SPIRE Instrument - Filters Subsystem Development Plan

Draft 1.0

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1. Scope of the document

This document describes the development plan for the FIRST/SPIRE instrument optical filters.
The development plan is based on the applicable documents cited in paragraph #2.

2. Documents

2.1. Applicable documents

	Title	Author	Reference	Date
AD1	SPIRE Filters subsystem specification	P.Hargrave	TBD	
AD2	SPIRE FPU PDR viewgraphs	P.Ade, C.Tucker, M.Griffin, P.Hargrave	TBD	7-9 July 1999

2.2. Reference documents

	Title	Author	Reference	Date
RD1	Instrument Requirements Document	B.M.Swinyard	SPIRE-RAL-PRJ-000034 Iss .21	30 Nov 1999
RD2	SPIRE Instrument Development plan	K.King		

2.3. Glossary

AD	Applicable Document	JPL	Jet Propulsion Laboratory
CDR	Critical Design Review		
CoG	Centre of Gravity	LPE	Low Pass Edge
CQM	Cryogenic Qualification Model	MCA	Minimum Clear Aperture
DDR	Detailed Design Review	MGSE	Mechanical Ground Support Equipment
DM	Development Model	MSSL	Mullard Space Science Laboratory
DRCU	Digital Read-out and Control Unit	NA	Not Applicable
EGSE	Electrical Ground Support Equipment	o/d	Outside diameter
FIRST	Far InfraRed Space Telescope	OGSE	Optical Ground Support Equipment
FPU	Focal Plane Unit	PFM	ProtoFlight Model
FS	Flight Spare model	RAL	Rutherford Appleton Laboratory
FTS	Fourier Transform Spectrometer	RD	Reference Document
GSFC	Goddard Space and Flight Center	SPIRE	Spectral and Photometric Imaging REceiver
HPE	High Pass Edge	TBC	To Be Confirmed
i/d	Inside diameter	TBD	To Be Defined
		WE	Warm Electronics

3. Description of the filter subsystem

A full description of the filter subsystem is contained in document [AD1]. Figures 1 and 2, and tables 1 and 2 give a summary of the SPIRE filtering scheme.

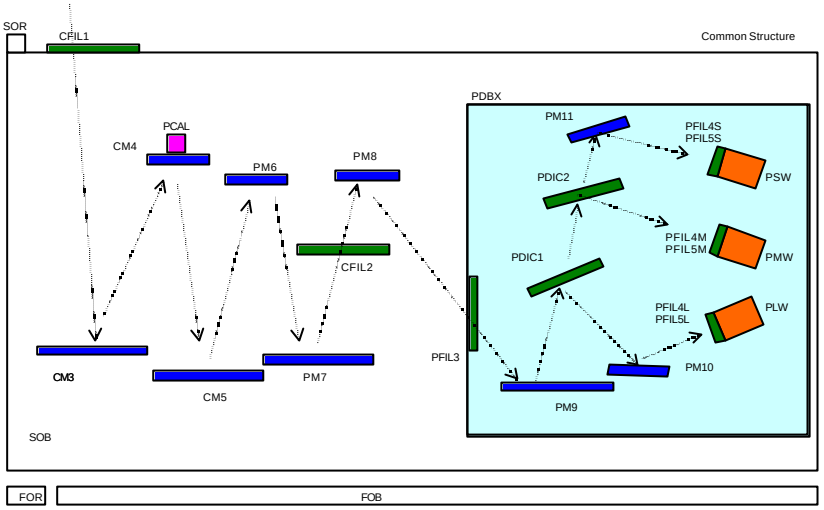

Figure 1 Photometer optics and filter locations

Table 1 List of photometer filters and dichroics

Specifications of photometer filters and dichroics						
Component ID	**Temp (K)**	**Location**	**Type**	**Edges (cm^{-1})**	**Minimum clear aperture (mm)**	**Comments**
CFIL1	4	Over entrance to 4-K box	Edge filter	10% 105 50% 100 90% 95	70 x 150 (Beam footprint on CIPM is 54 x 132)	Exact position TBD
CFIL2	4	Above CIPM (M3)	Edge filter	10% 84 50% 80 90% 76	70 x 150	Exact position TBD
PFIL3	2	Pupil between POFR2 and POFR3	Edge filter	10% 74 50% 70 90% 66	45 dia. (Pupil is 41 x 44 inc. 20% oversize)	
PDIC1	2	After POFR3	Low Pass Dichroic	10% 40 50% 37 90% 34	90 dia. TBC	Transmits long λ
PDIC2	2	After PDIC1	Low Pass Dichroic	10% 27 50% 25 90% 23	90 dia. TBC	Transmits long λ
PFIL4S	0.3	At SW array	Low pass edge High pass edge	53 38	40 dia. (Field is 19 x 38)	
PFIL4M	0.3	At MW array	Low pass edge High pass edge	36 25.7	40 dia.	
PFIL4L	0.3	At LW array	Low pass edge High pass edge	24 17 (if necessary)	40 dia.	
PFIL5S	0.3	At SW array	Edge filter	10% 70 50% 66 90% 62	40 dia.	
PFIL5M	0.3	At MW array	Edge filter	10% 46 50% 43 90% 40	40 dia.	
PFIL5L	0.3	At LW array	Edge filter	10% 27 50% 26 90% 25	40 dia.	

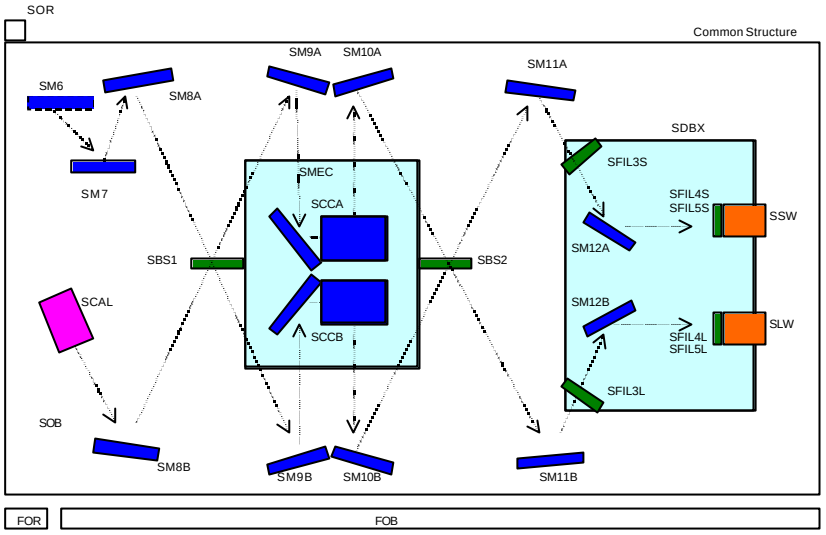

Figure 2 Spectrometer optics and filtering scheme

Table 2 List of spectrometer filters and beam dividers

Specifications of FTS filters and beam dividers						
Component ID	**Temp (K)**	**Location**	**Type**	**Edges (cm^{-1})**	**Clear aperture (mm)**	**Comments**
CFIL1	4	On entrance to 4-K box	Edge filter	10% 105 50% 100 90% 95	70 x 150 (Beam footprint on CIPM is 54 x 132)	Shared with photometer
CFIL2	4	Above M3	Edge filter	10% 84 50% 80 90% 76	70 x 150	Shared with photometer
SBS1	4	After SIRM	Beam divider	15 to 60 >90% 4RT	36 dia.	
SBS2	4	After SDCM-A or -B	Beam divider	15 to 60 >90% 4RT	36 dia	
SFIL3S SFIL3L	2	After SCAM-A or SCAM-B	Edge filter	10% 74 50% 70 90% 66	40 dia.	
SFIL4S	0.3	At SW array	Low pass edge High pass edge	50 33	15	
SFIL4L	0.3	At LW array	Low pass edge High pass edge	33 None?	15	
SFIL5S	0.3	At SW array	Edge	10% 70 50% 66 90% 62	15	
SFIL5L	0.3	At LW array	Edge	10% 46 50% 43 90% 40	15	

4. Constraints

4.1. Development constraints

4.1.1. Technical constraints

The main performance specifications are shown in table 3. Please note that these figures are for information only. Full details are contained in document [AD1].

Table 3 Performance requirements for the filter subsystem

IRD-PHOT-R01	Nominal pass band 250 mm, 350 mm and 500 mm (TBC) $\lambda/\Delta\lambda = 3$
IRD-SPEC-R01	Wavelength range Band A = 200-300mm, 33-50cm^{-1} (TBC) Band B = 300-670mm, 15-33cm^{-1} (TBC)
IRD-OPTP-05	Overall optical efficiency: Greater than 0.27
IRD-OPTP-R07	Out of band radiation: Requirement TBD until telescope optical properties defined

The main technical constraints are:

- SPIRE lifetime in orbit = 4.25 years
- Operating temperature = 0.3 K - 4 K
- Total mass of all filters = TBD kg including 20% margin
- Filter CoG position = TBD – list of all filters
- Filter Volume = TBD mm3 - list
- Level of radiation = TBD
- Vibration level = TBD at 4K
- Shock level = TBD at 4K
- Cleanliness = TBD

4.2. Responibilities

The filters will be: -

- Designed by QMW.
- Manufactured by QMW
- Qualified/accepted and calibrated under QMW responsibility, mainly at QMW, with RAL assisting with cryovibration tests. The qualification/acceptance program includes thermal cycling and warm and cold vibrations. The calibration program verifies the performance requirements.
- Transported to RAL under QMW responsibility.
- Integrated at RAL in the SPIRE FPU Structure under TBD (QMW/RAL/MSSL) responsibility.
- The SPIRE WE and the SPIRE FPU are integrated under RAL responsibility and undergo the project calibration program under RAL responsibility.
- SPIRE is delivered to ESA under RAL responsibility.
- SPIRE is integrated in the FIRST satellite under ESA responsibility.
- SPIRE CQM is to undergo the ESA cryoqualification program under ESA responsibility.
- SPIRE PFM is to undergo the ESA Acceptance program.
- SPIRE FS is prepared in the event of SPIRE PFM failure.

4.3. Organisation

QMW is responsible for the filter subsystem. This involves the design, manufacture and testing of all filters, dichroics and beam dividers for each instrument model.
RAL will assist with cryo-vibration tests.
MSSL is responsible for the structure to which the filters are integrated.
JPL are responsible for the structure to which the 300mK filters are integrated as part of the detector array modules.

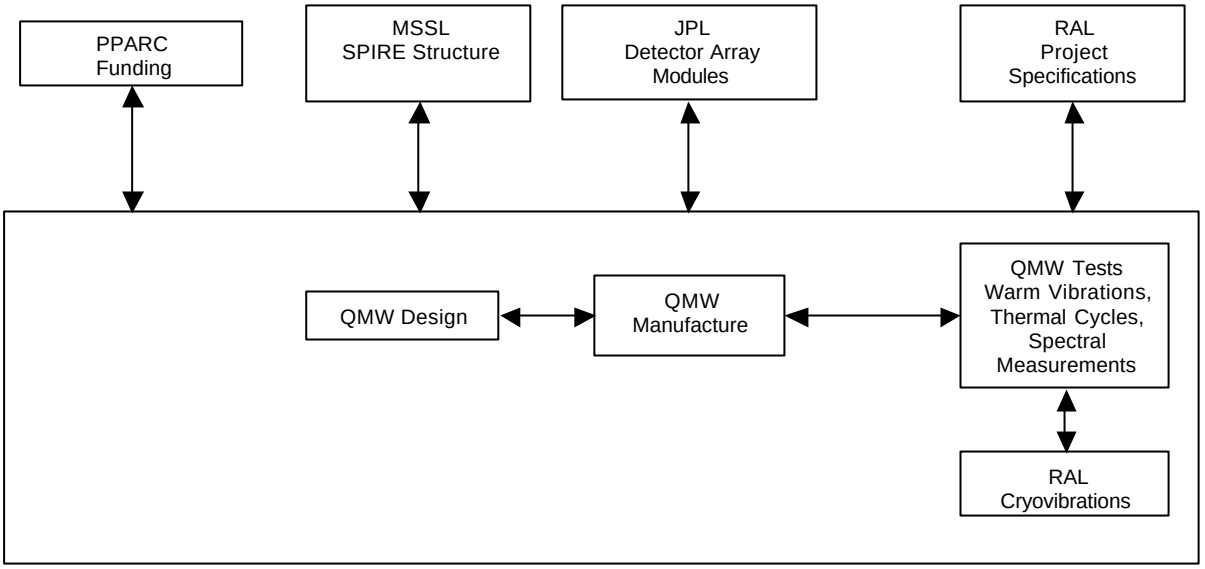

Figure 3 Organisation of the filter subsystem

4.3.1. QMW organisation– to be completed

4.4. Calendar constraints

The main SPIRE project milestones are [RD2]:

PDR	10 April 2000
DDR	
CQM filters delivery to RAL	15 Aug 2002
CDR	
SPIRE CQM delivery to ESA	
PFM filters delivery to RAL	15 Apr 2004
SPIRE PFM delivery to ESA	
FS filters delivery to RAL	15 Apr 2005
SPIRE FS delivery to ESA	
FIRST launch	2007

5. Risk analysis

There is minimal risk associated with the production of the edge and ND filters. These are standard filter types that are routinely produced by QMW for ground, airborne and space experiments. Any risks tabulated below are extremely small.

Risk	Impact	Preventive action	Note
Beam splitter qualification failure	Re-design of spectrometer	None	Prototype beam splitters have been built, and perform well on the SPIRE FTS optical test bed at QMW. However, these have not yet been subjected to any qualification tests.
Dichroic qualification failure	Re-design photometer optics	None	
CFIL-1 & 2 qualification failure	Need to re-locate filters to intercept a smaller beam cross-section. May affect instrument thermal balance and stray light environment	None	These filters have a higher than usual development risk associated with them, as they are larger than any manufactured by QMW in the past. New lithographic masters need to be ordered. See also section 7.2.1.

See also section 7.2.

6. Redundancy

There is no provision for filter component redundancy on SPIRE. Loss of edge or ND filters would change the background power on the detector arrays, as well as changing the power loading on the various temperature stages.
The items that would constitute a single point failure are: -

1. Dichroics – loss of a dichroic would compromise at least one photometer array, depending on the failure mode
2. Beam splitters – loss of a beam splitter would cause the loss of the FTS

7. Work description

7.1. Development and model philosophy

The model philosophy is compliant with the SPIRE project requirements and meets the QMW development needs.

7.2. Preliminary Design

The preliminary design will be presented at the Delta Preliminary Design Review, 26/27 June 2000. The PDR freezes the technical specifications and the interfaces.

7.3. Detailed design and CQM manufacture

The detailed design will encompass all the functions and interfaces of the filter subsystem.
The detailed design will be presented at the Detailed Design Review (mid October 2000). The DDR must have taken place before CQM manufacture can begin.

The design verification tests include:-

- Verification of the basic mechanical parameters (Mass, stiffness, resonant frequencies).
- Performance verification.Qualification tests .

After the delivery of the CQM filters, the SPIRE CQM is tested at project level.

The results of the qualification tests are to be presented at the SPIRE CDR which is the start point of the PFM and FS manufacture.
Then, the SPIRE CQM is delivered to ESA for cryogenic tests of the FIRST FPU.

7.4. Flight design modifications and PFM/FS manufacture

Following the SPIRE CQM tests, some modifications may have to be implemented in the design.
The design changes are to be implemented in the flight design and be validated using development models.
The PFM filters are then manufactured and undergo the acceptance tests and performance verification.
The FS filters are duplicates of the PFM filters and may be manufactured at the same time as the PFM. The FS filters undergo the acceptance tests and performance verification after the PFM.
It may be possible to use the CQM filters as the FS filters. This is TBC as it depends on ESA that the back delivery of the CQM arrives on time. For the moment, it is planned to manufacture a full new FS filter set.

7.5. Filter Development

The final design of the instrument structure and optics has a significant impact on the design of some filter components. Some ring-mounted components may need to be manufactured to non-standard sizes, so before QMW re-tools and prototyping of these components can begin, the instrument structure and optics design needs to be finalised. This section lists each filter component to be produced by QMW, and gives details of any factors affecting its design and manufacture.

7.5.1. CFIL1 and CFIL2 – Hot pressed LPE filters

The original location for CFIL-1 was over the entrance to the 11-K box, with CFIL-2 covering the aperture to the 4-K box. The 11-K box is no longer being implemented on SPIRE, so it is proposed to mount CFIL-1 and CFIL-2 together, intercepting the input beam at 4-K. The size of beam to be intercepted is dependent upon the position within the 4-K box. The smallest MCA will result from placing the filters at a beam waist, in this case the telescope focal plane. The implications of placing filter components here need to be investigated, and will be discussed at a splinter meeting around the time of the PDR, along with other options for modifying the structure.
QMW is waiting for the SPIRE structural model (CAD file) with the integrated optical beams from RAL, which will enable us to determine the filter sizes needed. This obviously depends upon the final position of these filters in the optical train.
These filters present a small schedule risk, as it is almost certain that the MCA needed will be greater than 110mm diameter, which is the largest set of lithographic masters that QMW have. To produce these large filters (possibly up to 150mm diameter), QMW will have to procure new masters. It is not anticipated that manufacture of these components will present a problem, as we have press tools which can handle up to 170mm diameter, although these components will need to be thoroughly prototyped and checked for de-lamination after thermal cycling.

7.5.2. PFIL3 - Hot pressed LPE filter

This item will be directly mounted to the structure with a clamping ring, and will not present a development problem/risk.

7.5.3. PDIC1 – Low pass dichroic

PDIC1 will be a hot pressed, dielectric gap component (TBC). However, this has to be flat (spec. TBD), and therefore ring mounted. Space restrictions in the instrument dictate that a ring of 80mm i/d, and 95mm o/d is needed, with a maximum thickness of 11mm. This is not one of the QMW standard ring sizes, and so QMW will need to re-tool to produce rings of this size. Before this can happen, QMW need final confirmation of the ring size. There is therefore a slight schedule risk relating to the re-tooling process.

7.5.4. PDIC2 - Low pass dichroic

PDIC2 will also be a hot pressed, dielectric gap component (TBC). As the present SPIRE structure is drawn, a ring of 72mm i/d, and 85mm o/d is needed. Again, this is a non-standard ring size. However, it may be possible to accommodate a ring of 75mm i/d, 90mm o/d, as this is a standard size. This will greatly help reduce delay and cost. We are working with MSSL to resolve this issue.

7.5.5. PFIL4-S,M,L – LPE/HPE hot pressed filters

These were baselined as combinations of two hot pressed filters to define the pass bands. However, the selection of the feedhorn option now means that the feedhorn waveguide may serve as a sufficient HPE filter. This will be discussed with JPL in early May.
These items will be directly mounted to the array modules, and will not present a development problem/risk.

7.5.6. PFIL5-S,M,L – LPE hot pressed filters

These items will be directly mounted to the array modules, and will not present a development problem/risk.

7.5.7. SBDI2,1 – Spectrometer beam dividers

As drawn, these components have to be 38mm i/d and 46mm o/d. These are non-standard sizes, and re-tooling will be necessary. QMW needs final confirmation of sizes before re-tooling and prototyping.
Prototype beam dividers are running on the SPIRE prototype FTS in the QMW lab, and perform very well. However, they have not yet undergone qualification tests. Additionally, these components need to be checked for microphonic effects.
These components present a small development risk.

7.5.8. SFIL3-A,B – Hot pressed LPE filters

These filters present no development problem/risk. However, as drawn in the SPIRE CAD model, there is provision for a mounting lip of only 1.5mm to the structure. This is not sufficient and has to be resolved. QMW is working with MSSL on this issue.

7.5.9. SFIL4-S,L - LPE/HPE hot pressed filters

These were baselined as combinations of two hot pressed filters to define the pass bands. However, the selection of the feedhorn option now means that the feedhorn waveguide may serve as a sufficient HPE filter. This will be discussed with JPL in early May.
These items will be directly mounted to the array modules, and will not present a development problem/risk.

7.5.10. SFIL5-S,L – Hot pressed LPE filters

These items will be directly mounted to the array modules, and will not present a development problem/risk.

7.6. Verification plan

The verification plan must be compliant with the project verification plan [AD2, RD1] and must fulfil the filter development needs.

In the tables below,

X =	a real test is conducted
A =	an analysis is conducted
NA =	Non applicable

300K vibrations are conducted at QMW.
Cryovibrations are conducted at RAL.
Vacuum cycles, soak cycles, thermal cycles are conducted at QMW.
Microphonics tests are conducted at TBD.
Performance tests are conducted at QMW.

7.6.1. Prototype filters

		Components
Mass measurement	X	All
CoG measurement		
Vibrations 300K	X	All
Vibrations 4K	X	All
Thermal/Vacuum cycle	X	All
Radiation tolerance	A(**)	All
Microphonics	X	SBDI1, SBDI2
Spectral measurements	X	All

(**) : The radiation tolerance is verified by analysis only, taking into account the materials involved and experience of previous space missions

7.6.2. CQM filters

		Components
Mass measurement	X	All
CoG measurement	X	All
Vibrations 300K	X	All
Vibrations 4K	X	All
Thermal/Vacuum cycle	X	All
Radiation tolerance	A(**)	All
Microphonics	X	SBDI1, SBDI2
Spectral measurements	X	All

(**) : The radiation tolerance is verified by analysis only, taking into account the materials involved and experience of previous space missions

7.6.3. PFM filters

		Components
Mass measurement	X	All
CoG measurement	X	All
Vibrations 300K	X	All
Vibrations 4K	X	All
Thermal/Vacuum cycle	X	All
Radiation tolerance	A(**)	All
Microphonics	X	SBDI1, SBDI2
Spectral measurements	X	All

(**) : The radiation tolerance is verified by analysis only, taking into account the materials involved and experience of previous space missions

7.6.4. FS filters

		Components
Mass measurement	X	All
CoG measurement	X	All
Vibrations 300K	X	All
Vibrations 4K	X	All
Thermal/Vacuum cycle	X	All
Radiation tolerance	A(**)	All
Microphonics	X	SBDI1, SBDI2
Spectral measurements	X	All

(**) : The radiation tolerance is verified by analysis only, taking into account the materials involved and experience of previous space missions

8. Ground support equipment

8.1.1. Simulators

No simulators required.

8.1.2. Tools

No special tools required.

9. Development calendar

Detailed design available	Dec 2000
CQM Prototyping	Dec 2000 – Apr 2001
CQM Manufacture	Apr 2001 – Sept 2001
CQM Modif, qualification & calibration	Aug 2001-Jan 2002
CQM delivery to RAL	28th Jan 2002
PFM Manufacture	July 2002 –Dec 2002
PFM Acceptance & calibration	Oct 2002 – Mar 2003
PFM delivery to RAL	25th March 2003
FS manufacture	June 2003 – Dec 2003
FS Acceptance & calibration	Sept 2003 – Feb 2004
FS delivery to RAL	25th Feb 2004

Detailed planning in file SPIRE_filt.mpp

10. Description of deliverables

10.1. Filters

The filter sets are delivered to RAL.

Model	Flight representativity	Difference with flight	Deliverables
CQM	100% (TBC)	None (TBC)	1 set
PFM	100%	None	1 set
FS	100%	None	1 set

10.2. Associated equipment

No special equipment is required for integration and alignment.

10.3. Associated documentation

The documentation is TBD.
Test reports.
QA/PA reports.