from the Goddard meeting (see viewgraph and updated action list below).

#### **5 CEA arrays**

Laurent Vigroux gave a brief introduction to the CEA array development programme and Louis Rodriguez gave a detailed account of the programme and its current status – see viewgraphs.

Some important issues still to be addressed were:

Optical responsivity (optical tests will be started soon on the single-pixel detector already undergoing tests at QMW)

Power load on the  $^3\text{He}$  fridge

Thermal isolation of the 2-K multiplexer

RC time constant (a 3-dB frequency of around 50 Hz is predicted)

#### **6 GSFC/NIST arrays**

This presentation was divided as follows:

Overview; mechanical design and electronics	Harvey Moseley
TES bolometer fabrication	Kent Irwin
Electronic system design	Jim Caldwell
Plans and Schedule	Juan Roman

The detailed contents are as in the viewgraphs. Below are some points raised or emphasised during the presentations

**Points raised during Harvey's talk:**

The envisaged filling factor is > 95% with > 80% absorption efficiency over the whole wavelength range.

The MK 1.8 readout electronics have been tested with the SQUID multiplexer, and tests with actual TES bolometers will be done in the near future

Magnetic shielding requirements: cylindrical L/D of around 3 will be needed to shield the detector module. The mechanical design will need to take this into account.

A "double TES" concept has been devised that could deal with the thermal background in orbit being higher than designed (i.e., prevent the TES from being driven normal by the high background). This will not be evaluated as part of the array selection process. However, it's viability, if shown convincingly, would remove one of the worries about the TES technology for SPIRE.

The cryoharness definition for the TES option is still not completely worked out – more details will be available soon (in time to present at the March 15 technical meeting with ESA).

RF shielding will be important for the SQUID detectors, and indeed for all of the SPIRE options. There are dangers of RF interference being conducted into the cryostat along cables or through the HIFI LO window. Preferably, all wires going into the cryostat should be filtered. RFI suppression should be raised as an important system issue with ESA at the March 15 meeting.

**Points raised during Kent's talk:**

A new fabrication technique should eliminate the noise "bump" shown on the viewgraph (which is due to the use of granular aluminium for the electrical leads).

Optical measurements on TES devices are expected soon (weeks).

Different bi-layer options are being studied: Al/Ag (baseline); Mo/Au (attractive as it is very stable wrt high temperature processing); Mo/Cu

$T_c$  can be controlled to a couple of mK

The 4 x 8 element array for the detector selection can be manufactured at NIST or at Goddard (providing some backup in the case of problems at either institute). The basic processes are the same with minor differences (e.g., Pd/Au is used for the absorber at NIST and Bi is used at Goddard).

**Points raised during Jim's talk:**

The TES option does not require a Buffer Amplifier Unit on the cryostat outer shell (TBC).

The wire count is TBC, but with around 1000 wires for the worst case. Requirements on the wire resistance etc. will be specified soon.

The front-end frame rate should be between 10-100 kHz (preferably at the lower end of this range, using 12-bit ADCs).

It is Goddard's preference to specify the warm electronics for procurement by Saclay rather than to supply boards or boxes. Discussions of the detailed electronic system design have taken place at the splinter meeting on Jan. 20).

**Points raised during Juan's talk:**

Testing of the mechanical prototype will begin soon.

Goddard needs the BACUS unit to be delivered in early March to be able to meet the test schedule.

At present, no major problems are foreseen with delivering the popup arrays on schedule for testing at QMW.

## **7 JPL/Caltech arrays**

Jamie Bock presented the Caltech/JPL feedhorn array option.

**Points raised during Jamie's talk:**

Caltech are examining an option with up to 600 detectors in total. This is fine provided that the Feedhorn option system design document presents a baseline number as in the SPIRE proposal with options for a larger number also presented with the implications for system parameters (Focal plane mass and volume, cryoharness requirements, warm electronics power, data rate, etc.)

The estimated mass of a typical array is about 170 gm.

It may be preferred to have the electrical interface (connectors) at 4 K.

Estimated heat load is 4.3  $\mu$ W at 0.3 K for 5 arrays.

An effective 16-bit ADC readout is required.

The low 1/f noise of NTD Ge detectors could make a slow-scan observing mode possible -this may be attractive for deep survey observations.

The main technical challenges for the feedhorn option are: implementation of the JFET module; implementation of the feedhorns for the FIS option; overall system design.

## **8 BACUS and the array test plan**

Peter Hargrave described the design of BACUS and the test schedule (see viewgraphs and Annex TBD)

**Points raised during Pete's talk:**



Commissioning of BACUS is envisaged to take place in early March. This is critically dependant on the delivery of the test dewars from Precision Cryogenics.

There is a problem with the first  $^3\text{He}$  fridge from Simon Chase - it does not prevent the fridge from working but results in a long re-cycle time. It is thought to be due to a problem with that particular unit rather than with the fridge design.

The possible use in BACUS of infrared illuminators from Jeff Beeman should be investigated.

Caltech and GSFC require delivery of their test dewars on or near on schedule to prevent slips in the delivery of their test arrays to QMW.

Given the extreme pressure on the schedule that is almost inevitable towards the end of 1999, it will facilitate the array evaluation if a lot of the tests carried out at QMW are largely to verify performance already measured at in the US groups' labs. This will allow more time for those tests that are planned to be done only at QMW (such as those using an ITS or telescope simulator).

If desired, filters to allow the IIS groups to configure their systems to be able to look out of the dewar could be provided (on a best efforts basis) by QMW.

The overall schedule is very tight and has already suffered some delays. It would be optimistic to believe that it will not suffer any further delays. Tests most relevant to the key array selection criteria will need to be given highest priority.

If a full SPIRE PDR is to be held in July, then this may divert much needed effort from the array programme. One option is to split the PDR into separate events. Ken King and Matt Griffin agreed to consider the optimum scheme for the SPIRE PDR.

## 9 Selection criteria and plan

Matt Griffin made a brief presentation on the array selection criteria. His note on this subject circulated. at the Goddard meeting has not yet been updated. He emphasised the need for selection to be based on a mature system design as well as the measured performance of prototype arrays and simulations of SPIRE observations.

## 10 Simulations

Laurent Vigroux presented an updated version of the note on simulations by Aussel et al. (see Annex TBD).

### Points raised during Laurent's presentation:

The telescope emissivity is a critical parameter. The temperature is not likely to depart much from the nominal 70 K, but the overall effective emissivity is very uncertain. This is particularly important for the TES detectors (as noted at the Goddard meeting).

It is important to distinguish between the NEFD (which is the most important parameter affecting mapping speed) and the confusion-limited sensitivity. If they meet their predicted performance levels, any of the detector options should be able to integrate down to the confusion limit for one field in a relatively

short time (well under an hour). But the ability of SPIRE to carry out a confusion-limited survey of a large area of sky depends on the mapping speed and so on how long or short this basic interval happens to be - it will dictate whether or not the proposed large area survey turns out to be feasible in a reasonable amount of telescope time.

Regardless of the details of the array implementation, the pixel beam pattern on the sky (system impulse response) should contain all of the information needed to evaluate the confusion-limited performance. It is therefore important to characterise this as accurately as possible for the filled array and feedhorn array options.

Fine sampling of the image will be very important regardless of the chosen option. This is significant as it affects the specifications for the chopper (more properly called a "beam steering device").

Seb Oliver reported that the Imperial College group have now set up a simulation package which effectively replicates what the Saclay group have done. It was agreed that having these independent capabilities would be beneficial to the programme.

## **11 Comments from reviewers and discussion of the programme**

**Comments from Ernst Kreysa (as noted - not necessarily with complete fidelity - by Matt Griffin at the time, and subject to revision by Ernst):**

1. The FIRST spacecraft should have a continuous scanning mode to facilitate the optimum operation of the detector arrays. This was not done for ISO and it was a mistake. Such a capability will be essential to carry out the large areas surveys efficiently.
2. Photons collected by FIRST will be very expensive - the available area in the focal plane should be filled with as many detectors as possible. The envisaged array sizes were not as large as one would like to see.
3. There are differences of opinion as to the relative merits of different array options which must be clarified before the selection can be made.
4. It is a matter of concern that the filled array options proposed for SPIRE have not yet been experimentally tested with submillimetre radiation even at this late stage. Ideally, this concept would be tried out on a ground-based telescope before being implemented in a space instrument.
5. The TES bolometer/SQUID multiplexer technology looks very promising for the future, but is perhaps not quite mature yet.

**Comments from Paul Harvey (by e-mail after the meeting):**

In general I was very impressed with the plan for development and evaluation of the three bolometer technologies. It is obviously ambitious and not forgiving of unforeseen delays, though. It is a bit scary that already there are problems with on-time delivery of the test cryostats, though those delays appear right now to not have significant impact.

As I said at the meeting, I think what scares me the most is the enormous pressures that will be on everyone late this year. Unless everyone is VERY lucky, there will almost certainly be delays in delivery

of some array(s) to QMW and there will be discussions along the lines of, "If I just had another two weeks, this problem could be addressed." Each of the three bolometer groups is under significant pressure to be successful for other reasons than just SPIRE. Your group at QMW is also under a great deal of pressure to develop the proper test environment to lead to making the right decision. Because two of the three technologies have never been used in a working astronomical instrument before, it is critical that they be evaluated with very stringent testing, yet there will be pressure to accept less-than-specified performance because of the improved capability such detectors would bring to SPIRE.

A smaller problem that became apparent more during some of the splinter meetings last week was the differences in system design that result for different bolometer choices. This is already leading to some duplication of effort at QMW that is unavoidable. Clearly your decision to proceed with a PDR before the "downselect" is necessary for you to meet your schedule requirements with ESA. So I encourage you to continue in that direction.

Finally, I'll again second Ernst Kreysa's comments about trying to install the largest array possible, whichever technology is chosen. I think you'll feel pretty silly ten years from now if someone asks why a 1.5 or 2 x larger array wasn't used if the reason turns out to be something of the scale of "number of wires." I know there are a large number of system issues involved in an issue like this, but many of them can be dealt with if addressed early enough. A related issue to this point is the capability to observe unchopped with a "slow-scan" mode. Although, I personally am not used to thinking about this, coming from the direction of the KAO and SOFIA, it is clearly likely to be a very good idea for SPIRE on FIRST. This puts requirements on the detector technology as well as opening up the focal plane for larger arrays.

## **12 Summary and actions**

### **12.1 Summary of the meeting and discussion session at the end (Matt Griffin)**

1. A lot of progress has been made since the Goddard meeting on the technical development of the arrays and the definition of their implementation in SPIRE. System designs are not yet available in the appropriate form, but it is apparent that most of the information is there and merely needs to be properly documented.
2. Of all the actions generated at this meeting, the most urgent is that on the array groups to provide their System Design documents in time for the information to be used in updating the IID-B and in discussions with ESA at the technical meeting on March 15 (Action 20 in the table below). The important thing is not necessarily to have all parameters pinned down, but to have a reasonably clear idea as to the system aspects of each option, and to be able to present ESA with options/alternatives which may make different demands on spacecraft resources, perhaps justified by improved scientific return. It will be increasingly difficult to do this as time goes on.

The specification and design of the SPIRE warm electronics is also highly dependent on the array technology, and it is necessary now to examine the requirements for the electronics.

3. The BACUS schedule has already suffered some delays due to cryostat and cryogenic hardware procurement problems. There is now little room for further delay. Items that are on the critical path must be identified and monitored very closely.
4. The array fabrication and programme must be run actively. Excellent communication and clear understanding between QMW and the array groups will be essential. The progress of the programme should be monitored on a weekly time-scale to ensure that Peter Hargrave has up-to-date information

and visibility of any delays or modifications to the plan and that the array groups are aware of any potential delays on the QMW side. However, it is important that this be done in a manner that does not add any extra admin load on the already hard-pressed array groups.

5. The programme is vulnerable to disruption by various factors such as delays in delivery or commissioning of BACUS hardware, mishaps or problems with staff availability. The potential effects should be minimised and staff at the various sites may need to be flexibly deployed to accommodate events as they occur. The deployment of additional staff is not seen as likely, but any extra effort that could be brought in would be beneficial. For instance, more effort on system design work and technical documentation is clearly needed.
6. The QMW BACUS system will be the only test-bed for the CEA arrays, whereas the US arrays will have undergone some characterisation and calibration prior to delivery to QMW. Priority should therefore be given to CEA array testing in the QMW system if there is a schedule conflict.
7. The feedhorn option is the only one based on instrument-proven technology. To ensure that at least one viable choice is available at the time of selection, the feedhorn option must be developed to a sufficient degree of maturity that it can be chosen if necessary. This does not mean that it is favoured in the event of other options being selectable.

## **12.2 Other comments**

Laurent Vigroux: The CEA array fabrication process is time consuming and requires planning and definition well in advance. There will be little flexibility for re-defining the requirements from now on.

Harvey Moseley: If a LIS option is selected and larger arrays are wanted, this could increase the cost to NASA, and funding would need to be sought. The likelihood of such additional funding would need to be clear by the time of array selection.

## **13 List of actions**

The table below is a list of outstanding actions from the previous meeting plus additional ones from this meeting (some may have been closed since the time of the meeting).

<b>LIST OF DETECTOR ARRAY GROUP OPEN ACTIONS</b>				
<b>No.</b>	<b>Action</b>	<b>Responsible</b>	<b>Deadline</b>	<b>Status</b>
<b>Open actions from Goddard meeting, Sept. 17, 18 1998</b>				
8	Specify He-3 cold stage temperature requirements for SPIRE and BACUS.	Rodriguez, Moseley, Bock	21 Jan. 99	Open
20	<b>Provide Systems Design Documents based on template provided by Bruce Swinyard</b>	<b>Bock, Moseley, Rodriguez</b>	<b>Feb. 28</b>	<b>Open. Information essential for Systems Team meeting on March 4, 5 and March 15 meeting with ESA</b>
24	Revise array selection criteria document	Griffin	Nov. 13	Open
25	Ask Lionel Duband to provide cooling power vs. temperature curve for baseline He-3 fridge	Swinyard	Feb. 18	Open
27	Define limiting resource dictating maximum permitted number of detectors in the focal plane for feedhorn option	Cunningham	March 20	Open
<b>New actions from this meeting</b>				
28	Seek information from ESA on the parasitic load on the CVV	Griffin	March 15	Open
29	Check validity of warm electronics power dissipation numbers	Cunningham	Feb. 15	Open
30	Raise RF filtering as FIRST system issue	Griffin	March 15	Open
31	Provide array groups with 3-D CAD model of the FPU for use as a design aid	Swinyard	Feb. 1	Open
32	Draw up detailed draft test plan for the in-house and QMW-BACUS	Hargrave (with array groups)	Feb. 15	Open
33	Investigate availability of illuminators from Jeff Beeman	Hargrave	Feb. 15	Open
34	Define the nature of the SPIRE design review in June 1999	King, Griffin	March 7	Open
35	Revise the array selection criteria document	Griffin	Feb. 15	Open
36	Establish scheme for weekly monitoring of array test programme (with minimal additional admin. overhead)	Hargrave	Immediate	Open
37	Provide written comments on the array programme based on this meeting	Kreysa, Harvey	End Feb.	Open

No.	Action	Responsible	Deadline	Status
38	Write minutes of splinter meetings on: Feedhorn Option ----- Warm electronics ----- FPU wiring and connectors -----	MJG/CRC Cara Cunningham	Feb. 15	Open
39	Provide Laurent Vigroux with comments on latest simulations documents	All	Feb. 15	Open
40	Ask ESA about envisaged practical limit on the scan rate	Griffin	March 15	Open
41	Generate nominal beam profiles for 0.5F $\lambda$ and 2.0F $\lambda$ pixels and provide Laurent Vigroux with input map projected through the photometer optics onto the detector focal plane	Swinyard	Feb. 1	Open
42	Include Co-I level meeting on array selection guidelines at the Caltech meeting in May	Griffin	May meeting	Open
43	Seek advice from Anthony Murphy on feedhorn design for FTS long wavelength channel	Griffin/Ade	March 1	Open

## 14 Reports on splinter meetings

### 14.1 Splinter meeting on feed-horns for the FTS on Jan. 20 (Bruce Swinyard)

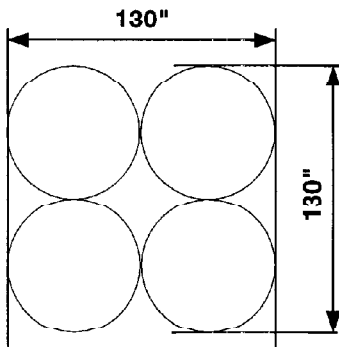
**Present:** William Duncan; Jamie Bock; Matt Griffin (part); Colin Cunningham; Bruce Swinyard

**Background:** The FTS on SPIRE is presently envisaged to have two detection bands – one covering 200-300  $\mu\text{m}$  and the other covering 300-670  $\mu\text{m}$ . The scientific rationale for the extension to 670  $\mu\text{m}$  is to cover the important C1 line at 609  $\mu\text{m}$ . It is accepted that the core scientific objectives are to be met using the 200-400  $\mu\text{m}$  range and the performance in this wavelength range must not be compromised in going to the longer wavelengths.

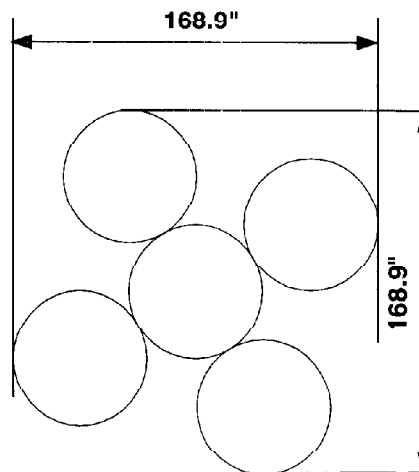
If filled arrays are employed then there should not be a problem in achieving the extension to longer wavelengths; except that the resonant absorber may have limited performance at the very longest wavelengths and the pixel size will not be optimum. In the case of the single mode feed-horns a problem arises because the width of the band would be too large for one size of horn  $\sim \lambda/\Delta\lambda \sim 1.3$ .

**The short-wavelength band:** At this meeting it was agreed that the nominal division between the bands should be maintained and that single mode feed-horns of size  $2f\lambda$  at 250  $\mu\text{m}$  should be employed in the 200-300  $\mu\text{m}$  band.

**Size of the field:** The nominal field size for the FTS is  $2 \times 2$  arcmin – the platescale at the detector focal plane is 12.5 arcsec/mm for a final focal ratio of  $f/5$ . For the feed-horn option the field size will have to change slightly to accommodate a whole number of pixels in the focal plane. The short-wavelength band could be arranged as shown in Figure 1.



**Figure 1:** Proposed arrangement for the 200-300  $\mu\text{m}$  band. The pixels here are 2.5 mm in diameter.



**Figure 2:** Possible arrangement for the 300-670  $\mu\text{m}$  band using 350  $\mu\text{m}$   $2f\lambda$  horns. These would be undersized towards the longest wavelengths and the efficiency would drop. The dotted circle shows the size of a  $2f\lambda$  circle at 550  $\mu\text{m}$ .

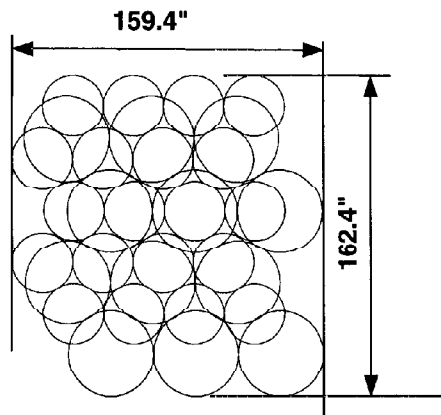
**The long-wavelength band:** The initial decision at the meeting was to adopt  $2f\lambda$  pixels at  $350\ \mu\text{m}$  to cover the whole of the long-wavelength band. These would become essentially  $1f\lambda$  pixels at the longest wavelengths. The layout of the focal plane would then be as shown in Figure 2.

Note that the field size has now grown to  $\sim 2.6 \times 2.6$  arcmin. Also shown in figure two is the size of the  $2f\lambda$  diameter circle at  $550\ \mu\text{m}$ . Some calculations are needed to see what response of the horns would be at this and longer wavelengths and what the detection efficiency would be. Another alternative to using the  $350\ \mu\text{m}$  horns out to the long wavelengths would be to have a third array centred on  $550\ \mu\text{m}$ . This would consist of only a few pixels – possibly only one. Two arrangements for the third array are shown in Figure 3.

Whichever solution is finally adopted, one pixel will need to be co-aligned on each array. This necessitates the arrays looking at slightly different portions of the sky and means that the field mirror will have to be oversized. Figure 4 shows the  $250$  and  $350\ \mu\text{m}$   $2f\lambda$  horn arrays laid on top of each other. The total field that will have to be let through the FTS in this case will be  $\sim 2.7 \times 2.7$  arcmin.

No definitive conclusion was agreed on the need for the third array and further studies on the performance of the  $350\ \mu\text{m}$  array at long wavelengths will now be conducted.

**Figure 3:** Two alternative arrangements for a third array at the output of the FTS to cover the  $420\text{--}670\ \mu\text{m}$  band. The second has the advantage that the off source position is sampled all around the object of interest although the field is obviously much larger.



**Figure 4:**  $250$  and  $350\ \mu\text{m}$  arrays superimposed and aligned on one pixel. The total FOV required for the FTS is thus  $2.7 \times 2.7$  arcmin assuming any third array is kept within the confines of this field of view.



## 14.2 Splinter meeting on FPU wiring and connectors on Jan. 21 (Colin Cunningham)

### 14.2.1 Introduction

The signal wiring within the cold focal plane unit, and between it and the warm electronics provides some of the major engineering challenges for SPIRE. The large number of wires means that tight thermal budgets have to be balanced against requirements to minimise microphonics, EMI, transmitted thermal radiation, and crosstalk. At the same time we need robust structures which can meet vibration loads, and we must have connectors at appropriate points to aid integration and test, while preserving reliability. The late choice of detector technology means that 3 different sets of constraints and trade-off need to be addressed during the period up to array selection. This document attempts to raise the issues, and start the process of coming up with solutions as part of the array and FPU systems design for review at PDR.

### 14.2.2 Responsibilities for wiring harnesses

As a reminder from the workpackage descriptions, the following table shows who has responsibility for definition, design and manufacture of the various categories of wiring harness. Note that ESA are responsible for procuring the harness between the FPU, BAU and DRC, but we must specify it in detail. While the responsibility for wiring harnesses rests with those responsible for subsystems within the FPU, they cannot be specified and designed in isolation especially from the structure workpackage with regard to ensuring proper support of signal wires to survive launch loads and to avoid microphonics.

Unit	Subsystem	Harness	Cold End Temp (K)	Warm End Temp (K)	Responsibility
FSFPU	Array	Array signals & control	2	4	Array Groups
	Array	Array signals & control	4	15	Array Groups
	FTS Mechanism	Control, position & temperature	4	15	LAS
	Cooler	Control & temperature	2	4	CEA- Grenoble
	Cooler	Control & temperature	4	15	CEA- Grenoble
	Chopper mechanism	Control, position & temperature	4	15	ATC
	FTS Calibrator	Control & temperature	4	15	GSFC
	Photometer Calibrator	Control & temperature	4	15	GSFC
	Shutter Mechanism	Control	4	15	??
	Structure	Temperature	2	4	MSSL
	Structure	Temperature	4	15	MSSL
	FET Box	Control, Signals, Temperature	15	15	JPL/Caltech
Cold Harness	FPU-BAU	Signals	15	80	ESA
	FPU - DRC	Control, Temperature, Positions	15	300	ESA
	BAU-DRC	Signals	80	300	ESA
Warm Electronics	FSWIR	Data	300	300	CEA-SAp
	DRCU-SPU				
	FSWIR DRCU-DPU	Data, Power	300	300	CEA-SAp
	FSWIR SPU-DPU	Data, Power	300	300	CEA-SAp
	DPU - Spacecraft	Data, Power	300	300	ESA

### 14.2.3 Issues raised

**Specification of ESA procured harness:** It is urgent that we develop the specification for the harness to link the FPU, BAU and DRC. ESA will include this spec in the ITT, and it will be a technical specification of wire impedances, capacitance to ground & other conductors, shielding, stiffness etc; not a technical prescription as to what technology to use to achieve this spec. They will tend to conservative solutions based on ISO experience (eg stainless steel wires in bundles with epoxy encapsulated heat sinks). We can show them other solutions such as ribbon cables, but will find resistance in getting them to consider such technologies.

The number of signal and screen conductors from the value specified in the IID-B for the CEA option is 430 signal and control lines, with 43 screens. For conventional screened wire bundles, the thermal conductance is dominated by the screens, so we are under pressure to keep the number of screens to a minimum. If we need to increase the number of detectors for the feed-horn option to 600, we would need over 1200 signal and bias lines, plus screens. The TES/SQUID option may need up to 1000 conductors.

Twisted pairs may be needed, depending on detailed EMC design. This could be especially important for the low-impedance SQUID option.

**Connectors:** ESA prefer 37-way MDM connectors with two rows of pins, both for their harness and for our cold harness. We may prefer 51 way MDMs (with 3 rows of conductors), 100 way MDMs (with 4 rows) or even Nanonics high-density connectors, if we are to conserve mass & space budgets, especially if we intend to increase the number of detectors. Again, we would have a difficult job persuading ESA to accept such connectors. Connectors may dominate the capacitance budgets.

It is advantageous to use connectors wherever cables cross a thermal boundary, for ease of assembly. However, space and mass budgets may preclude this.

**Screens:** The specification for cross-talk compared to detector impedance will determine how many signal pairs can be bundled within a screen, and we have seen that screens dominate thermal conductance

Alternative technologies such as ribbon cables may be needed to allow adequate screening

- Ribbon Cable technologies
- Kapton encapsulated ribbons: SIRTf will use manganin twisted pairs encapsulated in Kapton. This technology allows twisted pairs and screen wires to be used, and an overall screen of vacuum deposited Titanium. It can therefore be designed for controlled impedance and low thermal conductance, combined with robust NASA-qualified technology.
- Woven ribbons: SCUBA used superconducting woven cables in a Nomex weave, which again is robust and allows controlled impedance and good heatsinking. This technology has not been space qualified, but has been used extensively in ground-based instruments.

**Feed-through radiation shields:** There are several problems to deal with in taking wire-bundles or ribbon cables through the radiation shields:

**Heatsinks:** Depending on detailed thermal design, it is likely that heat will need to be intercepted at the 15-K and 4-K structures. This may be done by epoxy encapsulation, or relying on connectors. It is easy to get this wrong, and transmit excessive heat to the 2K stage, so careful thermal design will be needed.

**Thermal radiation transmission:** Preventing thermal radiation getting through radiation shields where

we have connectors or feed-troughs is not going to be easy. Epoxy connectors are transparent to far-IR & submm, and wire insulation can act as a wave-guide to IR. Careful design and choice of components will be needed to meet the low-background requirements of the detectors.

**Superconducting wires for SQUIDS:** The SQUID bias lines will need to conduct quite high currents, and will probably need to be superconducting to avoid dissipation and voltage drops. Again, this will make ESA nervous. We need detailed specs for these bias wires.

**Cable lengths:** The trade-offs between thermal loads, EMC and space available relative to wire lengths inside the FPU are yet to be made.

**Cable cross-section:** We need estimates of cross-sectional area and minimum bend radius for the candidate cable technologies, to see if they will fit in the space available.

**Cable mass:** We have not included the FPU harnesses in current mass estimates (I think!). For comparison, SCUBA ribbon cables weighed 260 g per metre for 135 detectors, each with a twisted pair and inter-pair screen wire.

**Stiffness of wires:** We will need to develop a microphonics model to specify cable stiffness and allowable acceleration from our mechanisms.

**Mechanical support of harnesses:** Support will be needed to survive launch forces. This will probably mean strapping cables to support structures. We decided that there was no point strapping to the thermal straps, as these will be almost isothermal.

### 14.3 Warm electronics for TES detector readout option (Christophe Cara)

Report to follow.

**D**

# **VIEWGRAPHS**

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**1**

**INTRODUCTION**

**MATT GRIFFIN**

---

## **Aim of this meeting**

### **1. Review the whole programme**

- **The schedule and requirements**
- **Array technology status and progress since Goddard meeting**
- **The system designs**
- **The qualification plans**
- **The array selection criteria**
- **The testing and evaluation programme**

### **2. Receive and react to comments from invited experts**

**Paul Harvey, Ernst Kreysa, Jean-Michel Lamarre**

### **3. Hold splinter meetings on specific topics**

## **Presentations/viewgraph packages to include**

- **Overview of the detector concept, principle of operation, advantages for SPIRE, etc.**
- **Summary of development status**
- **System design**
- **Qualification plan**
- **Assessment of technical challenges and risks**
- **Summary of manpower resources available before and after selection**

# Status of FIRST and SPIRE

## FIRST

- **Final mission confirmation and payload approval by the SPC in February (we hope)**
- **FIRST/Planck funding status was reviewed at a series of meetings in July, October, January**
- **3.8-m antenna under study by JPL**
- **Use of X-band transponders increasingly likely  
⇒ available data rate should go up by factor of ~ 4.**
- **Significant slip in FM delivery date not likely ⇒ PDR before detector selection**

## SPIRE

- **Consortium meeting held in December**
- **Intensity beam divider FTS option being studied as alternative to classical MP as in proposal  
- Decision in February**
- **Detailed photometer optical design under review. Division of focal plane between the three FIRST instruments may be changed.**
- **Second formal meeting with ESTEC project took place on Nov. 17 – several actions on us to be completed by after this meeting**
- **SPIRE project STILL needs to establish more formal and reliable lines of communication and reporting**



# **Schedule of future detector array meetings**

## **Detector array group meetings:**

**May 1999**                      **Caltech. (20/21 May 1999 - TBC)**  
**September 1999**           **Saclay**

## **Formal selection meeting:**

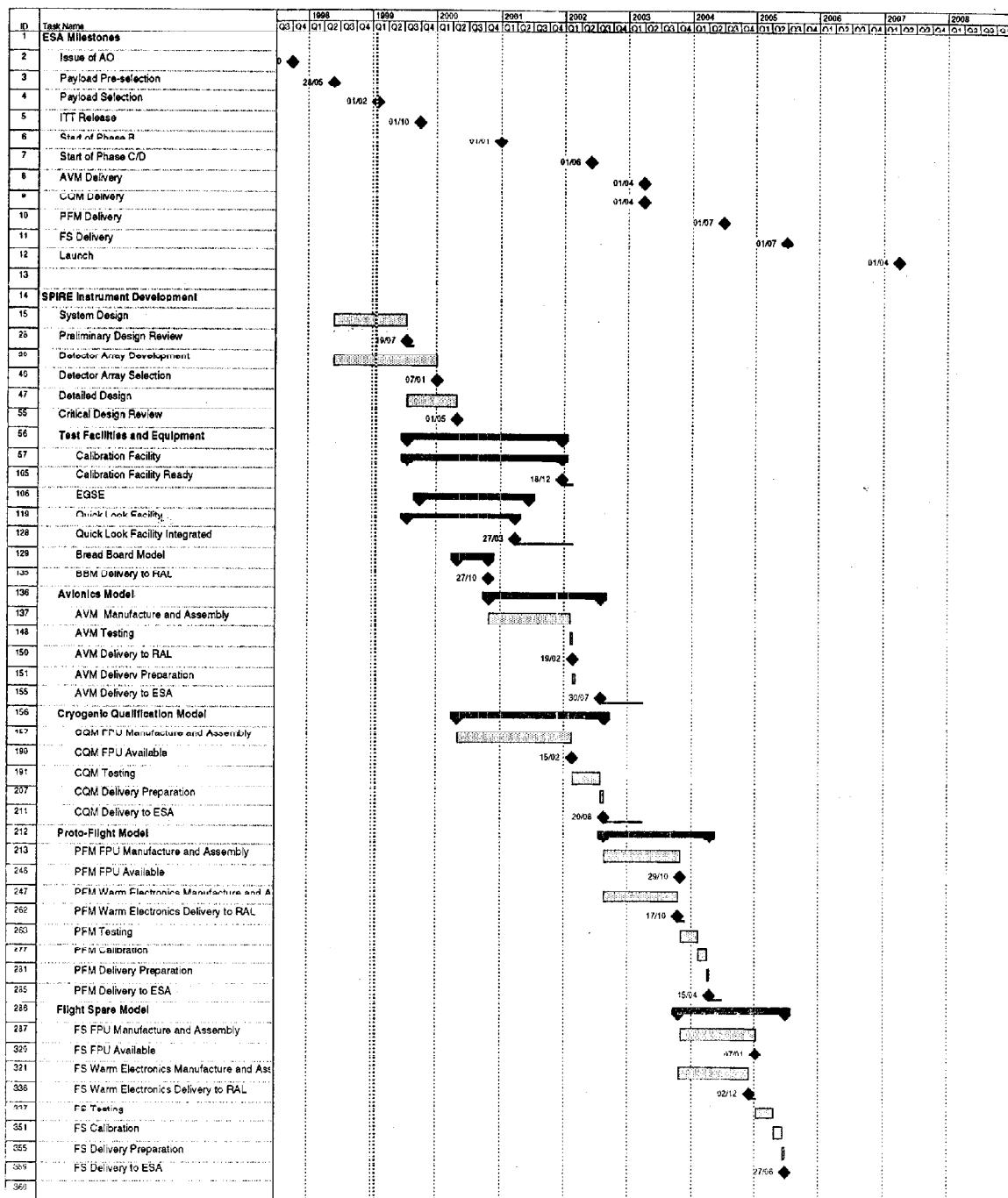
**January 2000**                **RAL**

**Full documentation to be provided by mid-December  
1999 (last minute updates in January if necessary).**

**2**

**SCHEDULE**

**KEN KING**





**Detector Development Milestones**

<b>Title: Pop-Up Detector Array</b>		
M01	26 Nov 98	He-3 refrigerator from QMW
M02	29 Jan 99	Calibration Module delivery form OMW
M02	3 Feb 99	Mounting hardware design ready
M03	4 May 99	Mounting hardware available
M04	10 May 99	1x 8 PUDs delivered to GSFC
M05	18 May 99	Fanouts delivered to GSFC
M06	31 May 99	Interconnects delivered to GSFC
M07	18 Jun 99	Evaluation array assembled
M08	2 Jun 99	Electrical System ready
M09	6 Jul 99	Cryogenic Dewar System ready
M10	1 Sep 99	Delivery of evaluation array to QMW
M01	18 Jun 99	Delivery of PDR Package

<b>Title: Feedhorn Detector Arrays</b>		
M01	1 Oct 98	Order JFET ✓
M02	14 Oct 98	Receive JFET dies ✓
M03	16 Oct 98	Order Load Resistor Module ✓
M04	30 Oct 98	Order Feedhorn Array Plates ✓
M05	2 Nov 98	Ship Ti/Nb TES Bolometer #1 to QMW
M06	26 Nov 98	Receive Load Resistor Module ✓
M07	15 Dec 98	Receive Test Dewar and Refrigerator
M08	15 Jan 99	Receive Feed horn Array Plates
M09	15 Jan 99	Receive Calibrator
M10	11 Feb 99	Ship Ti/Nb TES Bolometer #2 to QMW
M11	8 Jun 99	Deliver SPIRE 61-Element Array #1
M12	24 Aug 99	Deliver SPIRE 61-Element Array #2
M01	7 Dec 98	Provide RF Shielding Requirements to QMW
M02	1 Jan 99	Provide preliminary Warm Electronics Requirements to SAp
M03	14 Jan 99	Provide Focal Plane Support Structure Design to QMW
M04	14 Jan 99	Receive revised RF Shielding requirements
M05	18 Jun 99	Delivery of PDR Package

<b>Title: CEA Detector Arrays</b>		
M01	15 Oct 98	Delivery of prototype detector to QMW ✓
M02	1 Jan 99	1 <sup>st</sup> Receipt of prototype arrays from LETI/SLIR ✓
M03	1 Mar 99	Ship 1 <sup>st</sup> evaluation array to QMW
M04	1 Mar 99	Delivery of Manual Switchbox to QMW
M05	3 May 99	2 <sup>nd</sup> Receipt of prototype arrays from LETI/SLIR
M06	1 Jun 99	Ship 2 <sup>nd</sup> evaluation array to QMW
M07	1 Jun 99	Delivery of Acquisition System to QMW
M08	1 Jul 99	3 <sup>rd</sup> Receipt of prototype arrays from LETI/SLIR
M09	1 Sep 99	Ship 3 <sup>rd</sup> evaluation array to QMW
M01	18 Jun 99	Delivery of PDR Package

<b>Title: Array Evaluation Facility</b>		
M01	16 Oct 98	Mirrors to QMW ✓
M02	30 Oct 98	Calibration module stray light analysis results from RAL
M03	30 Oct 98	Calibration module electrical interface specifications from QMW (document) ✓
M04	6 Nov 98	Final engineering drawings of calibration module to RAL ✓
M05	15 Nov 98	Connectors delivered ✓
M06	26 Nov 98	He-3 fridge tests complete ✓
M07	26 Nov 98	Delivery of US He-3 fridges & shields to GSFC & JPL
M08	27 Nov 98	Filters complete
M09	18 Dec 98	Cryostat to QMW
M10	24 Dec 98	Illuminator arrays to QMW
M11	31 Dec 98	Construction of calibration modules
M12	29 Jan 99	Calibration module tests completed
M13	29 Jan 99	Delivery of calibrated calibration modules to GSFC & JPL
M14	1 Sep 99	Delivery of Pop-Up Detector Evaluation Array to QMW
M15	1 Sep 99	Delivery of Feedhorn Evaluation Array to QMW
M16	1 Nov 99	Delivery of CEA Evaluation Array to QMW
M17	31 Dec 99	Evaluation of prototype detector arrays completed

# **3**

## **SPIRE INSTRUMENT DESIGN STATUS**

**BRUCE SWINYARD**

DETECTOR ARRAY MEETING.

QMW 21/22  
JAN 1999

## INSTRUMENT DESIGN

- "AO" INSTRUMENT DESIGN HAS/IS BEEN REVISED IN LIGHT OF:
    - a) FSEC RECOMMENDATIONS
    - a) MORE DETAILED SCIENCE REQUIREMENTS
    - c) STARTING TO THINK ABOUT THE DETAILED SYSTEM REQS.
  
  - STILL DUAL CHANNEL WITH 3-BAND PHOTOMETER AND TWO ~~3-BAND~~ BAND FTS.
-

## MAJOR CHANGES

### ● PHOTOMETER OPTICAL DESIGN

⇒ POOR PUPIL IMAGING

⇒ TILTED FIELD ⇒ ABERRATIONS.

⇒ KEITH'S NEW PHOTOMETER.

⇒ PERFECT PUPIL IMAGING

⇒ STREHL  $> 0.86$

⇒ CAPABLE OF TAKING WIDE FOU

⇒ DRAWBACK IS ANAMORPHIC  
FINAL IMAGE  $[f/4.2 \times f/5]$

\* IS THIS ACCEPTABLE?



MAJOR CHANGES.

● FTS DESIGN:

a) BASELINE - MP POLARISING  
WITH LINEAR MECHANISM  
À LA GSFC.

b) INTENSITY BEAMSPLITTERS

⇒ PARA HAS DESIGNED  
+ TESTED BROAD BAND  
BS WITH  $4RT \sim 1$

⇒ BREAD BOARD MODEL IS  
OUTSIDE HIS OFFICE  
(AND WORKS!)

⇒ NEED OPTICAL DESIGN.

⇒ FEEDHORN DESIGN

\* 200-300  $\mu\text{m}$  O.K.

\* 2F $\lambda$  350  $\mu\text{m}$  WILL BE USED  
FOR 300-670  $\mu\text{m}$  BAND.

---

DETECTOR  
MEETING

20-22 JAN 99  
QMW

ADDITIONAL .....

- SHUTTER: THE BACKGROUND INSIDE THE FIRST CRYOSTAT WILL BE U.LARGE. A SHUTTER IS REQUIRED
    - \* WHO WILL DO IT?
    - \* WHERE DOES IT GO?
  - STRAY LIGHT CONTROL:
    - CRITICAL TO THE INSTRUMENT SENSITIVITY.
    - BAFFLE DESIGN - RAL
    - BAFFLE PROCUREMENT - ?
- ⇒ LATEST JPL TELESCOPE DESIGN HAS SECONDARY  $\phi$  314 mm
-

OPTO-MECHANICAL  
SYSTEM DESIGN.

- NOT MUCH PROGRESS
    - ⇒ OLD 'AO' DESIGN HAS LAYOUT PROBLEMS WHICH HAVE BEEN FED BACK TO KIETIL
    - ⇒ SOME IDEAS BUT NO SOLUTION TO STRUCTURAL SUPPORT
    - ⇒ 2-K MASS MAY BE A "PROBLEM"
    - ⇒ SUPPORT AS MUCH AS POS. AT 4-K [COOLER.....]
    - \* ENVELOPE FOR DETECTORS SUGGESTED AS 60x60x100 mm
-

DETECTOR MEETING

20-22 JAN 1999

WARM ELECTRONICS

BUDGETS:	BAU	2.5 W (80K)	} WHAT IS THE QUALITY.
	DRCU	26 W	
	SPU	15 W	
	DPU	10 W	
	<u>TOTAL</u>	<u>51 W</u>	

CRYOSTAT WIRING

~ 600-800 WIRES.

TELEMETRY BUDGET

BASELINE IS 50 KBITS/S  $\Rightarrow$   $\uparrow$  FACTOR OF 4

# SYSTEMS: FPU

- Structure

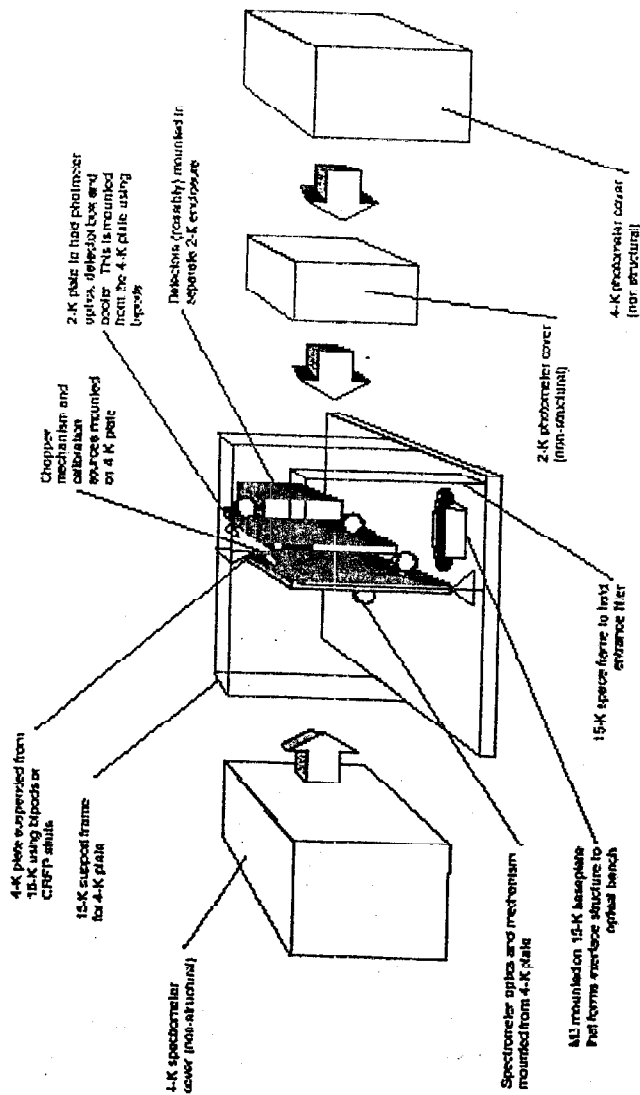


Figure 1: Conceptual layout for the SPIRE structure based on non structural covers (15-K cover not shown)

# SYSTEMS: FPU

- Thermal Budgets

Temp. Stage	Item	CEAT/IES						Feedhorn (150 dets)					
		ON	OFF	PHOT	SPEC	ON	OFF	PHOT	SPEC	ON	OFF	PHOT	SPEC
"15-K"		0	0	0	0	15	0	15	0	15	15	15	
"4-K"	Wires	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	
	Radiation	0.6	0.6	0.6	0.5	0.6	0.6	0.6	0.6	0.6	0.6	0.6	
	Mechanisms	0.0	0.0	2.0	7.4	0.0	0.0	2.0	7.4	0.0	2.0	7.4	
	Structure	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	
	Total	3.7	3.7	5.7	11.1	3.7	3.7	5.7	11.1	3.7	5.7	11.1	
"2-K"	Wires	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	
	Dissipation	2.0	0.0	6.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
	Cooler	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	
	Structure	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	
	Total	4.1	2.1	4.1	4.1	2.1	2.1	4.1	4.1	2.1	2.1	2.1	

4.0 FOR TES OPTIONS.

Notes:  
 All figures are in mW  
 Structure: Figures assume temperature of "15-K" shield is 11 K  
 Cooler: This is the continuous power load of the cooler when at 0.3 K  
 Feedhorn option: FET box only interfaces to "15-K" stage.



Colin Cunningham

SPIRE Consortium Meeting: December 98 RAL

# SYSTEMS: FPU

## • Mass Budgets

Project code	Instrument unit	# off	Dimensions (mm) *	Mass (kg)
FSFPU	Cold Focal Plane Unit	1	690 x 410 x 410 irregular shape	34(TBC) (including JFET box)
FSBAU	Buffer Amplifier Unit	1	200 x 150 x 120 (TBC)	2.5 (TBC)
FSDRC	Detector Read-out and Control Unit	1	285 x 256 x 234	12 (TBC)
FSSPU	Signal Processing Unit	1	240 x 218 x 239	9 (TBC)
FSDPU	Digital Processing Unit	1	200 x 200 x 160	5 (TBC)
FSHAR	Warm interconnect harnesses: FSDRC-FSSPU, FSSPU-FSDPU	3		2 (TBC)
<b>TOTAL</b>				<b>63.5 (TBC)</b>

\* Dimensions are given as Length x Width x Height. Length and Width define the fixation baseplate.

### Note

1 Dimensions and mass do not include margins

2 Harness FSFPU-FSBAU, FSBAU-FSDRC, FSFPU-FSDRC FSDPU-S/C will be ESA responsibility.



Logo Will Go Here	<b>SPIRE</b>	<b>Ref: SPIRE-RAL-MOM-nnnn</b>
	<b>Kjetil's New Photometer</b>	<b>Issue: .00</b>
	B. Swinyard	<b>Date: 13/01/99</b>
		<b>Page: 1 of 2</b>

Presented in this note is an outline design from Kjetil Dohlen for a re-optimised photometer channel and a precis of the subsequent exchange of e-mails between us on the 7 and 8 of January 1999.

The design is shown as a sketch in figure 1. In this design M3 is moved to the telescope focal plane to become a Fabry mirror, re-imaging the pupil onto the chopper mirror at M4. Mirror M5 converts the beam from  $f/8.68$  to  $f/5.0$  and re-images the focal plane onto another Fabry mirror at M6. This mirror also picks off the beam for the spectrometer and sends "over the other side". M6 forms a pupil image at the cold stop, which is now elliptical. Mirrors M7, M8 and M9 form an off axis Offner relay to take the image formed at M6 onto the detectors with a sufficiently long back focal length to allow the dichroics and folding mirrors to be incorporated with plenty of room for the detectors and fridge.

The pupil image quality is now very good as well as the final image quality with  $\$trehl > 0.86$  across the  $4 \times 4$  arcmin FOV. Kjetil reckons this same design is capable of taking up to  $4 \times 8$  arcmin still with reasonable imaging. The image distortion is less than 5% across the FOV.

The final focal ratio is optimised in the XZ plane, so here it is 5.00 and doesn't vary across the FOV. In the XY plane it has the following values:

Image coord	Fy
(0,2')	4.24
(0,0)	4.35
(0,-2')	4.42

So this design has a small anamorphism in the final image plane and a rectangular field on the sky, but the focal ratio does not vary as a very much function of the FOV. Kjetil reckons it will be difficult to get equal focal ratio in the two directions. A question for the array groups is -- does this matter?

There are some minor adjustments to be made to the design some we have already discussed are as follows -- comments on these from the appropriate people would be appreciated:

i) The chopper mirror is placed in the centre of the chopper structure in the sketches I have seen. This means that as presently designed the chopper structure would penetrate into the input beam. Kjetil says it is not a problem to open the angle on M4 but doesn't know how far he can go. Is it possible to move the chopper mirror with respect to the chopper structure (GFM)

ii) There isn't a lot of room around the beams for filters and apertures (except at the cold stop). Careful thought will have to be given to where the 2-K structure went. One would like to wrap it around M7, M8, M9 etc to make sure that no higher temperature radiation had a path through the cold stop. Also one would have to think about what temperature M3 was now placed at.

Kjetil is sanguine about the possibility of opening up the angles on the mirrors slightly to allow structure and filtering much the same as in the present design.

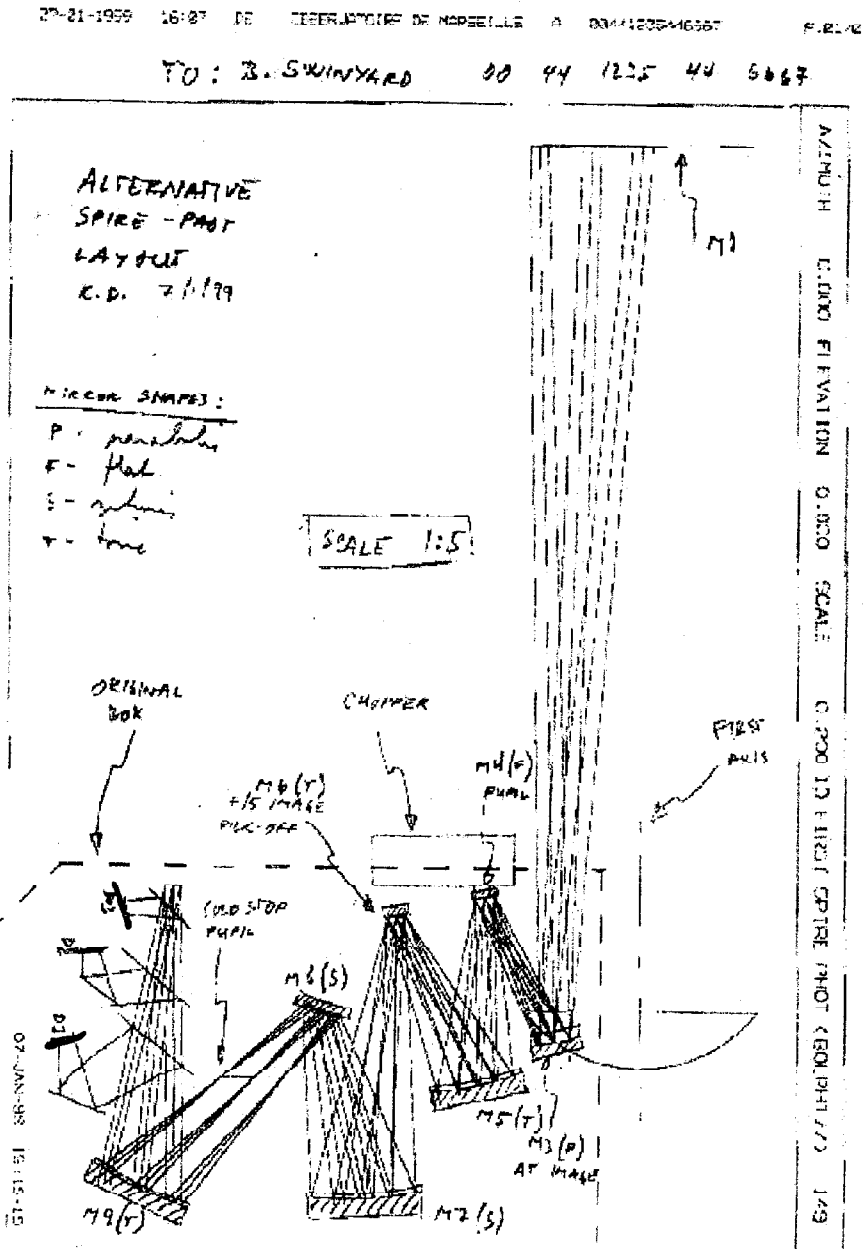
All in all this design looks to be robust and solves the pupil imaging and image quality problems of the original. There are some slightly tricky aspects -- the chopper is placed high in the instrument



Logo Will Go Here	<b>SPIRE</b>	Ref: SPIRE-RAL-MOM-mmm
	Kjetil's New Photometer	Issue: .00
	B. Swinyard	Date: 13/01/99
		Page: 2 of 2

for instance - but once these have been addressed I recommend we adopt it as our new baseline for the photometer and look at its accommodation.

Figure 1: Fax from Kjetil 7/1/99



# 4

Open actions from Goddard meeting, Sept. 17, 18 1998 (As updated at the meeting)				
No.	Action	Responsible	Deadline	Status
<b>Closed</b>				
13	Provide monthly reports on progress on the development programme to Matt Griffin, copied to Ken King	Rodriguez, Moseley, Bock, Hargrave	End of each month	Closed – superseded by need for all groups to provide monthly reports from now on
15	Produce draft array selection plan	King	Oct. 10	Closed
16	Define 3He fridge stability requirements for BACUS	Hargrave?		Closed (subsumed under 8)
18	Provide summary of FET box options to Thomas Passvogel based on input from Jamie Bock	Cunningham	Oct. 9	Closed
23	Provide written comments on existing draft of array selection criteria document to Matt Griffin	All	Oct. 30	Closed
28	Investigate creation of new SPIRE workpackage for a cold shutter	Griffin	Oct. 9	Closed - discussions with Canadians underway
29	Array splinter meeting actions	QMW, CEA, GSFC, Caltech/JPL	Various	Closed – to be updated in the minutes of this meeting
<b>Open</b>				
20	Provide first-draft of Systems Design Document	Bock, Moseley, Rodriguez	Feb 28	CEA: Closed GSFC: Open JPL: Open
8	Specify 3He cold stage temperature requirements for SPIRE and BACUS.	Rodriguez, Moseley, Bock	21 Jan. 99	Open
24	Revise array selection criteria document	Griffin	Nov. 13	Open
25	Ask Lionel Duband to provide cooling power vs. temperature curve for baseline He-3 fridge	Swinyard	Feb. 18	Open
27	Define limiting resource dictating maximum permitted number of detectors in the focal plane for feedhorn option	Cunningham	March 20	Open

# 5

## CEA ARRAYS

**LAURENT VIGROUX  
LOUIS RODRIGUEZ**

**See also Annex 1**

# Goals of the

## CEA developments

1) design of bolometer arrays

optimised for FIRST

- Large format
- image quality  
by sampling of PSF
- immune to cosmic ray
- $T_{op} = 0.3 K$

2) Design compatible with

ESA space mission constraints

- based on existing  
technology
  - production line  
compatible with  
ESA planning
-

## CEA organization

- DSM / DAPNIA / Service d'Astrophysique
    - Overall scientific and technical responsibility
    - specification
    - electrical and optical characterization (with QMW)
    - space qualification
  - DTA / DOPT / Laboratoire d'Infrarouge
    - design of the bolometer arrays
    - process of the different subsystem and integration
      - grids
      - ~~mux~~ MUX
      - Read Out
      - connecting support
-

**MONOLITHIC FILLED  
BOLOMETER DETECTOR ARRAYS  
& READOUT  
DEVELOPMENT  
FOR THE FIRST / SPIRE  
PROJECT AT CEA**

P. AGNESE, C. BUZZI  
CEA/LETI/LIR

J.L. AUGUERES, C. CARA, Y. LEPENNEC, L. RODRIGUEZ, L. VIGROUX  
CEA/DAPNIA/SAP

BOLOMETER ELEMENTARY PIXEL

THERMOMETER

IMPLANTED SILICON  
THERMISTOR  
COMPATIBLE WITH  
INTEGRATED CIRCUIT  
COLLECTIVE  
MANUFACTURE

PHOSPHORUS  
IMPLANTATION  
COMPENSATED  
BY 50 % BORON NEAR  
METAL/INSULATOR  
TRANSITION  
 $\alpha$  SLOPE ~ 40.

Noise ~ 1  $\mu$ K/Hz

BOLOMETER STRUCTURE

A STANDING CRYSTALLINE  
SILICON MESH TO REDUCE  
HEAT CAPACITY  
AND IONIZING PARTICLES  
SUSCEPTIBILITY.

THERMAL  
CONDUCTANCE  
TAILORED TO  
WANTED VALUES BY  
GEOMETRIC  
CONTROL OF THE  
SILICON SUSPENSION  
BEAMS

SILICON SENSORS  
MICROMACHINING  
TECHNIQUES AT LETI

SUBMM EM WAVES  
ABSORPTION

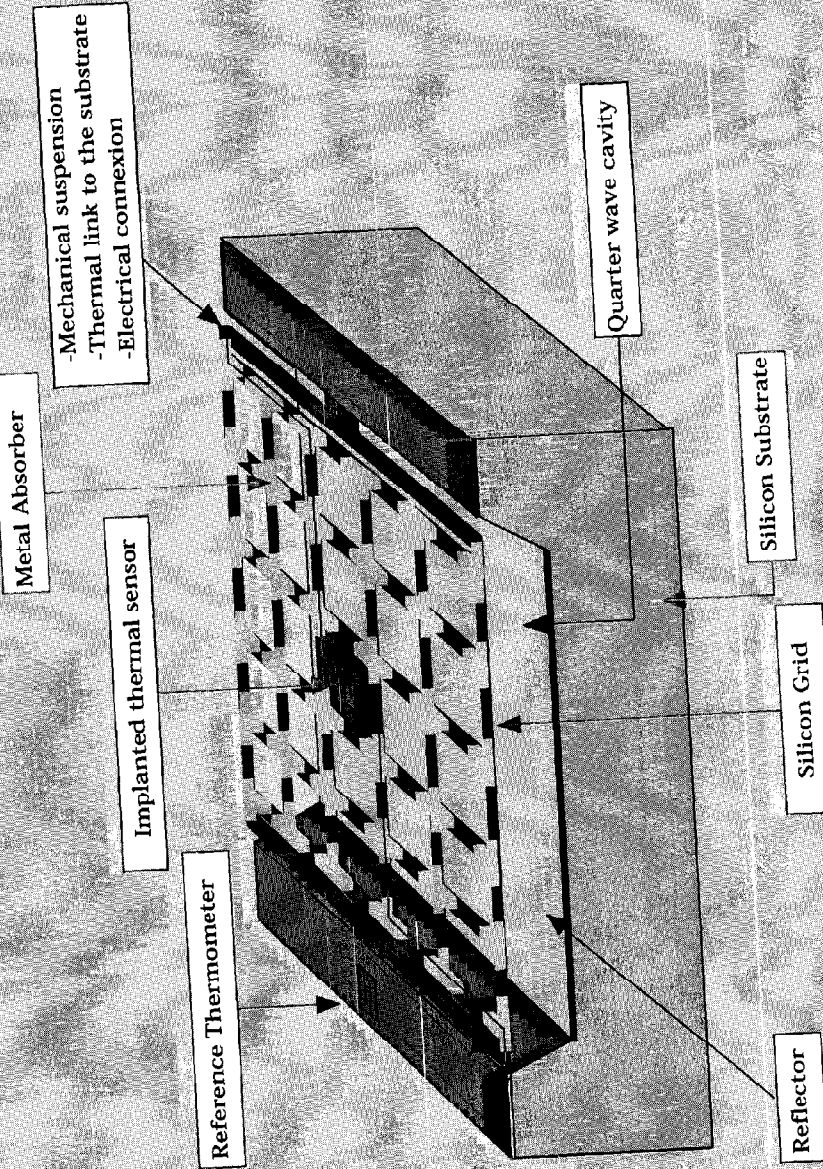
VERTICAL RESONANT  
ABSORPTION :  
METAL ABSORBER  
MATCHED TO VACUUM  
IMPEDANCE ON  $\lambda/4$   
REFLECTIVE CAVITY.

HORIZONTAL RESONANT  
ABSORPTION:  
METALLIC PERIODIC  
PATTERN

(inductive mesh, capacitive  
loops or crosses)  
ADJUSTED TO 377W/ $\square$   
DEPOSITED ON THE  
SILICON GRID

FIRST/SPIRE

## THE DETECTOR PRINCIPLE

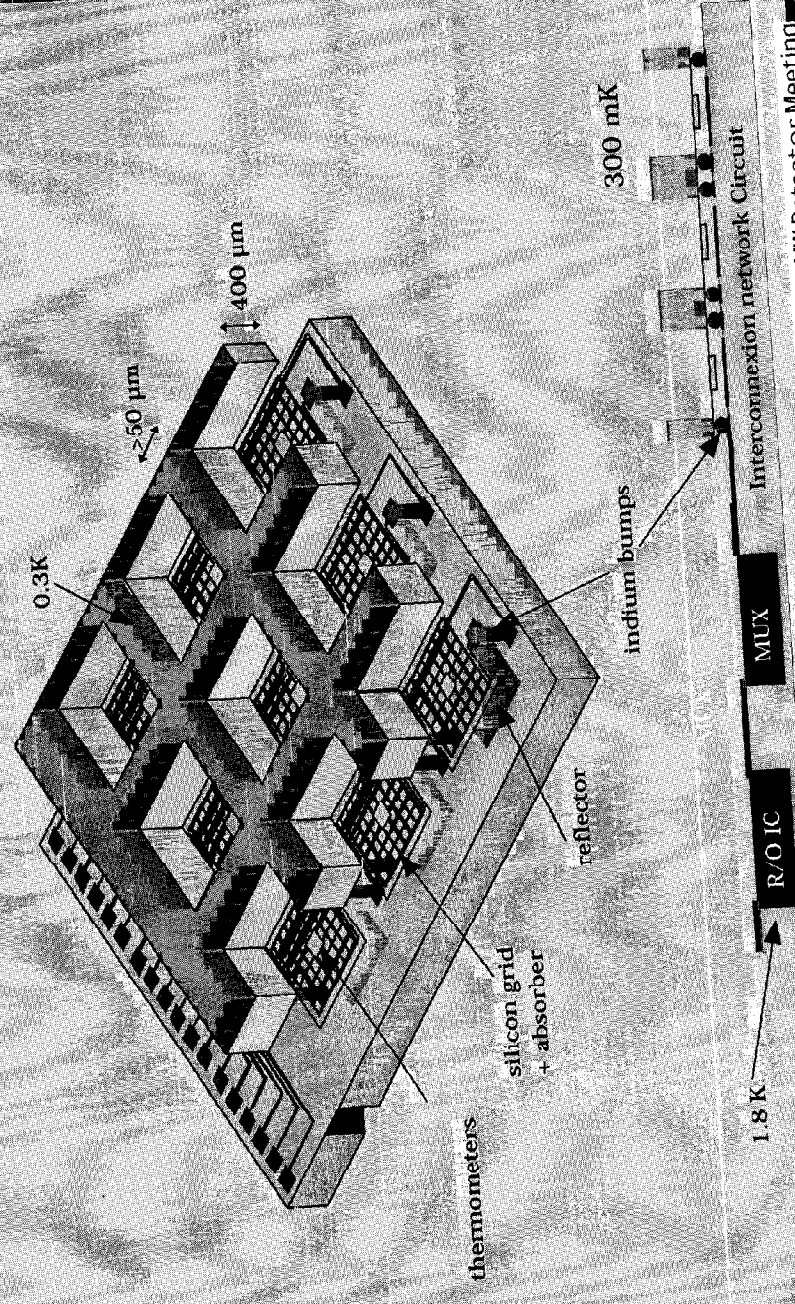


21/01/99-QMW Detector Meeting



FIRST/SPIRE

# THE ARRAY CONCEPT



21/01/99-QMW Detector Meeting

TO BUILD BOLOMETER ARRAYS

**TO HAVE ACCESS TO A TECHNOLOGY :**  
**HERE AT CEA/LETI**

Manufacture of integrated electronic circuits, and microensors for industry.

**TO HAVE KNOWLEDGE OF CRYOGENIC DETECTORS FOR SCIENTIFIC SPACE PLATFORMS: ISO and CASSINI.**

**TO HAVE ACCESS TO PHYSICAL PROPERTIES:**

OPTICAL ABSORPTION DATA.

**THERMAL CONDUCTANCES OF MATERIALS:**

Si, metal wires, others.

SPECIFIC HEAT DATA to compute heat capacity of the bolometer.

A THERMOMETER with known response and noise density to compute SENSITIVITY.

**TO DEVELOP MODELS**

For observations

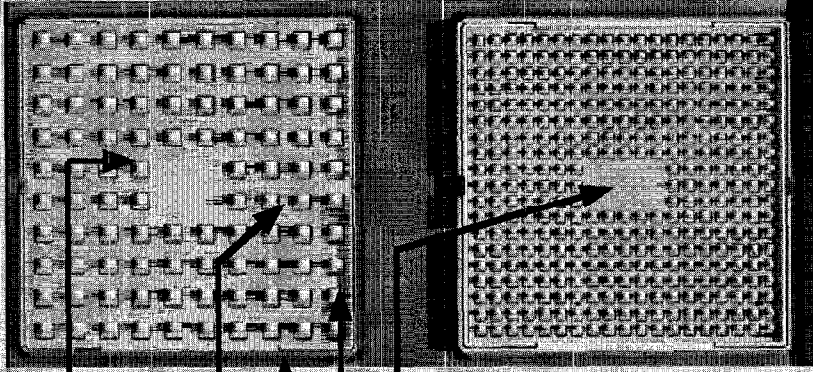
For optical absorption

For thermal behaviour of the bolometers, bandpass and expected sensitivity

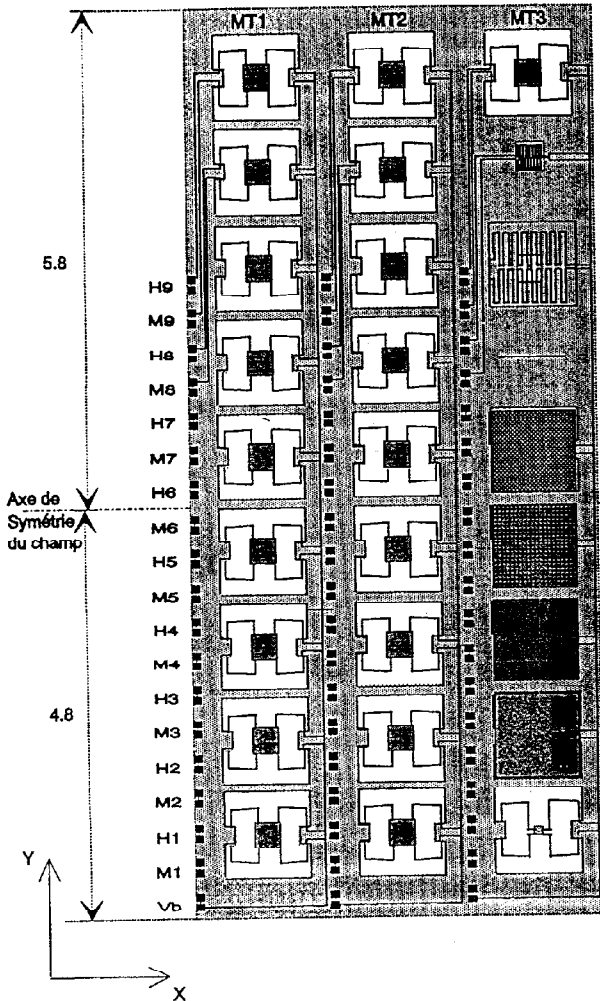
For electrical read out and signal processing

For thermal requirements of the focal planes.

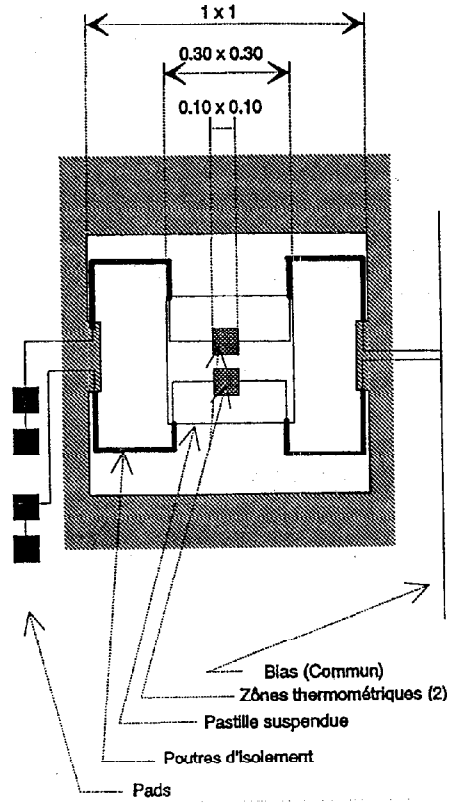
**TO ENSURE THAT SOLUTIONS ARE CONSISTANT WITH AVAILBLE TECHNOLOGIES FOR SCIENTIFIC SPACE BASED INSTRUMENTS**



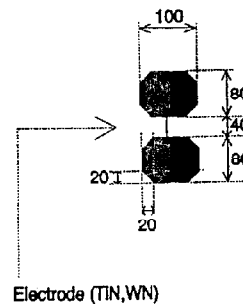
## Description de la zone motifs thermiques(D)



Détail d'une structure type MT1 & MT2

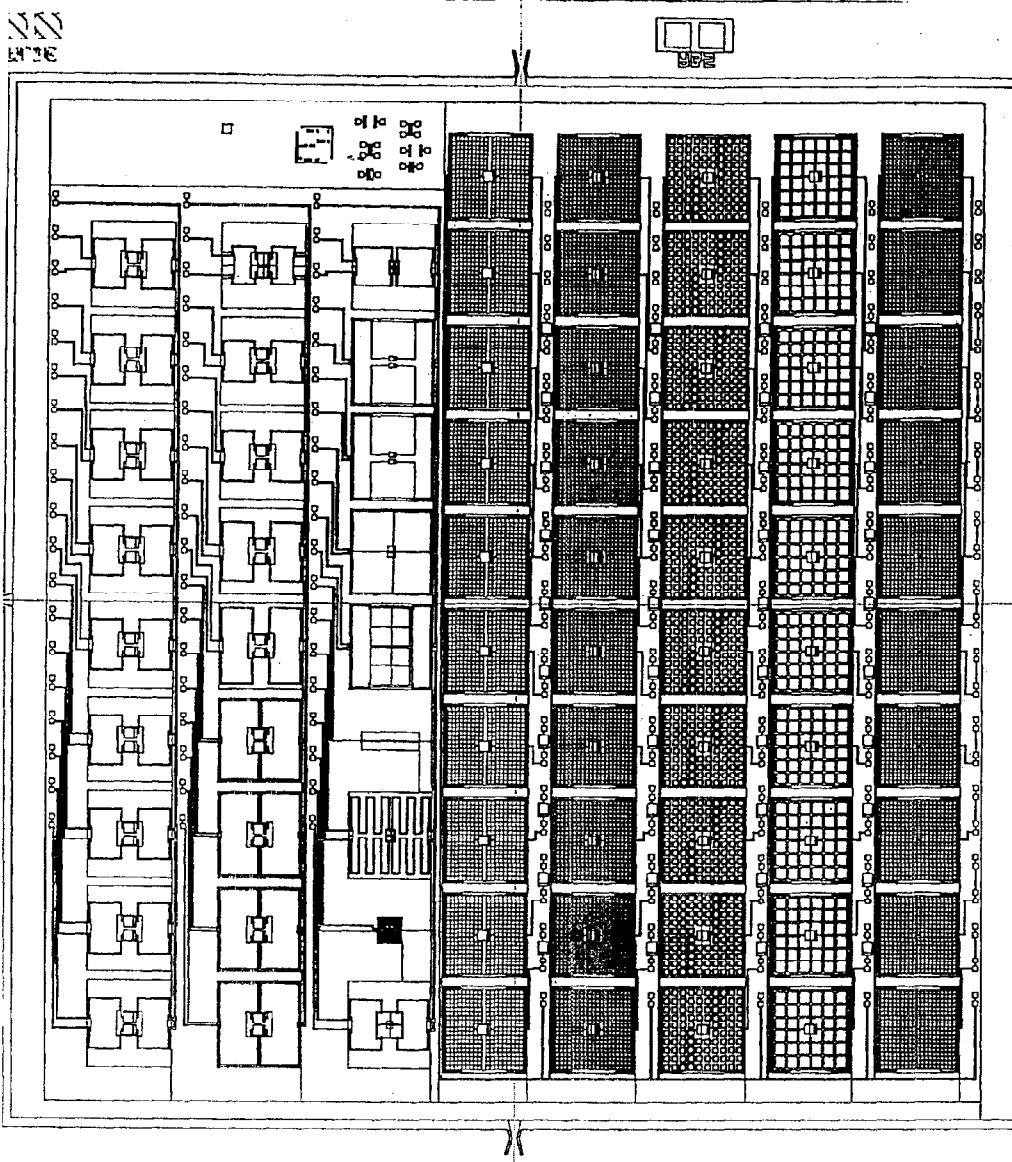


Définition du Pad élémentaire (dédoublé)  
Côtes en  $\mu\text{m}$

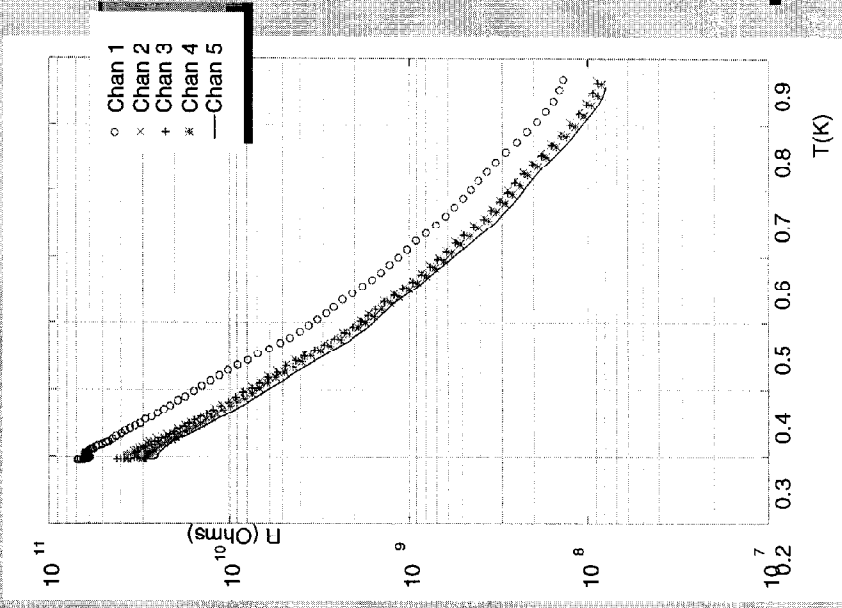


- PAS en X: 1.3
- PAS en Y: 1.1
- Mur d'isolement en X: 0.3
- Mur d'isolement en Y: 0.1
- Pas des pads en Y: 400  $\mu\text{m}$ . Nombre: 19 ( 1 bias + 18 ponts bores) dont 12 au dessous de l'axe de symétrie du champ, 7 en dessus.
- Cf. document pour définition des géométries des poutres et des membranes suspendues

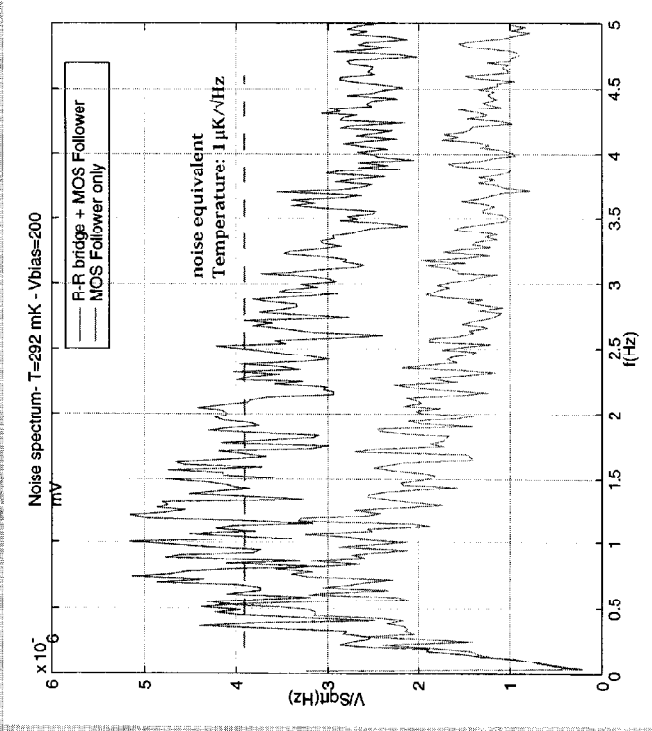
# 97 PROTOTYPE ARRAY



THERMAL RESPONSE



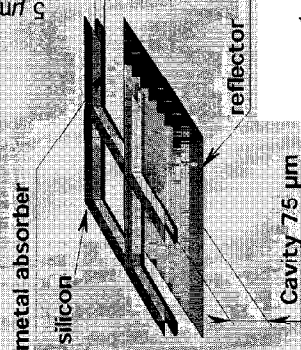
NOISE MEASUREMENTS



$\alpha \sim 40$

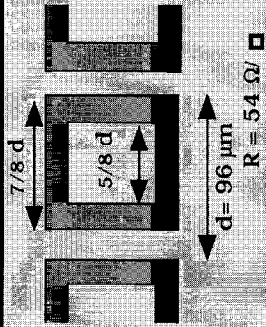
**FIRST/SPIRE**

**VERTICAL RESONANCE**

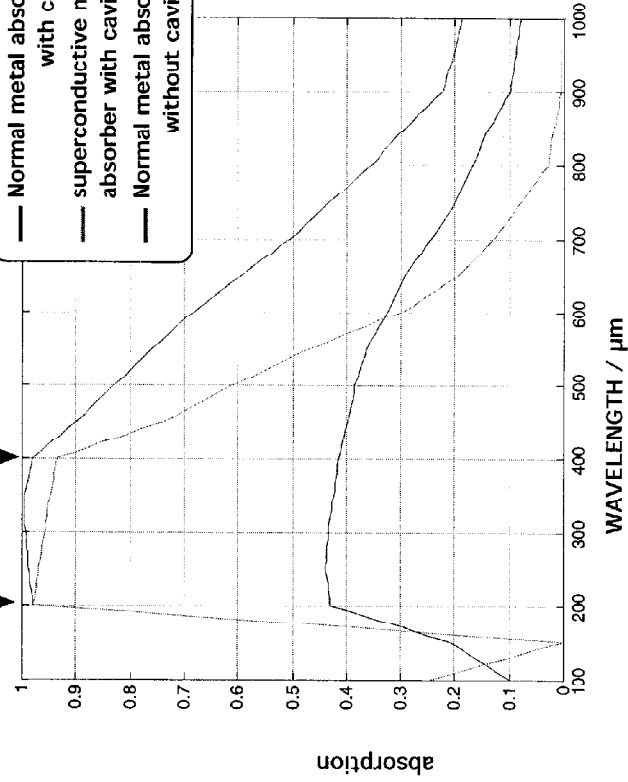


**ABSORPTION SIMULATIONS**

**HORIZONTAL PATTERN RESONANCE**



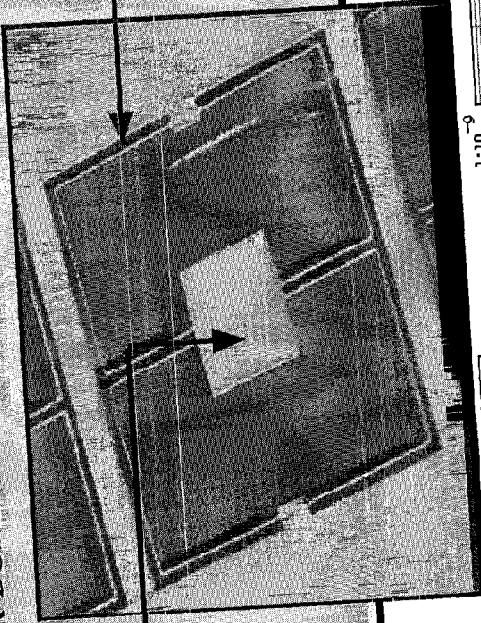
- Normal metal absorber with cavity.
- superconductive metal absorber with cavity.
- Normal metal absorber without cavity.





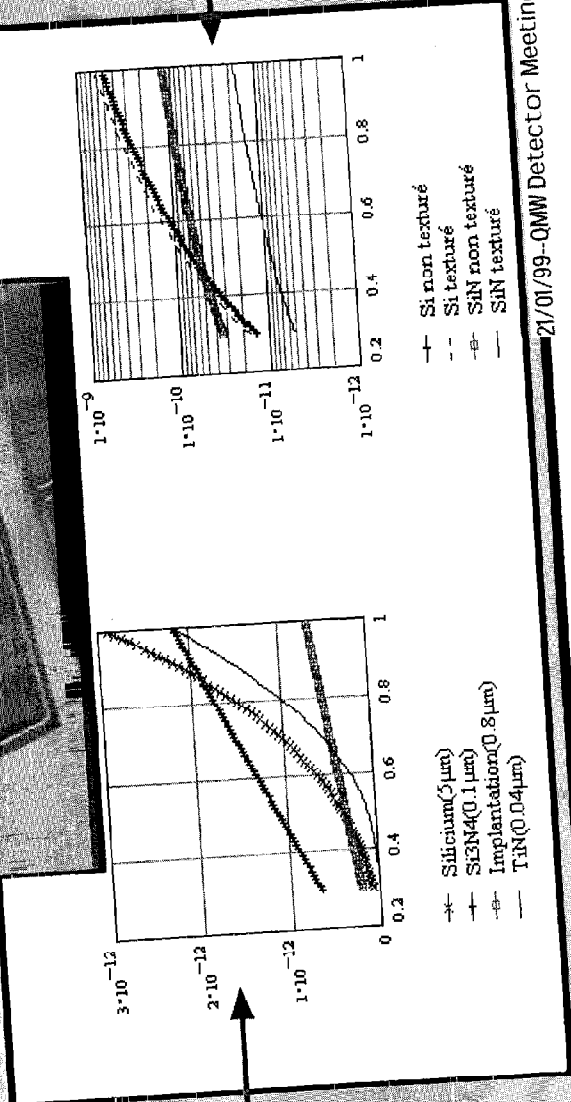
FIRST/SPIRE

# 300 mK BOLOMETER THERMODYNAMIC PROPERTIES



THERMAL  
CONDUCTANCE  
W/K  
700µm x 5µm x 4µm

HEAT CAPACITY  
J/K/mm<sup>2</sup>

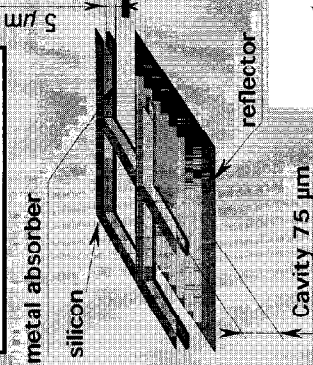


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# FIRST/SPIRE

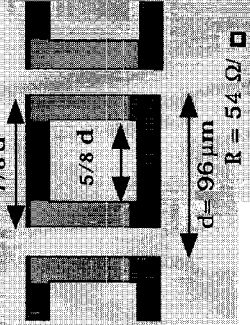
## VERTICAL RESONANCE



Cavity 75  $\mu\text{m}$

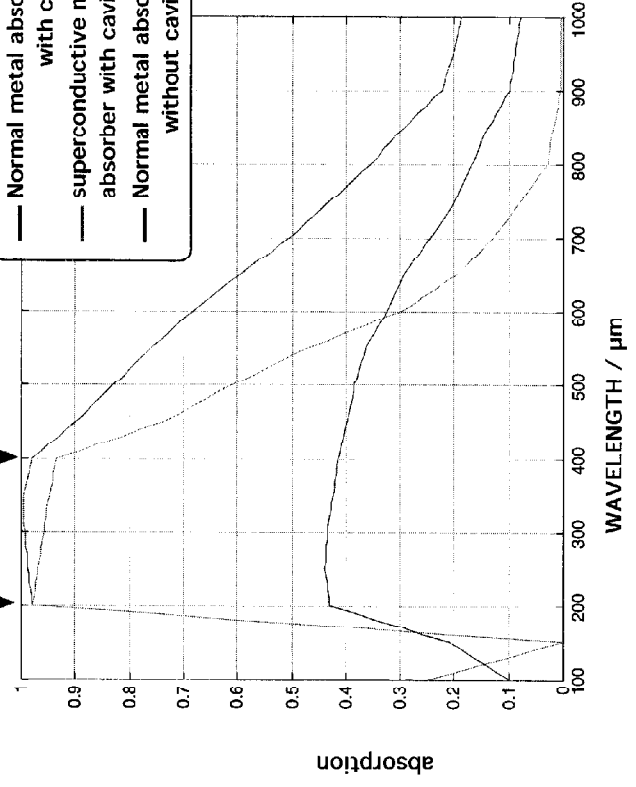
## ABSORPTION SIMULATIONS

### HORIZONTAL PATTERN RESONANCE



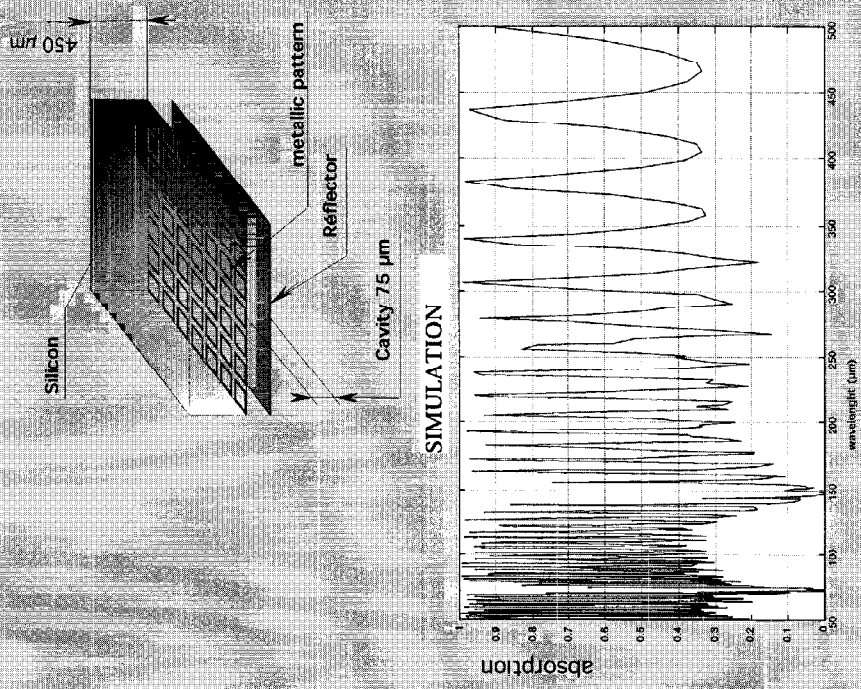
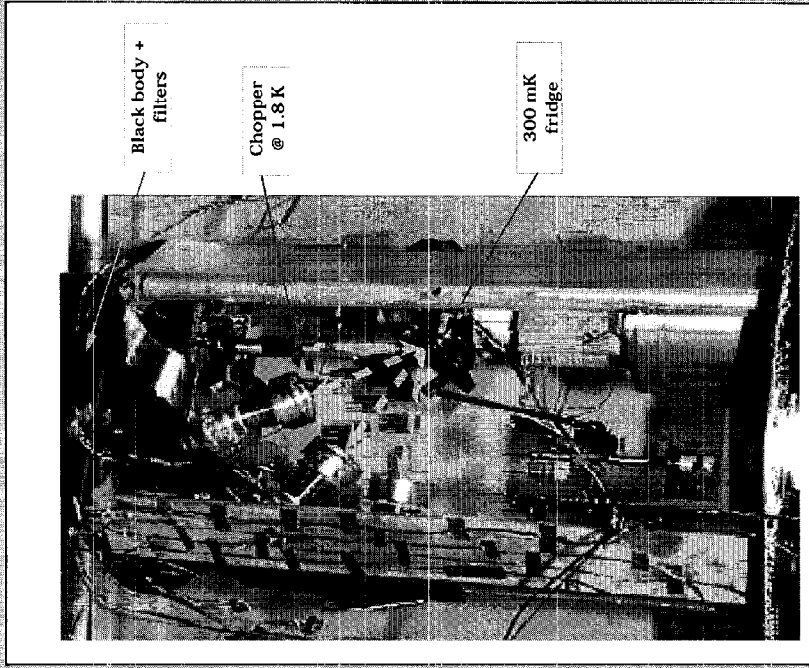
$d = 96 \mu\text{m}$   
 $R = 54 \Omega$

- Normal metal absorber with cavity.
- superconductive metal absorber with cavity.
- Normal metal absorber without cavity.

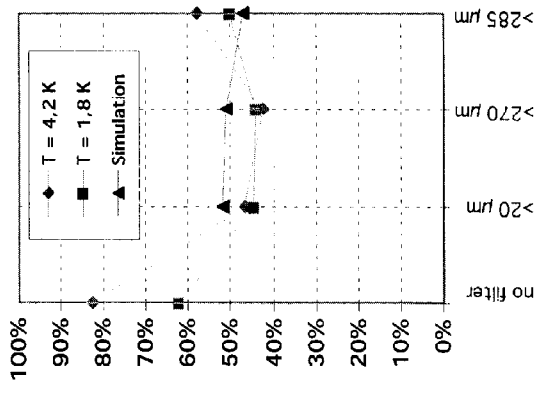
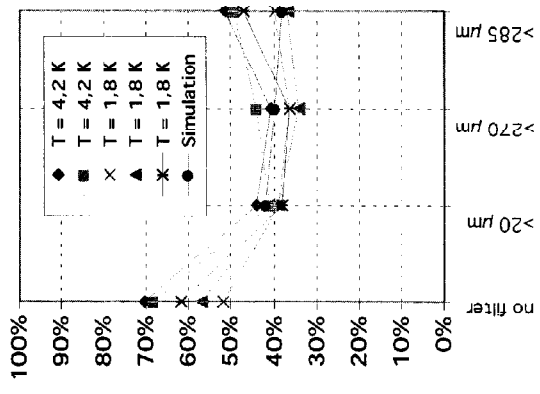
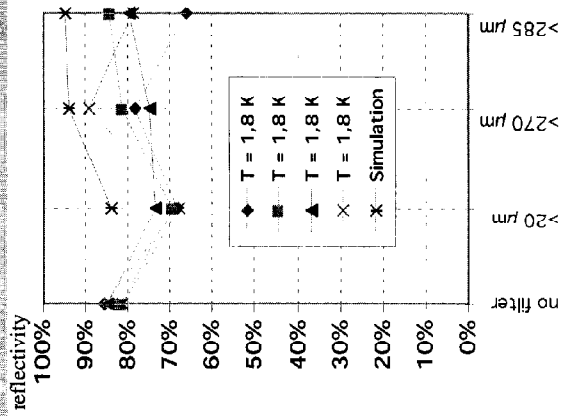
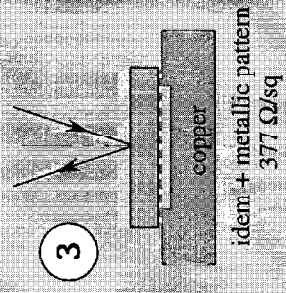
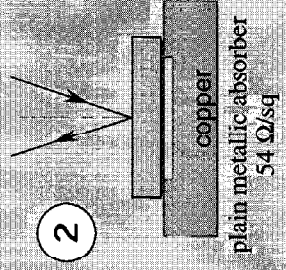
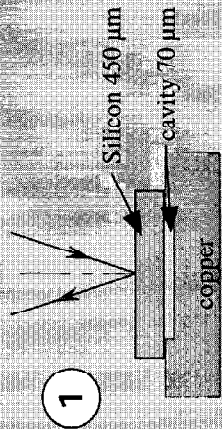


FIRST/SPIRE

### OPTICAL ABSORPTION MODEL (1)

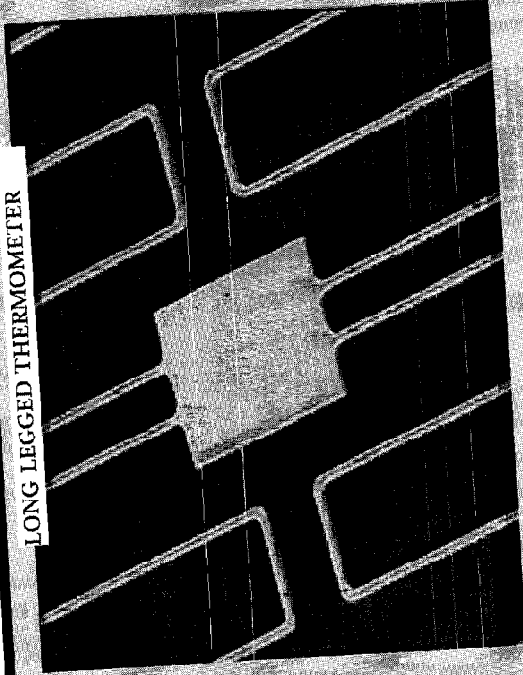


OPTICAL ABSORPTION MODEL (II)

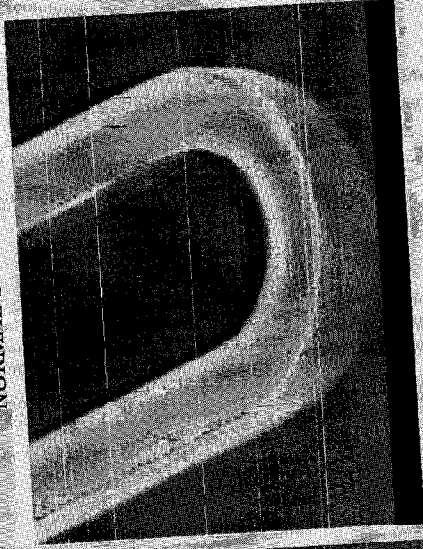


FIRST/SPIRE

LONG LEGGED THERMOMETER

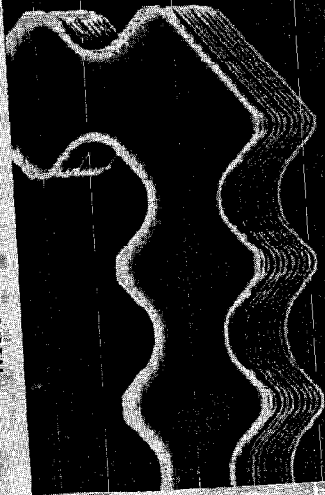


NORMAL DESIGN



SUSPENSION LEGS  
DETAILS

WIGGLED DESIGN



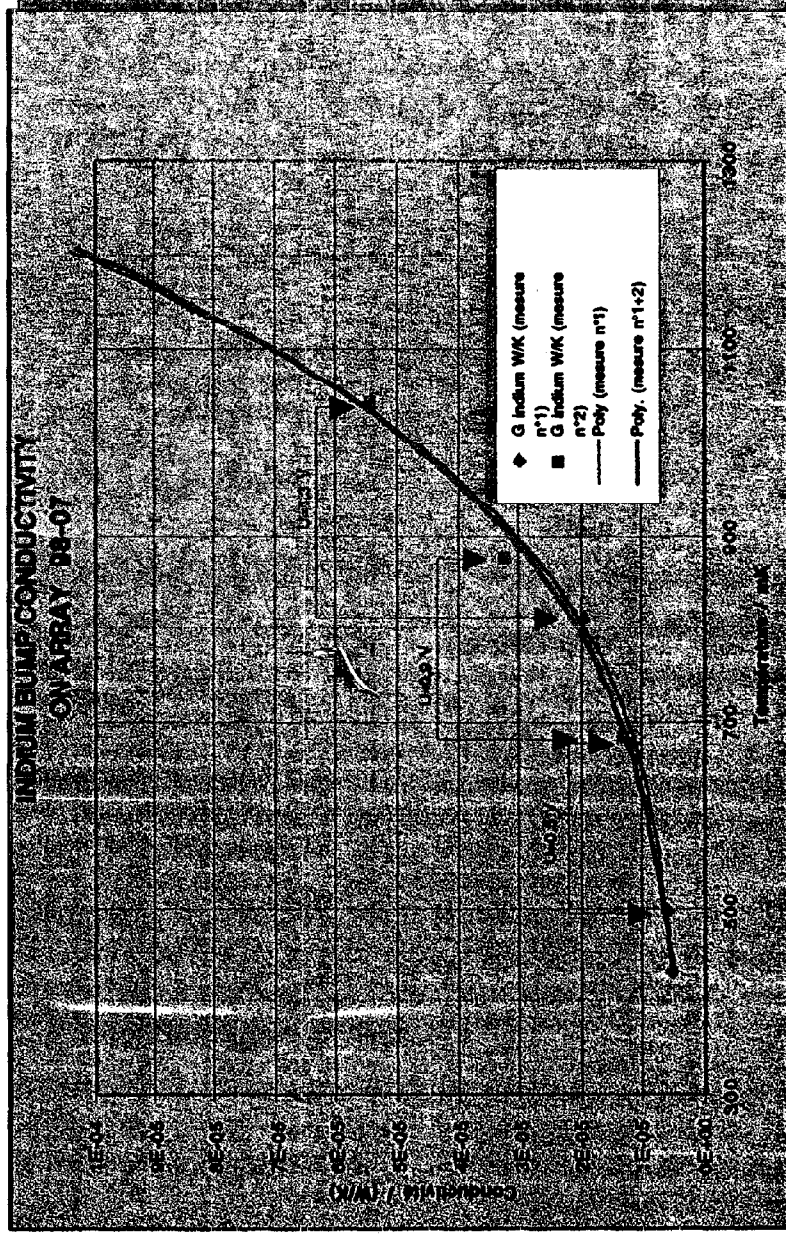
Ass'y Spool Main WD 2 1/2"  
1003V 4 0 6036 86 FB34110 R114/0001/01/0014

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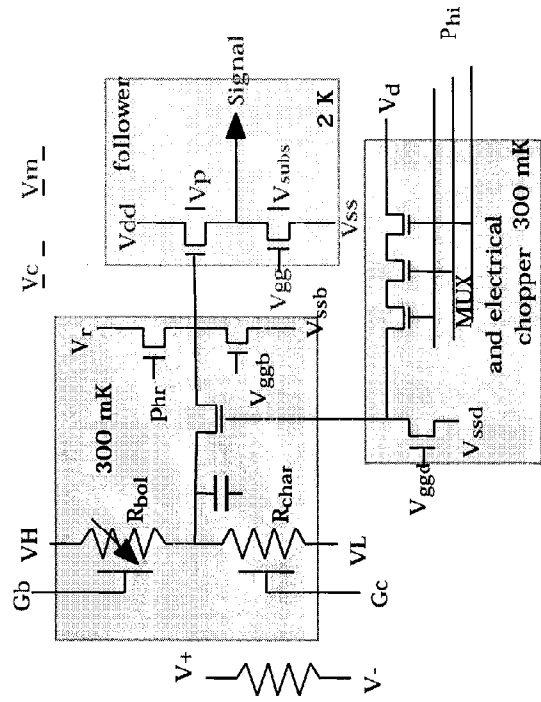
## INDIUM BUMPS THERMAL CONDUCTIVITY

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 .

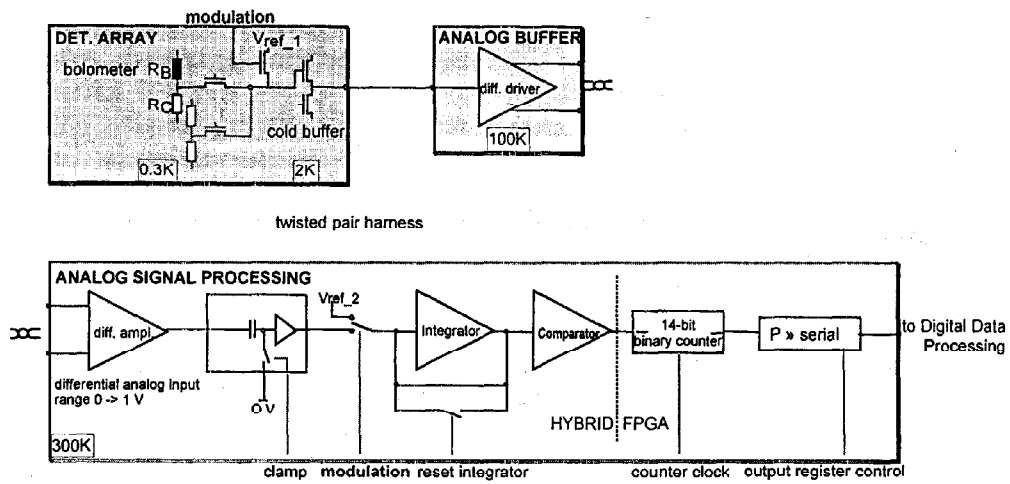
We measured a conductivity variation with T<sup>3</sup> in place of T, incompatible with admitted thermal load on the 3He fridge.



# THE COLD READOUT ELECTRONICS

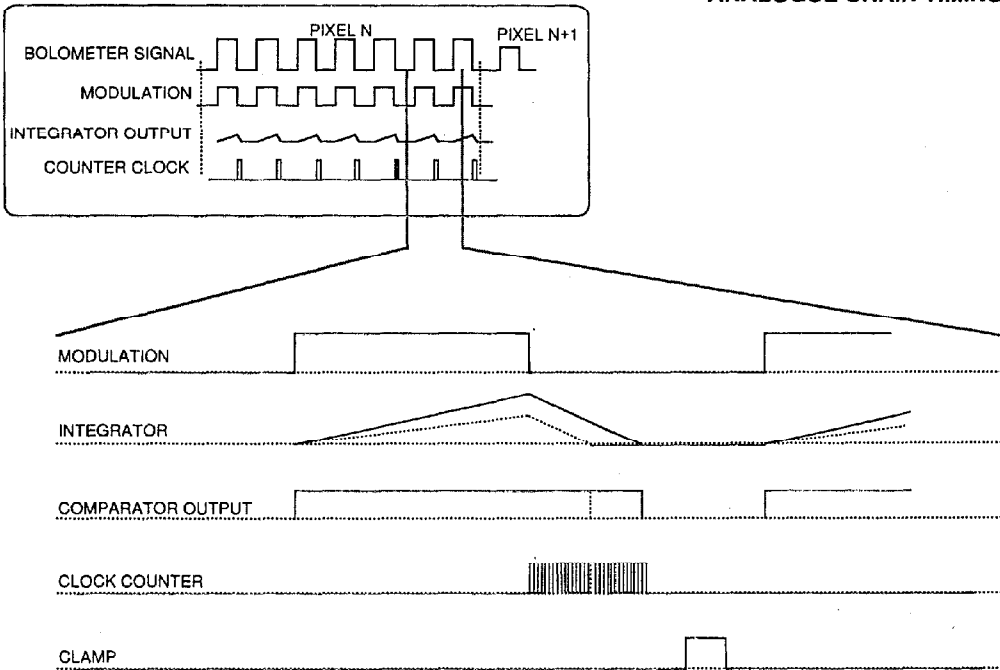


**SPIRE ANALOG CHAIN BLOCK DIAGRAM  
(LETI/LIR BOLOMETER)**

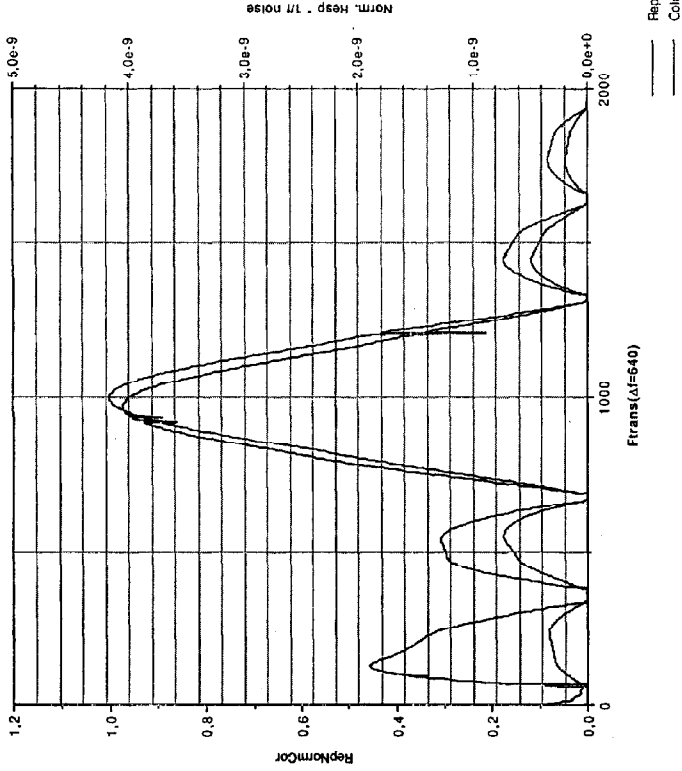


Note : all signals are generated by the Detector Array Sequencer

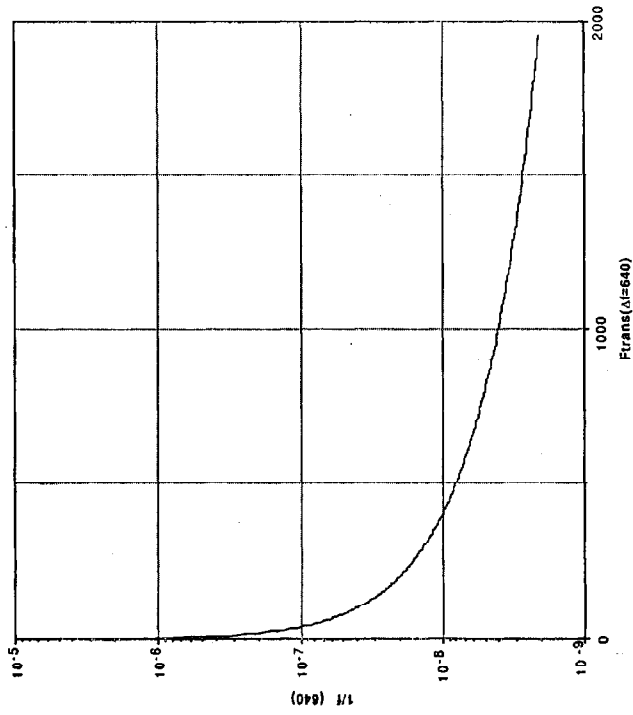
**ANALOGUE CHAIN TIMING**



**ANALOGUE CHAIN RESPONSE VS FREQUENCY**  
 (Fmod = 1 kHz - Fpix = 320 Hz)



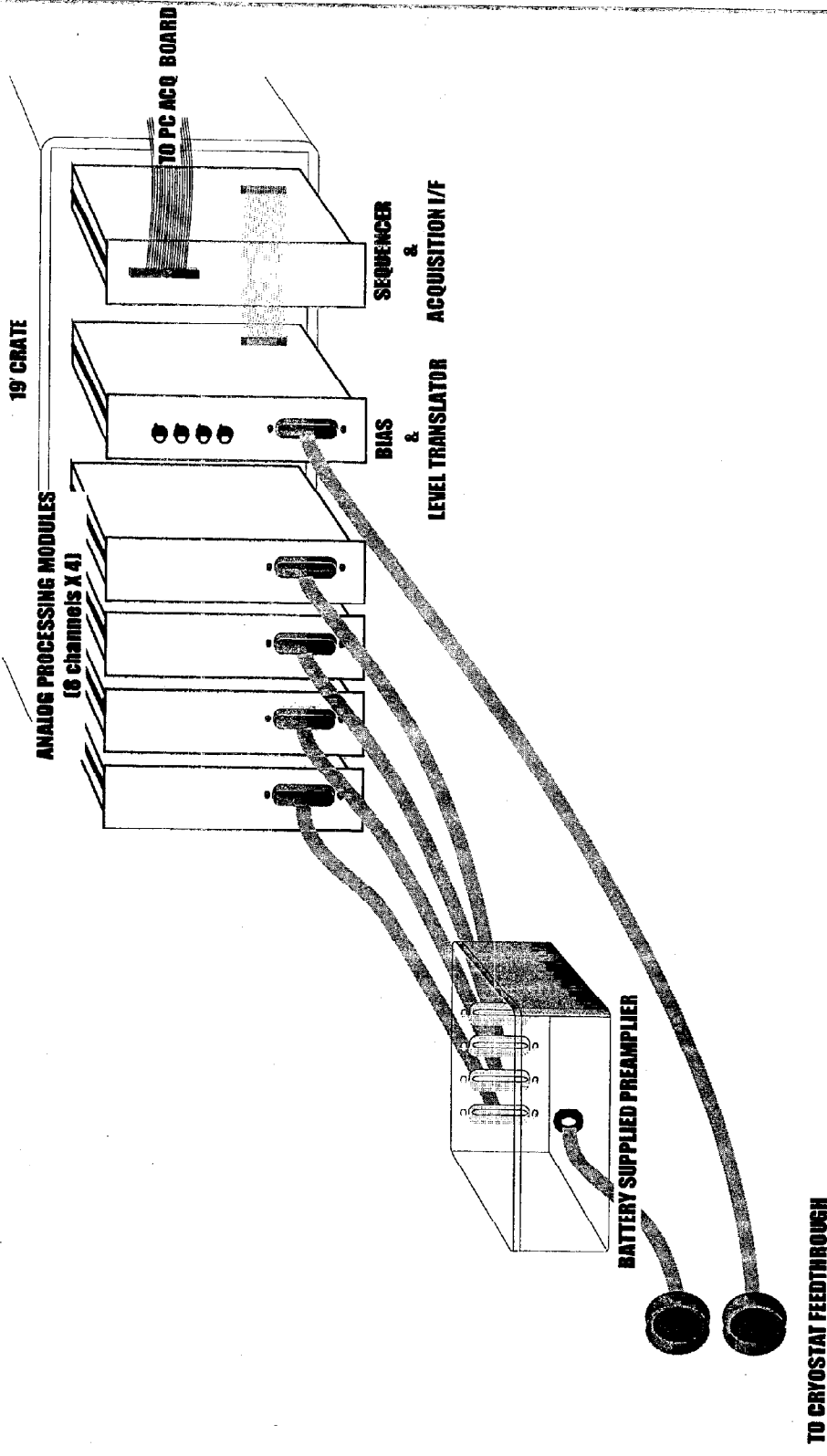
**COLD BUFFER 1/f NOISE**  
 (2 μV/√Hz - 2 Hz)



Norm. Resp. 1/f noise



**BOLOMETER SELECTION ELECTRONICS**



19" CRATE

ANALOG PROCESSING MODULES  
(8 channels X 4)

TO PC ACQ BOARD

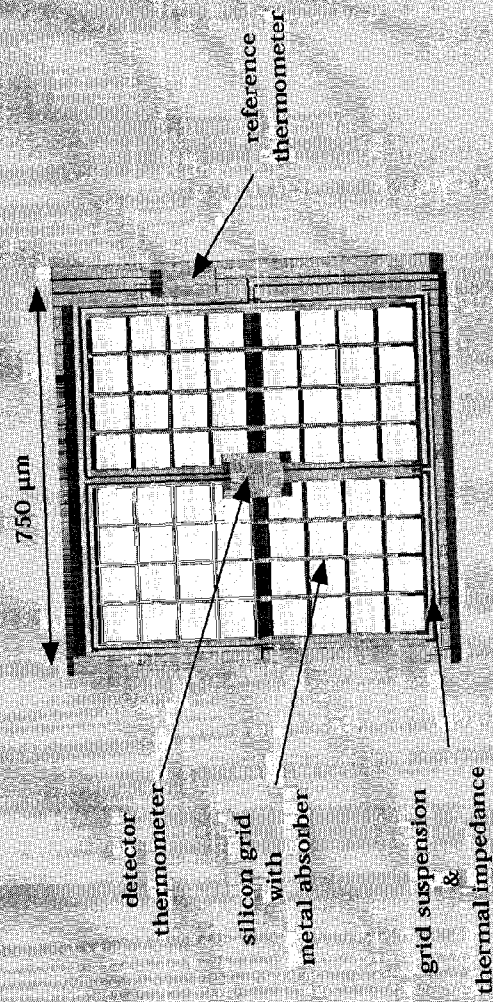
SEQUENCER  
&  
ACQUISITION I/F

BIAS  
&  
LEVEL TRANSLATOR

BATTERY SUPPLIED PREAMPLIFIER

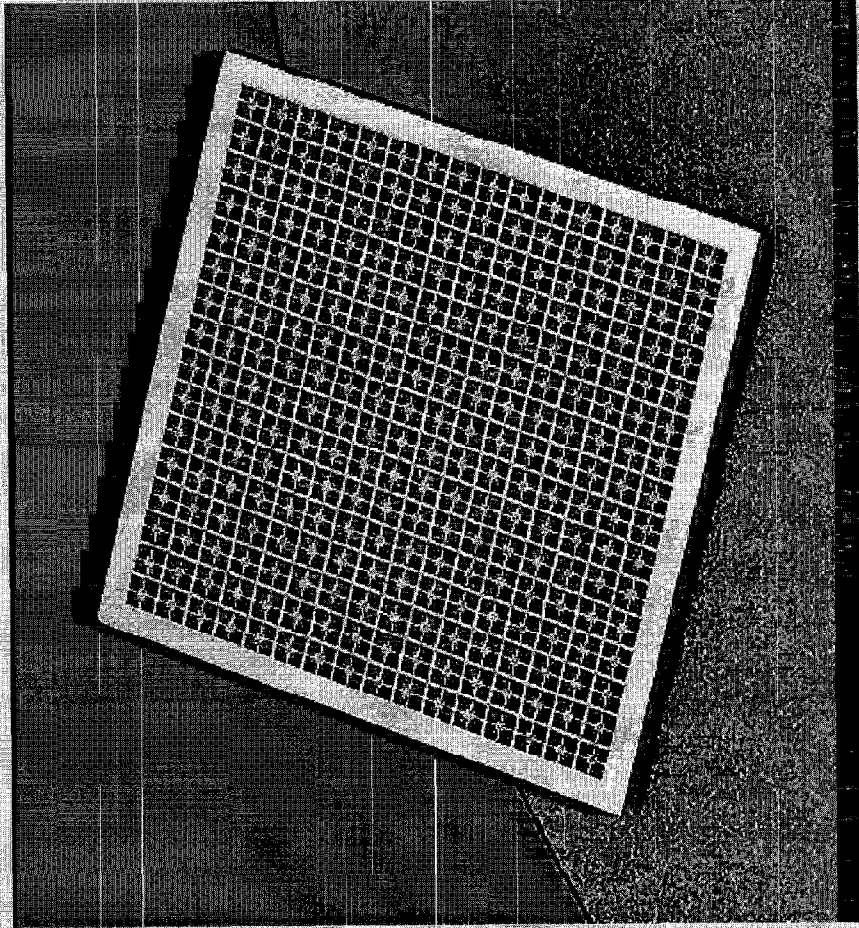
TO CRYSTAT FEEDTHROUGH

NEW DETECTORS ELEMENTARY PIXEL



FIRST/SPIRE

## NEW DETECTORS PIXEL BOLOMETERS



21/01/99-QMW Detector Meeting



CEA BOLOMETER ARRAYS: SYSTEMS DESIGN IMPACTS

ADVANTAGES

LIGHT COLLECTION

- Airy disc sampling

BOLOMETER STRUCTURE

- Low heat capacity
- controlled thermal conductance
- Good immunity to ionizing particles
- high mechanical resonances=
- low microphonic susceptibility

LIGHT->HEAT CONVERSION

- close to 100% efficiency.
- Absorption profile tailored by
- horizontal pattern

THERMOMETRIC PERFORMANCES

- High T dependence a~40.
- can be adjusted in flight (TBC)
- Noise level OK->goal: NEP<sub>opt</sub> ~ 10<sup>-17</sup> W/√Hz

GENERAL

- Complete focal plane sampling
- Easy baffling
- small devices (8 x 5 x 2 cm<sup>3</sup>)
- High elect. Integration MUX 8->1

DRAWBACKS

LIGHT COLLECTION

- Low directivity need baffling

BOLOMETER STRUCTURE

- LIGHT->HEAT CONVERSION
- TBC

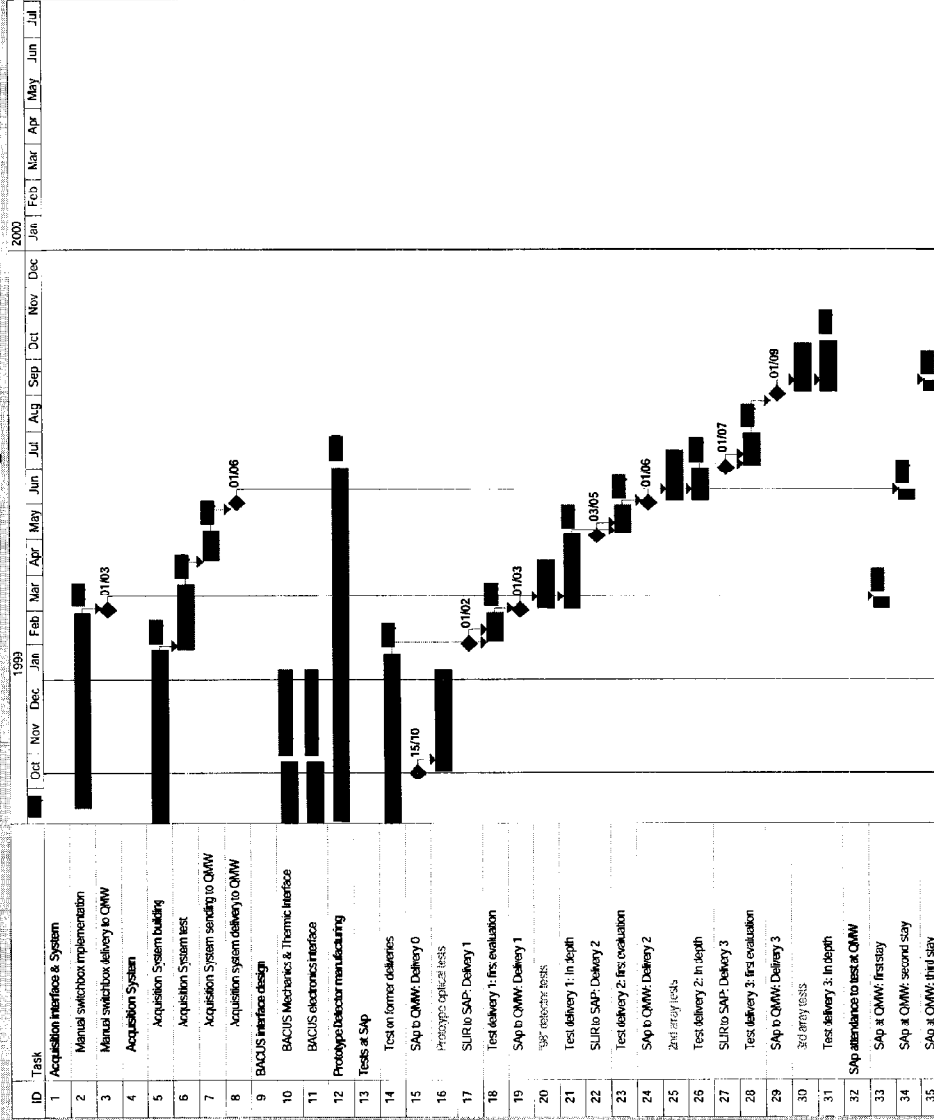
THERMOMETRIC PERFORMANCES

- High impedance thermometer
- Need 2K close readout.
- Complex lock-in amplifier
- Noise performances < NTD Ge

GENERAL

- COST
- Success oriented development
- Few physic properties still to evaluate

# CEA Detector Development Schedule



## CONCLUSIONS AND PROSPECT

• These last years have been a very exciting period. We started, two years ago, from a single concept, to end up with a new detector in hands.

• Although, all the physical principles at work in these arrays are (well?) known, this realisation is an original combination of sophisticated techniques ( not always under control!).

• For this reason, most of the final (before evaluation) design is frozen.

• A few aspects have yet to be explored ( mesa detectors, gate effect on the thermistors etc.)

• A large amount of work is still necessary to sort out a satisfactory array.

• In parallel to the detector characterisations, an important effort will be done to manufacture the warm signal processing electronics.

• A pre-qualification process will be done internally at Grenoble ( vibration tests).

• Susceptibility to ionising particles will be soon tested also. The simulation program has already started. The bonus is, maybe, to be able to measure easily the individual electro-thermal bolometer characteristics without a calibrated sub millimeter source.

# 6

## GSFC/NIST ARRAYS

**HARVEY MOSELEY  
JIM CALDWELL  
JUAN ROMAN  
KENT IRWIN**



# THE NIST TEAM

KENT IRWIN

JAY CHERVENAK

ERICH GROSSMAN

TODD HARVEY

JOHN MARTINIS

CARL REINTSEMA

DAVE RUDMAN

---

# OUTLINE

## ● SINGLE PIXEL PERFORMANCE

- SCALING TO SMALL TES
- EXCESS HIGH FREQ. NOISE ELIMINATED

## - TES FABRICATION

Al/Ag + Mo/Au + Mo/Cu

## ● 4x8 FABRICATION STATUS

DONE

- CONTACT PADS, GRANULAR AL LEADS, PdAu ABSORBER, BACKSIDE KOH ETCH, FRONTSIDE PUNCH-THRU MASK REMAINING

- SOME MICROMACHINING, TES DEPOSITION

- RISK REDUCTION THROUGH

REDUNDANT FABRICATION @ GSFC + NIST

## ● SQUID MUX CHIPS (1x8)

- SUFFICIENT INVENTORY FOR DOWN SELECT OF BOTH SQUID MUX AND NYQUIST FILTER CHIPS.

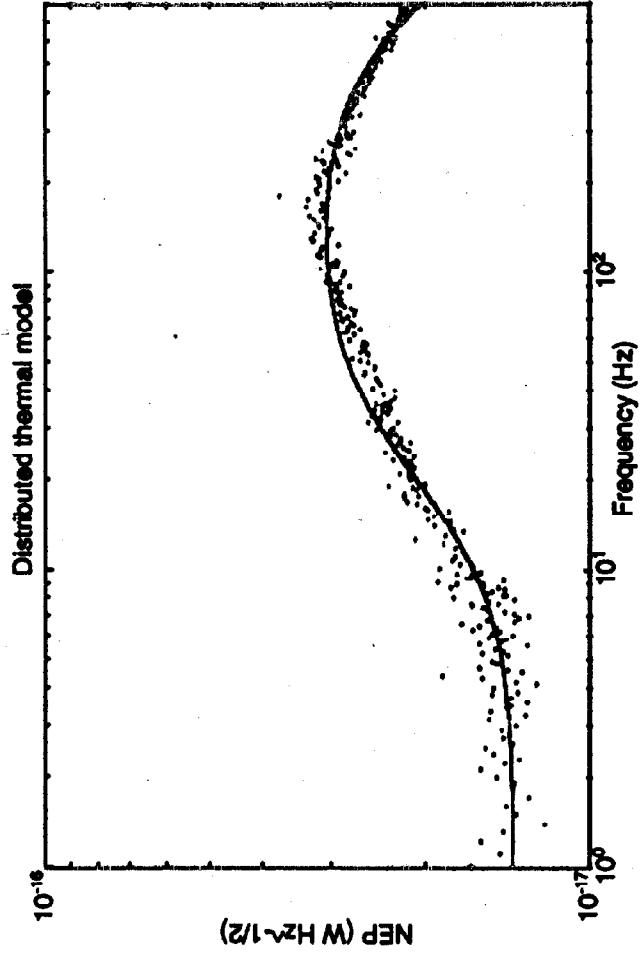
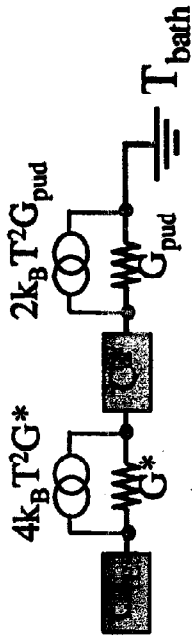
## Thermal Circuit Model

Fit to two free parameters:

$$G^* = 300 G_{\text{pud}}$$

$$C^* = C_{\text{TES}}$$

Thermal conductance within pud  
Extra heat capacity (from granular Al)

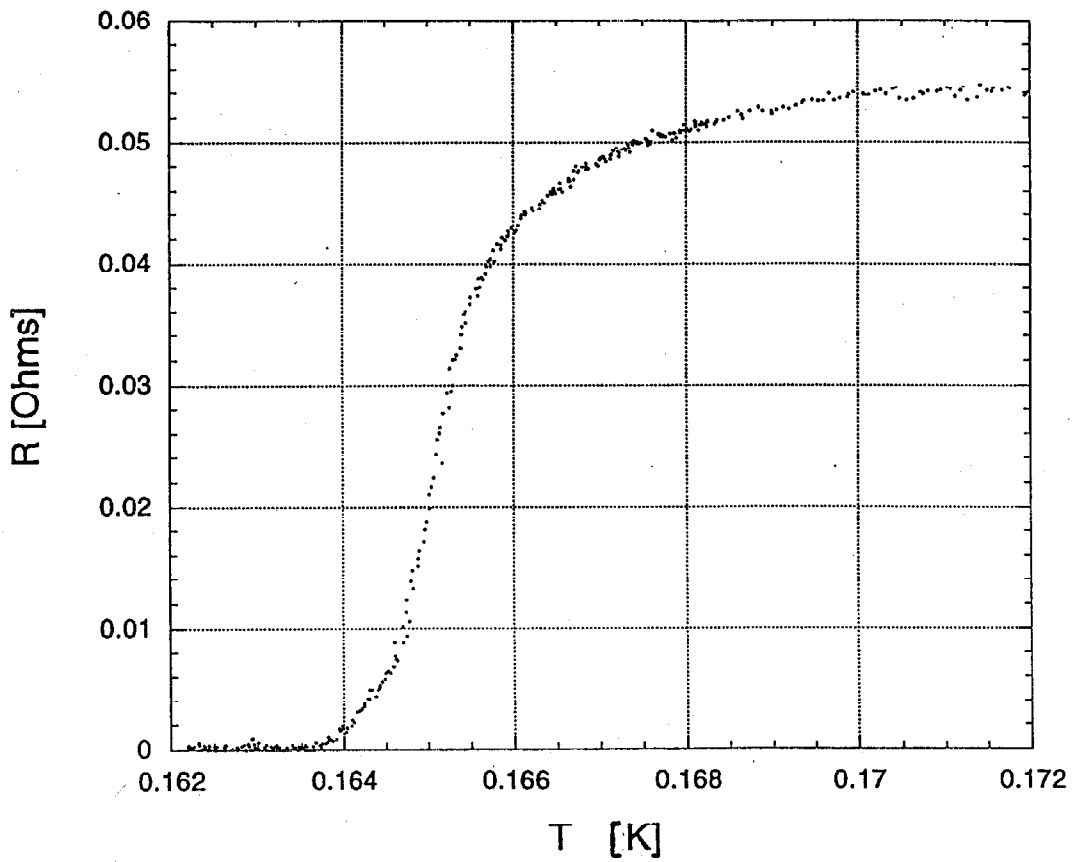


**NIST** Boulder

RECENT, PRELIMINARY RESULT:  
NOISE BUMP ELIMINATED

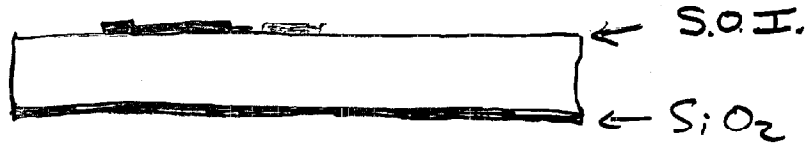
# Mo/Au Superconducting Transition

Thermal anneal tests (400 C) very promising

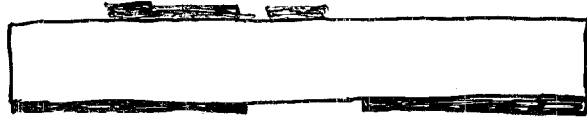


# TES / PVD FAB PROCESS

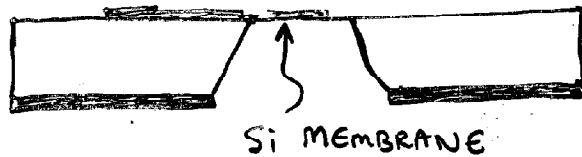
- ① FRONTSIDE METALLIZATION  
(CONTACTS, LEADS, ABSORBER)



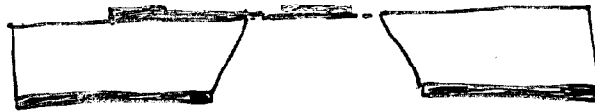
- ② BACKSIDE ETCH MASK



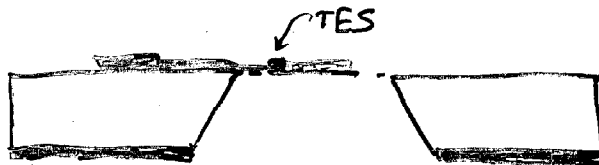
- ③ KOH ETCH OF Si



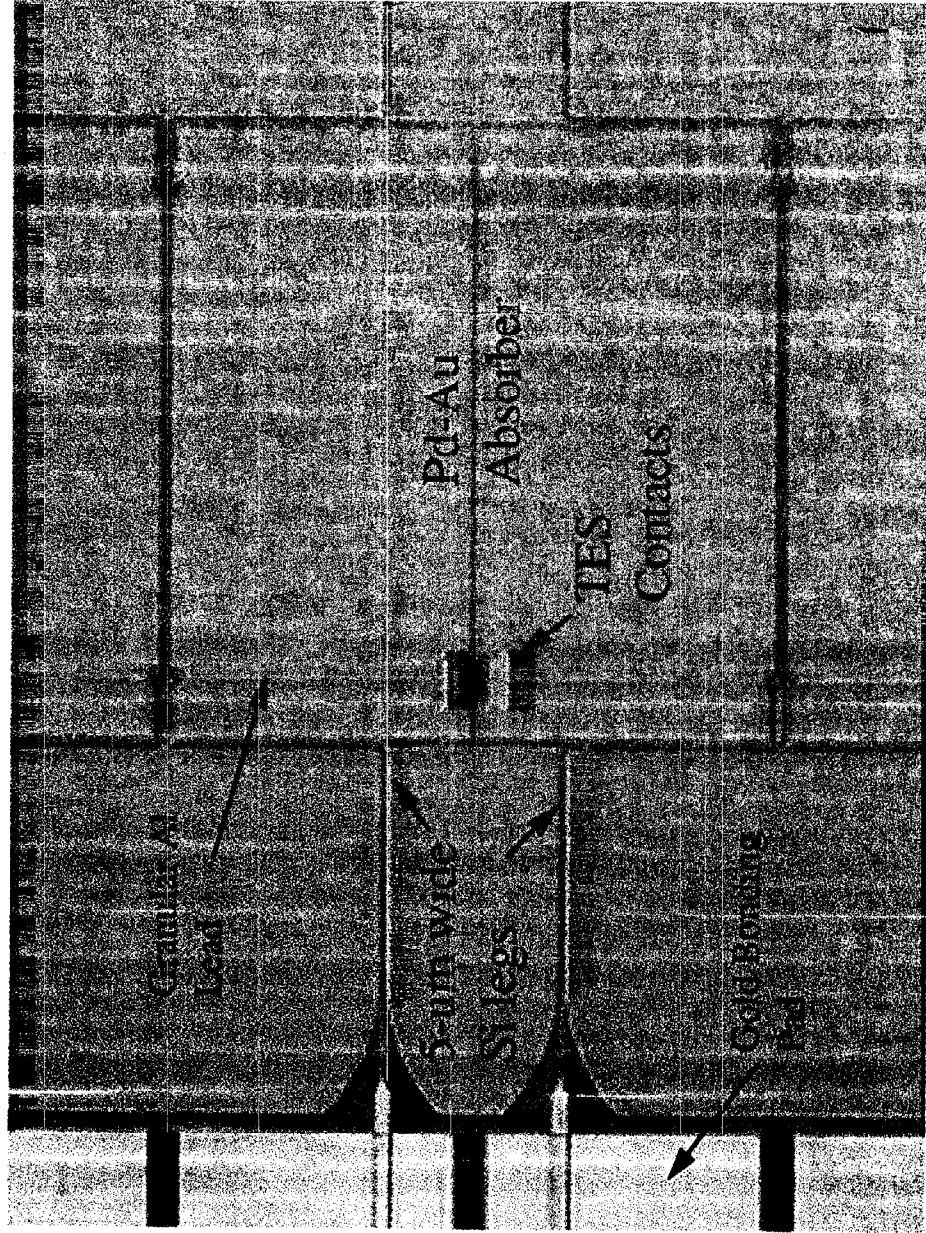
- ④ FRONTSIDE Si PUNCH-THROUGH ETCH



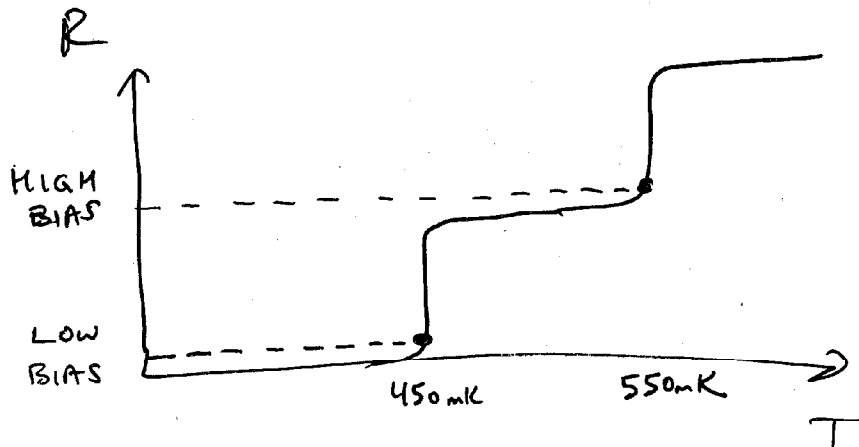
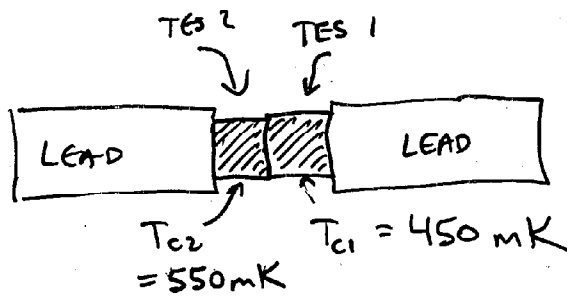
- ⑤ SHADOWMASK DEPOSITION OF TES



One Pixel of a Partially Fabricated 1 x 8 TES Bolometer Array



# TWO-TES DEVICE



BY CHOOSING EITHER THE LOW OR HIGH BIAS POINT, THE ARRAY CAN BE OPERATED AT TWO POWER LOAD/NEP TRADEOFF POINTS.

A RISK REDUCTION MEASURE



**SPIRE**

**TES ELECTRICAL**

**Ref:**  
SPIRE/RAL/N/0051  
**Issue:** .10  
**Date:** 21-Jan-99  
**Page:** 1 of 11

**James N. Caldwell**

**NASA/GSFC**

**Detector Development Meeting**

**Jan 21, 1999**






## SPIRE

### Assumptions

**Ref:**  
SPIRE/RAL/N/0051  
**Issue:** .10  
**Date:** 21-Jan-99  
**Page:** 2 of 11

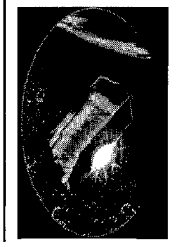
- Assumptions:
  - Each Detector Array has its own Front end Electronics
  - Instrument configurable to Photometer OR Spectrometer
  - Electronics design is same for FTS or Photometer arrays
  - Simultaneous sampling of Photometer arrays
  - Buffer Amplifier in the TES system is located in the Warm Electronics box.
  - Chopper Motion and FTS Scan Mechanism synchronized with DRCU/SPU

	<p><b>SPIRE</b></p> <p>Electronics Properties</p>	<p><b>Ref:</b> SPIRE/RAL/N/0051 <b>Issue:</b> .10 <b>Date:</b> 21-Jan-99 <b>Page:</b> 3 of 11</p>
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- Physical properties are being determined
- Warm Electronics Box
- Footprint; Height . . . . . TBD
- Mass . . . . . TBD
- Power . . . . . TBD
- Input . . . . . TBD
- Dissipation . . . . . TBD
- Detectors and Cold Electronics
- Preliminary Wire Count . . . . . 1010
- Power Dissipation at 4K, 1.8K and 0.3K are in agreement with the specification



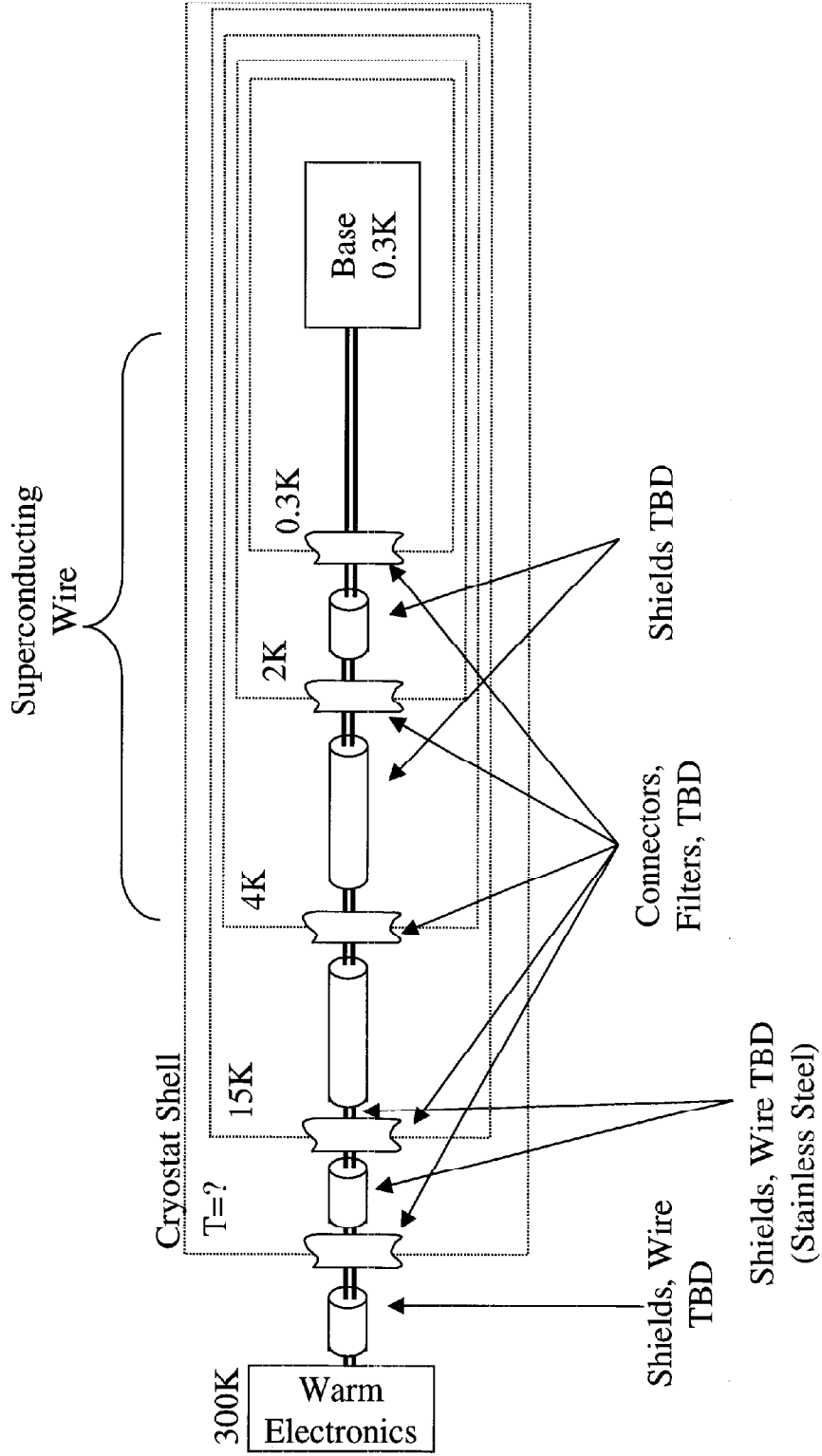




# SPIRE

## Typical Cryostat Harness Definition *Preliminary*

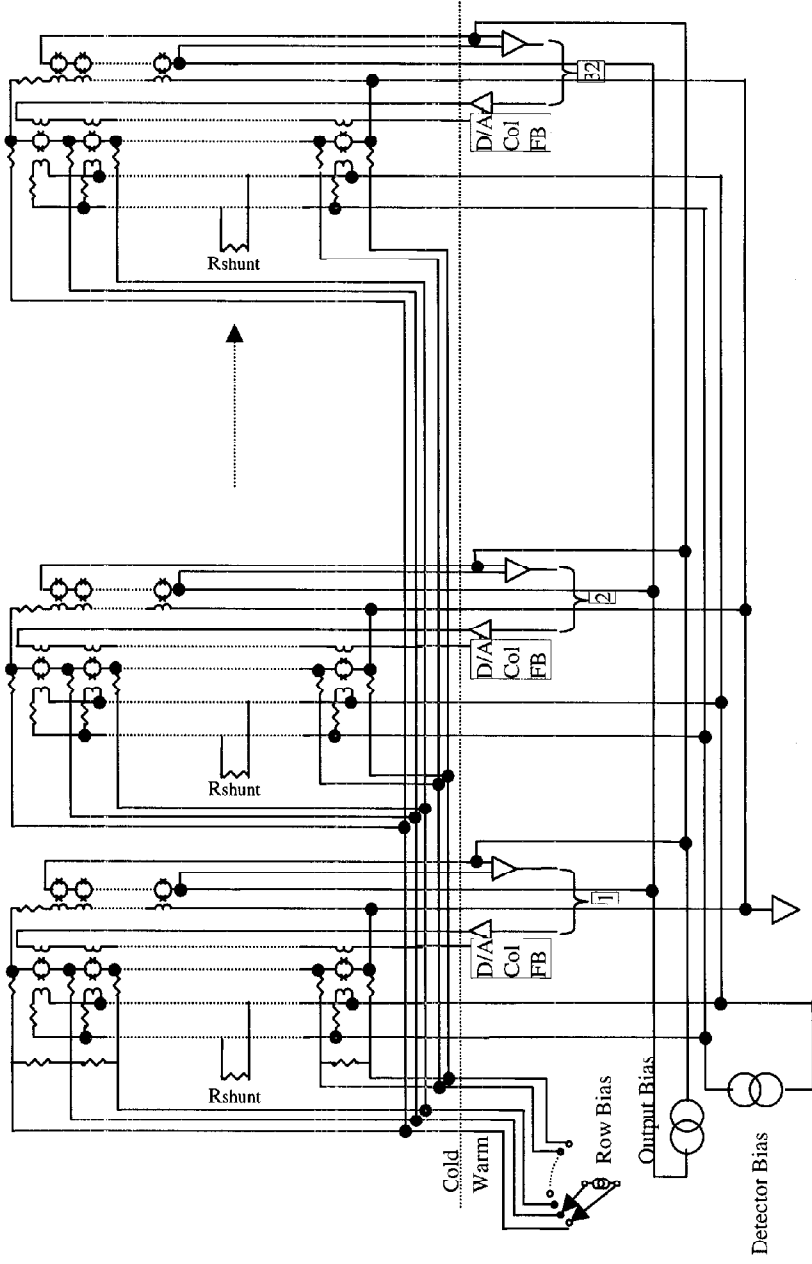
Ref: SPIRE/RALN/0051  
Issue: .10  
Date: 21-Jan-99  
Page: 6 of 11



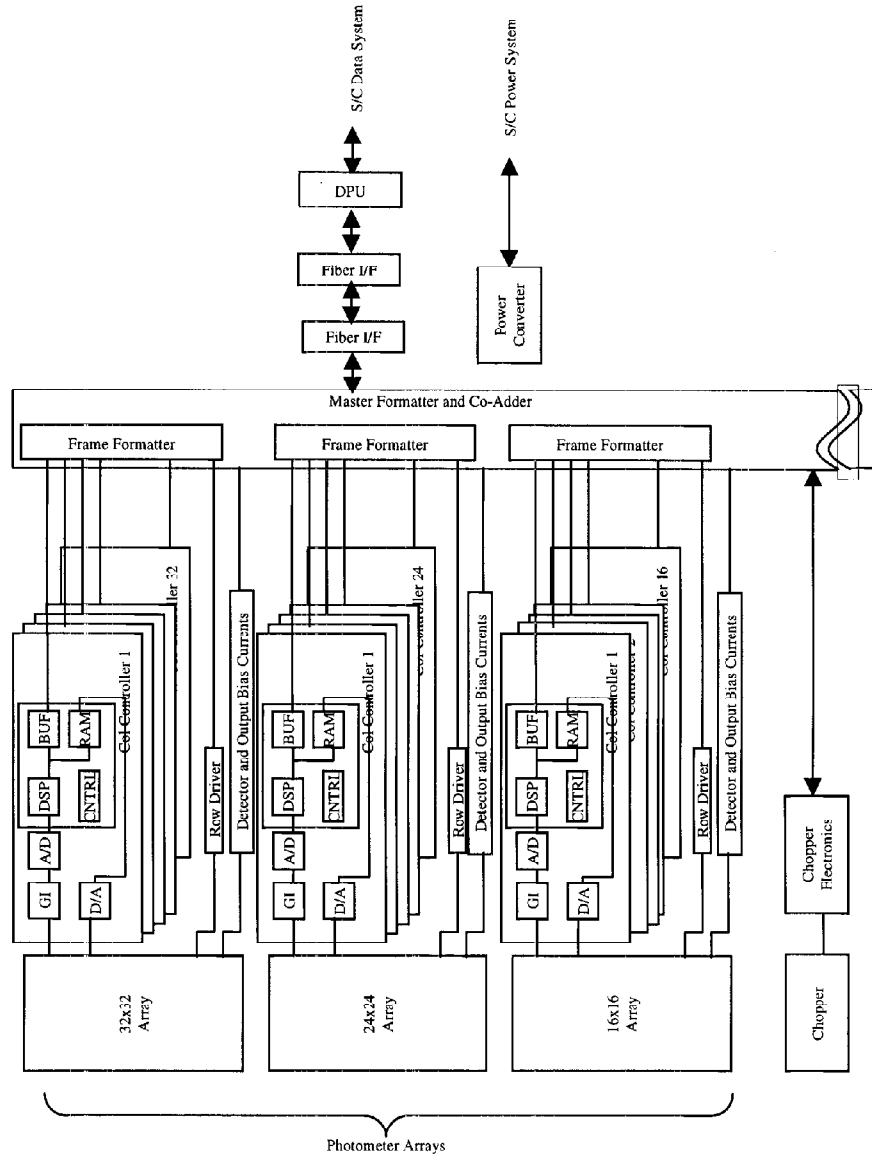
# SPIRE

## Cold Electronics Architecture *Preliminary*

Ref: SPIRE/RAL/N/0051  
Issue: .10  
Date: 21-Jan-99  
Page: 7 of 11



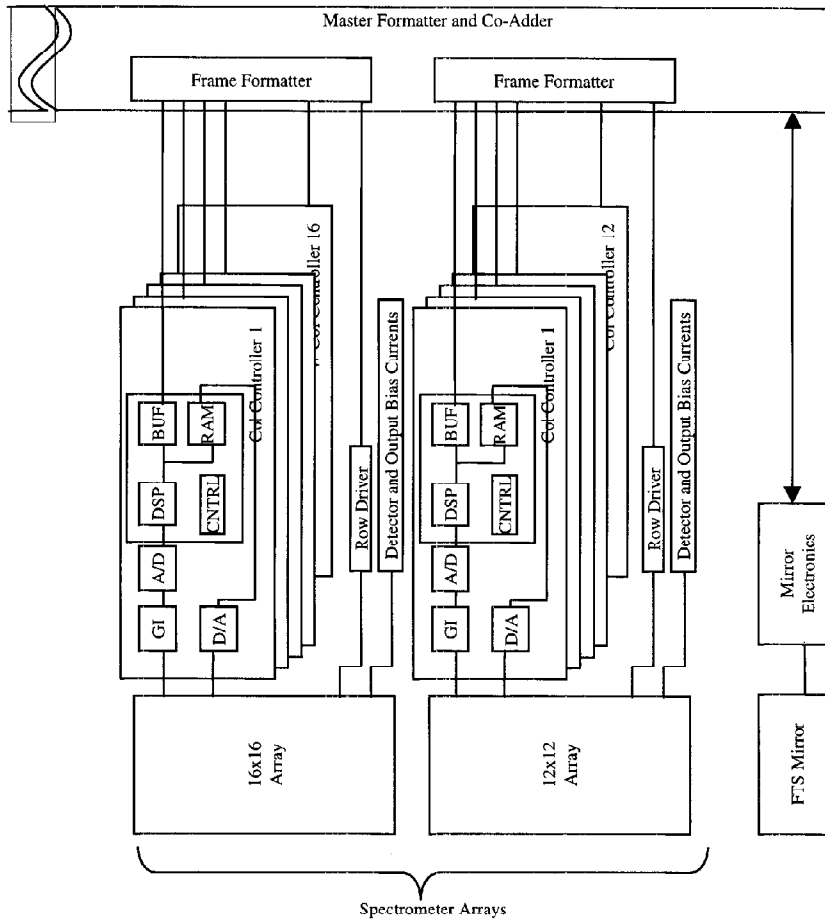
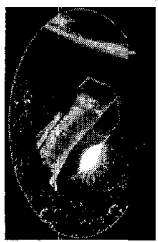
Warm Electronics Architecture



# SPiRE

## Warm Electronics Architecture

Ref: SPIRE/RAL/N/0051  
Issue: .10  
Date: 21-Jan-99  
Page: 9 of 11







## SPIRE

### DPU Requirements

**Ref:**  
SPIRE/RAL/N/0051  
**Issue:** .10  
**Date:** 21-Jan-99  
**Page:** 10 of 11

Sample Rate 5 - 50 Hz

Memory data size DPU

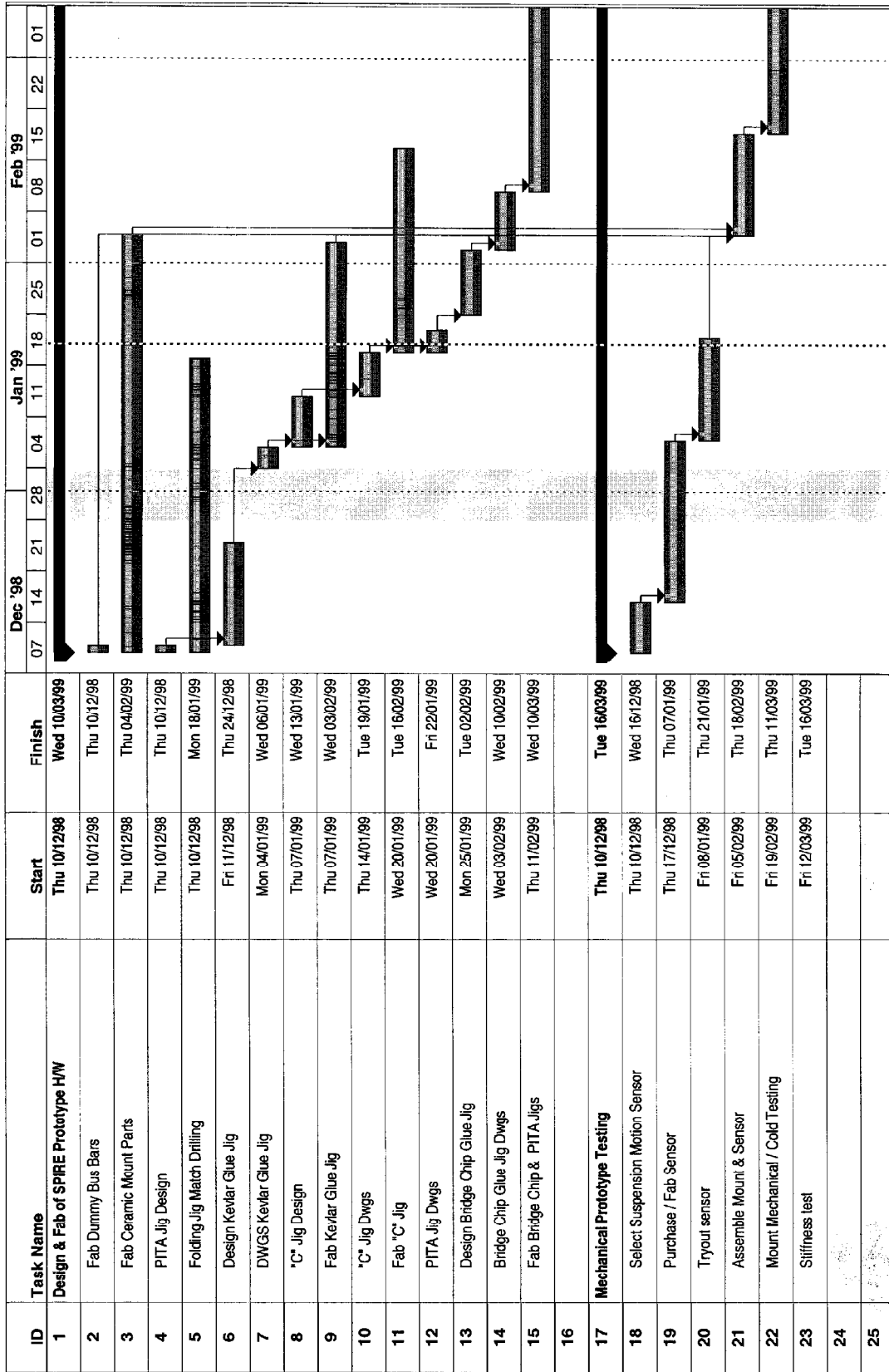
With Co-adding in DPU

< 3 Mbytes in DPU and < 20 Kbytes in Master Formatter

With Co-adding in Master Formatter

< 20 Kbytes in DPU and < 3 Mbytes in Master Formatter

Data Throughput < 40 Kbps and Mode dependant









## **SPIRE Detectors TES/Popup Option**

---

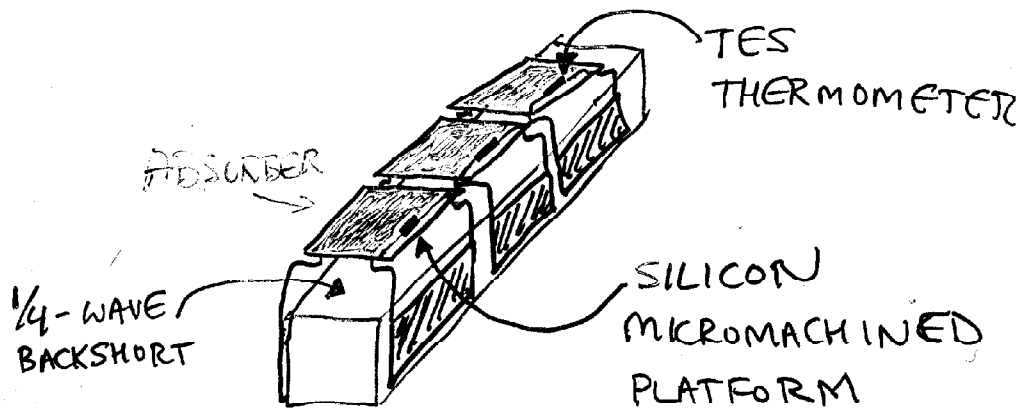


- Mechanical and Electronics      Harvey Moseley
- Bolometer Fabrication            Kent Irwin
- Electronics System Design        Jim Caldwell
- Plans and Schedule                 Juan Roman

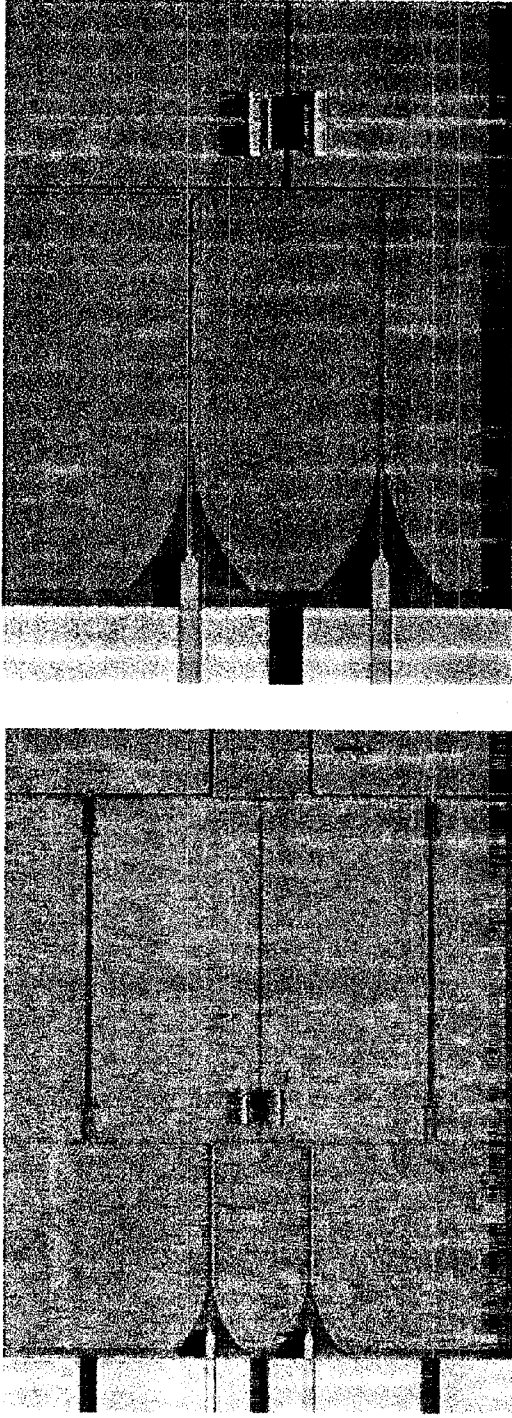
# SILICON "POPU" BOLOMETER

0.5 f $\lambda$  OPTION

- 3-DIMENSIONAL MICROMACHINED SILICON STRUCTURES



# Silicon Popup Detectors



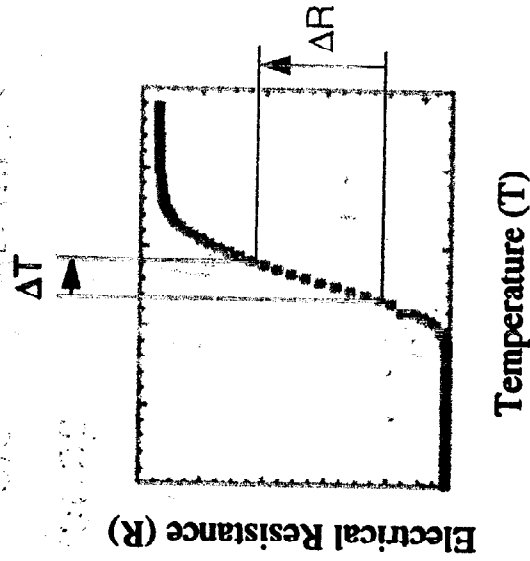
A 5 x 32 array of 1 mm x 1 mm popup structure

**NIST** Boulder

# Superconducting Transition-Edge Sensor (TES) Thermometer

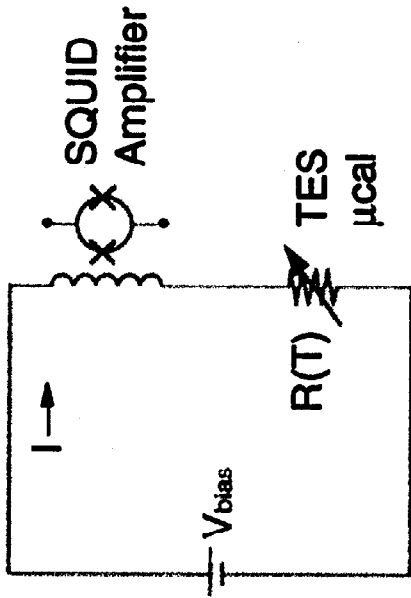
## Advantages of TES Thermometer

- High Sensitivity ( $\alpha$  is 10-100 x higher than thermistors. Allows absorber heat capacity 10-100 x bigger)
- Uses low power SQUID amplifiers instead of FETs
- Low Impedance (less microphonics)





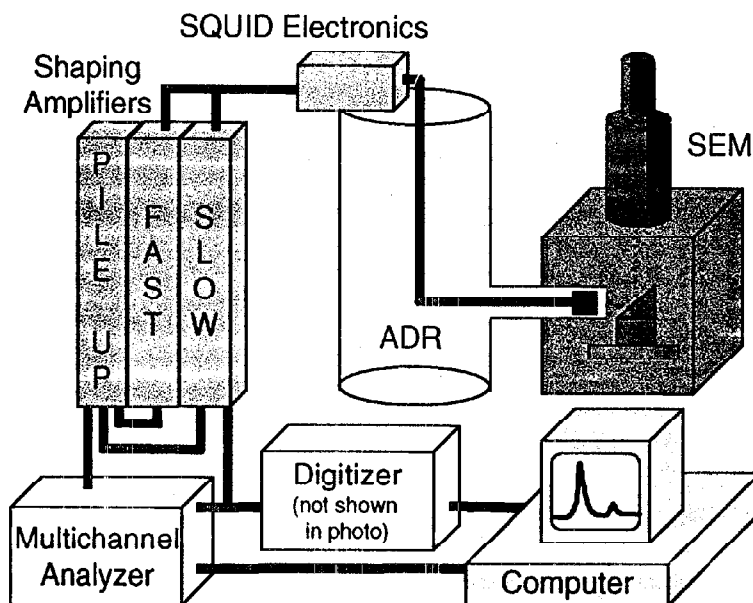
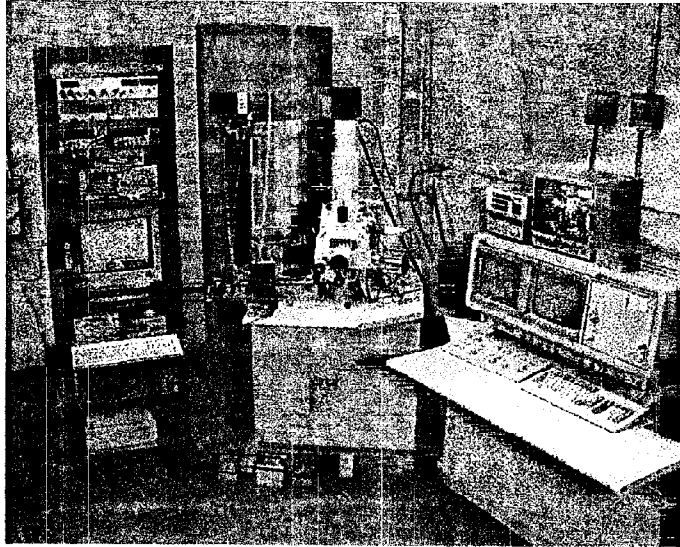
# Superconducting Quantum Interference Device (SQUID) Current Amplifier



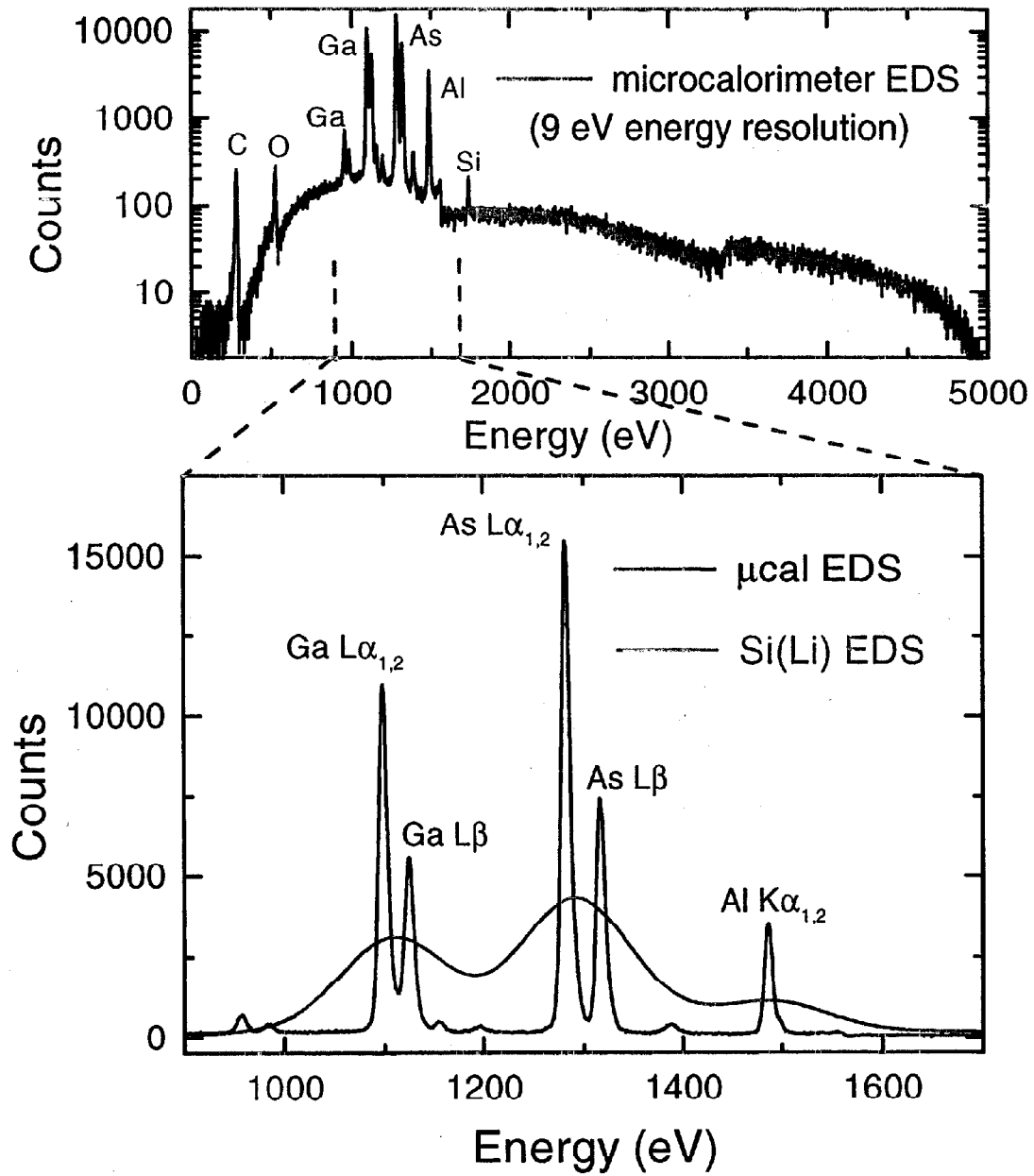
## Advantages of SQUID readout

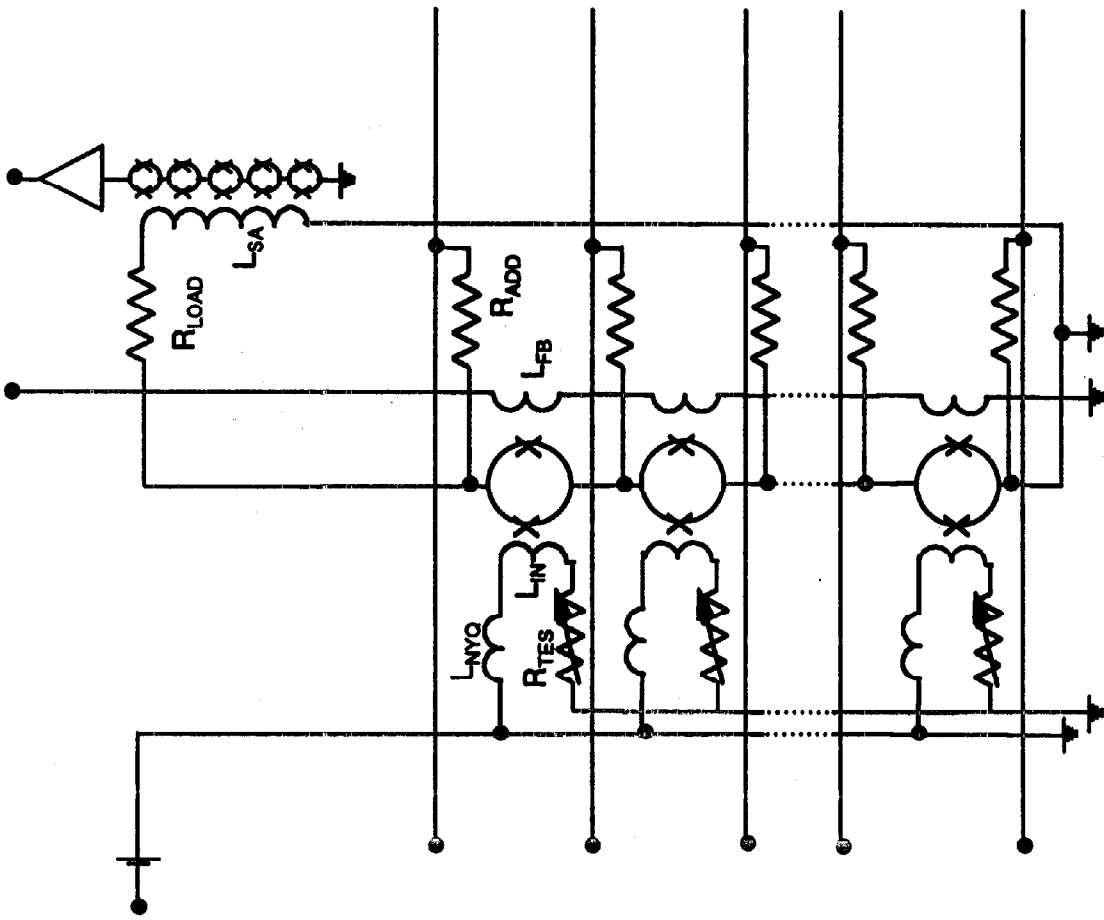
- Low Power (SQUID  $\sim 1$  nW, FET  $\sim 1$  mW)
- Low Temperature (SQUID  $< 100$  mK, JFET  $\sim 77$  K)
- Low Noise (Noise T: SQUID  $\ll 100$  mK, FET  $\sim 1$  K)
- Low Impedance (better microphonics)

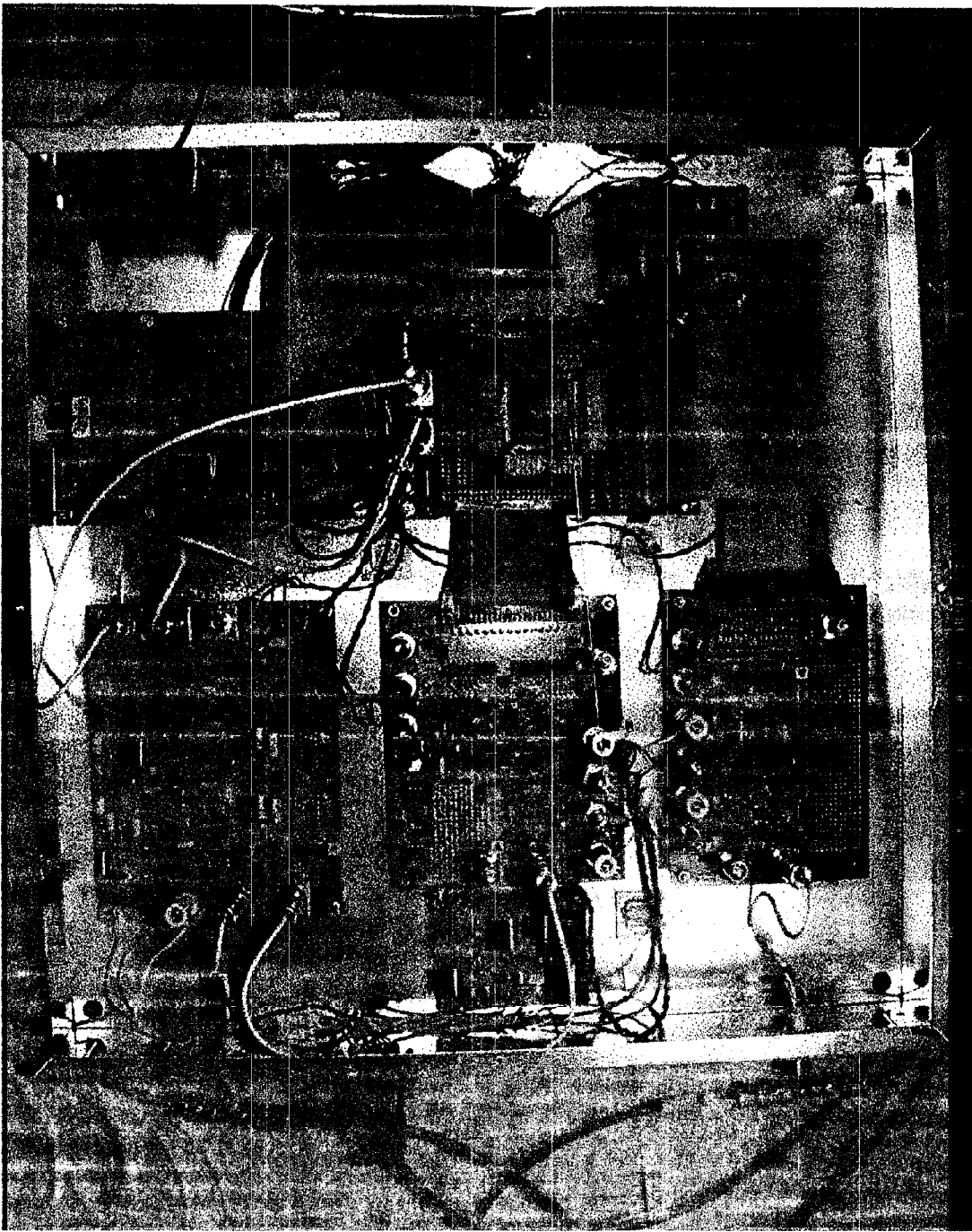
# NIST Microcalorimeter EDS system

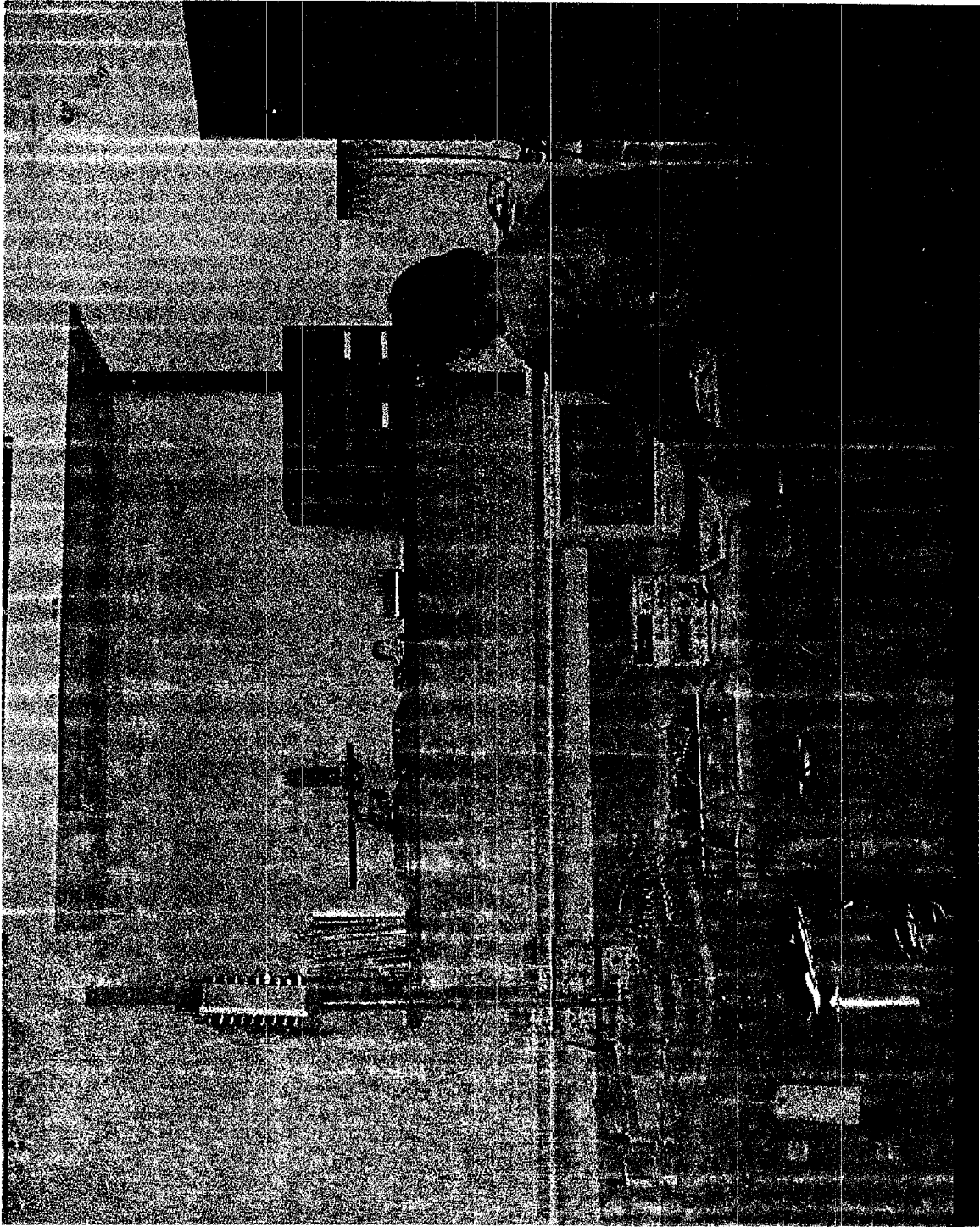


# AlGaAs

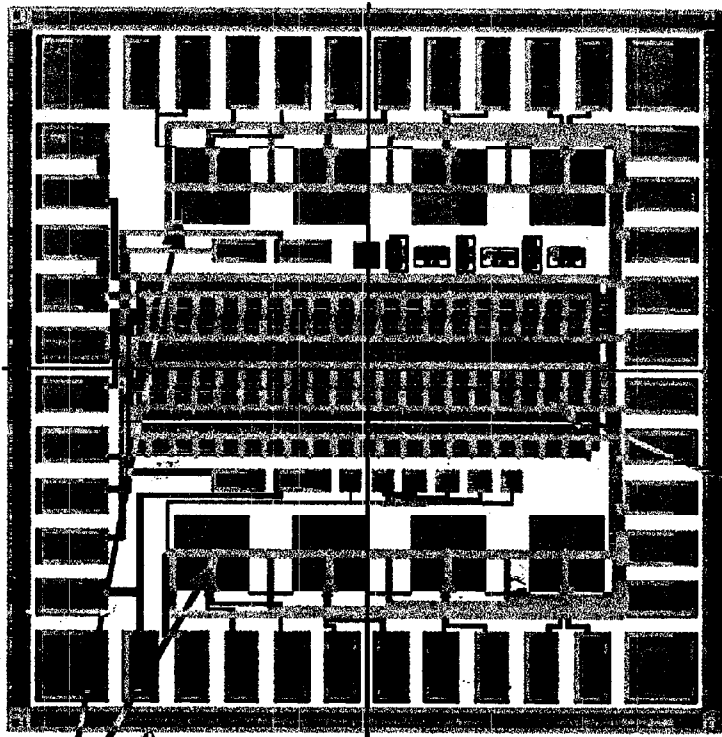








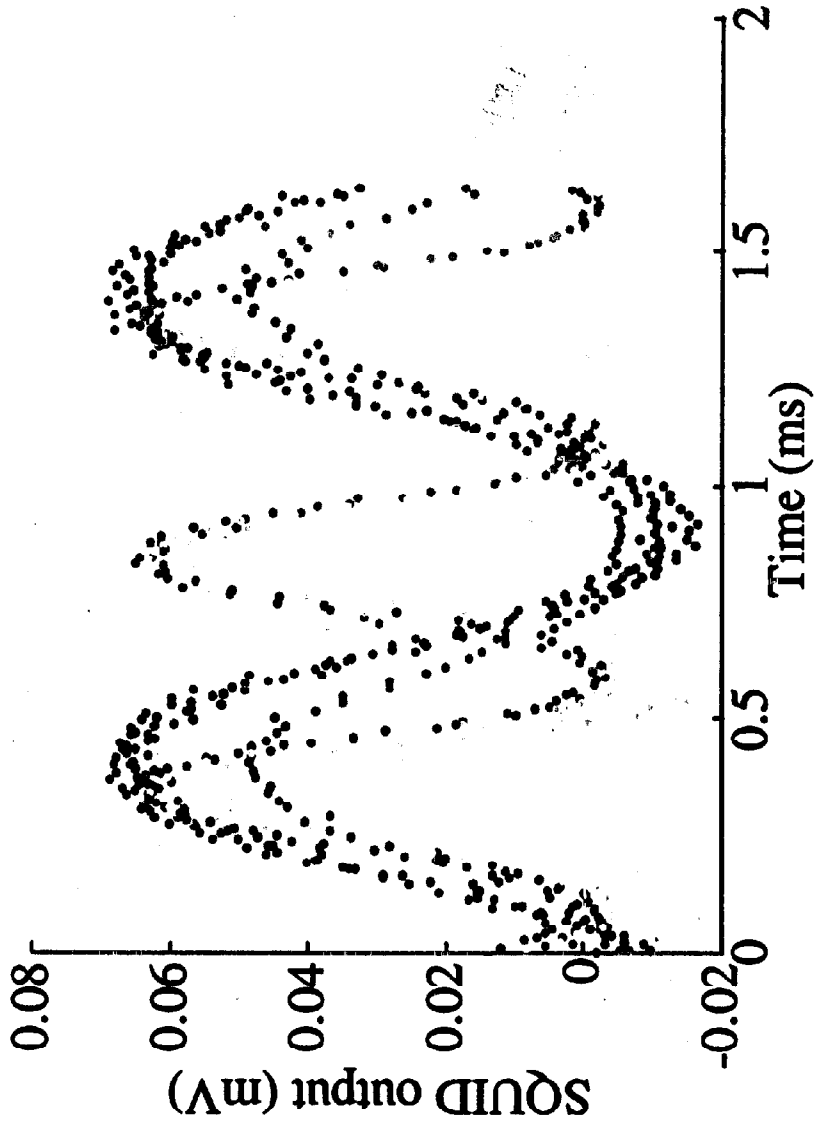
# SQUID multiplexer design & layout



1 x 8 SQUID  
multiplexer  
(one column)

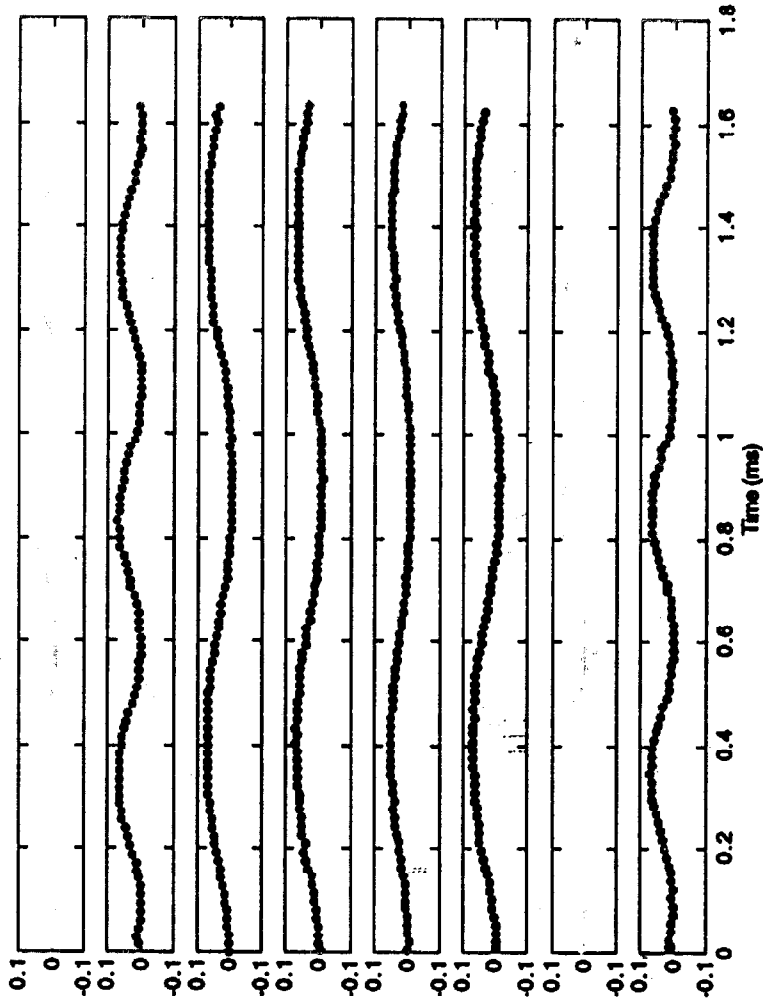
100 SQUID series array

1 x 8 Multiplexed SQUID Channels





# 1 x 8 De-Multiplexed SQUID Channels



# SPIRE Personnel

## GSFC

- Project Manager - Juan Roman.
- Detector Fab Lead - Christine Allen
- Mechanical Lead - Mike Amato
- Electronics Lead - Dave Bergman
- Electrical Systems Lead - Jim Caldwell
- Systems Engineer Lead - George Voellmer.



## PUD Detectors



### Detector mechanical design

- Current design can accommodate various array sizes (25x32, 1mm pitch for example) with minor changes.
- Planning static load and cryo tests of prototype to confirm design stability.
- Design conduction thermal losses between coldest stage and slightly warmer stage of detector assembly should be less than ~10 microwatts for 12x32 array.



## PUD Detectors



### Detector mechanical design

- The diameter of the assembly is under 10.2 cm (4 in)
- Prototype design has detector pixel row spacing of 1 mm (currently working with +/- ~ .025 mm (.001 in) mechanical tolerance goal).
- Prototype designed to handle 50G static equivalent loads in any direction (can accommodate higher)



## PUD Detectors



- **Detector mechanical design** - A good way to describe the detector subassembly is to work from the inside out which is also how the system is, in a simplified sense, assembled.

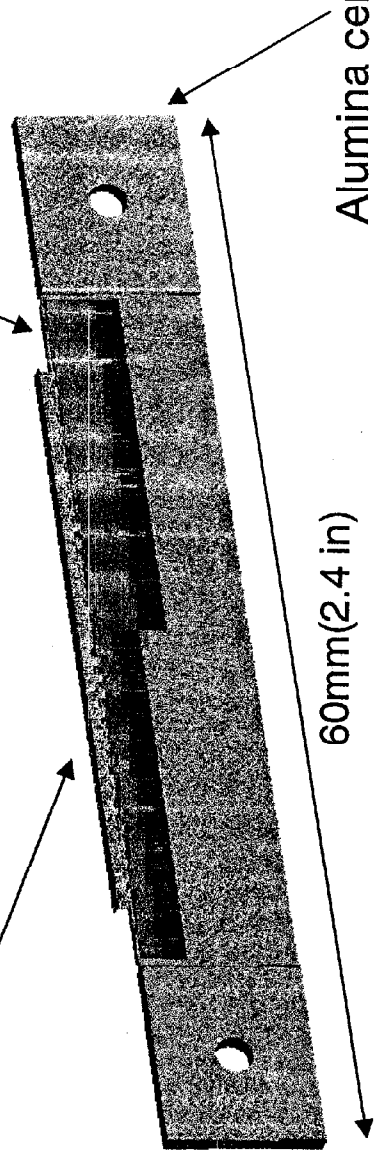


## PUD Detectors

- The PUD chips are folded and epoxied to the buss bars.

32 (depends on array size desired)  
'pop up' detectors

PUD chip



60mm (2.4 in)

Alumina ceramic  
buss bar



## PUD Detectors

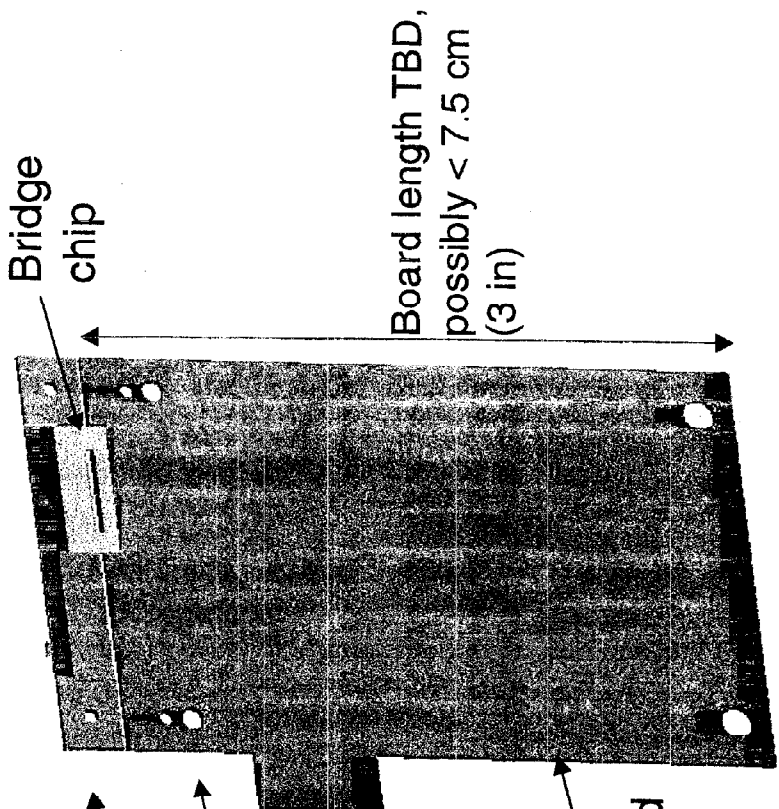
- The bridge chips are epoxied to a buss bar and a squid-mux board

0.2 K  
(for prototype)

4 K  
(for prototype)

Electrical connection  
can be on side  
or at the bottom

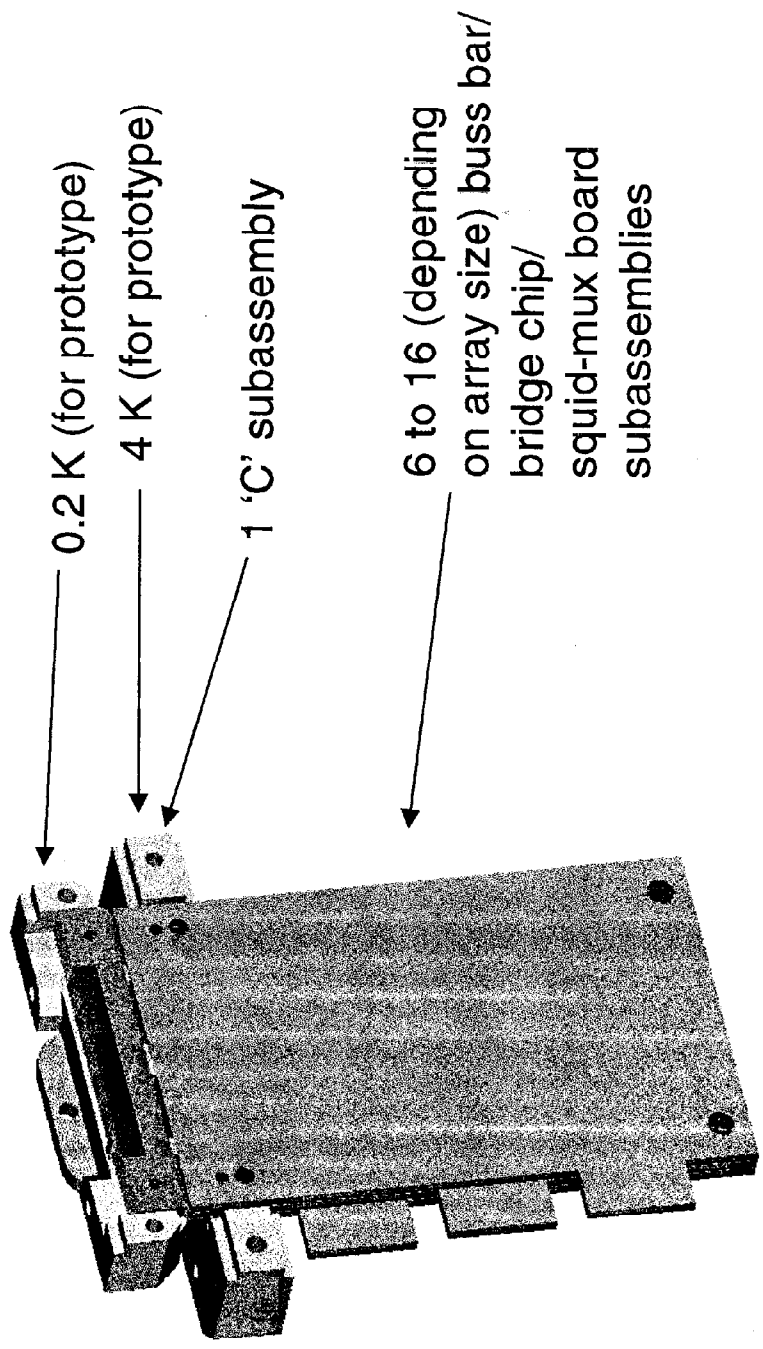
Alumina squid-mux board





## PUD Detectors

- Six buss bar/bridge chip/squid-mux board subassemblies are aligned and epoxied to each ceramic 'C' subassembly.

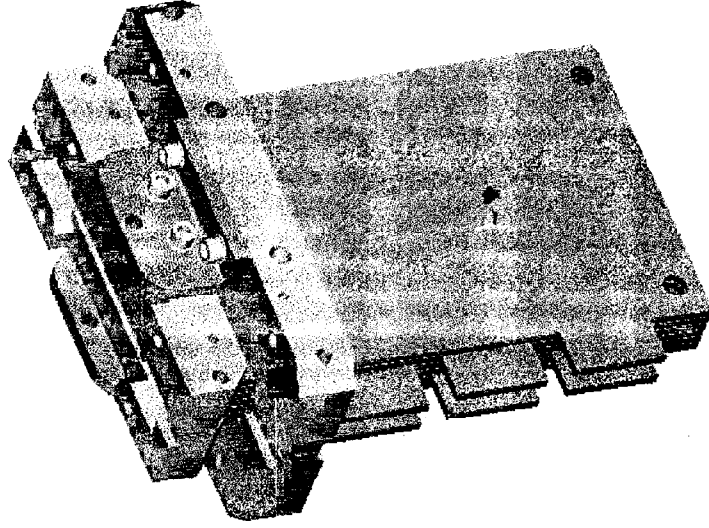






## PUD Detectors

- Two of the resulting subassemblies are aligned and bolted together to form an array (12X32 shown here).



Two half detector subassemblies joined into one full detector array subassembly

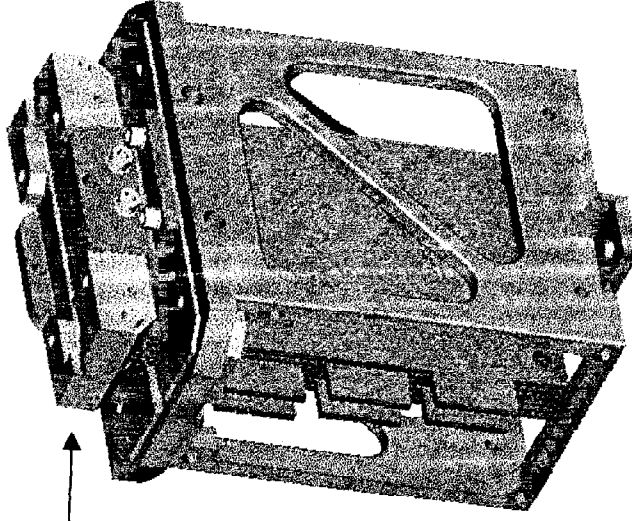


## PUD Detectors

- The resulting detector assembly is lowered into and bolted to the card-cage interface structure.

Full detector array  
subassembly from  
previous picture

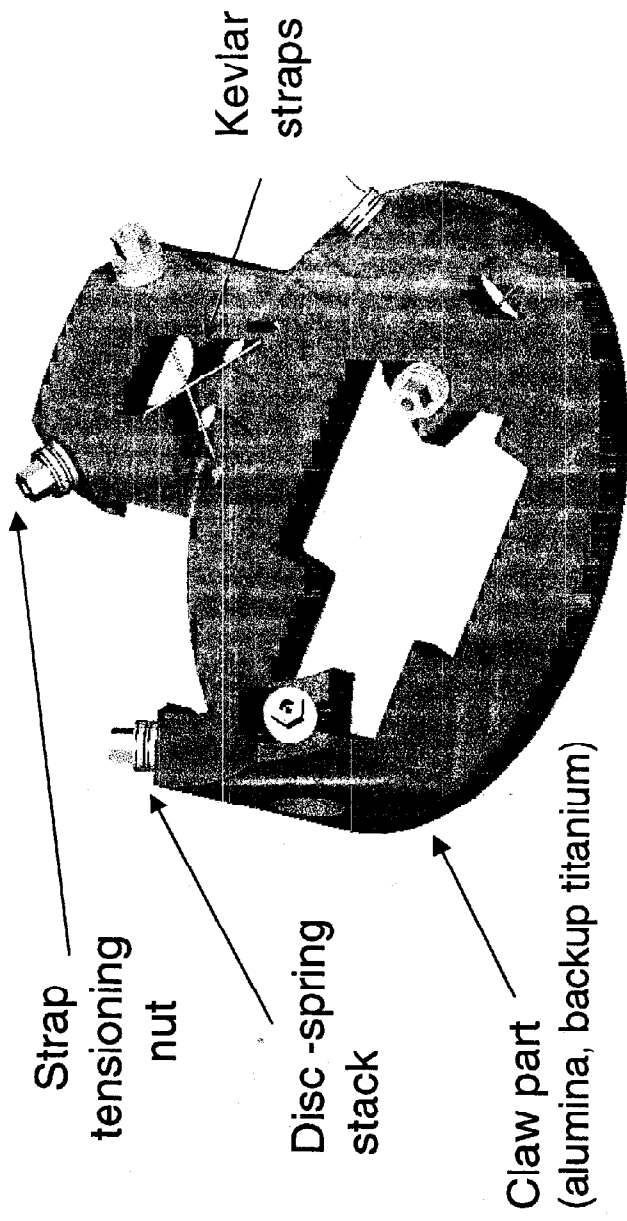
Card cage interface  
structure (ceramic, or titanium)





## PUD Detectors

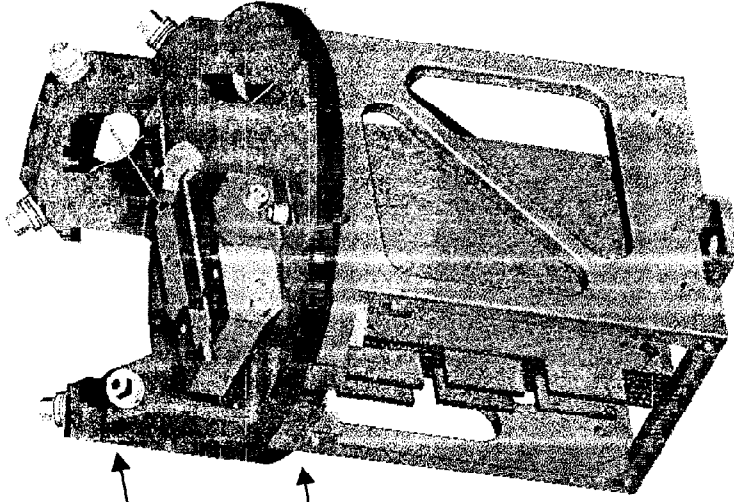
- The six kevlar straps are epoxied to end hardware and tensioned into the claw with a Belleville spring stacks on the top ends.





## PUD Detectors

- The claw is lowered over the detector array and bolted to the lower 'C's



Suspension claw with tensioned kevlar straps

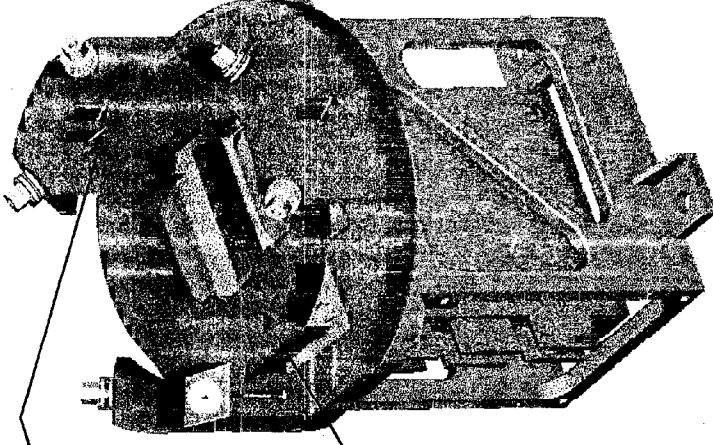
Full detector array in card cage structure



## PUD Detectors

- The cold plate is lowered, twisted into position with its 'hooks' or 'grooves' at the kevlar straps, and bolted or epoxied to the upper 'C's.

Cold plate epoxied to  
kevlar straps at each  
strap set crossing point

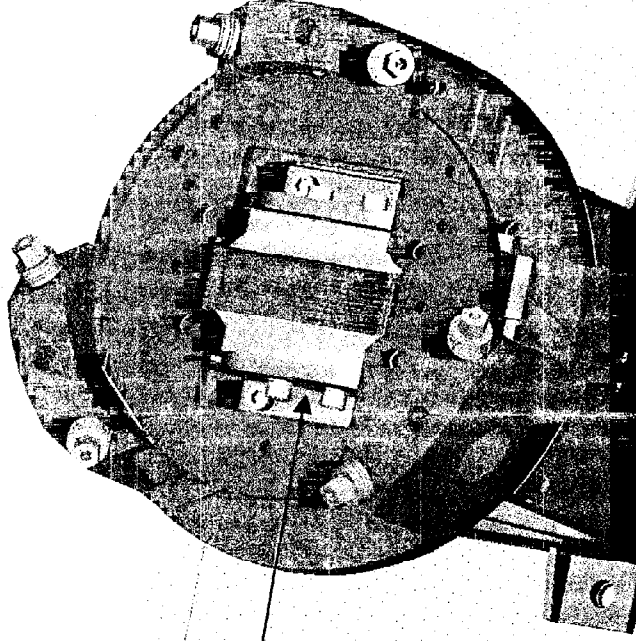


Cold plate (alumina)



## PUD Detectors

- The ADR heat strap is attached to the cold plate, electrical connections made and the suspension brackets which suspended the detectors during the assembly are removed.



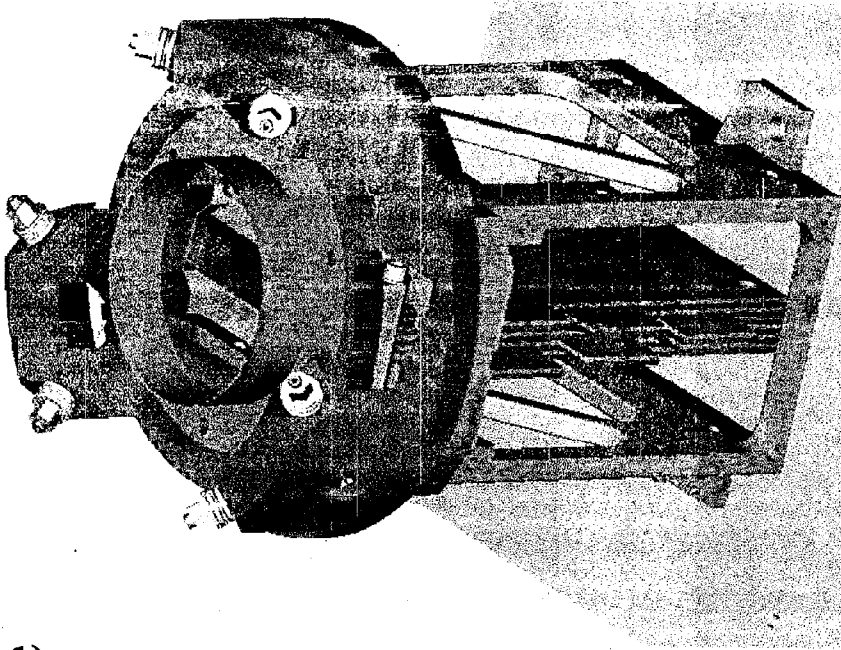
Spacer  
brackets  
removed



## PUD Detectors



- Filter baffle



**7**

**JPL/CALTECH ARRAYS**

**JAMIE BOCK**

**[ TO FOLLOW ]**



# 8

## **BACUS AND THE ARRAY TEST PLAN**

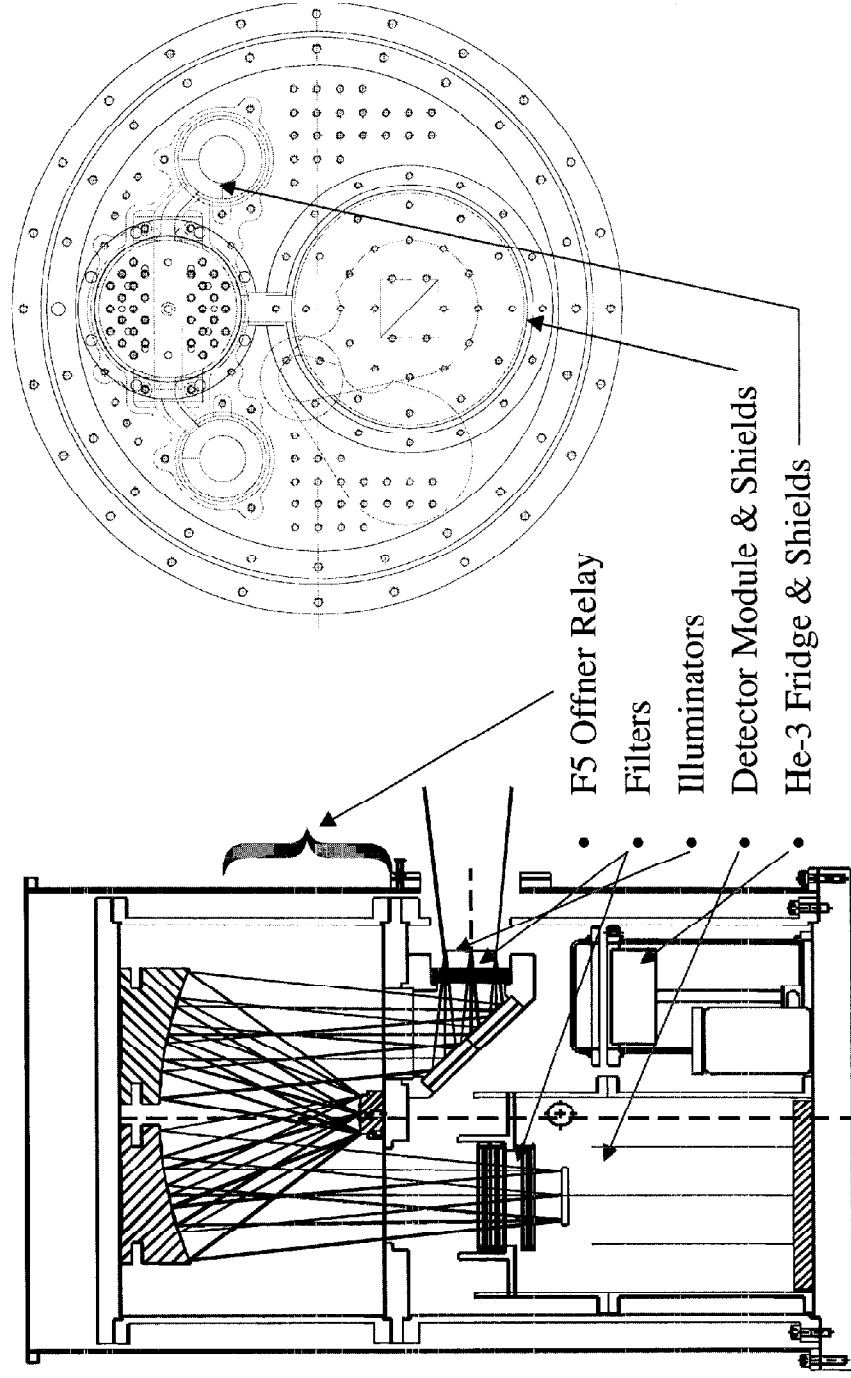
**PETER HARGRAVE**

**See also Annex 2**

# BACUS Status & Array Test Plan

P.Hargrave, B.Maffei, F.Gannaway,  
G.Gannaway, M.Griffin, P.Ade &  
R.Hermoso

# Design of BACUS Module



# Cryogenics

- Cryostat from Precision Cryogenics (Indiana)
- Optics at 1.5K (Pumped L<sup>4</sup>He Bath)
- Detector stage at 300mK - Kevlar isolated stage linked to <sup>3</sup>He fridge (Chase Research)
- Array providers will supply 300mK detector shields

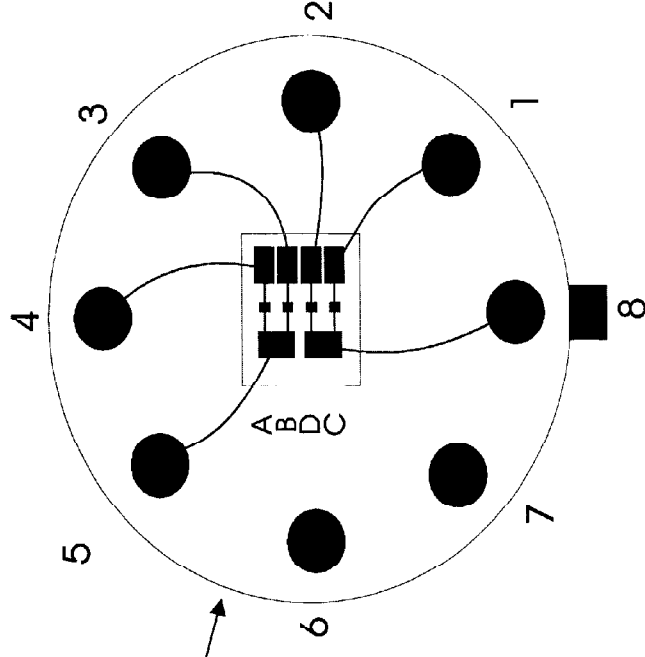
# Optics

- F5 Offner Relay
- Mirrors from Symons Mirror Technology (diamond turned Al-6061)
- All optics at 1.5K
- Baffling scheme will be finalised once stray light analysis is completed (RAL)



# Illuminators

- ND + Edge filters for work in R-J region
- GSFC illuminator evaluated - new design being built for optimisation at 350  $\mu\text{m}$
- Need to be modulated  $\sim 10\text{Hz}$  or more
- Uniform source plate - variable temp.
- QMW dewar will have window to outside

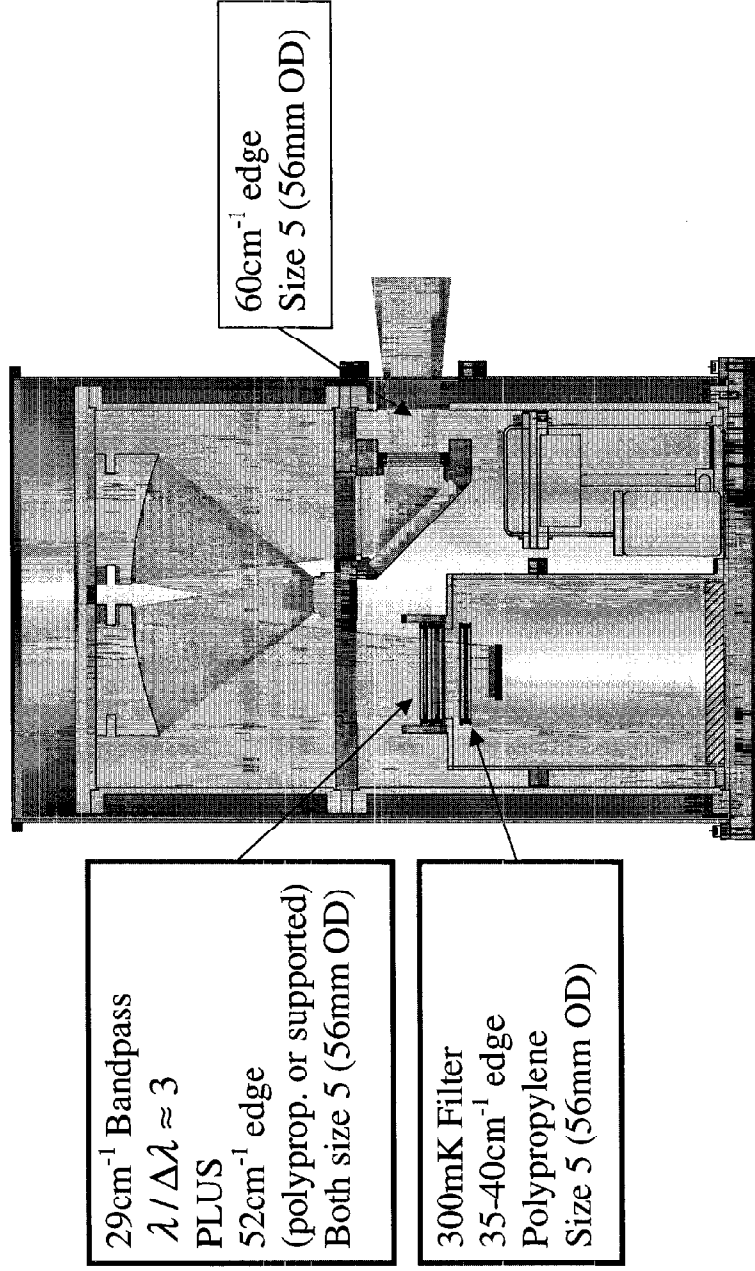


## Connectors

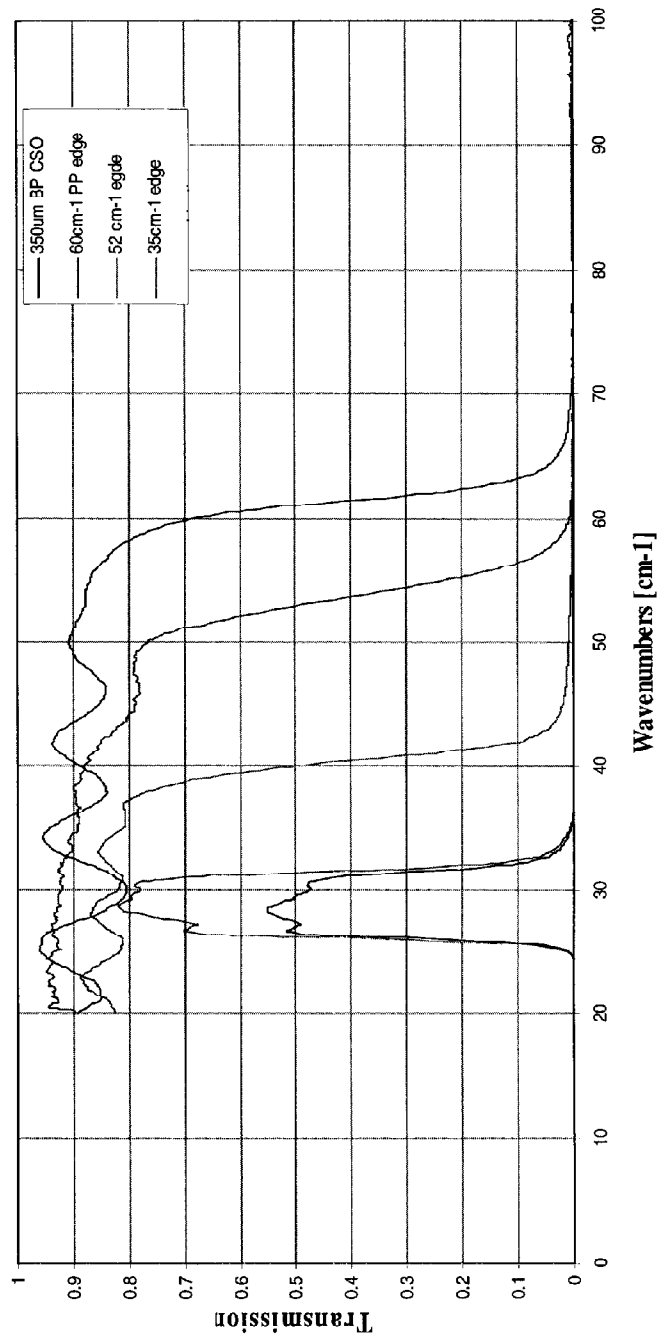
- 1x79 way - for detector arrays
- 1x32 way - for illuminators
- 1x26 way - for housekeeping
- All connectors are box flange mount conforming to MIL-C-38999/21
- All connectors are now in the possession of the array groups.



# Proposed BACUS Filtration Scheme



# BACUS filters



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# BACUS Capabilities

- V-Is - blanked or with uniform background
- Speed of response
- Flat fielding / array uniformity
- Cross talk
- Sensitivity
- Dynamic Range
- Linearity
- Optical NEP
- Spectral response
- Fringing between optical elements
- Calibration of detector responsivity (external black body)
- Connection to telescope simulator

# Test Plan

- Three identical cryostats and BACUS modules are being built
- US detectors to be built into their own dewars & pre-tested before shipment to QMW
- Final definitive tests to be carried out at QMW using the “master” BACUS module
- All CEA/Sap detector integration and testing to be conducted in the QMW lab
- All detector groups will supply staff effort at QMW to assist with/oversee tests.
- CEA/Sap test plan
  - Prototype single pixel device being tested in QMW lab
  - Iterative tests on successive generation devices through 1999 with final device delivery at the end of October 1999
- JPL/CALTECH test plan
  - Will provide NTD Ge pixel for characterisation of BACUS stray light
  - Initial array tests to be conducted in JPL lab
  - Final array expected at QMW Sept./Oct. 1999
- GSFC test plan
  - Initial array tests to be conducted in GSFC lab
  - Final array expected at QMW Sept./Oct. 1999



# Current Status

- QMW mirrors arrived late October - US mirrors due 2nd Feb.
- RAL progressing with stray light analysis
- Illuminator work progressing - fall back option is to use IR Labs TRS devices (as used on ISO)
- Two of the three He-3 fridges are in the QMW lab - testing should be complete early Feb. Shields are also complete.
- RAL drawings have been submitted for manufacture - completion early Feb.
- Filtration scheme now defined - manufacture at QMW.
- Connector acquisition complete.
- Wiring scheme defined.
- Cryostats - components have been sent from Precision Cryogenics to CALTECH for gold plating. Delivery has been quoted as 2 weeks after parts are returned to Precision Cryo.

# **Array evaluation and selection criteria**

- **We must have absolute confidence at time of selection that the chosen option will work**
- **A full system design document shall be produced by each array group, compliant with SPIRE design, spacecraft resources and IID-A requirements.**
- **A detailed array fabrication, test and delivery schedule shall be provided (at least up to CQM)**
  - **Including relevant warm electronics**
  - **Consistent with the SPIRE schedule**
  - **Realistic**
- **Credible space qualification programme and schedule shall be provided**
- **Performance and comparison of array options in SPIRE shall be evaluated by simulating the complete system**

# 9

## SELECTION CRITERIA AND PLAN

MATT GRIFFIN



# Summary

- BACUS schedule has slipped since the last meeting - current completion date is early March
- Two of the three He-3 fridges are now in the QMW lab and should be fully tested by early February
- Preliminary tests can be carried out in another dewar once He-3 fridges are fully tested by QMW (early February)
- Schedule is very tight - we need realistic estimates, with reasonable notice, for when we can expect devices at QMW
- QMW staff should visit US labs for pre-tests for device familiarization to avoid subsequent delays and to be prepared for any specific requirements of the technology
- Illuminators need serious consideration - if new GSFC modules can't be developed within our timescale, we have to use eg. IR Labs TRS devices (slow!) and conduct speed tests at QMW using an external chopped source.

## Potential Delays

- Delivery of test dewars
- Delivery of GSFC/JPL optical components
- Construction & testing of illuminator arrays
- Delivery of externally manufactured parts



**10**

**SIMULATIONS**

**LAURENT VIGROUX**

**See Annex 3**

# 11

## SUMMARY AND ACTIONS


MATT GRIFFIN

See minutes

# E

## Attachments

1. *The CEA Filled Detector Arrays*  
L Rodriguez
2. *SPIRE Detector Test Programme –  
Description and Status*  
P Hargrave *et al.*
3. *Confusion Noise in SPIRE Surveys, V0.2*  
Aussel *et al.*

 <p><b>SPIRE</b> DSM-DAPNIA SAp</p>	<p><b>The CEA Filled Detector Arrays</b></p>	<p>Ref : SAp-SPIRE-LR-12-99 Issue : 1.0 Date : 21/01/99 Author : L.Rodriguez</p>
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## **The CEA Filled Detector Arrays**

**SAP-SPIRE-LR-12-99**

**Issue: 1.0**

**Jan. 21, 1999**

**L.Rodriguez**

# **THE CEA FILLED DETECTOR ARRAYS**

## **I-INTRODUCTION.**

SPIRE is a spectro-imaging mid-resolution camera dedicated to the observation of the universe in the submillimetric spectral band. The exact wavelength range and ultimate resolution are not already totally frozen: they depend mainly on available mature technology and scientific needs. Today, goal values are 200-650  $\mu\text{m}$  for the spectral coverage and  $R= 3\text{-}500$  for the spectral resolution.

This instrument will be built during a very exciting time period. Ground based instruments on large telescopes are now in operation and drive the instrument technology. The final processing of ISO data is in progress. It gives access to the most sophisticated image analysis available. In effect, unfortunately, because the wavelength shift, in spite of an almost 4 meter mirror, the image resolution of SPIRE will be less than those from the ISO camera. This drawback could be partially overcome by sampling the optical Airy disk, and using deconvolution techniques. High complexity sensitive detector arrays and low optical distortion are two goals driving the instrument.

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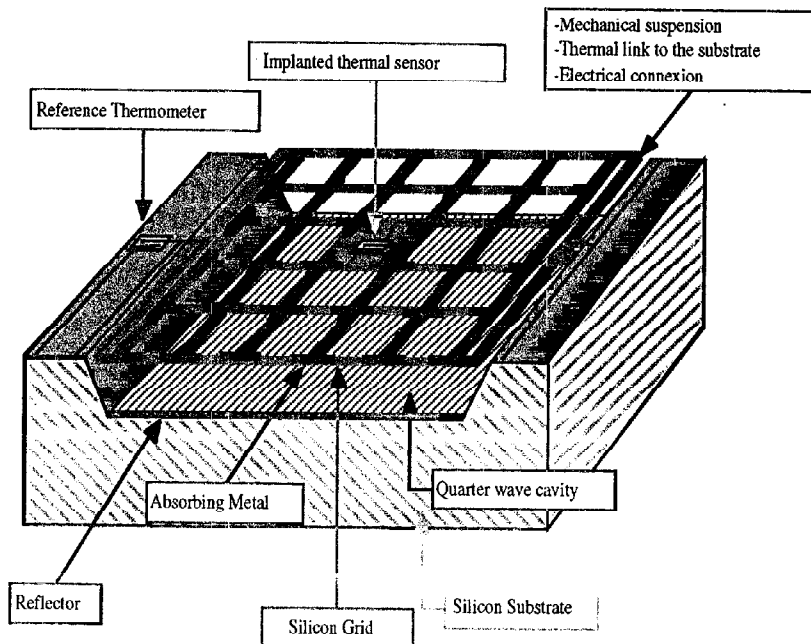


## II-DESCRIPTION.

### THE DETECTOR ARRAY CONCEPT.

The CEA detector concept is an attempt to develop monolithic bolometer detector arrays, similar to usual quantum technology ones: filled focal planes without light concentrators and collective manufacture, including portion of the integrated readout circuits.

Large and thin mono crystalline silicon grids, self-suspended to a frame by microscopic silicon "beams" are the sensitive part of the detectors. The temperature sensor, in the grid centre, is an implanted silicon structure. The conversion of radiant energy to temperature is done by metal deposition on the silicon grid.

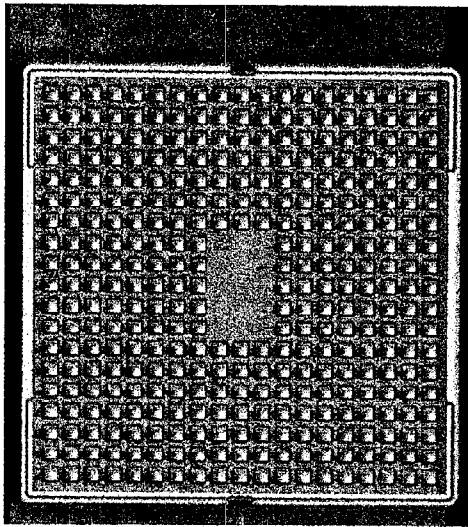


To achieve detectors efficiency close to one, we use the resonant absorption effect by making a quarter wave reflective cavity under the detection grids (Fig 1).

**Figure 1: The detector principle.** A suspended grid with defined pattern absorber, on a quarter wave reflective cavity, defines the pixel. At the detector centre an implanted thermometer measure the temperature variations of the pixel. On the detector edge, a second thermometer acts as a charge resistor. The signal is the bias variations at the R-R bridge middle point. Heat is extracted towards the surrounding substrate by microscopic silicon beams.

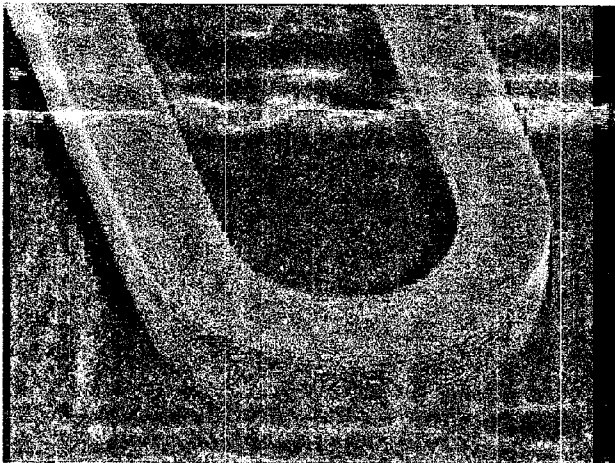
## THE ARRAY COLLECTIVE MANUFACTURE.

The structure of the 2D detector arrays is obtained by micro machining silicon techniques, originally developed at CEA/LETI for micro sensors production. These standard techniques are used to produce, at an industrial level, airbags accelerometers, methane sensors, or integrated pressure gauges.



These techniques are used for etching the 450  $\mu\text{m}$  mono crystalline silicon wafer to produce a honeycombed structure ended on one side with thin square grids. Each grid is 5  $\mu\text{m}$  thick including a thermometric structure. The pixel size here is 900  $\mu\text{m}$ . The thermometric structure and implanted *vias* are then passivated and the metallic layer deposited on the silicon grid. Figure 2 shows a typical suspended grid of the prototype array. The grids are linked mechanically and thermally to the substrate by tiny silicon beams (700  $\mu\text{m}$  long, and  $2 \times 5 \mu\text{m}^2$  section). Many grids aspects were tested during the prototyping phase 97-98. See on the figure 3, a detail of the beam showing the geometry of the silicon cut, which does not follow the crystalline edges of the mono crystal.

**Fig. 2** Detail of the suspended grid which defines the bolometer array pixel. The thermometer is implanted in the grid centre. Heat is transferred towards the substrate by the four microscopic suspension beams.



**Fig. 3:** Micro photography of a detail of the microscopic beam geometry.

The resonant cavity structure is obtained by indium bump hybridisation of the bolometric array on a network circuit (NC) with metallic reflectors. The indium bumps ensure two functions:

We measured a slight noise excess with regard to a MOS amplifier. As bias is increased, as the detector impedance drops with temperature, the noise is reduced to the MOS level. The noise equivalent temperature is close to  $1\mu\text{K}/\sqrt{\text{Hz}}$  (Fig. 11).

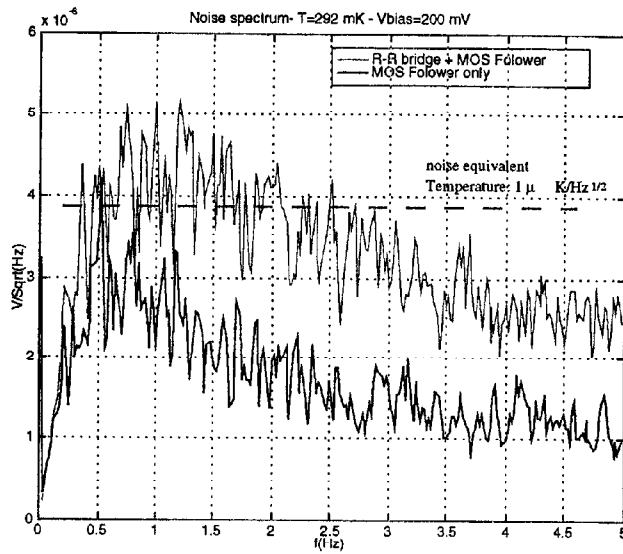


Fig 11 Low frequency noise spectrum.

#### THERMODYNAMIC PARAMETERS.

The determination of the thermodynamic properties of the bolometers, was made thanks to the thermal tests vehicles implanted in the prototype detector arrays. We can see on the figure below the geometry of one of these test vehicles. In the central part **two thermometers** are implanted, one used as heat source the second to measure the dynamic temperature elevation.

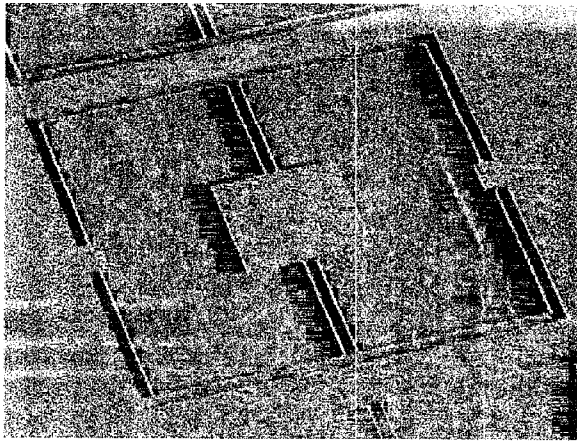


Figure 12: The Thermal test vehicles.

The experimental results are in good agreement with theoretical calculations. Figure 8 shows the  $T_0$  obtained with our thermometers in the low field limit compared to our numerical hopping model and other experimental works. The typical responsivity is  $10V/^{\circ}K$ . Non ohmic behaviour is consistent with a field effect model where the mean hopping length  $L$  varies quadratically with  $T$  (Fig. 10).

The relative dispersion on the arrays is less than 0.8, while the close R-R bridges are only a few percent. This is an important result for the bolometer array application.

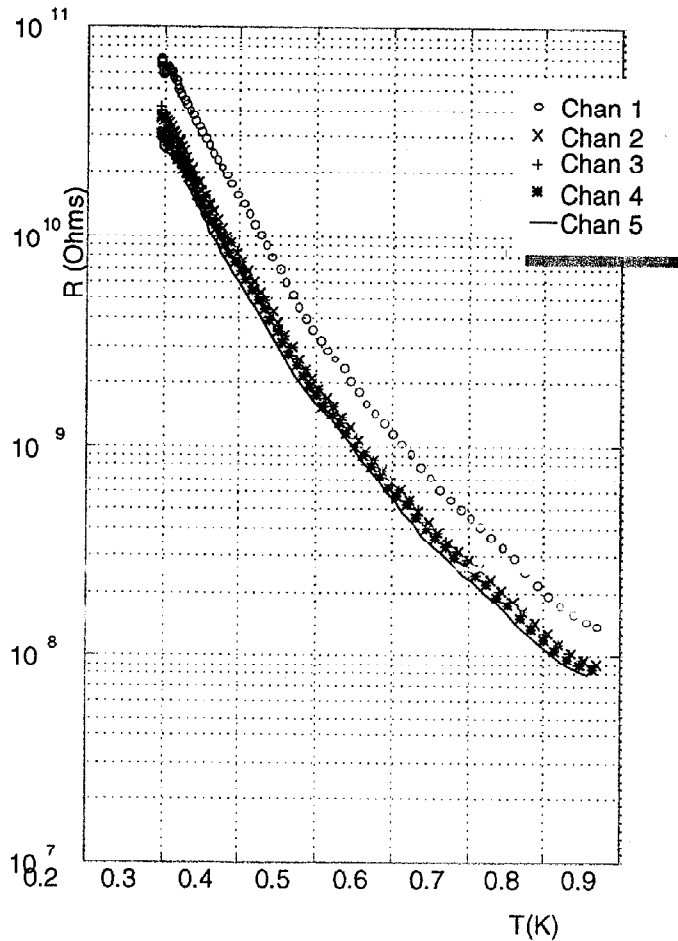


Fig. 10 Bolometers resistance variation dependence with temperature

Measurement of absolute values of detector efficiency is not a trivial test: as bolometer are wide band detectors, all the parasitic sources must be controlled, and calibrations must be done with well known adapted blackbodies

The dynamic response, is not only the measurement of the detector frequency dependence, but also the knowledge of the thermalisation process. In this case the impulsional response will be measured to determine possible interaction between the different elements of the pixel.

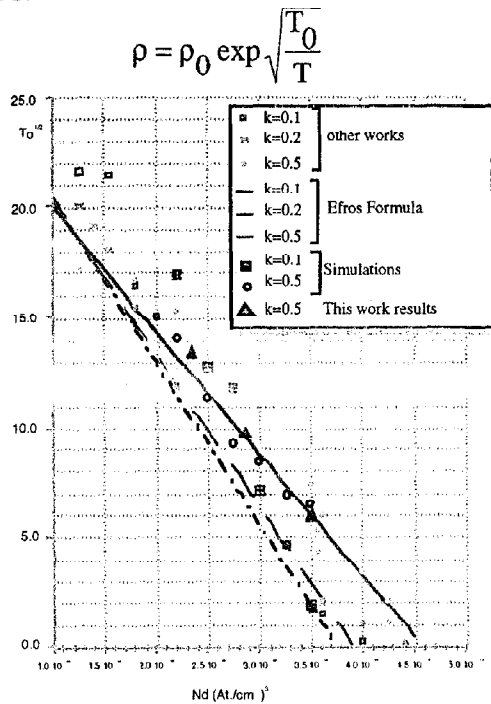
**THERMOMETER PERFORMANCES.**

Theoretical studies of charge transport in doped semiconductors at low temperature have shown that thermally activated tunnelling between doping sites is the dominant conduction mechanism on the insulator side of the metal insulator transition. In an effort to have quantitative tools, we developed a numerical model of conduction in the doping band. The resistivity has a temperature dependence which is highly correlated to the shape of the Density Of States in the silicon impurity band. The first step of the calculation was to determine the DOS for different doping and compensation levels. The results show clearly the appearance of the Coulomb gap as compensation ratio (**k**) is increased.

The second step was to establish a model of Variable Range Hopping carrier transport. The calculated responsivity is consistent with the Coulomb Gap Model [2]:

$$R(T) = R_0 \exp((T_0/T)^{1/2})$$

The sizes of manufactured thermometers ranged from 10 x 10  $\mu\text{m}^2$  to 100 x 100  $\mu\text{m}^2$  with width ratios between 0.2 and 5.



Comparison of current results with Efros Model and Monte Carlo calculations

Fig. 9: see figure captions.

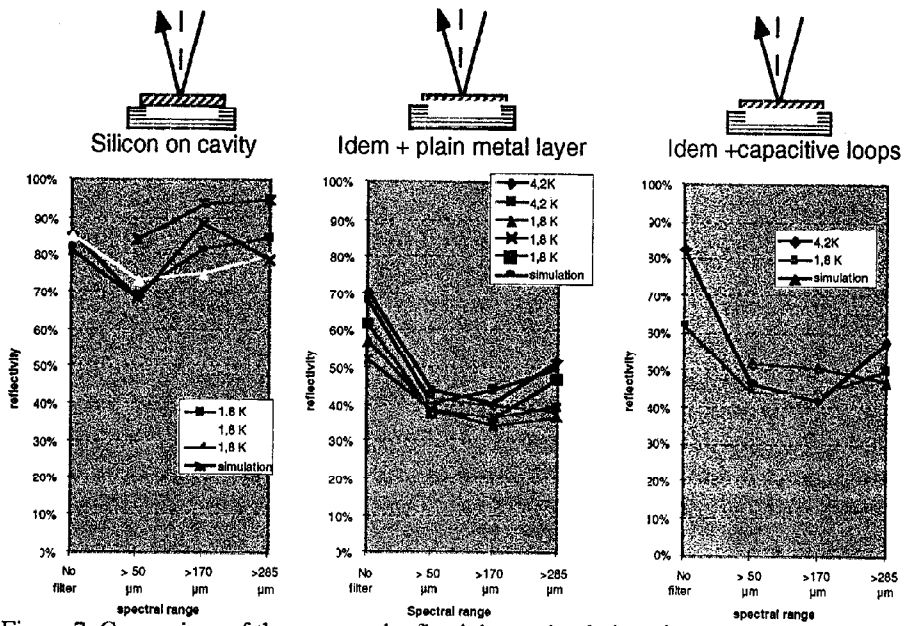


Figure 7: Comparison of the measured reflectivity to simulations for three configurations.

This measurement permitted also to confirm that the two metal alloys layers are well below the superconductive transition at 300 mK (fig. 8).

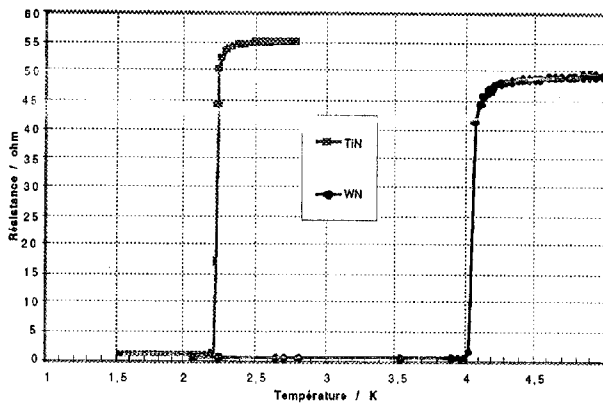


Fig 8 DC resistance of the metallic absorber layers

At the end of 1998, we started with the QMW group a development program to test different aspects of the detectors electro-optical behaviour. Two different test are planned: detector efficiency and dynamic response.

absorber layers, and test some resonant absorbing patterns, in comparison with a well known reflector.

The radiation produced by a small blackbody developed for ISOCAM, was wavelength filtered and routed by an off axis parabolic mirror, a flat mirror, and an oversized waveguide to the sample mounted on a moving platform on top of the 300 mK fridge. The reflected radiation amplitude was measured by three InSb hot electrons bolometers from IRLab company. The electromagnetic input beam was modulated by a fork type, 1.5 K chopper at the oversized guide output.

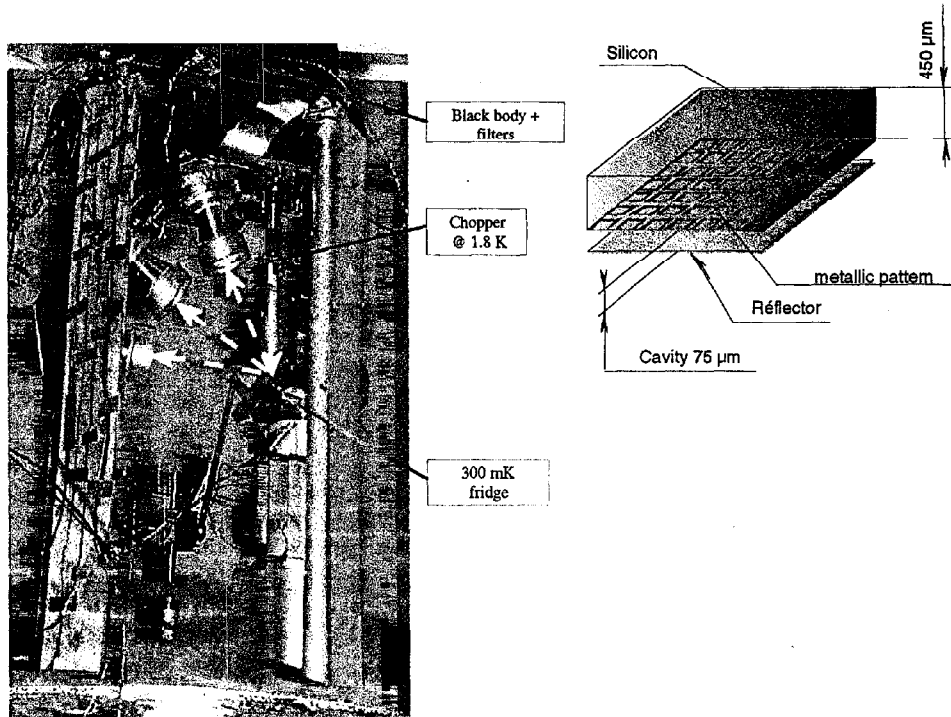


Fig. 6 : Absorption test set up and scheme of the sample.

The strongest difficulty was to build a sample representative of the final detector design. We overcame this difficulty by deposition of the absorber metal (with or without pattern) on a silicon film over a 75  $\mu\text{m}$  copper cavity.

Two metallic alloys were tested: WN and TiN, known to be compatible with IC manufacture technology.

Comparisons were made for different filter ranges to the code results. All the code prediction were confirmed within experimental errors as shown in Fig 7.

Once we have identified the technical method to build the detector arrays, we have to define the different parameters necessary for the detectors design. A bolometer being mainly a thermal machinery, we had, in a first step, to determine the main thermodynamic properties in the temperature range foreseen for our application : heat capacitance of the different elements which constitute the pixel structure (silicon crystal, passivation layer, [P:B] thermometer & metallic absorber), and the thermal conductivity of the microscopic beam which links the pixel to the silicon substrate.

**AVAILABLE PHYSICAL PROPERTIES.**

**ABSORPTION OF THE ELECTROMAGNETIC RADIATION.**

The absorption of the submillimetric radiant energy by the metallic layer deposited on the silicon grids is the first element to determine the detectors efficiency. A 3D integral Maxwell code, developed for military applications, was adapted to our problem. Many simulations were then done to optimise the pixel drawings. We determined the influence of the silicon grid and pattern geometry to achieve a broad absorption profile. One solution is to combine the vertical resonance made by the quarter wave cavity (which gives a well known bell shaped profile), with horizontal resonance(s) induced by the metallic pattern deposited on the grids. Many pattern types were tested. The best result, we have found, is obtained by capacitive loops with main resonances located at wavelengths of 200 and 400  $\mu\text{m}$ . A typical calculated absorption profile is shown in figure 5.

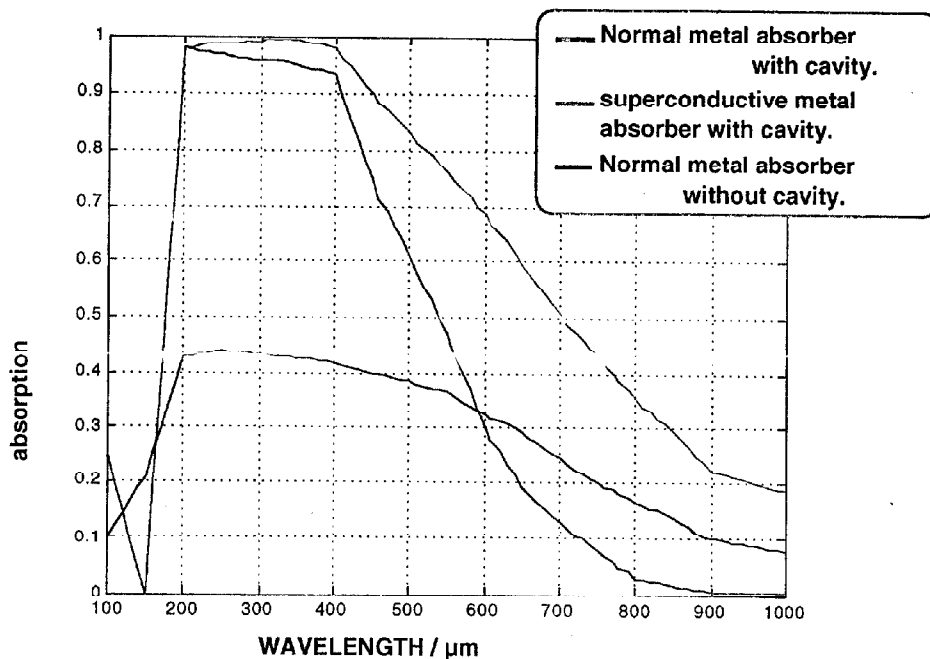
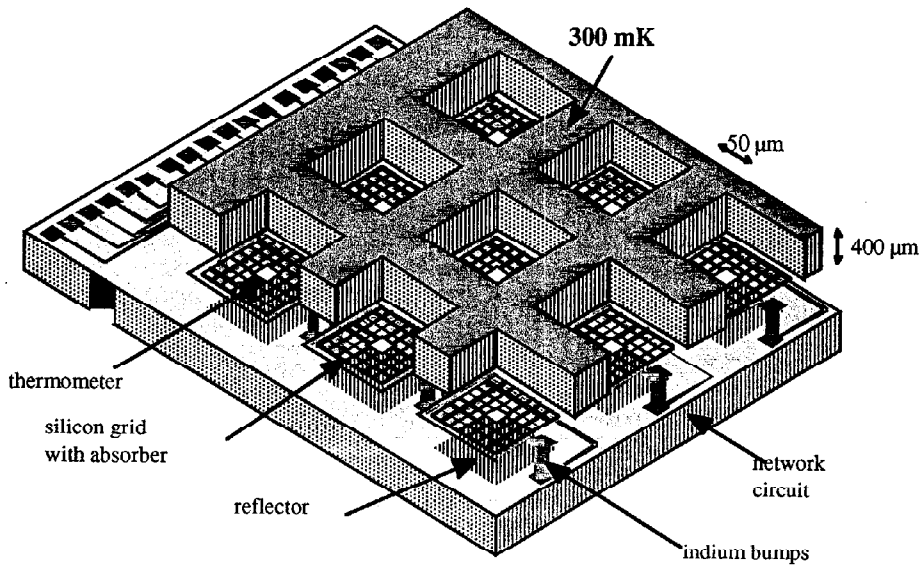


Figure 5: Detector calculated absorption

Well before the prototype array manufacture, we have built a cryogenic test set up to validate the code results. The principle was to measure the relative reflectivity of different metallic



adjust the cavity size, and connect each thermometer to a multiplexer (MUX) and to the readout chip (R/O IC) located on one side of the network circuit (fig.4). A kapton harness extracts the detector signals towards the warm electronics.



**Fig. 4: Scheme of the detector assembly. The bolometer circuit and the network circuit are hybridised by Indium bumps, which ensure the  $\lambda/4$  cavity separation and electrical contact.**

One of the technological constraints to build large filled detector arrays is to be able to access to each individual pixel using a reasonable number of wires. This implies the necessity to multiplex signals from the array towards the readout circuit. As demonstrated on ISOCAM LW detectors, MOS preamplifiers can operate at very low temperature: 1.5 K and below, and enables the read out circuit to be close to the detector array to reduce electrical capacity, EMI pollution and microphony. The MOS transistors are also used as gates for the multiplexing function of the detectors (fig. 15).

A reference thermometer (used as charge resistor) is implanted on the pixel edge (on the inter pixel separation wall). As detector warms up under the effect of radiant power converted by the absorbing metallic layer, the thermometer resistance decreases modifying the middle point bias of the resistor bridge. Bias variations are then injected at the MOS preamplifier input. The preamplifier output impedance is now of the order of few  $k\Omega$ , and signals can be extracted a few meters away without significant losses

The MOS preamplifier readout requires high impedance sources ( $R > 10 G\Omega$ ) for proper operation. We then explored new ranges of thermometer impedance, offering the possibility to have more sensitive sensors.

Thermometric structures are obtained by Phosphorus silicon doping compensated with 50% boron.

The doping ions are implanted at several different energies to control as precisely as possible the shape of the thermometric doped channel, in order to get a flat topped profile.

## THE PIXEL GEOMETRY.

The Pixel geometry was modified in different ways. The pixel step is a little reduced now:  $750\ \mu\text{m}$ . The inter pixel wall is  $50\ \mu\text{m}$  and the suspension beams length are reduced to  $600\ \mu\text{m}$ . A large fraction of the silicon in the grid is eliminated to reduce the bolometer heat capacity. The mechanical rigidity is obtained by the wide cross shaped structure. The thermometer is implanted in a platform at the grid centre. The three metallic patterns (grids, loops and crosses) will be deposited for processing different arrays types, in TiN or WN alloys.

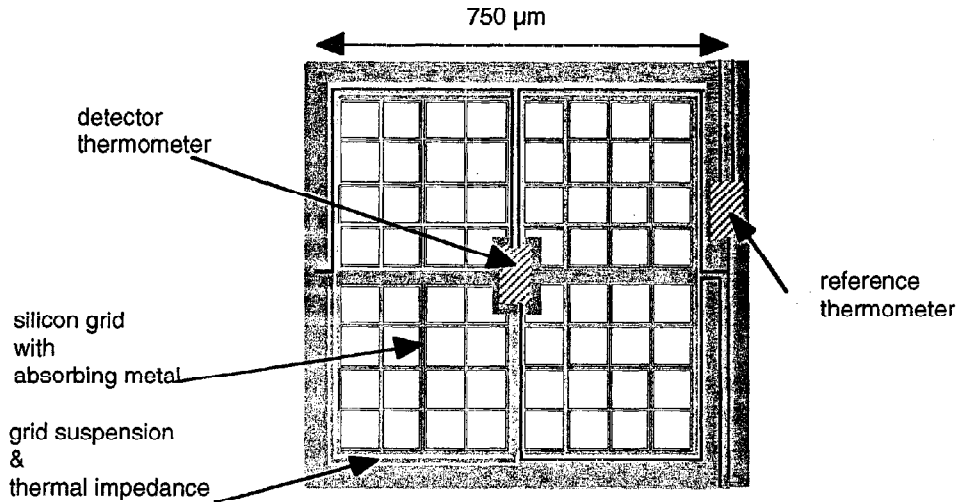


Fig. 18 The new array geometry: pixel.

## THE THERMAL SENSORS.

One of the major technologic exploration this year will be made on the thermometer design. Two thermometer options are foreseen: the traditional deep implantation, and mesa thermometer technology.

In the first option, we will have to explore the effect of bias on the thermistor gate. An increasing bias could affect the effective conduction channel and recover the detector performances in case of unexpected high background level.

In the second option, a double SOI wafer is used, and the doping ions are implanted in the  $1\ \mu\text{m}$  upper silicon layer. This layer is separated from the grid structure by a thin oxide barrier; the doping profile is then flattened by high temperature baking without diffusion in the grid structure. The aim of this development is to increase the thermal response homogeneity of the arrays and test the thermometer shape influence. The only way to avoid the non-ohmic thermometer behaviour, is to increase the doped channel length, reducing then the local electric field. This can be done easily if we give a "S" shape to the thermometers avoiding a large extension of the sensor. Unfortunately with implanted thermometers the effect is not seen, probably because a current leakage appears between close circuit portions at different electrical potential.

### III-PRESENT STATUS.

#### THE NEW DETECTOR ARRAY DESCRIPTION.

New detector arrays were designed and manufactured in 1998. Design parameters were deduced from all the physical properties found during the different characterisations made these past years and described before. One of these new arrays will be used for the evaluation process at QMW by the end of this year.

Main changes from the prototype detector arrays are discussed below.

#### THE ARRAY GEOMETRY.

New arrays are 16 x 16 pixels with a cavity of 75  $\mu\text{m}$ . The central absorption wavelength is close to 320  $\mu\text{m}$ . They include the MUX and readout chips on the detector side. The readout chip which is the most power consuming element of this assembly can be isolated from the 300 mK stage by a silicon membrane and linked to the 2 K structure. Fig 17 shows a picture of the detector with MUX and readout circuit.

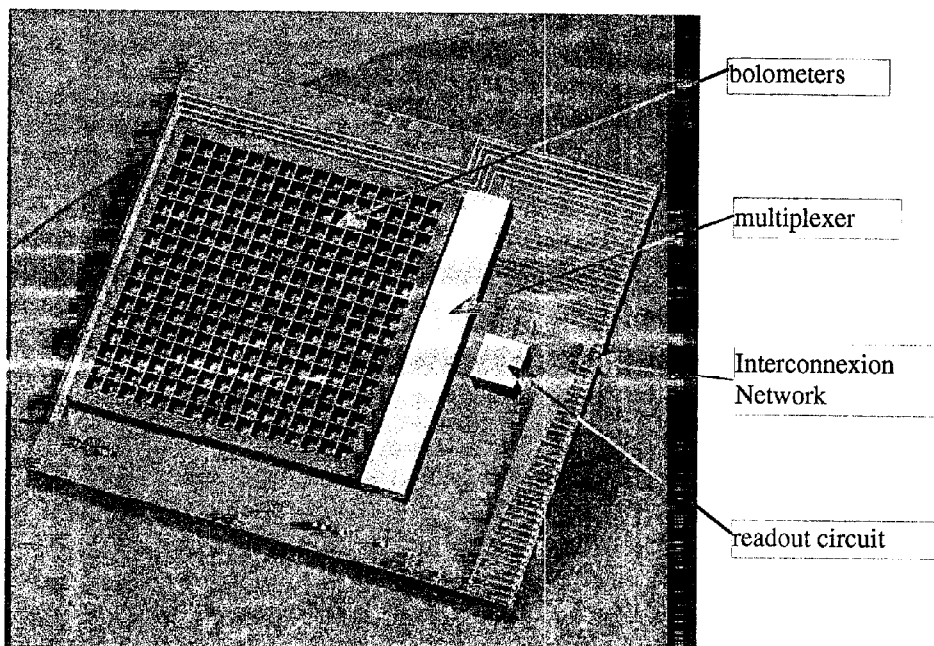


Fig. 17: The new 16 x 16 pixels detector array.

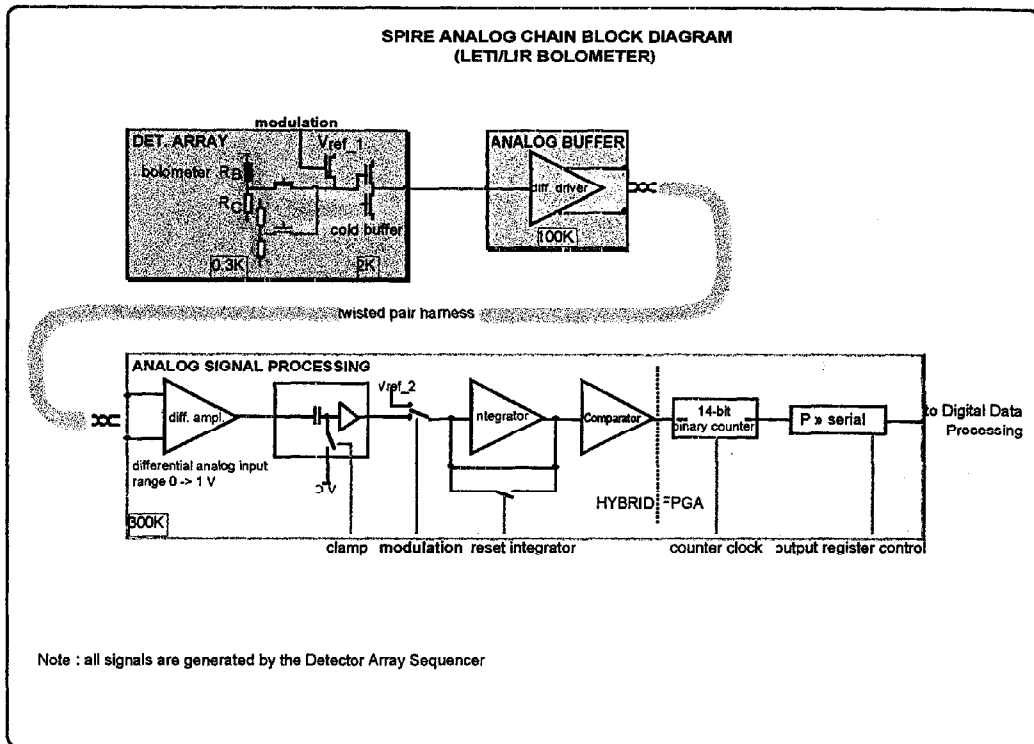


Fig 16. :Analogue Electronics Diagram

The resistances of the thermometer and the charge can be adjusted independently by the voltage applied to the thermistor gates (Gb & Gc).

## **ANALOG SIGNAL PROCESSING ELECTRONICS.**

This electronics will be in charge of processing the analogue signal before conversion into digital signal. It receives preamplified differential signals from the BUFFER AMPLIFIER UNIT. Its concept is based on a dual slope integrator system running at the bolometer signal modulation frequency. The integrator input is switched between the bolometer optical signal (signal dependant positive slope) and an internal reference signal (fixed negative slope). This integrator discharge occurs up to its output cross 0 volt. The system features also analogue to digital conversion by measuring the total duration of this discharge phases. This measurement is performed by implementing a gated binary counter running at a frequency given by the pixel rate and the digital signal resolution (typically 1 MHz). A more sophisticated design may be considered to reduce the counter frequency or to increase the dynamic range : the conversion time is divided into two steps : a coarse for the lower resolution bits and a fine for the higher resolution bits. The analogue signal processing also includes a clamp functionality between the input differential receiver and the integrator. At the end of the conversion period the digital data is stored in a register for acquisition. Since all bolometer array output are processing in parallel for both the photometer and the spectrometer instruments 282 identical analogue chains are required (232 for the photometer and 50 for the spectrometer – bolometer output multiplexing ratio : 8->1).

In order to keep low power consumption for the overall analogue electronics special care must be taken for the choice of components, only CMOS parts must be considered.

The command pulses required to operate this electronics are generated by the Detector Array Sequencer synchronously with the detector array operation. The following figure shows the diagram of a complete analogue chain including the cold buffer, the analogue buffer electronics and the analogue signal processing electronics.

This concept takes advantage of the bolometer signal modulation (i.e. 1 kHz) to limit the signal bandwidth efficiently (especially for  $1/f$  readout noise reduction). Its operation is equivalent to a double correlated sampling (high pass filter) followed by a low pass filter without requiring many high precision capacitors. Its also takes into account the low pixel readout frequency which allow to design low speed and low power analogue chain.

### **Implementation**

Due to the large number of detector array outputs this electronics will take advantage of hybrid or surface mounted components technologies. In the case of hybridization 8 analogue chains are implemented in one package.

---

The major result with respect to our application is the thermometer heat capacity, which was uncertain at the project start. The total heat capacity is dominated by the Si<sub>3</sub>N<sub>4</sub> passivation layer. It can be removed without impact on future bolometers.

All these results were used as inputs for the design of the new bolometers arrays produced by end 1998. Rather fast thermal operations are expected: 50 -> 70 Hz thermal bandwidth.

## ELECTRONICS.

### COLD READOUT ELECTRONICS

The CEA array incorporate cold electronics at the detector level. The cold readout electronics scheme is shown in figure 15.

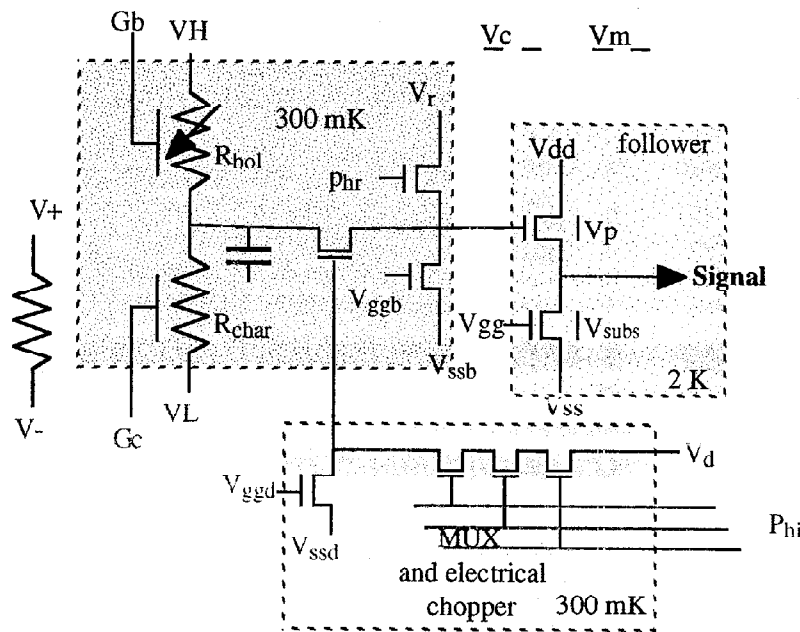


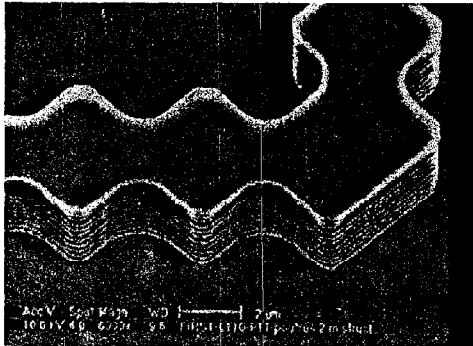
Fig 15 Cold readout electronics scheme.

On the left side of this scheme we can see the bolometer and charge resistance bridge. The middle point of the R-R bridge is linked to the gate of the MOS preamplifier at 2 K. An integrated MOS transistor at 300 mK inserted in this link connect one bolometer amongst 8 to the preamplifier thanks to the MUX circuit electrical configuration ( $\Phi$ ). As detector resistance is high, large voltage can be applied to the detection circuit ( $VH-VL$ ), and large signal is expected at the follower output.

The major noise source in this circuit is the follower preamplifier. Introduction of a modulation between the detector and the preamplifier permit to recover the detector performances : the follower is periodically connected to the bolometer and to a stable voltage source  $V_r$  by the MUX circuit switch  $V_{ggd}$  and the gate connected to  $Phr$ .

### DETECTOR THERMAL IMPEDANCE.

The determination of the bolometers thermal impedance is relatively easy. The first step is the thermometer calibration. This calibration is done on a "substrate" thermometer close to the test vehicle by varying of the  $^3\text{He}$  fridge temperature. Then we "switch on" the "heater" at the test vehicle centre, and measure the equilibrium temperature. The knowledge of dissipated power and temperatures gives access to the thermal conduction. The measurement was done for different configurations: straight beams, wiggled beams (fig. 13), with, or without passivation layer or metallic track.



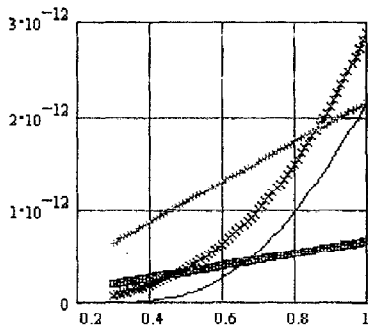
**Figure 13: Wiggled suspension beam.**

For straight beams, the conduction measured is close to calculated values. No effect was seen for wiggled beams, except for the SiN passivation layer conduction (see fig. 14b SiN texturé). We explain the conduction decrease in this case by an effect on 2D phonon propagation. In the case of the wiggled beams, the phonon specular reflection is affected by the inhomogeneous geometry. This effect is not seen on the silicon beams because wiggles are only present on the vertical edges.

### PIXEL HEAT CAPACITY.

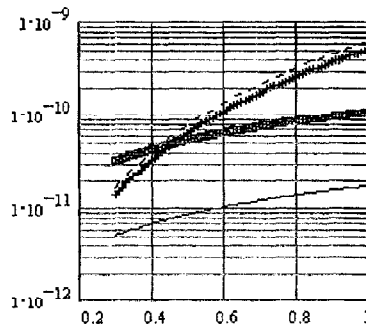
Heat capacity was measured on the same test vehicles. From one test vehicle to the other only one parameter was modified: the thermometer size, the silicon pad size, the passivation layer, or the metallic absorber layer. An ohmic impulse was then injected, and the temperature variation recorded. Knowing the beams thermal conductance, the total heat capacity was deduced from the temperature slope. Then the peculiar heat capacity for each element was obtained by subtraction. The figures hereafter give a summary of all the thermodynamic measurements.

CAPACITE CALORIFIQUE EN J/K/mm<sup>2</sup>



\* Silicon(5 μm)  
 + Si<sub>3</sub>N<sub>4</sub>(0.1 μm)  
 □ Implantation(0.3 μm)  
 ○ TiN(0.04 μm)

CONDUCTANCE THERMIQUE(W/K)  
DE POUTRES(700 μm x 5 μm x 4 μm)



+ Si non texturé  
 - - Si texturé  
 □ Si<sub>3</sub>N<sub>4</sub> non texturé  
 ○ Si<sub>3</sub>N<sub>4</sub> texturé

Fig 14: Summary of detectors thermodynamic properties: a-heat capacitance for pixel components. b-thermal conductance to the substrate.





We expect to be able to deliver three detector arrays in the coming months, before the last formal delivery in November 1999 for final evaluation.

## CONCLUSIONS.

In a two years period, a large amount of work have been done to produce a new technology bolometer array. Even, if all the technical processes are used in different fields of detector or micro-sensors are already well known. This detector manufacture is a first attempt to combine these technologies.

Many unexpected problems arose during these combinations, some have been overcome, others due to the lack of time have been bypassed. Some interesting problems of fundamental physics, like the effect of wiggles on the heat transport at low temperature, have been seen but unfortunately not studied. By chance, the behaviour of compensated thermometers seem to have awaked some interest for solid state physicists, our student C. Buzzi have the matter for a good thesis. The effect of resonant absorption process in our application have been measured and discussed by an other engineer student with great success. He is now working with us, in Saclay, on another subject relative to SPIRE: the Fourier Transform Spectrometer.

These aspects are highly satisfactory for the people involved in this development. It is not always easy to show, only these aspects of a technological work, to the founding institutions, even if only one step, of a complex process have been done. We have the opportunity today to show a major milestone of the detector array development ( fig 19).

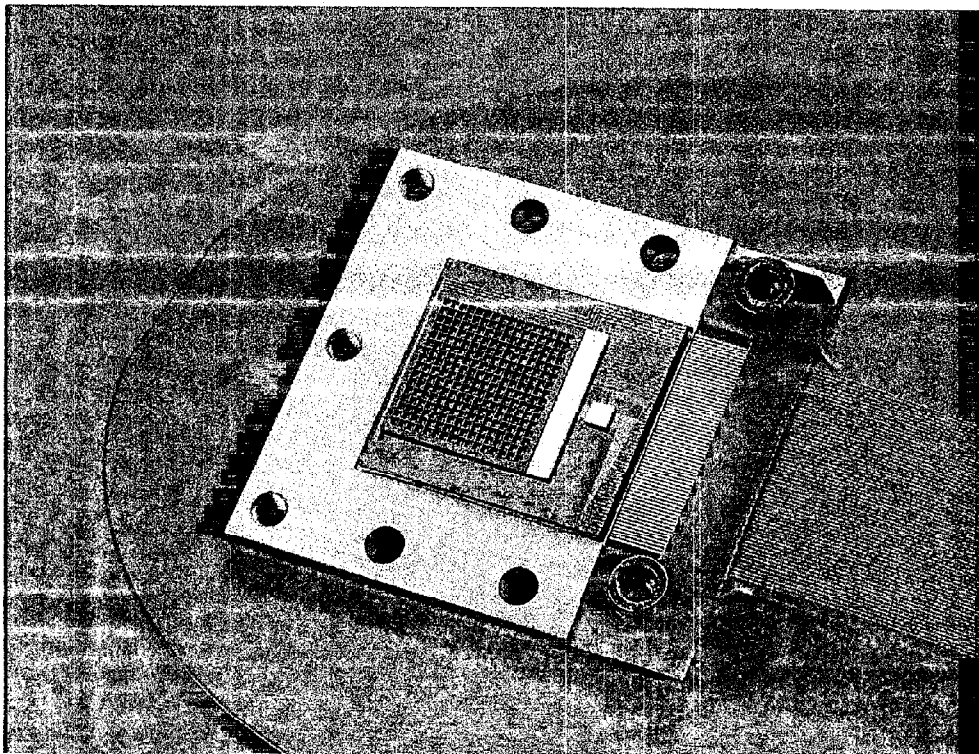


Fig 19 The new bolometer detector array in an almost complete configuration.

# SPIRE detector test program – Description and Status

*Peter Hargrave, Bruno Maffei, Raul Hermoso & Matt Griffin*

This document describes the test and evaluation program for the candidate detector technologies for the SPIRE instrument. The first section describes in some detail the tests to be carried out, while the second part describes the current status of the test program.

## 1. Detector Tests

The majority of detector tests will be carried out in a dewar with a specially designed test and calibration module called BACUS (Bolometer Array Calibration Unit for Spire). This section will first give a detailed description of the BACUS module, followed by a list of the tests we propose to be performed on each detector array.

### 1.1 The BACUS test module

A sketch of the BACUS module in relation to the detector position and associated cryogenics is shown in figure 1.

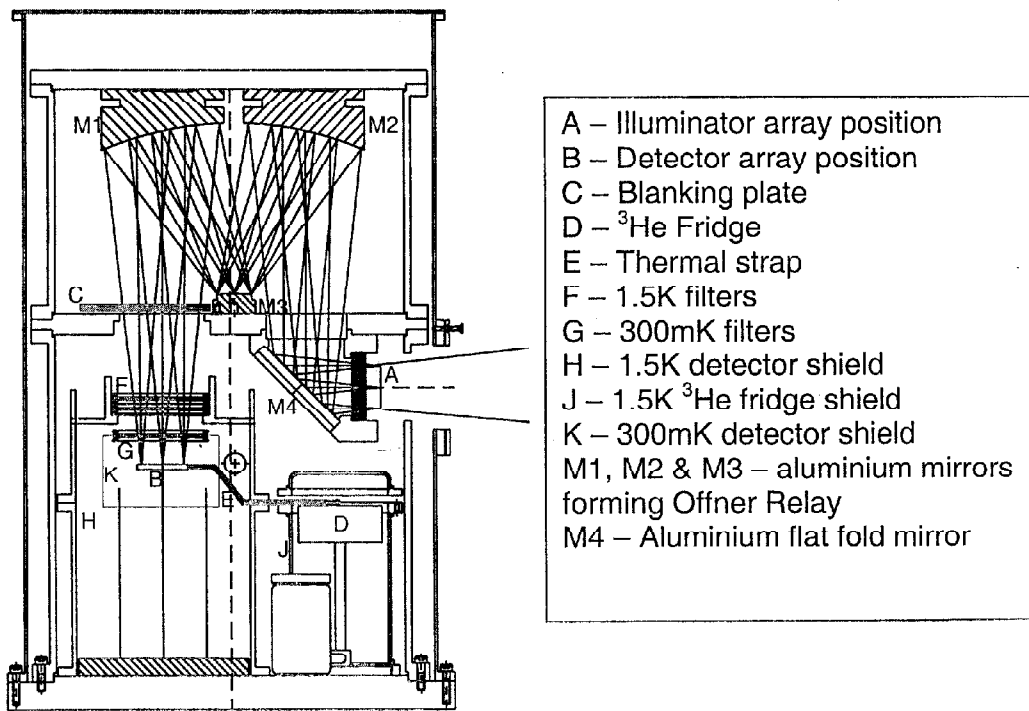


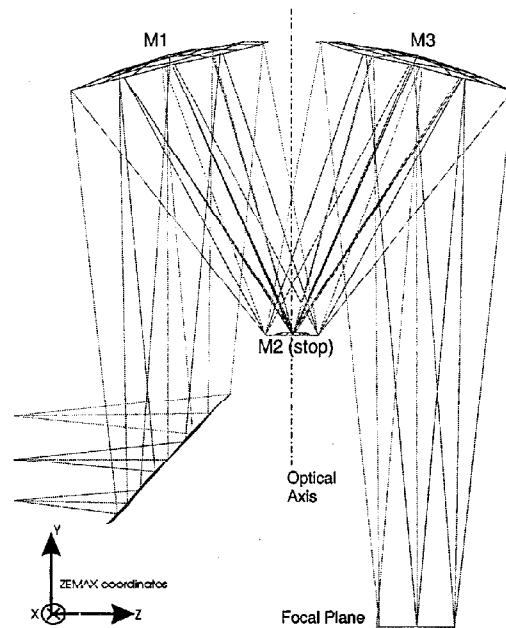
Figure 1 The BACUS module in the test cryostat.

The basic concept of the BACUS module is the employment an F5 Offner Relay to re-image an array of illuminators (or, when removed, the input from an external

telescope simulator) onto the detector array. In addition to this, a variable temperature blanking plate may be moved into position above the array.

### 1.1.1 Optics

The optics (M1, M2 and M3 on figure 1) form an F5 Offner Relay. This is a 1:1 re-imaging system that gives good image quality over a wide field. An Offner Relay is formed in this case by, in effect, two spherical mirrors. One is convex, radius  $R$ , and is placed at the focus of the other concave mirror of radius  $2R$ . In this application, the larger concave mirror has been formed from two smaller mirrors M1 and M3 in order to minimise stray light, as shown in figure 2. In this configuration, M2 forms the system stop.



**Figure 2** Illustration of BACUS Offner Relay system

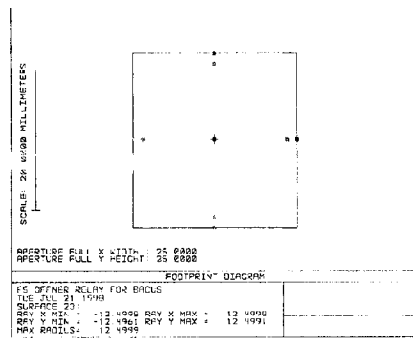
The ideal Offner Relay has been slightly “tweaked” using a commercial ray-tracing package (ZEMAX – Focus Software Inc.) to provide optimal image quality on the detector array. The parameters used for the final mirror positions in BACUS are shown in table 1. In this table, the zero in the “Z” direction is taken as the optical axis, while the zero in the “Y” is the focal plane.

**Table 1** Parameters for perfectly aligned system.

Mirror	M1	M2	M3
Radius (mm)	35.2	10.1	35.2
Radius of Curvature (mm) (-ve=concave)	-200	100	-200
X-offset (mm)	0	0	0
Y-offset (mm)	200	100	200
Z-Offset (mm)	-42.5	0	42.5
Tilt about X (degrees)	-12	0	12
Tilt about Z (degrees)	0	0	0

This system has been modeled in ZEMAX with the following constraints:-

- In the model, M2 was designated the system stop, and the ray tracing was performed with paraxial real reference ray aiming switched on, i.e. the rays were launched from the system stop. This was to account for pupil aberration.
- The image plane was defined as a 25x25mm square aperture centered on the array.
- All mirrors were defined as apertures equal to their actual radii. Therefore any vignetted rays were not traced.
- The object fields chosen for ray tracing were  $\pm 12.5\text{mm}$ ,  $\pm 11\text{mm}$ , and on axis. This was for the purpose of a misalignment analysis - any misalignment that caused non-tracing of the  $\pm 11\text{mm}$  rays was considered to be the tolerance limit (see figure 3).



**Figure 3** Footprint diagram showing position of fields used in the analysis.

The predicted optical performance of this system is shown in figures 4-7.

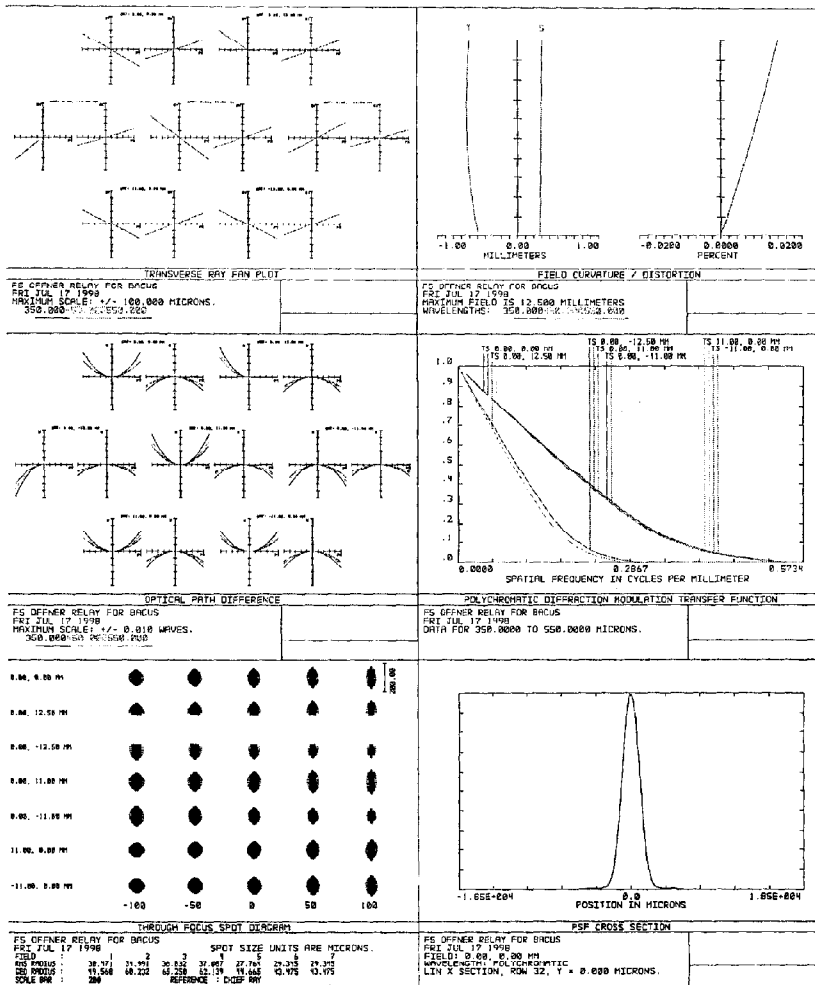


Figure 4 Performance of ideal system

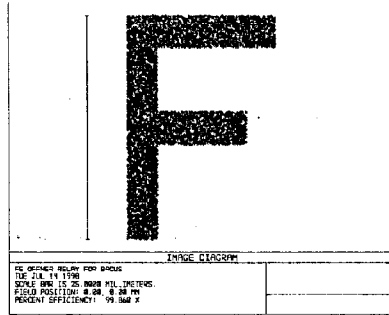


Figure 5 On-axis image quality

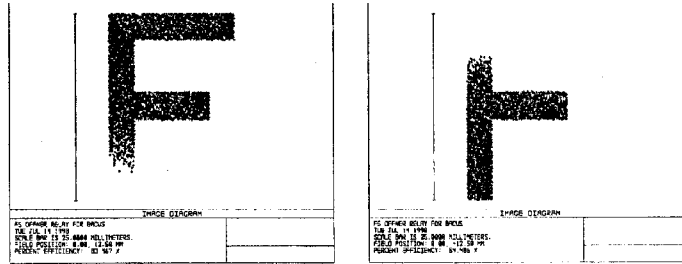


Figure 6 Image quality for 25mm objects at field limits (assuming no image plane aperture).

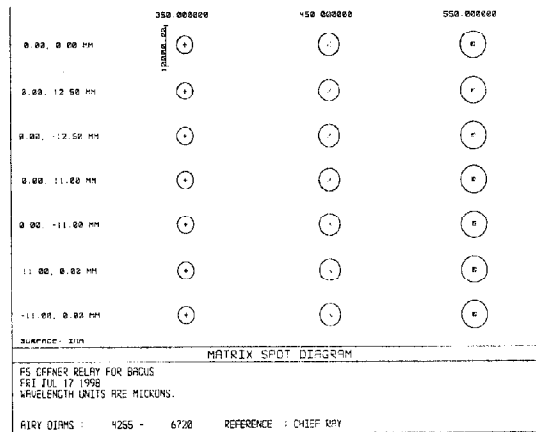


Figure 7 Matrix spot diagram for 350, 450 and 550 μm, using the Airy disc as a scale.

The mirrors for BACUS are manufactured from diamond turned Al-6061 (Symons Mirror Technology)

### 1.1.2 Cryogenics

The test cryostats are being provided by Precision Cryogenic Systems Inc. (Indiana, USA). These have a 10" Helium cold plate and extension tubes to house the BACUS module. This will enable the optics to be cooled to 4.2K or 1.5K. Bolted onto the cold plate will be a  $^3\text{He}$  refrigerator supplied by Chase Research. An earlier incarnation of this fridge has been proven to provide 360mK with a 4.2K bath, or 298mK with a pumped  $^4\text{He}$  bath (1.5K), while the version to be used in BACUS has additional heat exchangers on the support legs which should provide extra cooling power. The detectors will be located on a thermally isolated (from the  $^4\text{He}$  bath) support which will be connected to the  $^3\text{He}$  fridge via a thermal strap.

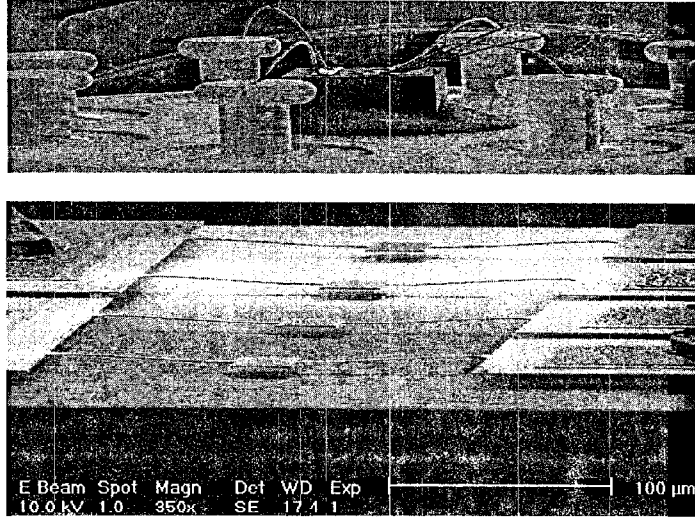
### 1.1.3 Blanking Plate

In order to make loading measurements, a plate mounted on a motor will be placed near the aperture of the 300mK shield. This will allow the bolometers to be blanked, or enable them to look at the calibration source without having to warm and open the dewar. The temperature of this plate, coated with highly absorbing material, is variable between 1.5K and 50K by means of a heater. This uniform source will allow us to measure device load-curves under varying background levels, as well as allowing measurements of array uniformity.

### 1.1.4 Calibration Source

Work is progressing to develop an array of illuminators for the BACUS facility. These illuminators should emit well at around  $300\mu\text{m}$ , and have the ability to be modulated at  $>10\text{Hz}$ . So far, two illuminator types have been tested at QMW to assess their suitability for this application:-

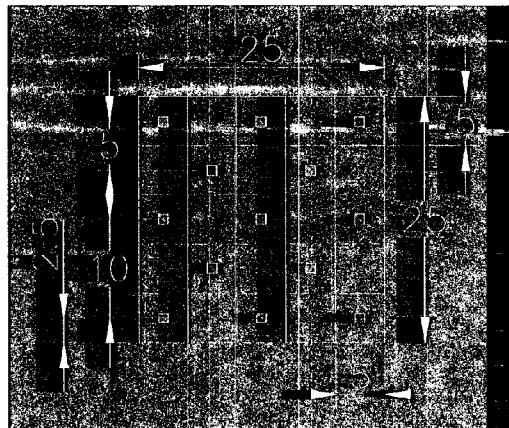
- InfraRed Labs TRS (Thermal Radiation Source) device – This type of illuminator was used as a calibration source on board ISO. These devices emit well at  $300\mu\text{m}$  but are slow, with a maximum modulation frequency of around 1.5Hz.
- Goddard Space Flight Center microlamps – These consist of 4 suspended doped silicon micro-beams (4 for redundancy) as shown in figure 8. These are being used as calibration sources on the InfraRed Array Camera (IRAC) on SIRTf. While these devices are approximately 50 times more efficient than the IR Labs TRS at  $28\mu\text{m}$ , dropping to 5 times more efficient at  $85\mu\text{m}$ , there was no detectable emission at  $350\mu\text{m}$ . This is unfortunate as these devices are very fast, with a 2ms time constant. Work is in progress in collaboration with GSFC to redesign the microlamps for optimal emission at around  $300\mu\text{m}$ . This will involve increasing the emitting area of the microlamp, and so will compromise the speed and power consumption.



**Figure 8** Electron micrographs of GSFC silicon microlamps.

We are also investigating the use of Indium Antimonide chips as potential illumination sources.

The illumination sources will be arranged on a 25x25 plate, divided into a 5x5 grid. A total of 13 illumination sources will be used, arranged as in figure 9.



**Figure 9** Arrangement of illuminator array (all dimensions in mm).



### 1.1.5 Wiring and Connectors

Three external hermetic connectors are being used as follows:-

- 1 x 79 pin (shell size 21)– for detector arrays (Ultratech)
- 1 x 32 pin (shell size 19)– for illuminator arrays (Sealtron)
- 1 x 26 pin (shell size 17)– for housekeeping (Ultratech)

All connectors are box flange mount conforming to MIL-C-38999/21 (screw connectors), and will be mounted on the dewar top plate.

The 79 pin connectors for the detectors will be wired according to the individual requirements of the detector array types. However, the illuminator and housekeeping wiring schemes must be standardised for compatibility during the final testing phase. These schemes are defined below in tables 2 and 3.



### 1.2.2 Speed of response

Detector speed of response may be measured either by modulation of the internal illuminators, or by removing the illuminator module and using a chopped external source. Alternatively, an external gamma-ray source may be used.

### 1.2.3 Array uniformity

Array uniformity may be tested by use of the variable temperature blanking plate.

### 1.2.4 Cross talk

### 1.2.5 Sensitivity

### 1.2.6 Dynamic range

### 1.2.7 Linearity

### 1.2.8 Optical NEP

### 1.2.9 Spectral response

### 1.2.10 Fringing between optical elements

### 1.2.11 Calibration of detector responsivity

### 1.2.12 Connection to external telescope simulator

## **2. Test Plan and Current Status**

Each detector group will have their own test dewar and BACUS module to enable them to integrate their arrays and run pre-tests (the CEA/SAP dewar to reside at QMW). The complete dewar with integrated array will then be shipped to QMW for testing and evaluation with the one "master" BACUS module.

### **2.1 Current BACUS status**

#### 2.1.1 Optics

- Mirrors arrived late October
- Stray light analysis being carried out by RAL – will also model baffling.

#### 2.1.2 Illuminators

- GSFC illuminators tested with bolometer at 350  $\mu\text{m}$  – seem to give negligible output at this wavelength.
  - Working with Goddard to redesign the illuminators for optimisation at 350  $\mu\text{m}$ .
  - Array of 13 illuminators needed for each BACUS module – designing array with Dave Robinson (GSFC).
  - Following a suggestion by Louis, we are going to try using InSb as a reverse HEB illumination source.
-

**Table 3 Illuminator Wiring scheme**

<b>Illuminators</b>				
<b>32 pin connector (19-32P)</b>			Illuminator 2xMDM15	
Male (plug) on dewar (MIL-C038999/21)			15SSB on cable	15PSB on cable
pin #	Function	Wire (1.5K to 1.5K)	15PSB on illum.	15SSB on illum.
pin #	Function	Wire (1.5K to 1.5K)	Pin#	Pin#
1	Element (E) 1+			3
2	E1-	Cu Twisted Pair		4
3	E2+			5
4	E2-	Cu Twisted Pair		6
5	E3+			7
6	E3-	Cu Twisted Pair		8
7	E4+			9
8	E4-	Cu Twisted Pair		10
9	E5+			11
10	E5-	Cu Twisted Pair		12
11	E6+			13
12	E6-	Cu Twisted Pair		14
13	E7+			1
14	E7-	Cu Twisted Pair		2
15	E8+			3
16	E8-	Cu Twisted Pair		4
17	E9+			5
18	E9-	Cu Twisted Pair		6
19	E10+			7
20	E10-	Cu Twisted Pair		8
21	E11+			9
22	E11-	Cu Twisted Pair		10
23	E12+			11
24	E12-	Cu Twisted Pair		12
25	E13+			13
26	E13-	Cu Twisted Pair		14
27				
28				
29				
30				
31				
32				

**1.2 Detector tests**

This section describes the tests to be carried out on the candidate detector arrays.

**1.2.1 Detector load curves**

V-Is can be obtained with the detectors blanked or with a uniform background by use of the blanking plate, which can be heated from 1.5K to around 50K. In addition, with the blanking plate out of the way, and with the illuminator module removed, V-Is can be obtained using external loads.

## 2.2 Testing Status

### 2.2.1 QMW/SAP

- CEA/SAP have delivered an array to QMW for optical tests (single pixel activated). Test plan for this device has been formulated.
- Cryophysics dewar has been wired and tested in preparation for He-3 fridge tests, and then subsequent use for testing the SAP prototype.
- Initial fridge/array tests in progress at the moment.

### 2.2.2 JPL (this is a copy of their last progress report dated 12/12/98)

- Operation of BOLOCAM prototype array in the dark successful with expected thermal conductivities and impedances. Noise is 12 nV/rtHz before demodulation. Electronics noise is  $< 4$  nV/rtHz. BOLOCAM science array is complete (and has been for some time) up to NTD Ge attachment step. Awaiting new NTD Ge chips.
- Prototype 350um horn array completed. We would like to send it to QMW for testing as soon as possible as we must place the order for the test arrays very soon to be ready for the test dewars.
- Memo describing design of JFET modules completed. Mask design for membrane to support GSFC JFETs completed.
- NJ132L JFET dies for testbed received from Interfet.
- Production of SPIRE test arrays now beginning.
- NTD Ge for arrays completed through implant, metalization of contacts, and In bumps. Should be diced and completed in about a week.
- Transfer of Goddard focal plane support structure completed. We have the focal plane installed in the mount (in Autocad that is) and would like to get some feedback on the mechanical envelope to guide our design.
- Tests of TES bolometers show that 1.2 pW of electrical power heats device to the transition at 450 mK. Implied thermal conductivity is 8 pW/K, and the phonon NEP =  $7e-18$  W/rtHz. Device shows excess 1/f noise that increases with electrothermal feedback. Excess resistive noise in the film or the contacts should decrease with electrothermal feedback, so the excess noise is better described by energy fluctuations. We will conduct further tests to find out the source of the 1/f noise.

### 2.2.3 GSFC

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### 2.1.3 He-3 fridge and thermometry

- Two of the 3 fridges are now in the QMW lab and are being tested.

### 2.1.4 He-3 fridge shields

- These have been completed and are ready for shipment with the tested fridges.
- Design of thermal strap needs to be finalised. Need to consult with US array groups re. their 300mK detector shield design.

### 2.1.5 He-4 detector shields

- Currently being manufactured by RAL.

### 2.1.6 General structure (support tubes etc)

- JPL/GSFC will purchase complete, tested BACUS modules. RAL are building structural components for all 3 BACUS modules, which will then be sent to QMW for assembly & testing before shipment to the US. RAL engineer visited QMW in mid October and has put together a cost/delivery estimate. He is overseeing work at RAL. Bruce has ordered mirrors for the 2 additional BACUS modules from Symons Mirror Technology – delivery expected 2<sup>nd</sup> February.

### 2.1.7 Filters

- Scheme needs definition, and then QMW to build filter stacks.

### 2.1.8 Connectors

- Supplier – Ultratech (France) and Sealtron (US). Ultratech have supplied the 79 pin and 26 pin connectors types (in possession of Goddard), while the 32 pin connectors (Sealtron) have been shipped to QMW. There is one spare connector of each type, although JPL has bagged the spare 79-pin connector. All connectors will be distributed at the January meeting at QMW.

### 2.1.9 Wiring scheme

- This has now been defined and is included with this document.

### 2.1.10 Cryostat

- Expecting delivery of dewar end-January.
- Components have been sent from Precision Cryogenics to JPL for gold plating. Once gold plating is completed, Precision Cryogenics will deliver within 2 weeks.

## 2.3 Current test plan and status

Three identical cryostats and BACUS modules are being built for distribution to Goddard, JPL and QMW. The American detector arrays will be built into their own cryostats and pre-tested before shipment to QMW for final testing with the "master" BACUS module, while all SAp detector integration and testing will be conducted in the QMW lab. All detector groups will supply staff effort at QMW to assist with/oversee tests.

### 2.3.1 CEA/SAp test plan

- Prototype single pixel device is currently being tested in the QMW lab. QMW will perform the following tests:-
  - Test and calibrate the output PMos
  - Dark noise tests and V-Is on detector + PMos
  - Noise and V-Is with known illuminator power on detector + PMos
  - All above tests on detector alone (without PMos)
- Iterative tests on successive generation devices throughout 1999, with final device delivery at the end of October 1999.

### 2.3.2 JPL/CALTECH test plan

- Will provide NTD germanium pixel for characterisation of BACUS stray light environment.
- Initial array tests to be conducted in JPL lab.
- Final array expected in QMW lab September/October 1999

### 2.3.3 GSFC test plan

- Will provide illuminator modules pending test results
  - Initial array tests to be conducted in GSFC lab
  - Final array expected in QMW lab September/October 1999
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# Confusion noise in SPIRE surveys

## Version 0.2

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November 30, 1998

### Abstract

We present a simplified model of extragalactic surveys with SPIRE, the Spectral and Photometric Imaging REceiver on board of FIRST, performed at 250  $\mu\text{m}$  and 500  $\mu\text{m}$ , in order to study the impact of confusion noise. We show on preliminary simulations that confusion is the major issue for dealing with extragalactic source extraction.

*Note* : Some of the remarks of the note of the 26 October 1998 by Griffin, Oliver and Gear have been taken into account.

## Introduction

This report address the problem of confusion noise for SPIRE, the FIRST bolometer instrument, for its survey mode. Indeed, confusion could be the main limitation of the instrument, due to the high number of extragalactic sources per square arc degree that are predicted by various number counts models. In order to investigate the problem of confusion, we have developed a very simplified model of a SPIRE survey and we have simulated observations at 250  $\mu\text{m}$  and 500  $\mu\text{m}$  with two kind of detectors : square pixel matrix of bolometers and array of horns (back-up option). We describe in section 1 the model we have used.

## 1 The model.

### 1.1 Model for source fluxes and positions

To model the sky as observed in SPIRE surveys, we have used two of number counts models presented in [1], namely the number counts model of Franceschini et al. (1997) [2], and the one of Rowan-Robinson (1998) [4], because they are two extreme models from the point of view of the predicted source density, the counts predicted by the model developed by Guiderdoni et al. (1998) [3] lay between the values predicted by the two others.

Each model result is a function that gives the number  $N$  of sources brighter than a given flux  $S$  per square degree as a function of  $S$ . The derivative of this function  $N(> S)$  is the number of sources  $dN$  with a flux  $s \in [S, S + dS]$ , multiplied by a factor  $-1$ . If one consider only a given flux range,  $[S_1, S_2]$ , one can build a function  $f$ , that gives the number of sources per square degree *dimmer* than a given flux  $S$

and brighter than  $S_l$  :

$$f(S) = \int_{S_l}^S dN(s)ds \quad (1)$$

If one consider now the function  $F(S)$  defined by :

$$F(S) = \begin{cases} 0 & \text{if } S < S_l, \\ \frac{f(S)}{f(S_u)} & \text{if } S_l < S < S_u, \\ 1 & \text{if } S > S_u. \end{cases} \quad (2)$$

The function  $F$  grows from 0 to 1 when  $S$  varies between  $]-\infty, +\infty[$ . In this sense,  $F(S)$  can be interpreted as the *partition function* of the random variable  $X_S$ , the flux of a source. We can therefore build a random flux generator, that follows the number counts model, by computing the function  $F$  and using the classical computer implemented uniform generator. The random variable  $X = F^{-1}(U)$ , where  $U$  is a random variable following the uniform law, will have  $F$  as partition function.

To simulate a given area of sky  $A$ , the models predict that the number of sources brighter than  $S_l$  will be  $n = A \times N(> S_l)$ . We work on an area large enough so that poissonian fluctuations ( $\propto 1/\sqrt{n}$ ) can be neglected.

We choose to simulate an area of 400 square arc minutes, where the number of sources brighter than 15  $mJy$  is roughly of 130, according to the Franceschini model. For our simulations, we choose  $S_l = 100 \mu Jy$  and  $S_u = 10 Jy$ . This  $S_l$  value gives a number  $N$  of sources in our simulation of 16746, with the Franceschini model,  $N = 6822$  with the Rowan-Robinson model.

The fluxes of the sources are generated with our random flux generator. The counts obtained from the simulated sets are shown in figure 1 for the various models. The positions in the images are generated by using a uniform generator.

## 1.2 Simulation of the focal plane

Once the positions and fluxes of the sources are known, we compute a oversampled image of the focal plane of FIRST. The resolution choosed for the computations is 0.5 arcsec, allowing for a good accuracy of the computations, since the smallest pixel size of SPIRE to be considered is 9 arcsec.

We assume an ideal telescope *i.e.* a single circular aperture. Therefore, the intensity of the diffraction limited image of a point source (PSF) is :

$$I = I_0 \left[ \frac{J_1(m)}{m} \right]^2 \quad (3)$$

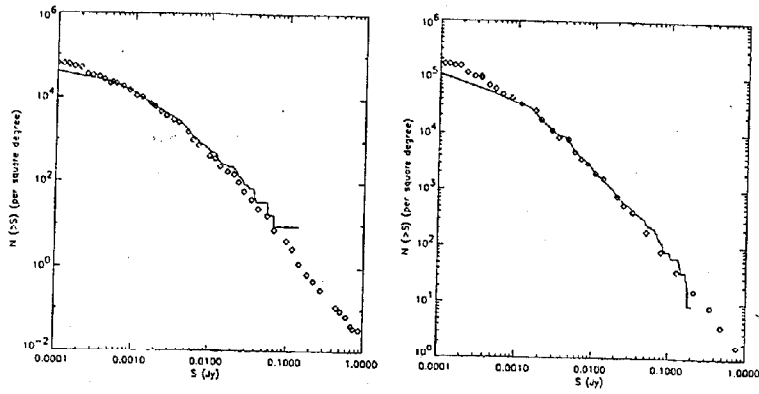
where  $J_1$  is the Bessel function and with :

$$m = \frac{\pi a i}{\lambda} \quad (4)$$

where  $a$  is the telescope aperture ( $a = 3.5m$ ),  $\lambda = 250 \mu m$  or  $\lambda = 509 \mu m$  is the wavelength, and  $i$  is the incidence angle (we use the approximation of small angles).

We have computed PSF with a resolution of 0.5 arcsec on the focal plane, on an area of  $240 \times 240$  arcsec. An image of  $20 \times 20$  arcmin with a resolution of 0.5 arcsec is computed by adding one PSF multiplied by the flux for each sources.

Figure 2 presents two simulated fields from each of the two models used.



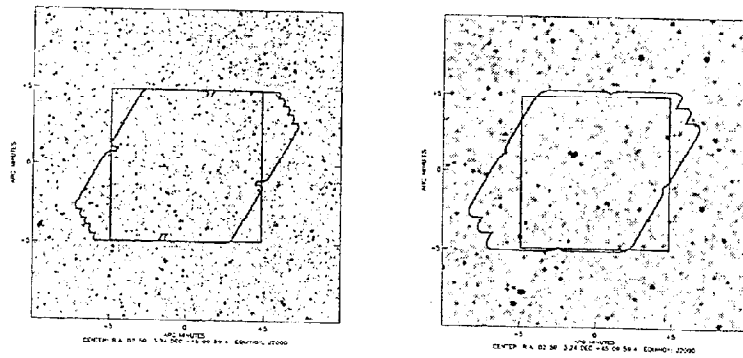
(a)  $\lambda = 250 \mu\text{m}$  counts model from Rowan-Robinson (1998)[4]

(b)  $\lambda = 250 \mu\text{m}$  counts model from Franceschini et al. (1997)[2]

Figure 1: Comparison of the counts obtained with the simulated fluxes with the models.

Line : counts derived from the simulation of a 400 arcmin area.

Diamonds : predictions of the model



(a)  $\lambda = 250 \mu\text{m}$  counts model from Franceschini et al. (1997)[2]. Upper cut is 0.2 mJy/arcsec<sup>2</sup>.

(b)  $\lambda = 500 \mu\text{m}$  counts model from Franceschini et al. (1997)[2]. Upper cut is 0.1 mJy/arcsec<sup>2</sup>.

Figure 2: Simulated images of a  $20 \times 20$  arcmin area of the sky, as observed at the focus of FIRST telescope at  $250 \mu\text{m}$  with a resolution of  $0.5$  arcsec. The images are displayed with a resolution of  $2 \times 2$  arcsec. At  $500 \mu\text{m}$ , confusion is already a problem for faint fluxes with the Franceschini et al. (1997) [2] model (b) at the resolution of the display, that is four times broader than the resolution of the computations. The area surveyed with option 1 and 2 (squares) and option 3 are outlined.

Option	$\lambda_{obs}$	Pixel size	Number of pixels
1 ( $F\lambda$ )	250 $\mu\text{m}$	18"	16 $\times$ 16
	500 $\mu\text{m}$	36"	8 $\times$ 8
2 ( $F\lambda/2$ )	250 $\mu\text{m}$	9"	32 $\times$ 32
	500 $\mu\text{m}$	18"	16 $\times$ 16
3 ( $2F\lambda$ )	250 $\mu\text{m}$	36"	61
	500 $\mu\text{m}$	72"	19

Table 1: Detailed parameter of the detectors.

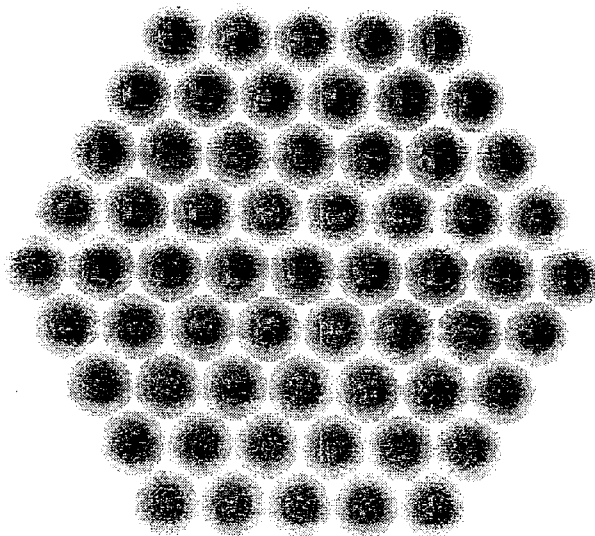


Figure 3: Image of the response of the 61 horns bolometers array

### 1.3 Simulation of the detectors

We have considered three kind of detectors summarized in table 1 :

1. array of 16  $\times$  16 square pixels of  $F\lambda$  of size, i. e. 18 arcsec at 250  $\mu\text{m}$ , and 8  $\times$  8 pixels of 36 arcsec at 500  $\mu\text{m}$ . The pixels are contiguous and their response is constant over the whole pixel.
2. array of 32  $\times$  32 square pixels of  $F\lambda/2$  of size, i. e. 9 arcsec at 250  $\mu\text{m}$ , and 16  $\times$  16 pixels of 18 arcsec at 500  $\mu\text{m}$ . The pixels are contiguous and their response is constant over the whole pixel.
3. array of 61 bolometers horns (backup option). The horns hexagonally placed and separated by  $2F\lambda$ . Their response is a gaussian of  $F\lambda$  FWHM. Figure 3 present a image of the array response.

The calculated image of the survey is projected on the detector, to simulate each pointing of the raster for cases 1 and 2, or of a jiggling map for case 3.

In SPIRE, we have taken two sources of noise into account :

1. detector noise with Noise Equivalent Power (NEP) equal to [1] :  
 $NEP_{det} = 3 \times 10^{-17} W.Hz^{-1/2}$

2. photon noise  $NEP_{ph}$ , that is dominated by the telescope itself.

The photon Noise Equivalent Power is computed from the RMS fluctuation  $(\Delta n)^2$  of the number  $n$  of photon of a black body that arrive on the detector [5]. Thus we have:

$$(\Delta n)^2 = n(n+1) \quad (5)$$

The photon emission is dominated by the telescope, with emissivity  $\epsilon$  and temperature  $T = 80$  K [1]. Last, this energy is received by a bolometer with quantum efficiency  $\eta_{bol}$ , with a telescope of collecting area  $A_t$  seeing the pupil under the solid angle  $\Omega$ , in the frequency range  $\Delta\nu$ , through an optic with efficiency  $\eta_{opt}$ . The fluctuation of the number  $N$  of photon arriving on the detector is therefore :

$$(\Delta N)^2 = \epsilon \eta_{bol} \eta_{opt} N (1 + \epsilon \eta_{bol} \eta_{opt} N) = \frac{\epsilon \eta_{bol} \eta_{opt}}{e^{\frac{h\nu}{kT}} - 1} \left( \frac{\epsilon \eta_{bol} \eta_{opt}}{e^{\frac{h\nu}{kT}} - 1} + 1 \right) \quad (6)$$

Each photon has an energy  $h\nu$  and the density of states it can occupy is :

$$d = 2 \times \frac{2h\nu^3}{c^2} \quad (7)$$

Therefore we have :

$$NEP_{ph}^2(\lambda) = A_t \Omega \int_{\Delta\nu} 2 \times \frac{2h\nu^3}{c^2} (h\nu) \frac{\epsilon \eta_{bol} \eta_{opt}}{e^{\frac{h\nu}{kT}} - 1} \left( \frac{\epsilon \eta_{bol} \eta_{opt}}{e^{\frac{h\nu}{kT}} - 1} + 1 \right) d\nu \quad (8)$$

We have for SPIRE [1] :

$$A_t \Omega = \alpha \lambda^2 \quad T_{tel} = 80K \quad \epsilon_{tel} = 0.04 \quad (9)$$

$$\eta_{opt} = 0.3 \quad \eta_{bol} = 0.8 \quad \Delta\lambda = \frac{\lambda}{3} \quad (10)$$

The value of  $\alpha$  depends on the configuration, taking into account Lyot spot and area of the bolometer. Following [6], we take for option 3  $\alpha = 0.8$  so that  $A_3 \Omega_3 = 0.8\lambda^2$ . For square pixels,  $\Omega = \pi/4F^2$  [6] is the same (the telescope has the same optical configuration) and the collecting area are  $A_1 = (F\lambda)^2$  and  $A_2 = (F\lambda)^2/4$ , where  $F$  is the focal length of the telescope.

The total noise equivalent power of the bolometer  $NEP_{tot}$  is then :

$$NEP_{tot} = \sqrt{NEP_{ph}^2 + NEP_{det}^2} \quad (11)$$

If one observes a point source radiating with the flux density  $S_{\nu,s}$ , assumed to be constant over  $\Delta\nu$ , the bolometer receives the power :

$$P_b = S_{\nu,s} A_t \Delta\nu \eta_{tel+det} \eta_{pix} \quad (12)$$

where  $\eta_{pix}$  is the portion of the PSF intercepted by the bolometer,  $\eta_{tel+det}$  is the overall efficiency of the instrument and telescope. We have :

$$\eta_{tel+det} = \eta_{opt} \eta_{bol} \eta_{chop} \quad (13)$$

$f\lambda$                        $0.5 f\lambda$                        $2 f\lambda$

		option 1 $\alpha = \pi/4 = 0.785$	option 2 $\alpha = \pi/16 = 0.196$	option 3 $\alpha = 0.8$
Wavelength	Noise	NEP ( $10^{-17} W.Hz^{-1/2}$ )	NEP ( $10^{-17} W.Hz^{-1/2}$ )	NEP ( $10^{-17} W.Hz^{-1/2}$ )
250 $\mu m$	photon	9.06	4.53	9.14
	detector	3.00	3.00	3.0
	total	9.54	5.43	9.62
500 $\mu m$	photon	5.05	2.53	5.10
	detector	3.00	3.00	3.00
	total	5.88	3.92	5.92
Wavelength	Noise	r.m.s. (mJy)	r.m.s. (mJy)	r.m.s. (mJy)
250 $\mu m$	total	0.63	0.36	0.63
500 $\mu m$	total	0.77	0.52	0.78

Table 2: Noise equivalent power and noise level ( $1 \sigma/\text{pixel}$ ) for simulation of 15 min exposures.

where  $\eta_{chop} = 0.45$  is the chopping efficiency and  $A_t = \pi 3.29^2/4$  [1].

If this sources is observed during the time  $t$ , the noise reduces as  $\sqrt{t}$  and the signal over noise ratio is therefore :

$$S/N = \frac{S_{\nu,s} A_t \Delta\nu \eta_{tel+det} \eta_{pix}}{\frac{NEP_{tel}}{\sqrt{2 \eta_{obs,t}}}} \quad (14)$$

Note that the observing time has been multiplied by a factor  $\eta_{obs}$ , the observation efficiency, to take into account the overheads i. e. that not all the time dedicated to the observation is used to take data.

The equation 14 allow to compute the signal over noise for the detection of a point source. In our case, we are interested in computing the noise level in one pixel. Thus, we have to consider for this purpose the observation of a constant extended source and use the following equation :

$$S/N = \frac{S_{\nu,s} A_t \Delta\nu \eta_{tel+det}}{\frac{NEP_{pix}}{\sqrt{2 \eta_{obs,t}}}} \quad (15)$$

where  $\eta_{pix}$ , the pixel efficiency, that is the average flux recieved by a pixel when observing a source, is no longer taken into account.

Setting  $S/N$  to 1 in equation 15 gives us the flux density r.m.s. of the noise, which, in this case is equal to  $S_{\nu,s}$ .

Values of  $\alpha$  and NEPs are summarized in table 2. Note that we assume that the noise is independant of the simulated sources, because we assume that photon noise due to the sources is neglectible against those of the background and telescope.

Once the projection of one pointing (raster step or jiggling step) has been computed, a gaussian noise with r.m.s. corresponding to the option and wavelength is added to the image.

#### 1.4 Map reconstruction

Once each image (i.e. the flux collected by each bolometer for a given pointing) has been computed, they are coadded in a "raster" or "jiggle" map. We follow for this

the prescriptions of the IRAM reduction package NIC [7]. Each pointing is added to the raster map with a weight  $W$  :

$$W = \left( \frac{\sin(ud)}{ud} \right)^2 T \quad (16)$$

$$u = \frac{2\pi D}{\lambda} \quad (17)$$

where  $d$  is the distance between the position of the final map and the center of the bolometer and  $T$  is the value of the transfer function of the bolometer at this point. A noise map is also produced, using  $W^2$  as weight.

The map of the observation is then interpolated on a regular RA-DEC oriented grid using bilinear interpolation. In option 3, where directions of the "jiggling" are not perpendicular, care has been taken to have a flux conservative reprojection.

## 2 Results

The model described in the previous section has been used to simulate survey observations with the three kind of detectors. Due to SPIRE design the three (of which two are simulated) are observed at the same time. This means that the same pointings and same integration time are used for the two channels. To fully sample the PSF at the longest wavelength, one has to scan the sky by steps of  $\lambda/2$  in both axis. These leads to a scan in only  $\lambda$  for the shortest wavelength thus leading to an undersampled map. Thus the minimal sampling rate is  $\lambda/2$  at  $250 \mu\text{m}$  that gives  $\lambda/4$  at  $500 \mu\text{m}$ . Together with this minimal sampling, we have simulated oversampled maps at  $\lambda/4$  at  $250 \mu\text{m}$  and  $\lambda/8$  at  $500 \mu\text{m}$ .

While the shortest wavelength commands the raster or jiggle step size, the longest wavelength commands the number of steps : the bolometer size has to be fully covered in order to obtain an homogeneous map. If a  $\lambda/2$  step at  $250 \mu\text{m}$  requires  $4 \times$  steps to obtain a full coverage of the PSF at  $250 \mu\text{m}$ , this translate to  $\lambda/4$  at  $500 \mu\text{m}$ . Thus, a  $8 \times 8$  map is in fact required.

### 2.1 Observations

In order to ensure a proper comparison of the three detector, we have simulated observations of an area of *fixed surface* within a *fixed total observation time* at a *fixed resolution*. The area for each configuration is  $100 \text{ arcmin}^2$ , except for option 3 (2 FA horns) at  $500 \mu\text{m}$  where the 27 horns cover a slightly larger surface giving a total area of  $113 \text{ arcmin}^2$ . To cover at  $\lambda/4$  and  $250 \mu\text{m}$  this area, 4 "jiggle" maps of 64 pointings each are required. We set the observing time to 64 minutes, giving an exposure time of 15 seconds per pointings in this configuration. The exposure time per pointing for each other options were computed to fill the same total observing time. For exemple, an array of  $16 \times 16$  square pixels of  $18''$  can map the same area in the same time and stay  $60''$  at each pointing, with 4 raster maps with half a pixel steps.

The detectors are detailed in table 1 and the observations are detailed in table 3

### 2.2 Images

Figures 4, 5 and 6 present the images obtained at  $250 \mu\text{m}$  and  $500 \mu\text{m}$  with the low resolution and high resolution mode, on the field simulated with Franceschini et al. number counts [2]. Figures 4, 5 and 6 present the same results for Rowan-Robinson number counts [4]. Note that we had to modify the lower cut of option 3 results



Option	Resolution at 250 $\mu\text{m}$	Number of pointings	Exposure time	Covered area	Total time
1 ( $F\lambda$ )	$\lambda/2$	$4 \times 4 \times 4$	1 min	100	1.07
	$\lambda/4$	$8 \times 8 \times 4$	0.25 min	100	1.07
2 ( $F\lambda/2$ )	$\lambda/2$	$2 \times 2 \times 4$	4 min	100	1.07
	$\lambda/4$	$4 \times 4 \times 4$	1 min	100	1.07
3 ( $2F\lambda$ )	$\lambda/2$	$8 \times 8 \times 4$	0.25 min	100	1.07
	$\lambda/4$	$16 \times 16 \times 4$	0.0625 min	100	1.07

Table 3: Details of the simulated observations. For each option, the step size (resolution) at 250  $\mu\text{m}$  is given, as well as the number of pointing required for a complete coverage at 500  $\mu\text{m}$ . The number of pointings is given in the following way :  $N_{step_1} \times N_{step_2} \times N_{raster}$  where  $N_{raster}$  is the number of independent raster or jiggle maps needed to cover the area.

to leave some dynamics in the image. Indeed, lower cut is  $10 \sigma$  while it is  $1 \sigma$  for options 1 and 2.

It is clear from the output images that confusion dominates all the maps for source extraction. With option 3 ( $2F\lambda$  horns), only a few pixels are below the  $1 \sigma$  level, at the edge of the map where redundancy is small, and most of the pixel are above the usual  $3 \sigma$  level used for source detection. Moreover, many sources appear blended together, whatever the detector being used.

Depending on the kind of observations and the detector, the effects of confusion are more or less severe :

- The mapped obtained at a better resolution are less affected.
- The smaller the pixels, the less prominent is confusion at high flux level.

When dealing with exposures as long as the ones simulated, the detector and photon noise originating from the telescope mirror become neglectibles, especially for large pixels.

Two ways can be though to overcome the confusion problem :

- use pixels as small as possible to fight this effect, but big enough to avoid to be dominated by instrument noise.
- observe with scan maps rather than pointed “jiggle” maps, in order to obtain a high resolution on the final map. This is only possible if the relative pointing accuracy and control of the satellite is good.

Two techniques are usually used detect sources against confusion : the deconvolution and the P(D) analysis. Both require a good understanding of the instrumental noise, as well as accurate measures of the beam profile, that are difficult to obtain, especially when the the instrument is very sensitive.

### 3 Conclusion

We have presented a simplified model of extragalactic surveys with SPIRE, the Spectral and Photometric Imaging REceiver on board of FIRST, performed at 250  $\mu\text{m}$  and 500  $\mu\text{m}$ , in order to study the impact of confusion noise. We show on preliminary simulations that confusion is the major issue for dealing with extragalactic source extraction. We show that a detector made of small pixel ( $F\lambda/2$ ) is

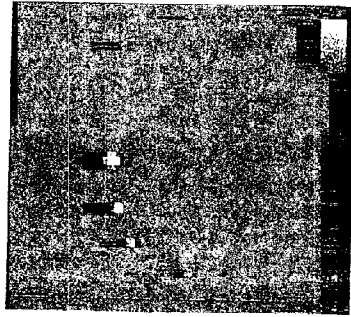
less sensitive to this problem. Observations obtained with very small steps between pointings or scan technique are also preferred.

Beyond the scope of extragalactic surveys, the problem rises the question of finding a good "empty" place when using chopping techniques. The probability of finding a source bright enough to be above the noise level for in any part of the sky is large, even for short exposures.

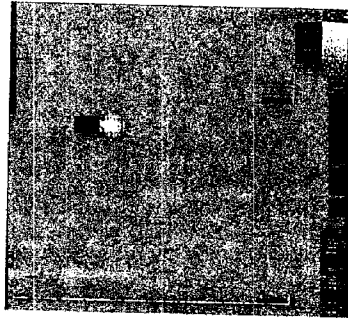
This study will be extended to take into detectors closer to reality : non homogenous response of the pixels, pixels with filling factor lower than one, etc... Moreover, tests of P(D) and deconvolution will be done to analyse the outputs of the simulations.

## References

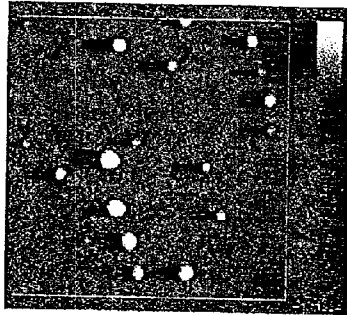
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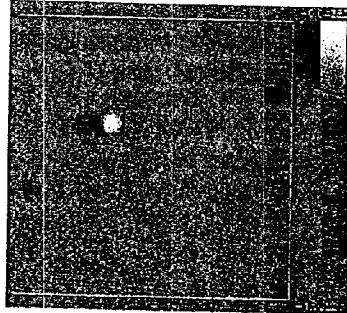
(a)  $\lambda = 250 \mu\text{m}$ , resolution of  $\lambda/2$ . Display is  $\text{Log}(f \text{ mJy/pixel})$ . Lower cut is  $1\sigma$ , upper cut is  $20\sigma$ .



(b)  $\lambda = 500 \mu\text{m}$ , resolution of  $\lambda/4$ . Display is  $\text{Log}(f \text{ mJy/pixel})$ . Lower cut is  $1\sigma$ , upper cut is  $40\sigma$ .

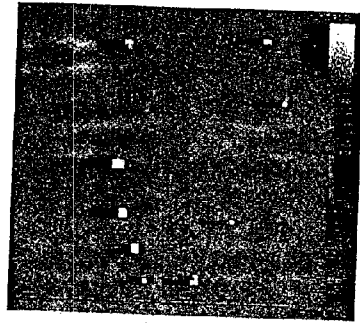


(c)  $\lambda = 250 \mu\text{m}$ , resolution of  $\lambda/4$ . Display is  $\text{Log}(f \text{ mJy/pixel})$ . Lower cut is  $1\sigma$ , upper cut is  $20\sigma$ .

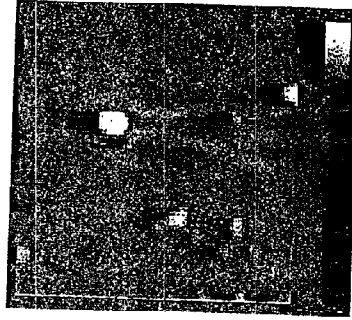


(d)  $\lambda = 500 \mu\text{m}$ , resolution of  $\lambda/8$ . Display is  $\text{Log}(f \text{ mJy/pixel})$ . Lower cut is  $1\sigma$ , upper cut is  $40\sigma$ .

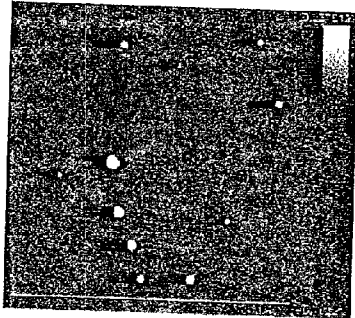
Figure 4: Observation with option 1 ( $F\lambda$  square pixels), with a final resolution of  $\lambda/2$  at  $250 \mu\text{m}$  (panels a and b), and with a final resolution of  $\lambda/4$  at  $250 \mu\text{m}$  (panels c and d)



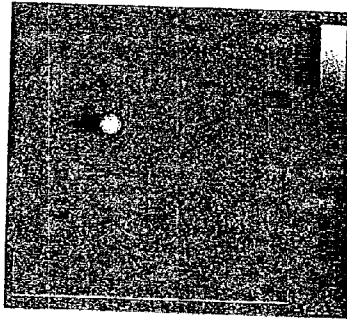
(a)  $\lambda = 250 \mu\text{m}$ , resolution of  $\lambda/2$ . Display is  $\text{Log}(f \text{ mJy/pixel})$ . Lower cut is  $1\sigma$ , upper cut is  $40\sigma$ .



(b)  $\lambda = 500 \mu\text{m}$ , resolution of  $\lambda/4$ . Display is  $\text{Log}(f \text{ mJy/pixel})$ . Lower cut is  $1\sigma$ , upper cut is  $80\sigma$ .

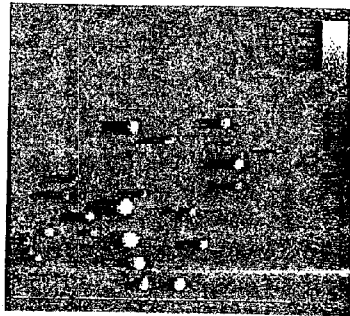


(c)  $\lambda = 250 \mu\text{m}$ , resolution of  $\lambda/4$ . Display is  $\text{Log}(f \text{ mJy/pixel})$ . Lower cut is  $1\sigma$ , upper cut is  $40\sigma$ .

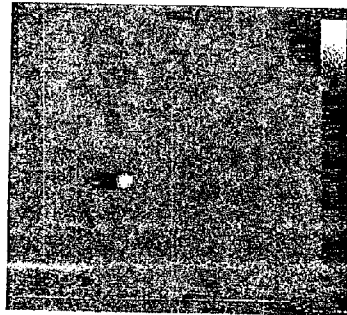


(d)  $\lambda = 500 \mu\text{m}$ , resolution of  $\lambda/8$ . Display is  $\text{Log}(f \text{ mJy/pixel})$ . Lower cut is  $1\sigma$ , upper cut is  $80\sigma$ .

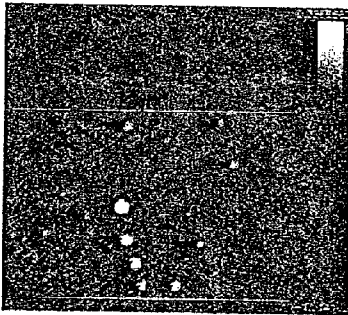
Figure 5: Observation with option 2 ( $F\lambda/2$  square pixels), with a final resolution of  $\lambda/2$  at  $250 \mu\text{m}$  (panels a and b), and with a final resolution of  $\lambda/4$  at  $250 \mu\text{m}$  (panels c and d)



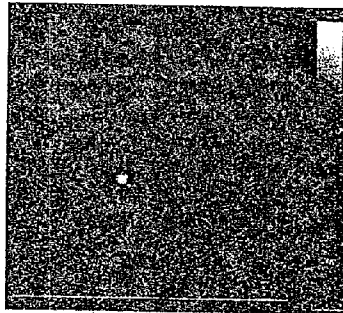
(a)  $\lambda = 250 \mu\text{m}$ , resolution of  $\lambda/2$ . Display is  $\text{Log}(f \text{ mJy/pixel})$ . Lower cut is  $10\sigma$ , upper cut is  $400 \sigma$ .



(b)  $\lambda = 500 \mu\text{m}$ , resolution of  $\lambda/4$ . Display is  $\text{Log}(f \text{ mJy/pixel})$ . Lower cut is  $10\sigma$ , upper cut is  $800 \sigma$ .



(c)  $\lambda = 250 \mu\text{m}$ , resolution of  $\lambda/4$ . Display is  $\text{Log}(f \text{ mJy/pixel})$ . Lower cut is  $10\sigma$ , upper cut is  $400 \sigma$ .



(d)  $\lambda = 500 \mu\text{m}$ , resolution of  $\lambda/8$ . Display is  $\text{Log}(f \text{ mJy/pixel})$ . Lower cut is  $10\sigma$ , upper cut is  $800 \sigma$ .

Figure 6: Observation with option 3 ( $2F\lambda$  horns), with a final resolution of  $\lambda/2$  at  $250 \mu\text{m}$  (panels a and b), and with a final resolution of  $\lambda/4$  at  $250 \mu\text{m}$  (panels c and d)