BOL/QMW/M/0021·10

Minutes of BOL technical meeting at RAL, Aug. 22 1997

Prepared by: Matt Griffin

Date: Aug. 23 1997

Purpose of meeting: To plan BOL input for IID/Industrial study planning meeting with ESA/Industry on Sept. 2 and 3

Present:
Tom Bradshaw (for items 4 and 5)
Matt Griffin
Ken King
Bruce Swinyard
Colin Cunningham
Ian Hepburn
Bruno Maffei

Agenda:

1. Preparation required for meetings with ESA and industry on Sept. 2 and 3
2. Assumptions for baseline instrument
3. JFET box specification
4. Stray light model
5. Dilution cooler interface specifications
6. Helium-3 cooler alternative
7. Operating modes and pointing requirements
8. Telemetry rate
9. Implications of FTS option

1. Requirements for Sept. 2/3 meeting

For the purpose of inputs to the industry merger study and to complete the AO documentation meetings with the participation of Industry Teams, and the FIRST instrument teams and ESA will be held at ESTEC on 2, 3 (am) September for FIRST. The schedule is as follows (information from Harm Schaap):

Sept. 2	1	Introduction (FIRST)	09.00 - 09.15
	2	FIRST Instrument definitions and interfaces	09.15 - 10.45
	2.1	BOL	09.15 - 09.45
	2.2	PHOC	09.45 - 10.15
	2.3	HET	10.15 - 10.45
	3	Detailed review of FIRST IID-B	11.00 - 17.00
	3.1	BOL	11.00 - 12.30
	3.2	PHOC	14.00 - 15.30
	3.3	HET	15.30 - 17.00
Sept. 3	4	FIRST specific Inputs to IID-A	09.00 - 12.00
	5	AOB	

Notes on the items above:

2 Each instrument team should make a small presentation on his/her instrument, thereby concentrating on critical issues such as:
- cryostat optical bench interfaces (cooling, mechanical)
- dissipation in the instrument (heat budget, thermal model)
- cryo-harness requirements

- operating modes (parallel operation to others)
- TM rates

2.1 **BOL:**
- all cooling interfaces to dilution cooler (is there one?)
- JFET unit definition (size, interfaces, requirements)
- straylight model
- pointing

2.2 **PHOC:**
- straylight model (update necessary?)

2.3 **HET:**
- Local osc. unit (new definition of windows)
- Local osc. unit alignment to FPU
- EMC
- cryoharness (coax cables?)

3 IID-B as usual

4 The most important items to cover with industry and instrument teams are:
- pointing
- FIRST telescope definition
- straylight
- alignment requirements
- model philosophy
- HET windows
- instrument modes (prime, parallel)

2. Assumptions for base-line BOL instrument

ACTION: MJG/BMS to specify f/9.6 single grating option and new focus position as new base-line for the IID and the industrial study (by Fri. 22 Aug.)

3. FET box (BOL2) specification

The following draft specification was agreed:

Assumption:	Single-grating spectrometer option with two rows of 20 detectors Total no of detectors = 117 (photometer) + 40 (spectrometer) = 157
Size	200x200x40 mm (TBC after analysis of room needed for connectors)
Location	On first radiation shield (i.e., the one next to the cryostat outer can)
Temperature	Box: 75 or 80 K in orbit; 150-200 K on ground Internal: Nominally 120 K; FETs should function (but out of spec.) at 150-200 K
Mass	1.5 kg
Cable length BOL1-BOL2	0.5 m max.
Harness specification	TBD; Stainless steel; shielding etc. TBC **ACTION:** MJG and CRC to specify for Sept. 2 Fri. 29 Aug.
Power dissipation	Est. 200 mW (we should ask ESA if it's critical) (Based on ~ 1 mW per FET pair + some heater power)
Connectors	About 10 37-way connectors in and same number out (157 detectors) **ACTION:** BMS to provide CRC with connector details **ACTION:** CRC to get it drawn up to estimate reqd. size by Fri. 29 Aug.

Grounding	Metal box bolted to metal radiation shield FET circuits inside will be isolated from the box
Heater control	Open loop with internal FET module heaters and thermometers
RF filters	On low impedance side of FET box **ACTION:** BM to send details of RF filters used at QMW to CRC by Wed. 27 Aug.

ACTION: MJG to summarise FET box parameters in prep for Sept. 2 (by Fri. 29 Aug.)

Some questions concerning the FET box:

1. Will there be MLI on the radiation shield on which the box is to be mounted?
2. Would it be better to put the FET box on the outer shield?
   - Advantage: Simpler and much better for reliability, integration and access
   - Disadvantages:
     - Longer cable length to FPU
     - Possibly worse for EMC (?)
     - FETs would be at 300 K on the ground, except in thermal vacuum chamber
3. Availability of small, space-qualified/qualifiable RF filters capable of operating at 70 K.
4. Availability of connectors with integral RF filters
5. Feasibility of requesting that RF filters be incorporated into the cryoharness or the CVV vacuum feed-through.

4. Stray light

ACTION: BMS to arrange for Martin Caldwell and/or Tony Richards to look at PHOC document on their stray light model (PHOC/ESA/R0008.1) and see if we can do the same for the BOL (by Wed. Aug. 27)

ACTION: RAL team to get in touch with PHOC on details of their analysis and the applicability of something similar to the BOL (ASAP)

ACTION: BMS to ask MC to try to specify what apertures/temps are usable (by Wed. Aug. 27)

5. Operating modes and pointing

ACTION: MJG to describe consequences of pointing inaccuracy in presentation at Sept. 2 meeting

ACTION: MJG to expand section 4.6 of the IID (with input from BMS) and include notes on parallel operation of the detectors (by Aug. 29)

ACTION: ROE to do outline design study on the question of whether the chopper should/can be capable of (i) carrying out jiggle motions for mapping; (ii) peaking up internally (date not critical but will be essential for purposes of proposal).

6. Dilution cooler

The dilution cooler is still the base-line, even though a 0.3-K cooler is regarded as increasingly likely. Simple drawings showing the interfaces between the dilution cooler and the instrument were made at the meeting, but insufficient information is currently available to specify these interferes in detail

ACTION: BM to produce diagram showing how we think it should be done (early in week of Aug. 25)

ACTION: BM to visit IAS and talk to J-J Fourmond and J-M Lamarre about dilution cooler, and to contact Benjamin Pouilloux (CNES, Grenoble) if appropriate.(early in week of Aug. 25)

7. ^{3}He cooler alternative

ACTION: IDH to produce short note on essential parameters of He-3 system (by Aug. 27)

ACTION: IDH to contact Lionel Duband and discuss ^{3}He option

8. Telemetry rate for new single grating (40 dets in spectrometer)

Current figure in the IID is 50 kbs without compression with both the photometer and the spectrometer operating at full capacity. This is based on the cross-disperser option, which is now unlikely to be adopted.

The following revisions to the data rates (without compression) were provisionally agreed.

157 dets.	Photometer + spectrometer operating together	43.3 kbs
117	Photometer only	33.7
40	Spectrometer only	15.2

Partner mode with PHOC for deep surveys (if feasible)	33.7	(photometer only)
Parallel mode	33.7	(or less if pressed)
Serendipity (when slewing)	33.7	(or less if pressed)

ACTION: MJG to estimate allowable telescope temperature fluctuation and give results to CRC (by 29 Aug.)

ACTION: MJG to estimate max. source strength we need to observe and corresponding signal level (by 29 Aug.)

9. Implications of FTS option

BMS analysis as outlined in a note in preparation indicates FTS has performance competitive with the single grating option.

Mechanism drive design and power dissipation is one of the main uncertainties.

ACTION: BMS will look at option of using something similar to the LWS grating mechanism (by Aug. 29)

ACTION: MJG and BMS to estimate rough values of system parameters for FTS option (mass, volume, power profile, wiring, no. of detectors, data rate, etc.) (by Aug. 29). Assumption: FTS with two arrays of 20 detectors

ACTION: BMS and MJG to revise and extend BMS's FTS sensitivity model (by Aug. 29)

List of actions from BOL technical meeting at RAL, Aug. 22

1	MJG,BMS	Specify f/9.6 single grating option and new focus position as new base-line for the IID and the industrial study	Aug. 22
2	MJG, CRC	MJG and CRC to specify for Sept. 2	Aug. 29
3	BMS	Provide CRC with connector details	Aug. 22
4	CRC	Get FET box drawn up to estimate required dimensions	Aug. 29
5	BM	Send details of RF filters used at QMW to CRC	Aug. 27
6	MJG	Summarise FET box parameters in prep for Sept. 2	Aug. 29
7	BMS	Arrange for Martin Caldwell and/or Tony Richards to look at PHOC document (PHOC/ESA/R0008.1) on their stray light model and see if we can do the same for the BOL	Aug. 27
8	BMS etc.	RAL team to contact PHOC team on details of their analysis and the applicability of something similar to the BOL.	Sept.
9	BMS	Ask MC to try to specify what apertures/temps are usable	Aug. 27
10	MJG	Describe consequences of pointing inaccuracy in presentation at Sept. 2 meeting	Sept. 2
11	MJG	Expand section 4.6 of the IID (with input from BMS) and include notes on parallel operation of the detectors	Aug. 29
12	CRC	Arrange for ROE to do outline design study on the question of whether the chopper should/can be capable of (i) carrying out jiggle motions for mapping; (ii) peaking up internally (date not critical but will be essential for purposes of proposal).	End Sept.
13	BM	Produce diagram showing our simple concept of dilution cooler interfaces	Aug. 27
14	BM	Visit IAS and talk to J-J Fourmond and J-M Lamarre about dilution cooler, and to contact Benjamin Pouilloux (CNES, Grenoble) if appropriate.	Aug. 29
15	IDH	Produce short note on essential parameters of He-3 system	Aug. 27
16	IDH	IDH to contact Lionel Duband and discuss ^{3}He option	End Aug.
17	MJG	Estimate allowable telescope temperature fluctuation and give results to CRC for data handling analysis	Sept. 12
18	MJG	Estimate max. source strength we need to observe and corresponding signal level	Sept. 12
19	BMS	Look at option of using something similar to the LWS grating mechanism (esp. power dissipation)	Aug. 29
20	MJG, BMS	Estimate rough values of system parameters for FTS option (mass, volume, power profile, wiring, no. of detectors, data rate, etc.) Assumption: FTS with two arrays of 20 detectors	Aug. 29
21	BMS, MJG	Revise and extend BMS's FTS sensitivity model	Sept. 12

4. Instrument description

4.1 Introduction

For low background direct detection at wavelengths longer than around 200 microns, the most sensitive detectors are cryogenic bolometers operating at temperatures in the 0.1 - 0.3 K range.

The FIRST Bolometer instrument (BOL) comprises a three-band imaging photometer covering the 200-500 micron range and a grating spectrometer with a resolution of order 1000 covering wavelengths between 200 and 350 microns. The detectors are bolometers cooled to 300 mK or less. The photometer is optimised for deep photometric surveys, and can observe simultaneously the same field of view in all three bands. The grating spectrometer is optimised for spectral rather than spatial multiplexing, the aim being to measure the complete spectrum as sensitively as possible.

4.2 Scientific rationale

The wavelength range 200 - 500 microns is largely unexplored. The thermal emission from many astrophysical sources peaks in this part of the spectrum, including comets, planets, star-forming molecular cloud cores, and starburst galaxies. The short submillietre region is also rich in atomic and molecular transitions which can be used to probe the chemistry and physical conditions in these sources.

Wavelengths between 200 and 350 microns are not observable from the ground and will not be observed by ISO. Low transparency submillimetre windows allow some observations to be made with difficulty from the ground, but with far lower sensitivity than can be achieved from space.

One of the most important scientific projects for the FIRST mission is to investigate the statistics and physics of galaxy formation at high redshift. This requires the ability to carry out deep photometric imaging at far-infrared and submillimetre wavelengths (100-500 microns) to discover objects, and the ability to follow up the survey observations with spectroscopy of selected sources. The FIRST bolometer instrument is essential for this programme, and is being designed so as to be optimised for these extragalactic imaging and spectral surveys. Another key scientific project for the BOL is a sensitive unbiased search for protostellar objects within our own galaxy.

4.3 Overall capabilities

The BOL instrument contains a three-band imaging photometer and a grating spectrometer.

4.3.1 Photometer

The imaging photometer operates at nominal wavelengths of 250, 350 and 500 mm with a spectral resolution of around 3. Three hexagonally close-packed detector arrays observe the same approx. 5-arcminute field of view imultaneously, with dichroic beam dividers separating the bands. The 250, 350 and 500 micron arrays have 61, 37 and 19 detectors, respectively. This array design is similar to that of ground-based bolometer array receivers such as the SCUBA instrument on the JCMT and the bolometer array on IRAM, using diffraction-limited feedhorns of a size comparable to the diffraction spot size. This involves spatial undersampling of the sky and the need to make a number of separate array pointings in order to acquire a fully sampled image.

It is possible that the detector array technology may be changed in the future to larger-format bolometer arrays designed to sample fully the telescope diffraction disc.

The focal plane arrays incorporate spider-web bolometers coupled by feed-horns. Signal readout is via cold JFETs located close to the instrument enclosure, but heated to a temperature of around 100 K.

4.3.2 Spectrometer

The grating spectrometer covers that range 200 - 350 mm with a resolution of around 400. It is designed for maximum spectral multiplexing, with a minimal capability for imaging. A two-dimensional array of around 100 bolometric detectors sample the spectrum produced by a cross-dispersed diffraction grating operating in reflection. The complete spectrum is sampled by scanning the grating.

4.4 Hardware description

The BOL consists of:

1. A cold focal plane unit (FPU) which interfaces to the 15-K, 4-K and 2-K temperature stages provided by the cryostat. Within the unit, further cooling of teh detector arrays to a temperature of around 250 mK is provided by a dilution refrigerator which is part of the instrument.

2. A JFET module for detector signal readout, physically close to the focal plane unit and connected to the 15-K stage by rigid but thermally isolating supports. There is a thermal connection to a higher temperature shield (50-120 K) to which the dissipated power is conducted.

3. A continuous flow dilution refrigerator system comprising helium-3 and helium-4 gas storage tanks mounted on the outside of the payload module, and piping at temperatures down to 100 mK.

4. Warm electronics boxes located in teh service module (SVM) at 300 K for (i) analogue signal readout; (ii) instrument mechanism control; (iii) digital data processing, instrument control and telemetry interface to the spacecraft; (iv) control of the dilution refrigerator.

5. Interconnecting harnesses between the FPU and the JFET module and between the warm electronics units.

4.5 Software description

4.6.1 Primary operating modes

4.6.1.1 Point source observation (photometer):

This mode produces a photometric measurement of a single position on the sky.

- Chopping
- Nodding (optional)

4.6.1.2 Point source observation (spectrometer):

This mode produces a full or partial spectral scan of a single position on the sky.

- Chopping but not nodding (TBC)

4.6.1.3 Mapping of one field (photometer):

This mode produces a fully sampled (less than half-beam spacing) map of an area equal to the BOL field of view.

- Chopping
- Raster pointing with typically 64 positions
- Grid separation typically 9"

4.6.1.4 Scan mapping (photometer)

This mode produces a map of an area typically much than the BOL field of view. It will be the prime mode for deep survey observations. It has the advantage over single-field mapping that there are no overheads due to telescope settling at each point in a raster.

4.6.2 Parallel/serendipity mode

4.6.2.1 BOL operation while telescope is slewing

The BOL photometer can take data during telescope slews, producing strip maps at three wavelengths.

The BOL spectrometer can take spectral data (with the grating in a fixed position) producing n sparsely sampled spectral data points where n is the number of detectors (around 100)

4.6.2.2 BOL operation in parallel with PHOC

TBD

4.6.3.2 BOL operation in parallel with HET

TBD

4.~~6~~.3 Standby mode

- FPU powered
- FET module powered
- Grating in rest position
- Chopper throw set to zero

4.6.4 Off mode

- FPU not powered
- FET box not powered

4.6.5 FPU operation at ambient temperature

- Chopper and grating can be operated and checked
- FETs can be switched on and checked for functionalit
- Detectors can be powered but do not function

characterisation

<---> parallel ?

standby ?

Op 1 Op 2 Op 3

BOL

FIRST Bolometer

Title: Evaluation of the FTS option for the BOL

Author: B. Swinyard - RAL

Doc No:
Draft

Date:
14/08/97
Page 1 of 4

Introduction:

The cross dispersed grating spectrometer no longer appears to give the advantage in time required for a full spectrum when "real" grating efficiencies are considered (e-mail from Matt 11 August 1997). The single grating option is then the baseline. There are still doubts about the practically achievable performance of even the simple grating spectrometer when, according the Matt's model, only a few tens of femtowatts of straylight will be enough to scupper the whole thing. And, being essentially detector noise limited, any degradation in detector performance on orbit will feed linearly into the minimum detectable flux. It also has the disadvantage that any imaging capability will be difficult to implement with the diffraction limited optics.

Attention has turned, therefore, to the possibility of implementing a Martin-Puplett Fourier transform spectrometer (MP-FTS). These have been employed in many applications in the FIR and sub-mm (e.g. SOFIA, REFIA, David Naylor's JCMT instrument etc...). Matt laid out the advantages of them over mono-chromator spectrometers in a note at the last meeting (appended). A more detailed trade off is required in order to fully evaluate whether the added mechanical complexity can be set against any advantage in sensitivity and/or the robustness of meeting any advertised specification - i.e. can we REALLY achieve what we set out to do?

This note sketches a possible configuration for an MP-FTS for BOL based largely on the SOFIA instrument. It is the result of a discussion that took place at QMW on the 3/7/97 with Peter Ade, Matt Griffin, Bill Duncan, Gillian Wright, Martin Caldwell and Bruce Swinyard. Taking the outline design a MathCAD model is then described that evaluates the first order performance of the instrument and checks on the robustness of the instrument specification against changes in detector performance and straylight.

Outline Model of an MP-FTS

Figure 1 shows a sketch of a possible implementation of an MP-FTS for BOL. For simplicity all the focusing elements are shown as lenses although they will, of course, be mirrors. No assumptions are made about pupil imaging, image quality, beam size, straylight control etc. and these are left to the detailed optical design.

In the outline design, filters are placed at the interface between the 15° K and 4° K boxes and the 4° K and 2° K boxes to reduce thermal loading and reject radiation outside the wavelength band of interest. The final detection of the spectrum makes use of the two output ports of the MP-FTS to split the detectors into two bands: one 25-38 cm^{-1} (~260-400 μm) and the other 38-50 cm^{-1} (200-260 μm). These were chosen to give approximately the same in band power on the two detector channels (see below for confirmation of this).

For the first order model of the instrument the parameters used are listed in table 1. Each element in the table is seen via the transmission of the elements below it and within the pass bands defined by the final filtering for each channel. The running total for the transmission is given in the final column. Note that **all elements** have been given an emissivity of 4% - this is likely to be too high for everything except the main telescope but does make some allowance

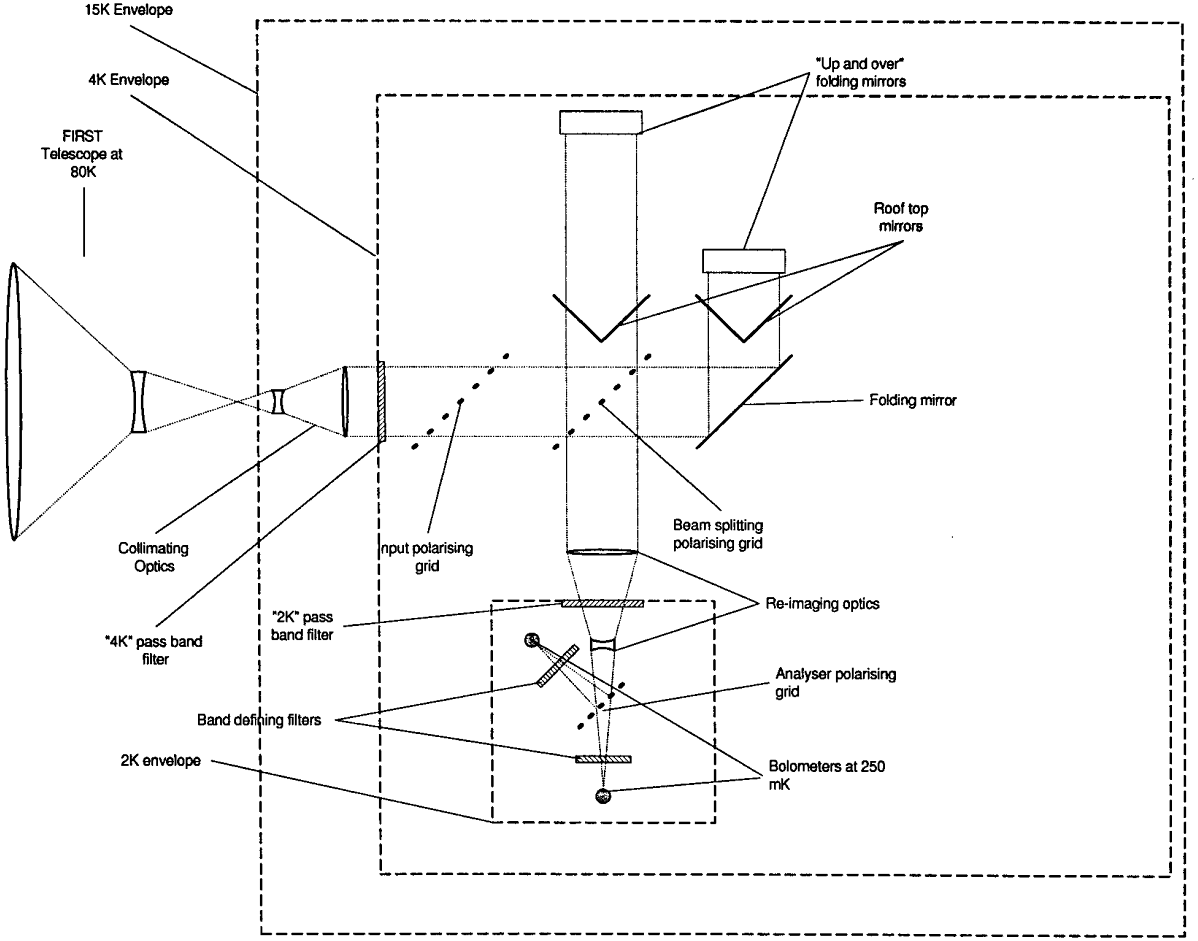


Figure 1: Outline layout for a Martin-Puplett polarising FTS for the FIRST-BOL instrument.

for contributions outside the nominal field of view (in any case it makes no difference to the final outcome - see below).

Element	Transmission	Transmission to detector	Temperature ° K	Central wavelength and resolving power
Main mirror	0.96	0.0737	80	-
Collimator mirror	0.995	0.0741	15	-
Collimator mirror	0.995	0.0744	15	-
4K filter	0.95	0.0784	4	300 μm R=1.5
Input grid	0.5	0.157	4	-
FTS*	0.5	0.313	4	-
2K filter	0.9	0.348	2	300 μm R=1.5
Focus mirror	0.995	0.35	2	-
Analyser grid	0.5	0.7	2	-
Band defining filter: 1	0.7	1.0	0.25	225 μm R=3.7
2	0.7	1.0	0.25	320 μm R=2.4

Table 1: Parameters used in the MathCAD model of the MP-FTS

* All elements of the FTS after the input grid and up to the 2K filter are treated as a single entity at 4^0 K and with a transmission of 0.5 = $<\cos^2>$ - i.e. all radiation emanating from sources before the FTS is modulated and the average throughput is $<\cos^2>$.

Other assumptions made in the model are that the grasp of the detectors is given by $A\Omega = \lambda^2$; the bolometer quantum efficiency is 0.8; the point source coupling efficiency is 0.7 and the feed horn efficiency is 1; the diameter of the telescope is 3.5 m and there is an observing overhead of 1.5 (probably too much but it makes for a straight forward comparison). These are the same assumptions as made by Matt in computing the performance of the grating spectrometer. There is no allowance for a chopping efficiency as this is not required with the FTS. The power falling on the detectors from each element is given in table 2.

Element	Power in Band 1 (W)	Power in Band 2 (W)
Main mirror	$1.532 . 10^{-12}$	$1.905 . 10^{-12}$
Collimator mirror	$2.676 . 10^{-14}$	$7.397 . 10^{-14}$
Collimator mirror	$2.69 . 10^{-14}$	$7.435 . 10^{-14}$
4K filter	$3.562 . 10^{-19}$	$3.018 .10^{-17}$
Input grid	$7.123 . 10^{-19}$	$6.037 .10^{-17}$
FTS*	-	$7.067 . 10^{-21}$
2K filter	-	$7.853 . 10^{-21}$
Focus mirror	-	$7.892 . 10^{-21}$
Analyser grid	-	-
Band defining filter	-	-

Table 2: Power falling on detectors from each element.

Note from table 2 that the contributions from the elements other than the main telescope are irrelevant and that, as predicted, the power falling on each of the detector bands is roughly equal. The contribution to the NEP from power falling on the detectors can therefore be calculated using only the contribution from the main telescope and is 5.815×10^{-17} W $Hz^{-1/2}$ for Band 1 and 5.437×10^{-17} W $Hz^{-1/2}$ for Band 2.

To test the sensitivity of the instrument to the intrinsic performance of the detectors, the limiting detectable flux densities and fluxes in each band have been calculated for detector NEP's of 1,3 and 5×10^{-17} for a spectral resolution of 400 - the same as used for the grating. In fact this will be the maximum resolution for the FTS as it has a variable resolving power. Table 3 gives the limiting fluxes and flux densities for each case.

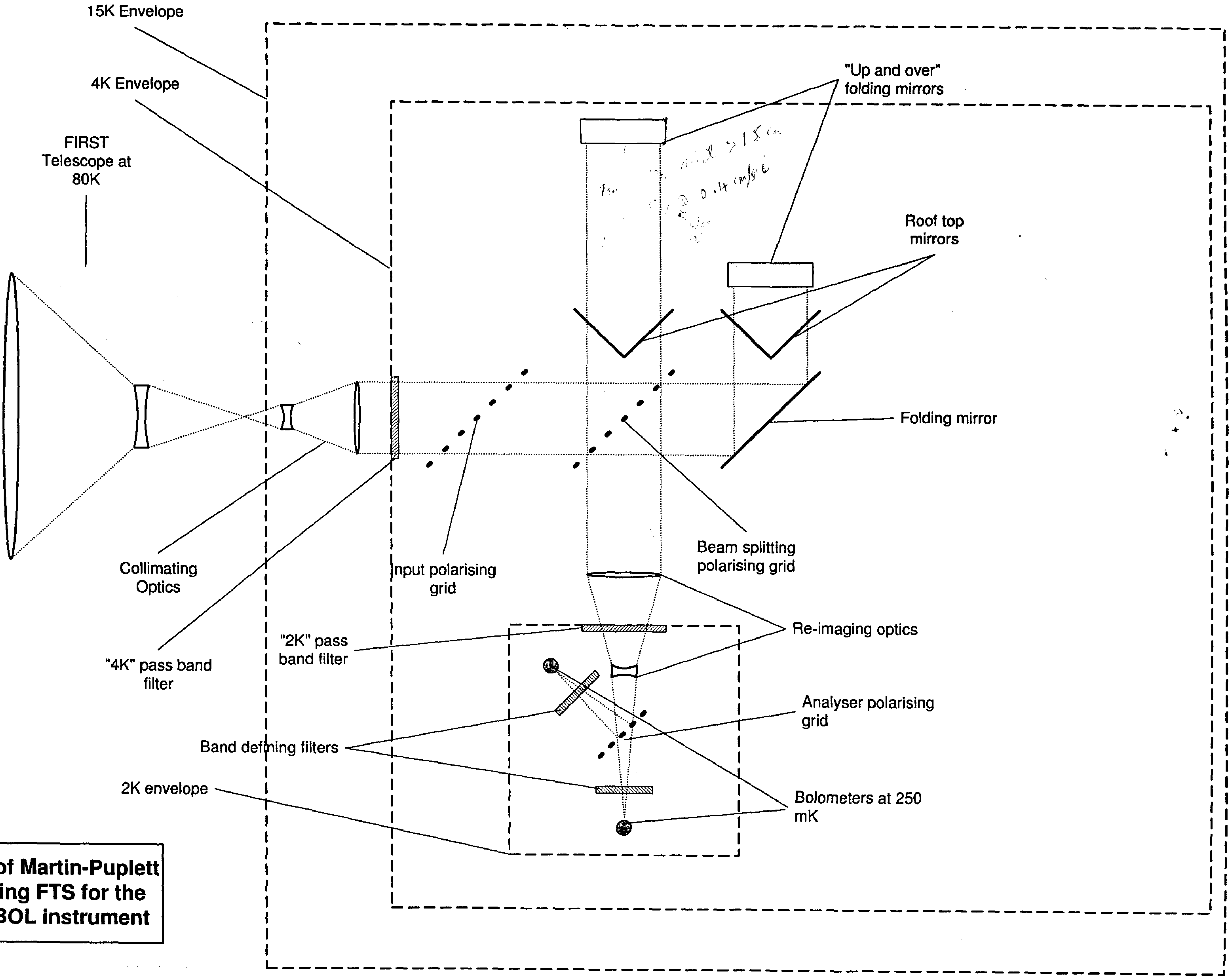
Detector NEP (10^{-17} W $Hz^{-1/2}$)	Band 1 (λ=225) Limiting Flux density (Jy)	Band 2 (λ=320) Limiting Flux density(Jy)	Band 1 (λ=225) Limiting Flux (10^{-18} W m^{-2})	Band 2 (λ=320) Limiting Flux (10^{-18} W m^{-2})
1	0.067	0.089	2.234	2.093
3	0.074	0.1	2.478	2.351
5	0.087	0.119	2.904	2.797

Table 3: Limiting flux densities and fluxes (1σ in 1 hour) for each detector channel for a range of detector performance.

Discussion:
The limiting flux density and flux for the grating spectrometer given by Matt in the meeting of 25-27 June 1997 (BOL/RAL/M/0018.1) are, for the full spectral survey 0.08 Jy and 2×10^{-18} W m^{-2}, and, for the measurement of a known line 0.046 Jy and 1.2×10^{-18} W m^{-2}. These are for a detector NEP of 1×10^{-17} W $Hz^{-1/2}$ and at 275 μm (?). However, the background power is only 14×10^{-15} W; this means that the instrument is detector noise limited and any degradation in detector performance will be linearly reflected in the final limiting flux. Also even the smallest amount of unexpected emission from the instrument would lead to a loss in performance.

The MP-FTS on the other hand is relatively immune to both these affects. Table 3 shows that the detector performance can degrade from 1 to 5×10^{-17} W $Hz^{-1/2}$ and the final performance will only degrade by ~30%. The initial specification can therefore be relaxed - making the detectors easier to make - and the instrument will be very much less sensitive to changes in detector performance. The large amount of power constantly falling on the detectors from the main telescope means that the instrument will also be relatively insensitive to unexpected stray radiation from within the instrument envelope.

The MP-FTS has other desirable characteristics such as the possibility of a limited degree of imaging and a variable resolving power that, taken with the performance figures given here, make it a serious alternative to the grating spectrometer at the cost perhaps of some mechanical complexity. The one drawback to the MP-FTS is that it will be rather less sensitive to the detection and measurement of lines at known wavelengths. This is not the prime science goal for FIRST-BOL but should be borne in mind when choosing between the two instruments.



Outline of Martin-Puplett polarising FTS for the FIRST BOL instrument