PRECISION RADIAL VELOCITY SPECTROMETER

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CHANGE RECORD

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0.1	19 July2006	All	First draft
0.2	1 Aug 2006	CCD	Details added about CCD camera system
0.3	4 Sept 2006		Revision by DM
1.0	16 Sept 2006		Final Review before issue to Gemini by DWL

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LIST OF ABBREVIATIONS

FDAS	Fibre Deployment and Acquisition Sub-system
FPRD	Functional and Performance Requirements Document
FOV	Field of view
FV	Fibre viewer
GCAL	Gemini facility calibration unit

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1. INTRODUCTION

This document describes the design of the Fibre Deployment and Acquisition Sub-system (FDAS) of the PRVS Precision Radial Velocity Spectrometer for the Gemini telescope.

2. APPLICABLE AND REFERENCE DOCUMENTS

Reference	Document Title	Document Number	Issue / Date
AD01	Science Requirements	PRVS-SPEC-00005-0001	1.0
AD02	Initial Functional Performance & Requirements Document	PRVS-SPEC-00003-0001	1.0

3. ITEM DEFINITION

The FDAS consists of the following sub-assemblies (SA):

- Pick off mirror SA, comprising the pick off mirror, mount and mechanism
- F-converter and beamsplitter SA, comprising the f-converter lens, beamsplitter and mount
- Fibre injection SA, comprising the object fibre holder
- Acquisition and guiding camera SA, comprising CCD camera
- Calibration fibre SA, comprising the calibration fibre holder, calibration fibre lenses and mount
- Mounting plate SA, comprising the mounting plate

3.1 KEY FUNCTIONAL REQUIREMENTS

The Fibre Deployment and Acquisition Sub-system is mounted on the ISS on the same face as GCAL. It picks off light from the telescope, converts the f-ratio to suit the fibre feed and injects this light into the object fibre. An acquisition and guiding camera performs target acquisition and slow guiding (~1Hz). Light from a calibration fibre can be injected into the object fibre on demand.

3.2 KEY PERFORMANCE REQUIREMENTS

Parameter	Requirement	Comment
Fibre FOV	>1.25 arcsec diameter	
CCD FOV	> 30 x 30 arcsec	
CCD format	> 512 x 512 pixels	
Image quality – 50% encircled energy diameter	< 0.18 arcsec	Fibre feed FOV, 1.25 arcsec
	< 0.18 arcsec	CCD, central 5 arcsec diameter FOV
	<0.5 arcsec	CCD, within 30 x 30 arcsec FOV

3.3 INTERFACE REQUIREMENTS

The Spectrometer SS has interfaces to the following sub-systems:

- Gemini telescope. There is an **optical** interface to the Gemini telescope. This is defined by the properties of the telescope beam. There is a **mechanical** interface to the Gemini telescope. This is defined by the mounting interface on the Instrument Support Structure.
- Fore-optics Fibre Sub-System. There is an **optical** interface to the Fore-optic Fibre SS. This is defined by diameter and f-ratio of the object fibre. There is a **mechanical** interface to the Fore-optic Fibre SS. This is defined by the mounting arrangement of the object fibre.
- Calibration Sub-system. There is an **optical** interface to the Calibration SS. This is defined by diameter and f-ratio of the object fibre. There is a **mechanical** interface to the Calibration SS. This is defined by the mounting arrangement of the object fibre.

4. DESIGN DESCRIPTION

Figure 1 shows the conceptual design of the Fibre Deployment and Acquisition Subsystem.

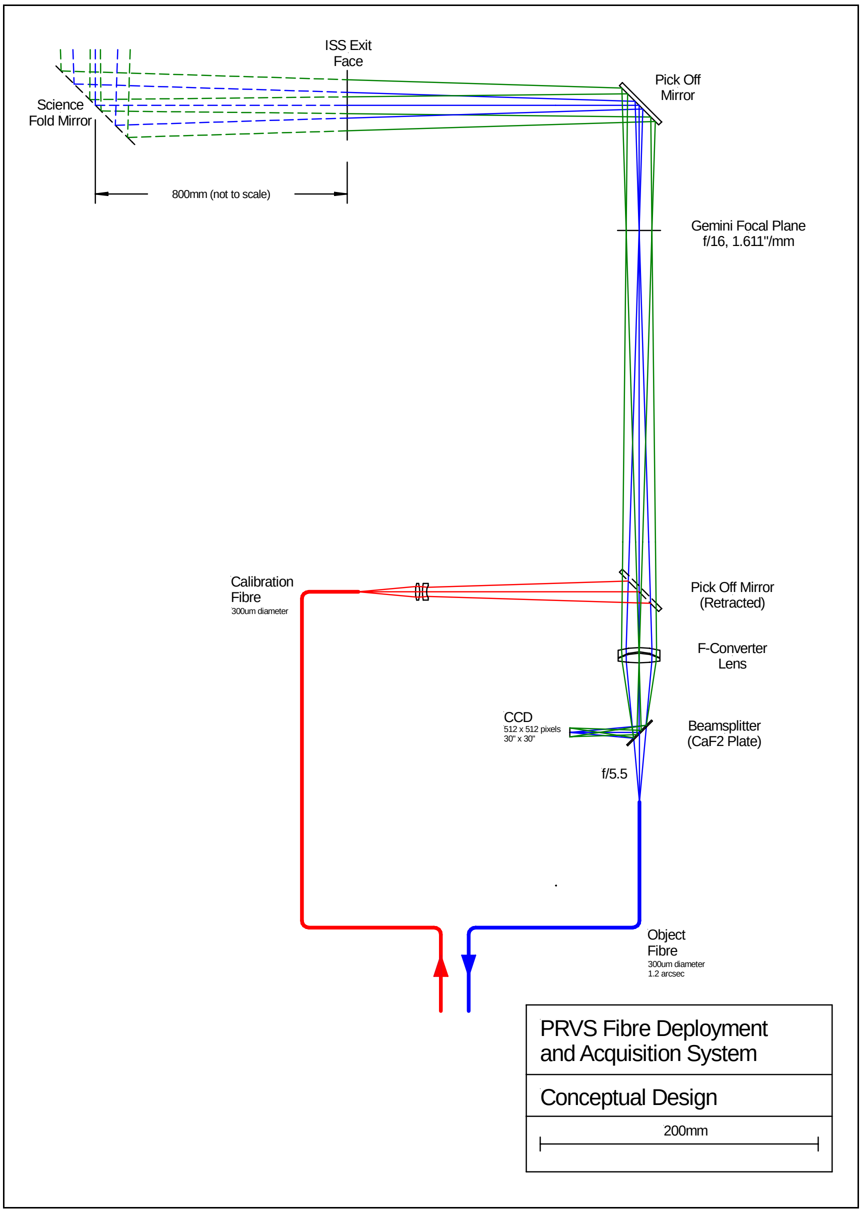


Figure 1 - Fibre Deployment and Acquisition System Concept

The science fold mirror sends the beam to GCAL where a two-position (in/out) small pickoff mirror sends the on-axis f/16 beam to a focal reducing achromatic doublet lens. This lens re-images the telescope focal at f/5.5 onto the object fiber. A focal ratio of f/5.5 is chosen to match the focal ratio of the fibre to minimize focal ratio degradation. The fibre is 300 μm in diameter and only uses 1.25″ of the re-imaged field. For median seeing of about 0.6″ at J the light loss (spill-over from the object fibre) is about 5%.

A CaF_2 substrate located behind the lens reflects about 2% of this beam through a fixed I-band (0.77-0.89μm) filter and onto a CCD camera. The bare substrate reflects enough signal for acquisition and guiding on our faintest RV targets (50σ1sec=15.5 at I) while at the same time minimizing the light loss in the main spectrometer path. The brightest stars in the RV survey are

M3 dwarfs (I=9.0). On-chip integration times of about 0.1 s are short enough to guide on these stars without saturating.

The offset between the guiding (I) and observing wavelengths (YJH) due to atmospheric dispersion (about 0.3″ between I and J at an airmass of 1.5) is corrected for in software. The lens, substrate, fiber, and CCD are all rigidly mounted and so there is no significant relative flexure (< one CCD pixel/hour). Any flexure in the pickoff mirror acts like a simple guiding error.

When the pickoff mirror is in the retracted position, it projects light from the calibration fibre into the object fibre. This is done before and after observing the science object.

4.1 OPTICAL DESIGN

The FDAS has three optical channels; the object fibre feed, the CCD camera and the calibration fibre feed. Each is described separately below.

4.1.1 Object Fibre Feed Channel

Figure 2 shows the optical layout of the object fibre feed channel. The pickoff mirror picks off the centre of the field of view and turns the beam out at 90° to the telescope axis. The f-converter lens converts the beam from f/16 to f/5.5 to feed the fibre. The image scale at the fibre feed is **4.686 arcsec/mm**, so a field of view on the sky of 1.25 arcsec diameter corresponds to 266μm. Allowing for coupling efficiency, pointing error, etc, a 300 μm diameter fibre is chosen.

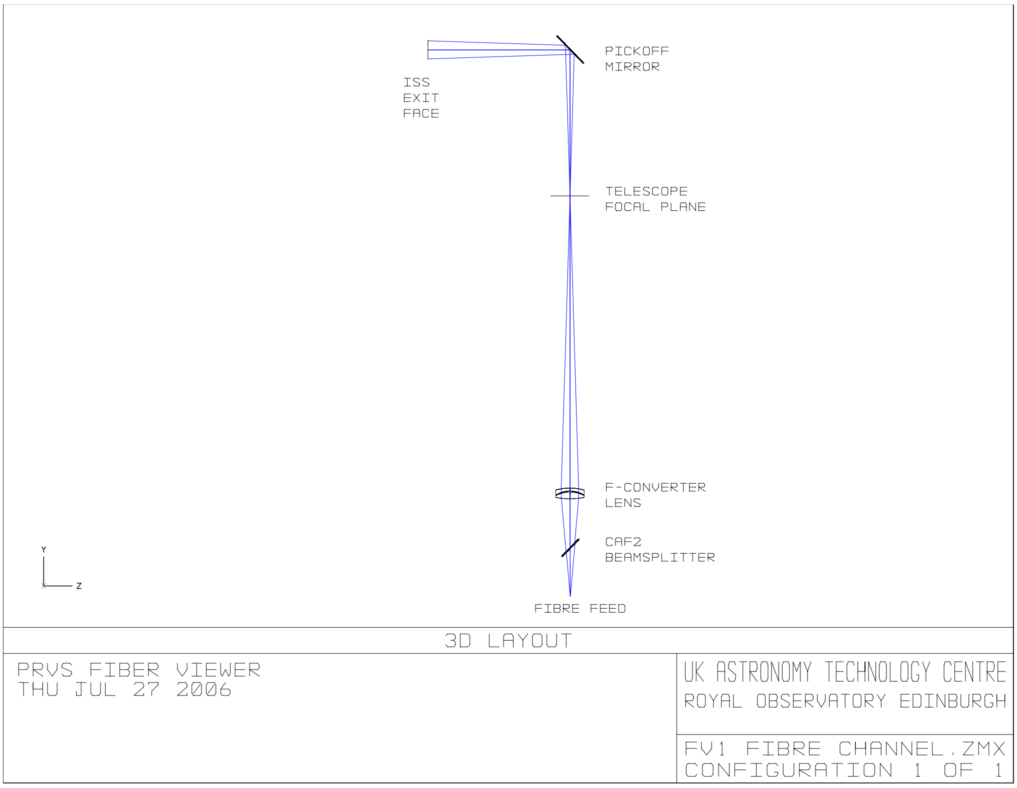


Figure 2 - Object Fibre Feed Channel - Optical Layout

The f-converter lens is a lithium fluoride/barium fluoride doublet, 30mm diameter. All lens surfaces are spherical. The beamsplitter is a calcium fluoride plate.

Figure 3 shows the spot diagram. The 50% encircled energy diameter is **24.68 μm**, which corresponds to **0.115 arcsec**, which exceeds the requirement of **0.18 arcsec**.

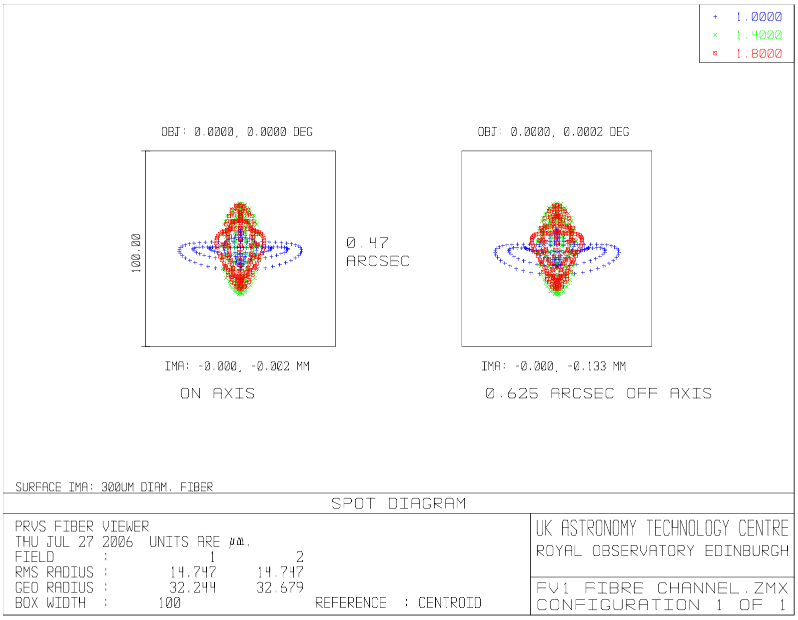


Figure 3 - Spot Diagram

4.1.2 CCD Channel

Figure 4 shows the optical layout of the CCD channel. The CCD channel follows the same optical path as the fibre feed channel as far as the beamsplitter. Here, the CCD beam is reflected off onto the CCD.

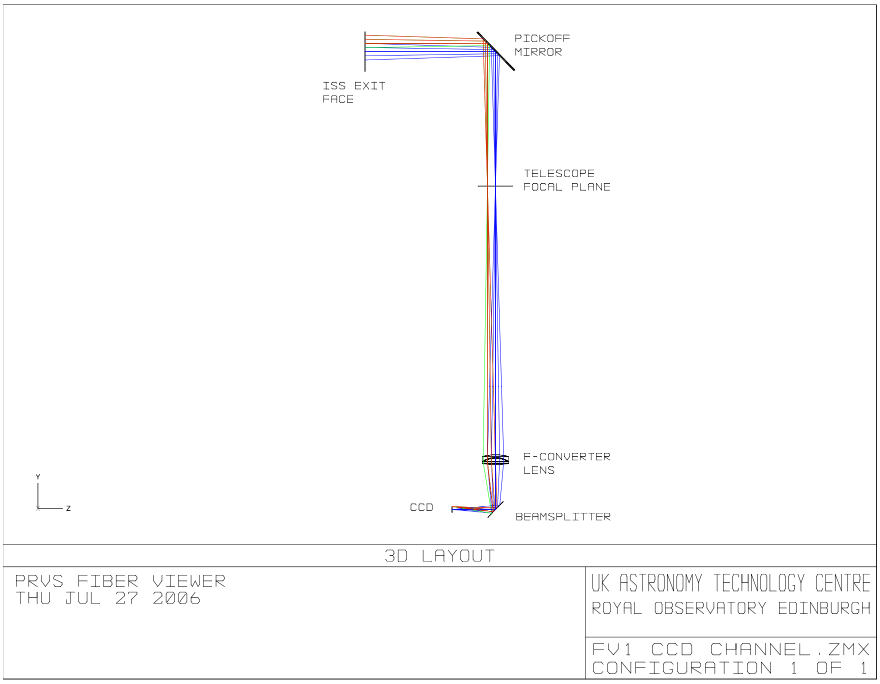
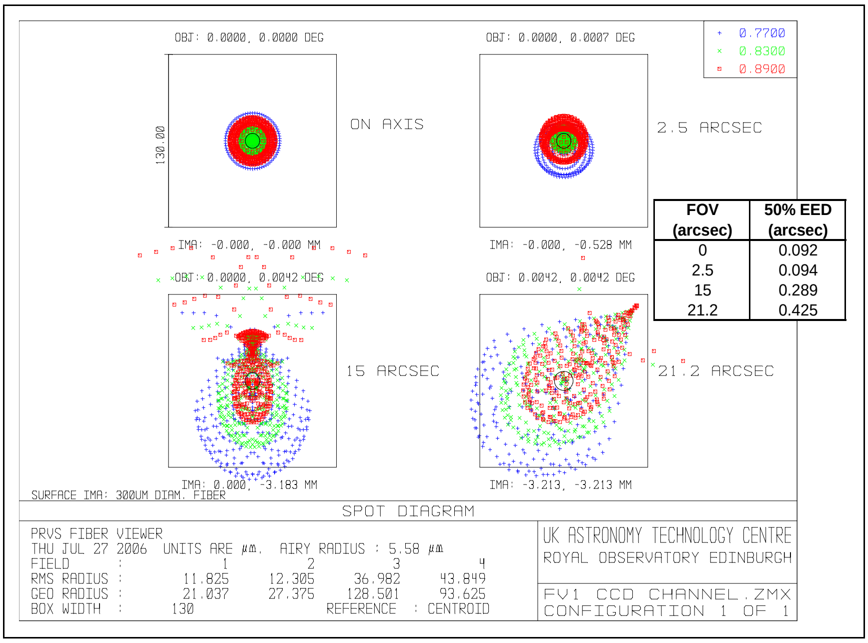


Figure 4 – CCD channel optical layout

The chosen CCD format is 1024 x 1024 pixels (13µm square pixels). The image scale of 4.686 arcsec/mm results in a pixel scale of **0.061 arcsec/pixel**. A field of 512 pixels therefore covers ~31 arcsec. The full field of 1024 pixels would cover 62 arcsec, however vignetting in the f-converter lenses limits the available field to **~48 arcsec diameter**.

Figure 5 shows the spot diagram for the CCD channel, along with the 50% EED values. The requirements of 50% EED < 0.18 arcsec (within a 5 arcsec FOV) and <0.5 arcsec within a 30 x 30 arcsec FOV are met.



FOV (arcsec)	50% EED (arcsec)
0	0.092
2.5	0.094
15	0.289
21.2	0.425

Figure 5 - Spot diagram

4.1.3 Calibration Fibre Feed Channel

Figure 6 shows the optical layout of the calibration fibre feed channel. Folds are omitted for clarity. The calibration fibre feed takes the f/5.5 beam from the calibration source fibre and converts this to an f/16 beam. This then reflects off the pickoff mirror when it is in the retracted position. The beam is then converted back to f/5.5 by the f-converter lens and is injected into the object source fibre.

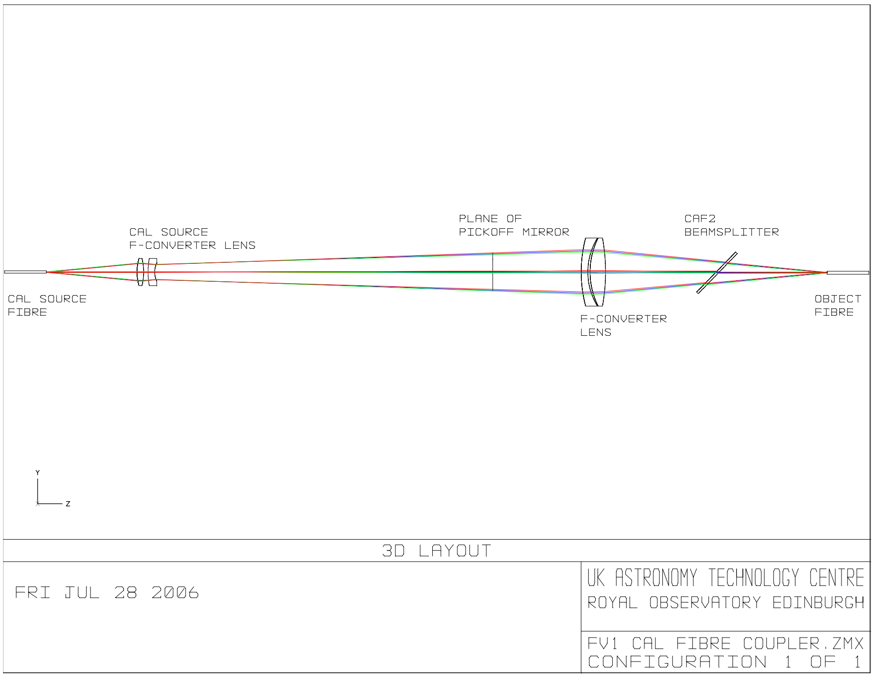


Figure 6 – Calibration fibre feed channel optical layout

Figure 7 shows the spot diagram for the calibration fibre channel.

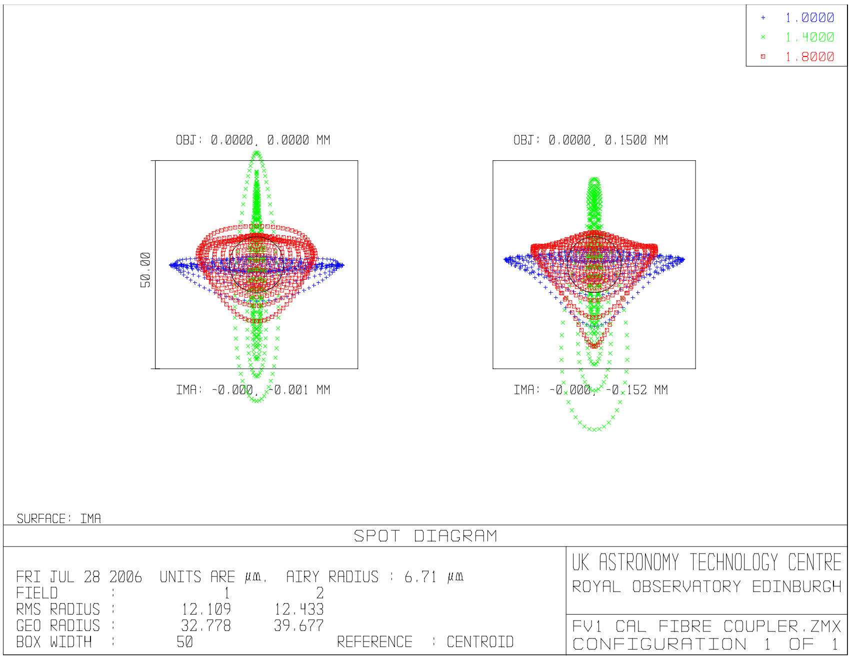


Figure 7 - Calibration fibre feed channel spot diagram

4.1.4 Optical Component Manufacturing

All of the optical components required in the FDAS are small (<50mm diameter) and easily manufactured. A number of manufacturers have the capability to make these lenses.

In the next phase of the design the use of off the shelf catalogue lenses will be investigated.

4.1.5 Opto-mechanical Alignment Philosophy

The critical alignment in the FDAS is the alignment between the object fibre and the CCD. This will be done using a simple telescope simulator which produces an f/16 beam. A pinhole and detector is placed at the object fibre interface, and the telescope simulator aligned until the beam is centred on the pinhole. The position of the spot on the CCD is then measured and this spot then becomes the “zero” point for alignment.

4.2 MECHANICAL DESIGN

4.2.1 Overview

Figure 8 shows the mechanical layout of the fibre deployment and acquisition system. Figure 9 shows the FDAS mounted on the Gemini ISS.

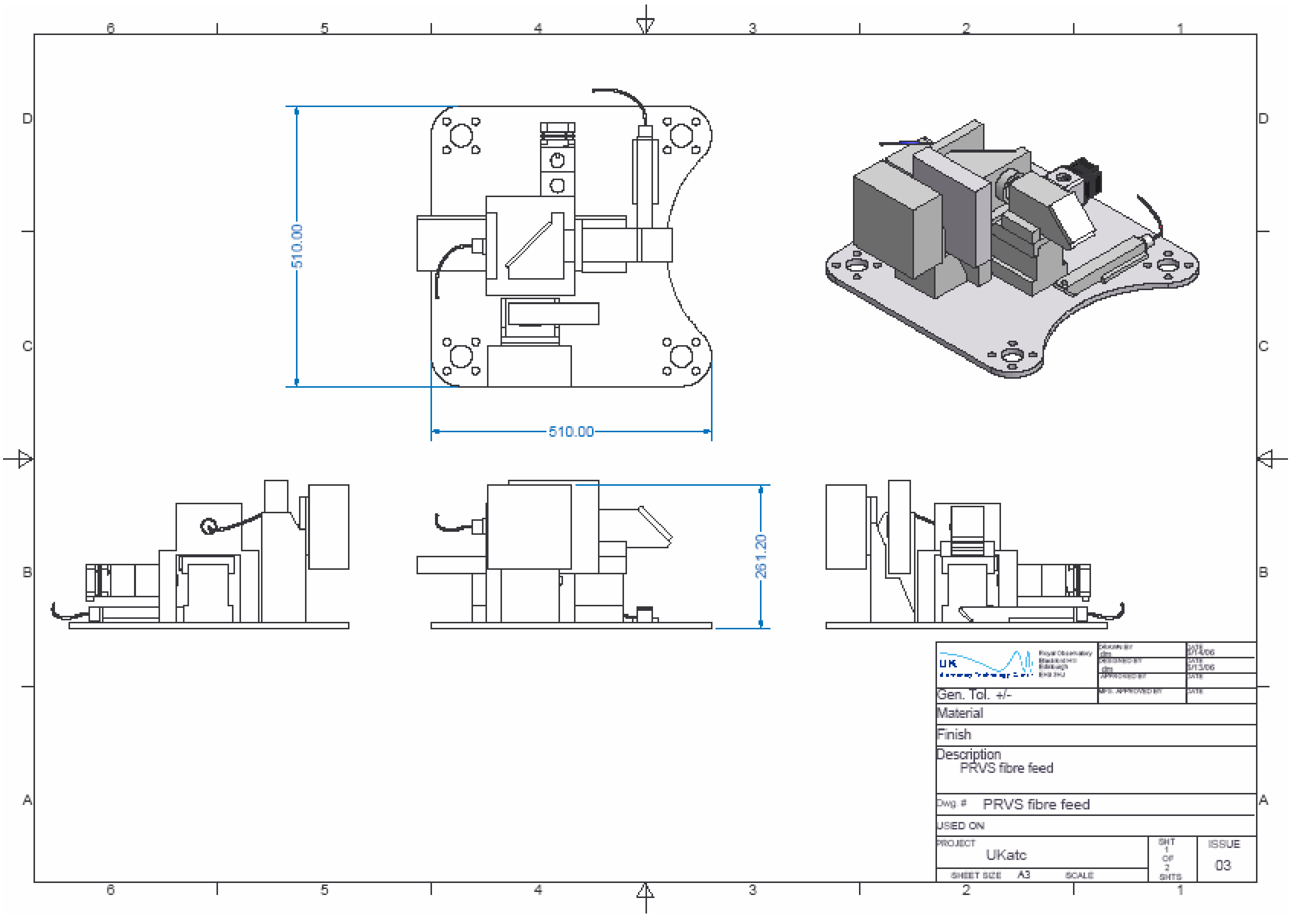


Figure 8 - Mechanical layout of Fibre Deployment and Acquisition System

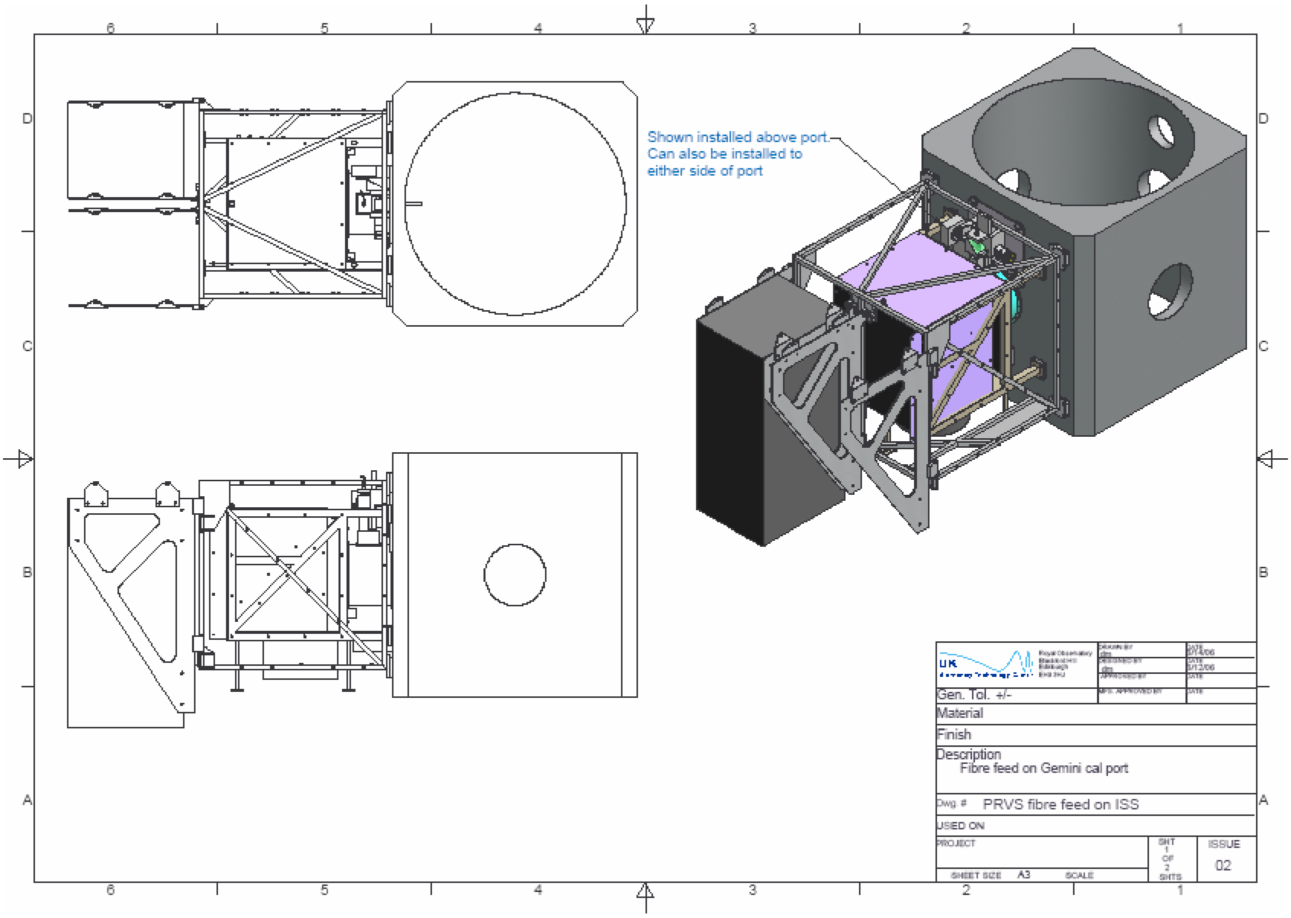


Figure 9 - FDAS mounted on Gemini ISS

The module is a self contained sub assembly which can be mounted on any port of the ISS. However, it is envisaged that it will be mounted on the same port as GCAL. It consists of a base-plate which interfaces to the instrument mounting pads of the ISS and supports the optical modules that comprise the unit. These include the deployable pick of mirror linear stage, guidance camera, f-converter/beam splitter and calibration source.

In order to deploy the mirror with GCAL in situ it will be necessary to replace the existing GCAL light baffle with another which has an aperture through which the pick off mirror can be deployed.

When the pick off mirror is in the retracted position, calibration light can be injected into the science beam optical train.

4.2.2 Base plate

This is a simple flat plate with a matching hole pattern to the location features and fasteners on the ISS. Two captive dowels will be used to ensure accuracy and repeatability of positioning. The top surface of the plate will have locating features and fasteners for the deployable pick of mirror linear stage, guidance camera, f-converter/beam splitter and calibration source. Handling features will also be provided in the form of handles for manual lifting.

4.2.3 Linear stage

The linear stage will be of the rod and V shaped roller variety. This can be set up to be internally pre-loaded and therefore free of backlash. The drive is by geared stepper motor and a rack and pinion. A passive brake will be used to stabilise the mechanism on power off and to control drive backlash. Positioning will be by step count from a datum defined by a micro-switch. Physical hard stops will be provided just beyond the normal range of travel. The stage is capable of placing the pick off at the centre of the field.

4.2.4 Pick off mirror

The pick off mirror is a simple flat mirror which will be clamped to 45 degree machine face of the pick off bracket. The bracket has a through hole for the passage of the beam and another at right angles for the calibration beam (used when the mirror is retracted).

4.2.5 Filter wheel

The filter mechanism is a commercially available unit from Oriel. It can hold up to 6 filters of 1 inch diameter.

4.2.6 Guidance camera

The guidance camera is mounted to the base plate by means of a bracket.

4.2.7 F-converter lens

This doublet will be mounted in a self contained bezel which mounts in turn on the bracket which holds the beam splitter.

4.2.8 Beam splitter

The beam splitter is a simple flat which will be clamped to 45 degree machine face of the beam splitter bracket. The bracket has a through hole for the passage of the transmitted science beam and another at right angles for the reflected acquisition beam.

4.2.9 Calibration source

The calibration source is comprised of a small block with an interface for the calibration fibre head at one end. There is an internal bore which incorporates a mount for the f-converter lenses and a 45 degree mirror at the other end which feeds the calibration beans through another hole at right angles to the first.

4.2.10 Mirror deployment mechanical design performance

Parameter	**Value**	**Comment**
Function	NA	Deploy the science pick off mirror to the centre of the ISS port and retract it completely outside the ISS port.
Performance		
Deployment/retraction time	20seconds	
Repeatability	0.1mm	Excluding flexure
Flexure	±0.1mm /1Mrad	All orientations, including backlash
Physical size of pick off	80mmx60mmx10mm	
Reliability	10^6 operations without maintenance	
Environment	Compliant with Gemini enclosure environment ICD	
	Must operate and meet performance specifications in any gravity orientation	
Interfaces		
ISS	Mechanical interface is the	

	Gemini ISS	
Space envelope	No clashes with GCAL or GCAL electronics rack support	Design requires modification the GCAL light baffle
Repeatability of mounting	±0.1mm	Refers to entire module relative the ISS port.
Mass	Less than 15Kg	(Complete module mass ex. electronics)
General	Must comply with general good practice and applicable safety standards.	

4.3 CCD CAMERA SYSTEM DESIGN

The CCD acquisition camera has the following requirements as summarised in the table below.

Description	Requirement	Comment
Pixel size	13 µm square	
Pixel format	> 512 x 512	1024 x 1024 probable
Read noise	<3 electrons rms	
Windowed readout rate	1 Hz	Assumed for 20 x 20 window at middle, top of device (worst case)
Quantum efficiency	Back illuminated device	
Full well	> 100 X 10^3 electrons	
Dark current rate	< 10 electrons/pixel/second	Peltier cooled, water heat exchanger assumed
Electrical interface	Ethernet or USB	Ethernet preferred
Size	To fit within FDAS space constraints	

There are a few manufacturers who produce off the shelf camera systems which more or less meet most of these requirements. For example the Apogee Instruments “Alta” series of cameras, model E47, fitted with an E2V Technologies Ltd, CCD47-10 back illuminated full frame CCD meets the requirements except for noise performance but only because they operate the devices at a faster rate than typically used on astronomical CCD cameras. This camera is Peltier cooled with an air heat exchanger but a water liquid recirculation system can be supplied. It also has an Ethernet interface and is supplied with LINUX driver support. It is packaged in a box which is 6” x 6” x 2.6” and only requires a 12V DC supply and the Ethernet interface. The liquid recirculation option may require a larger package.

An alternative camera option which can be considered if the Apogee system does not meet our noise requirements is the iKon camera “DU934N” series from Andor Technology. It meets all the requirements except that it has a USB interface. However the USB connection can be extended up to 50 metres using standard Ethernet cable and an extender kit available from the company. Either camera system will interface to a PC via their ethernet or USB port as described. The PC itself can be mounted with all the other electronics in the GEMINI pier lab. The only hardware required to be mounted on the telescope itself would be the DC supply for the cameras. These DC supplies are typically the size of a laptop supply and could be mounted on the FDAS itself or in a rack close by. It is also assumed that the liquid recirculation will be via the GEMINI infrastructure.

A block diagram of the acquisition camera system layout is shown below.

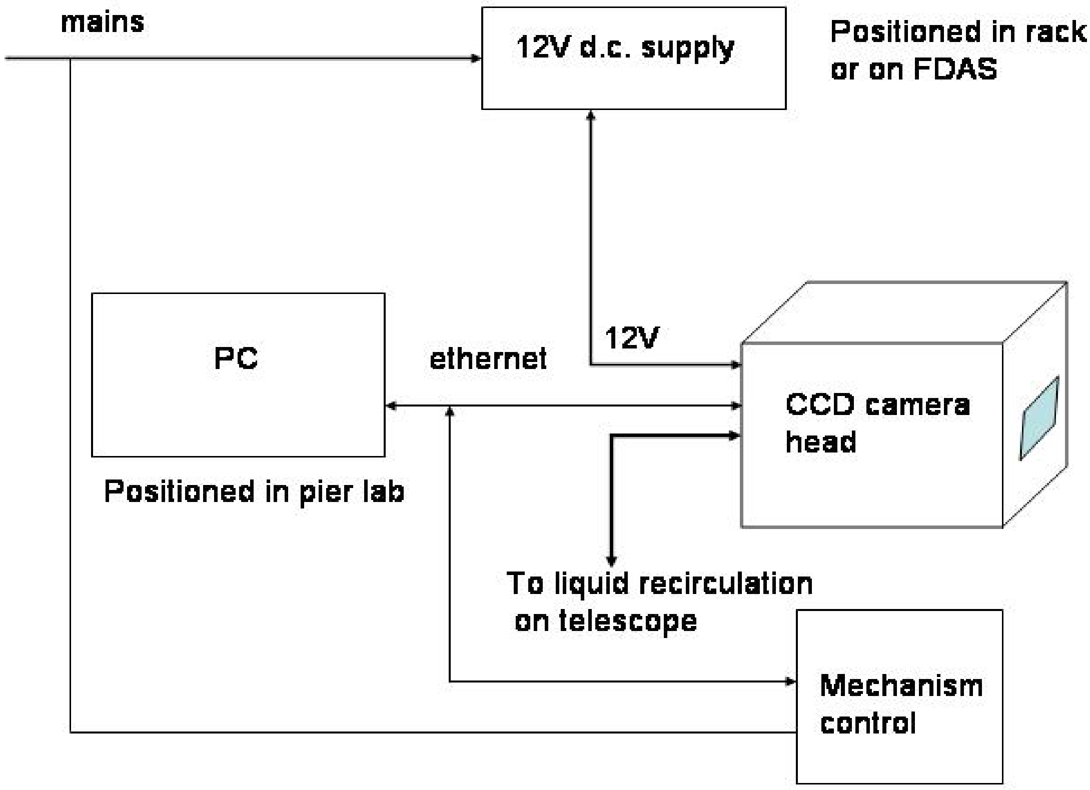


Figure 10 - Block diagram of CCD acquisition camera

Both manufacturers offer a range of CCD types. Likewise both camera systems offer typical read out modes such as binning, window and different gain settings.

4.3.1 Mechanism Control

The linear stage of the FDAS requires a stepper motor control with micro-switch feedback system. A very simple solution is to use the Galil (www.galilmc.com) 21x3 motion control system interfaced to the Galil SDM20620 amplifier via a daughterboard which is then connected to a 2 phase stepper motor from Vexta (www.oriental-motor.co.uk). This eliminates the need for separate cables between motion controller and amplifier and reduces the volume of the stepper motor controller. The only cables required would be from the amplifier to the 2 phase motor and then the ethernet connection and 12V DC supply to the controller. This complete stepper motor motion controller is show below.

Figure 11 - Galil 2 phase stepper motor motion control system

The controller could be mounted in a rack or off the fibre Deployment and Acquisition System.