PRECISION RADIAL VELOCITY SPECTROMETER

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CHANGE RECORD

Issue	Date	Section affected	Change Description
0.2	5 September	5.5.1, 5.5.2, 5.5.4, 5.6	Update to include design proposed at red team and standard Th-Ar
0.3	9 September	3.5, 3.5.1, 3.5.2, 3.5.3. 3.5.4, 3.6, 3.7	Added clarifying text and figures
1.0	16th September 2006	All	Final review before issued to Gemini by DWL

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List of Abbreviations

A+G	Gemini acquisition and guidance system
FPRD	Functional and Performance Requirements Document
FOV	Field of view
FV	Fibre viewer
GCAL	Gemini facility calibration unit
HR	High (spectral) resolution
NA	Numerical Aperture
OAP	Off-axis parabola
OCDD	Operation Concepts Definition Document
pm	picometers
PRVS	Precision Radial Velocity Spectrometer
SRF	Spectral response Function
R	Spectrograph resolving power
RV	Radial velocity
XD	Cross-dispersed

Definitions

TBD	To Be Defined : a requirement to be developed during the preliminary design stage of the instrument.
TBC	To Be Confirmed : a requirement that is correct with the current design information but requires confirmation during the preliminary design stage of the instrument.
TBR	To Be Reviewed : a requirement specified to meet the PRVS top-level requirements, but which might over-constrain the design.

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1. PURPOSE

This document describes the background and overall concept of the PRVS Calibration Assembly.

2. APPLICABLE AND REFERENCE DOCUMENTS

Reference	Document Title	Document Number	Issue / Date
AD01	Science Case	PRVS-SPEC-00004-0001	1.0
AD02	Science Requirements	PRVS-SPEC-00005-0001	1.0
AD03	Operations Concepts Definitions Document	PRVS-SPE-00002-0001	1.0
AD04	Fibre Deployment and Acquisition System	PRVS-TRE-00007-0001	1.0
AD05	Fore-Optics and Fibre Assembly	PRVS-TRE-00002-0001	1.0
AD06	Spectrograph Assembly	PRVS-TRE-00003-0001	1.0
AD07	Detector Sub-System	PRVS-TRE-00003-0002	1.0

3. CALIBRATION SYSTEM CONCEPT

3.1 FUNTIONS OF THE CALIBRATION SYSTEM

The PRVS calibration system serves four distinct functions:

1. Provide wavelength reference signals though a reference fibre to track any displacements in the spectrograph at the sub pixel level as well as any changes in the Spectral Response Function (SRF).
2. Provide wavelength reference signals through the signal fibre to allow accurate wavelength calibration for each order.
3. Provide Flat Field signal to the spectrograph using a Quartz-Halogen (QI) lamp.
4. Provide for a gas cell reference to provide a secondary measurement of overall wavelength calibration.

3.2 CALIBRATION OPTIONS

The *Instrument Design and Analysis Document* (PRVS-PLA-00006-0001) discusses the various calibration options that have and are being employed in planet searches. These are entirely limited to the visible spectral region sampled by CCD detectors. There are two basic techniques used. One technique is to pass the stellar light through a gas cell which imposes its absorption spectra on the stellar spectrum. Recently this has been done using an I_2 cell (Butler *et al.* PASP 108, 500 1996). The Keck HIRES, Hobby-Eberly HRS and UCLES at ATT all have current programs using Iodine gas cells. The second technique uses emission lines exposed in parallel with the stellar spectrum. This technique was first used by Brown et al. (Ap. J. **368,** 599-609, 1991) in studies of P-mode oscillation on Procyon on the Fibre Optic Echelle at NOAO and is employed on many fibre fed bench mounted systems, ELODIE, CORLIE, HARPS (See Table 1 in the above referenced *Instrument Design and Analysis Document*) and the AFOE (Brown *et al.*, PASP **106**, 1285-1297, 1994).

3.2.1 Gas Cells

We have investigated potential gas cells that could be used as a primary calibrator in the 0.9 to 1.7 μm region (Dent, *Summary of survey for suitable gas for a wavelength reference for PRVS*, 2006). In that study the following requirements were set:

- gas should have lines spread over the 0.97-1.7um windows
- line density should be (approx) >1 per 100 wavenumbers (i.e. to give a few lines per order), and <1 per 1 wavenumber (i.e. to give a density of 1 per 10 resolution elements for PRVS)
- line absorption depths should be >10%
- gas cell length ≤1m (pref ~20cm)
- temperature ~300-360K
- pressure <500mb
- 100% volume filling factor
- pref non-toxic, non-corrosive gas.

Table 1 below summarizes the results.

Table 1: Gas Cells results

Gas	Notes
12C2H2	Deep lines in small range at H band (1.51-154um). NIST standard
13C12CH2	Lines in small range at H band.
C2H4	No lines
C2H6	No lines

CH4	Forest of lines mainly at edges of windows. Line density too high.
HCN	Lines at H band (1.5-1.6um).
H13CN	Deep lines in H (1.53-1.57um). NIST standard
12CO	Lines in small range at H band (1.56-1.595um). 100x fainter overtones at 1.2um. NIST standard. Only 15% depth for 80cm path length at 1000 Torr
13CO	Lines in small range at H band (1.595-1.63um). 100x fainter overtones at J. NIST standard. Only 15% depth for 80cm path length at 1000 Torr
NO2	No lines
N2O	Lines around 1.28um, but very faint
HCl	Lines at 1.18-1.23μm (J), but only ~8% depth. Can be made in a gas cell.
HBr	Lines at 1.03-1.04 and 1.33-1.39μm (Y & J), but only ~1% depth. Can be made in a gas cell.
HI	Usable lines at 1.18-1.22 and 1.53-1.6μm (J & H). May react with light (tbc)
HF	Usable lines at 1.25-1.33μm (J). Toxic, reactive, but can be made in a cell
H2O, CO2	Confused by absorption in Earths' atmosphere
N2O	No bright lines
H2S, CH3OH	No lines
HDO, D2O	Lines too faint (<<0.1%) for any reasonable gas columns.
CFC's (in general)	No data could be found for the 1-4um region (most data exists at longer wavelengths)

Several of the gases (e.g. HCN, CO, C_2H_2) have suitably-deep lines, but only at H band; and only covering a small range (typically a 0.02% fractional wavelength). A mixture of gases can give the spectrum shown in Figure 1 (left panel).

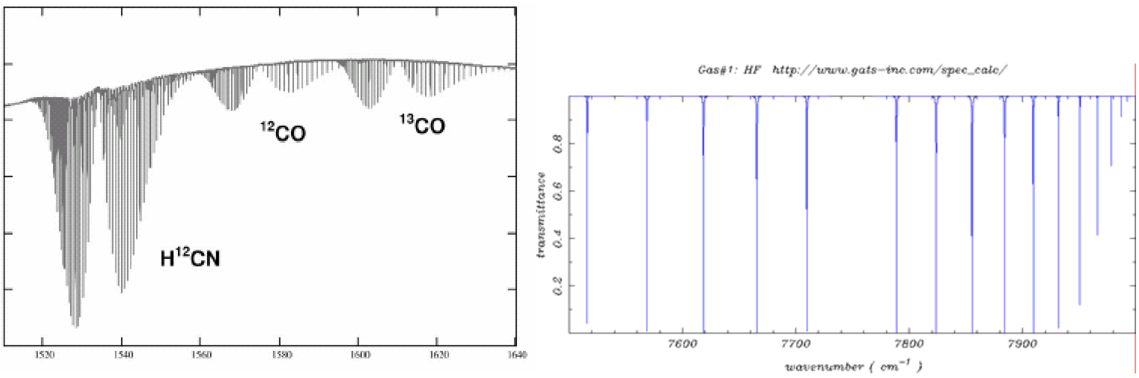

Figure 1: HCN/CO absorption at H band, and HF absorption at J band.

While a mixture of HCl, HBr, HI and HF covers most of J band and the centre of H band, for the most part the lines with reasonable length gas cells are weak; only a few percent. The exception here is HF which has strong absorption in the 7500-8000 cm^{-1} region (J-Band; see Figure 1, right panel). But there are no gases with usable (i.e. deep) lines in Y band. Investigations by other groups have come to a similar conclusion: the GIANO project for TNG may employ a HBr/HCL/HI mixture, but it is only useful for H and K bands[1]; NAHUAL for GTC is considering N_2O, H_2C_2 and CH_4, but again they are working at H and K.

In summary there is no gas (or mixture of gases) which can meet all the requirements listed above for a primary calibrator.

3.2.1.1 Gas cell stability and line accuracy

For the lines which are NIST standards, the wavelengths are known absolutely to ±0.1pm (1 part in 10^7) (e.g. NIST SRM 2517a). For long-term wavelength calibration the absolute accuracy is less important than the relative drift.

[1] See http://www.bo.astro.it/giano/optics/optics.html

Pressure dependence has been measured for HCN lines and is typically between + and -0.0015 pm/Torr (Swann & Gilbert, 2005, J Opt Soc Am. 22, 1749), depending on the line. This is equivalent to 0.3m/s per Torr. Pressure in the gas cell is set at manufacture to typically 25-300 Torr and should not change by more than 1%. Although optical RV spectrometers using I_2 cells do not experience pressure dependence, it would still be worthwhile monitoring atmospheric pressure.

Temperature dependence. Commercially-available gas cells using HCN, C_2H_2 or CO have measured shifts of <0.01pm/C (or <0.005pm/C for CO)[2]. This is equivalent to <2m/s per C. This indicates that it may be necessary to maintain the gas cell to better than $\pm$0.5C with a goal of $\pm$0.1C.

3.2.2 Emission Lines

As is clear from Table 1 in the *Instrument Design and Analysis Document*, visible instruments that use emission line calibration sources typically have thousands of lines over the spectral range covered due to the richness of Th-Ar hollow cathode tubes. Emission line sources in the NIR are nearly as challenging as gas cells. The requirements for the line density are set down by Webster *(reference)*: the precision from one line at full well depth (i.e. S/N=300) is 6 m/s. To reach the overall 0.4m/s calibration accuracy, we would require $(6/0.4)^2$ or ~200 lines at this S/N.

No single source has a high density of bright lines over the 0.95 to 1.7 μm range covered by the PRVS. Dent (*Arc Line Calibration*, 26 April 2006) looked at the data in Hinkle et al (2001) and NIST data for Argon over the PRVS bandpass. Figure 2 shows lines of a Th-Ar arc with relative line strengths superimposed on the atmospheric transmission. The many faint lines around 1.09, 1.28, 1.56 and 1.65μm are taken from the sensitivity results from Hinckle et al (2001). Also included are less sensitive NIST data[3] which only include the brightest lines, but cover the whole wavelength range. To achieve full well depth on ~200 lines (as required to achieve the necessary precision – see above) would require a dynamic range of ~1000 from this spectrum.

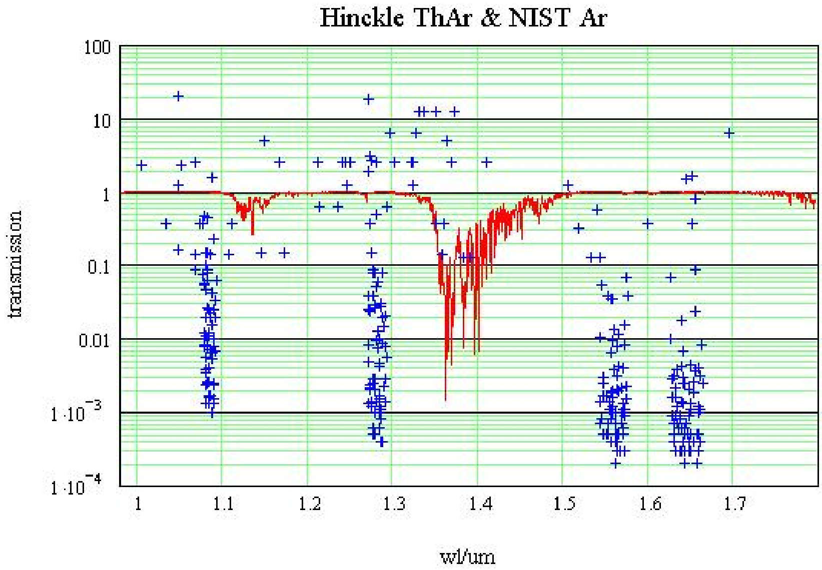

Figure 2: Th-Ar lines

Another approach is to combine emission lines from several sources. We have modelled the number of emission lines per order using Ar, Kr and Xe lines, with a dynamic range of intensity of about 100. Figure 3 shows the number of emission lines per order for the PRVS baseline resolving power of 70,000.

[2] See http://images.wolfpk.com/wavelengthreferences/pdf/hcn.pdf
[3] See http://physics.nist.gov/PhysRefData/ASD/lines_form.html

While the number is typically 3 or more there are three orders with only 1. However, the total number of lines within this dynamic range is ~200, meeting the requirements set down above. The relative intensities of the arcs will be preset to optimise the dynamic range.

To achieve the required dynamic range will necessitate the use of a fast windowing mode in the detector arrays to avoid saturation on the brightest lines. With a dynamic range of 100, and if the minimum readout time in the fast windowing mode is 2 seconds, an integration time of 200 seconds is required. This is acceptable in the continuous SRF monitoring mode using the reference fibre. If the dynamic range needs to be 1000 or more, the integration times would need to be >10^3 seconds. This longer time might be acceptable in the daily wavelength calibration of the spectrometer. In this case, a larger number of lines is required to constrain the wavelength polynomial for each order, so requiring a higher dynamic range.

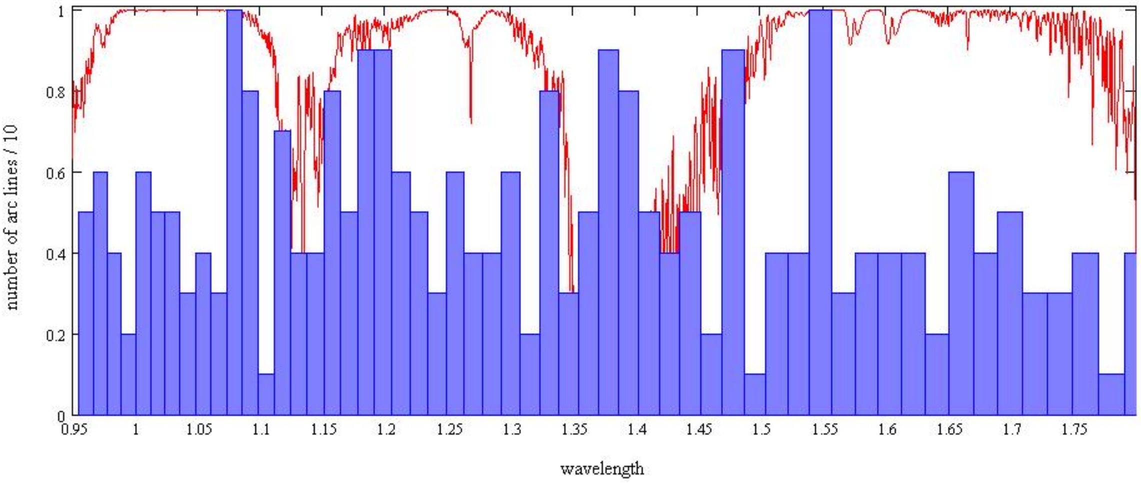

Figure 3 Number of emission lines per order

In addition to the low density of lines there are other issues that need to be addressed. Even by windowing the brighter lines and reading them out rapidly, there could remain a problem with scattered light from those lines in the spectrograph. Initial estimates show that this should not be a problem, particularly as the scattered light from the arc lines will be nearly constant in intensity. Further modelling of this will be done prior to PDR.

3.3 OTHER FACTORS AFFECTING ARC LINE CALIBRATION

Line blending. The effect of blending from weak lines on the nominal laboratory wavelengths of the brighter lines has been investigated in the optical for Thorium by de Cuyper and Hensberge (1998). They find effects at the level of a maximum of ~1 part in 10^5 for some lines. With careful selection and modelling of the blending effect, this may be reduced by a factor of ~10. We are interested in the *relative* rather than absolute wavelengths, so as long as the relative line strengths are constant, this would not matter. However, different lamps and drifts in the lamp characteristics may affect the relative strengths, and hence the blending. Thorium has a particularly high line density (see Figure 2). It may be preferable to use data from the other arcs with fewer lines, and this will be investigated.

Pressure and temperature. The experience of HARPS suggests that pressure and ambient temperature do not adversely affect arc line wavelengths. Nevertheless this will be tested by cross-comparison with the internal gas cell, both in the lab and on-sky.

3.3.1 Developing technology

As was pointed out in the Instrument Design and Analysis Document (PRVS-PLA-00006-0001) laser combs to provide multiple fringes to replace arc lines has been put forward for use in the proposed CODEX instrument on ELT at optical wavelengths. The potential and issues for laser combs are discussed in a note by Webster (*Laser Combs for PRVS*, 4 May 2006). This report concludes that a laser comb is potentially an ideal solution as it would provide densely spaced lines with less intensity contrast and know frequencies that are locked to reproducible standards. However, no suitable product or prototype exists at this time. Webster notes there are two potential development paths. One is path to make these devices work in the infrared, requiring higher frequency mixing, and the other is to develop Fabry-Perot filter that removes most of the lines. Both these options will require extensive and costly R&D.

Another developing technology that we will monitor is the development of fibre Bragg filters. At present these have high losses, are temperature-sensitive ($\Delta\lambda/\lambda \sim 5\times10^{-6}$/C, or 0.01K per m/s), and possibly subject to long-term drifts in the fibre refractive index. They are therefore not suitable for a primary calibration method. One possible application of such filters in the calibration system might be to remove the brightest emission lines. But it is possible that changes in slopes in the out-of-band response curves of these gratings would cause additional calibration errors in the other lines.

3.4 CALIBRATION METHOD

The observing and calibration method is described in the OCDD. The requirements this places on the calibration unit operation are:

3.4.1 Daytime

Before and after the nights run, the Cal Unit will need to provide:

- Spectral flat-fielding on the signal and calibration fibres
- Spectral flat-field with gas absorption lines for an overall wavelength calibration and cross-check, on the signal and calibration fibres
- Standard combinations of arcs for daily wavelength calibration of all the orders (plus possibly individual arc measurements to avoid line blending). This is applied to the signal and cal fibres

These cal observations may take ~1 hour. They need to be automated (i.e. independent of the Gemini telescope control system). So PRVS should be able to make cal observations on its own. It will also be necessary to do self-checks using the pipeline output to confirm that the results from daytime calibration are acceptable.

3.4.2 Night-time

During the observing, the Cal Unit is used to provide:

- Standard arc combination for continuous measurement of SRF changes or wavelength shifts. This is applied to the cal fibre only.

The lamps will be in continuous use during observing periods, although may be switched off during periods when PRVS is not used. A MTBF of >1 year and preferably >3 years is required, which for 50 nights/year is >1200 hours with a goal of >6000 hours.

3.5 DESIGN APPROACH

As noted above there is no ready and efficient gas cell solution similar to the molecular Iodine (I_2) that is ubiquitous in visible instruments used for planet searches. Similarly, there is no analogue to Th-Ar hollow cathode lamps in the NIR. However promising, we can neither undertake the expense or the risk involved with the development of a laser comb system. Thus we are left more or less on our own to develop an adequate solution based on existing technology. In the PRVS, we will use arc-lamp emission spectra that are simultaneously exposed along with the stellar target spectra. This is accomplished by placing a fibre illuminated by the arc lamps alongside the stellar fibre at the entrance of the spectrograph (see PRVS-TRE-00003-0001). As noted above this general approach has yielded excellent results in the visible on a variety of instruments. That said, it remains a challenge to implement in the NIR. Figure 4 is a sample of our test data obtained in the Y-band using a Hawaii 1K array and a 31 l/mm echelle spectrograph configured to give a resolving power of ~50,000. The broad bands apparent are the solar spectrum with wavelength increasing from top to bottom and from right to left. The bold numbers on the far right are echelle order numbers and the extreme wavelengths on the detector are shown for each order. Also apparent are several lines above and below the solar spectra. These are emission lines from an Argon pen light. The design approach we will use will employ use multiple emission lamps combined in an optical fibre to provide a mixed wavelength and SRF calibration signal to PRVS. Similarly, we will use Quartz Iodine lamps for the flat field signal and as a background for a gas cell signal with limited spectral coverage for periodic calibration. Quartz-Iodine lamps will give the best temperature match to M dwarfs for the optimum flat-fielding.

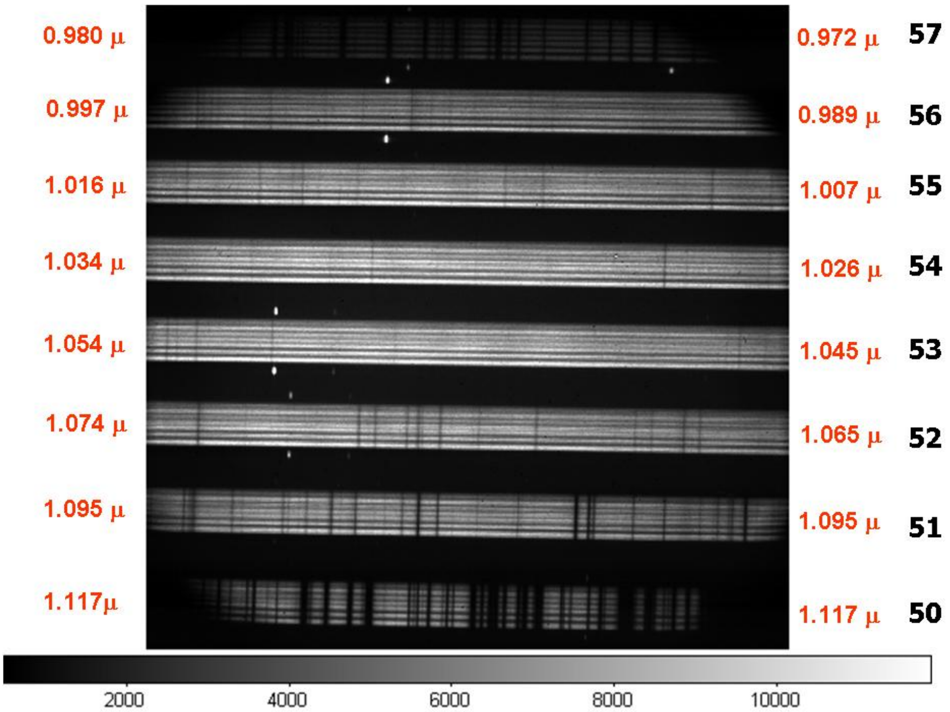

Figure 4: Sample of test data obtained in the Y-band

3.5.1 Calibration System Block Diagram

As is illustrated in Figure 5, we have five emission line lamps in our baseline design; Argon (Ar), Krypton (Kr), Neon (Ne) and Xeon (Xe) and a Thorium Argon (Th-Ar). In addition there is a Quartz Iodine (QI) incandescent lamp for the flat field signal. These six signals form the basis for the daytime and night-time calibrations. An additional QI lamp, shown in Figure 5 in the upper left corner is used as a continuum source for an absorption line gas cell. The gas cell will likely contain HCN/CO/^{13}CO, a combination which can give useful lines from 1.52-1.63μm (see Figure 1). We also include an additional *Standard* Th-Ar lamp. This Th-Ar lamp is not used nightly but employed periodically, along with the gas cell, to track any changes in the wavelengths of the main Ar, Kr, Ne, Th-Ar and Xe lamps when they are replaced. Either the gas cell or the *Standard* Th-Ar are directed to a seventh fibre. The default position is for the gas cell with a fold mirror being inserted by the motion of a linear stage when the *Standard* Th-Ar is selected.

Two optical fibres capture the light from each of the lamps. The Ar, Kr, Ne and Xe lamps are standard pen-lamps. For these the fibres are placed about 5 mm away. Each of these will be a 200 (TBC) micron core fibre with a 2.5 mm (TBC) ball lens epoxied to the end. The Th-Ar hollow cathode lamps will be standard 37 mm (TBC Cathodeon) lamps. We will epoxy a fast aspherical condenser lens on the end of the lamp which is imaged onto a 200 (TBC) micron fibre. Two sets of seven fibres, each with fibres from the Ar, Kr, Ne, Th-Ar, QI and gas cell/Standard Th-Ar lamp are packed tightly in a circular format and this is imaged onto an integrating fibre as illustrated in Figure 6. These fibres will specially made with acrylate buffers that can be easily removed with acetone so as to allow more efficient packing and coupling into the integrating fibres. The integrating fibres are standard 600 micron core polyimide buffered. A slight ~0.8 demagnification will be used in the transfer optics. This scheme of combining the light in the integrating fibres is adopted so as to assure maximum stability of the calibration system both with respect to the relative intensity of the reference lines and the modal distribution of the light to the instrument.

The relative intensities of the five different emission line lamps are optimized by means of a one-time adjustment with neutral density filters epoxied in front of the ball lens. In the case of the Th-Ar, no neutral density filter is used as the intensity of the hollow cathode lamp is controlled by the power supply current between 1 and 20 milliamps. As the flat field QI lamp is not used with the emission line lamps it is separately shuttered as illustrated in Figure 5. In addition the reference gas cell or Th-Ar lamp is separately shuttered.

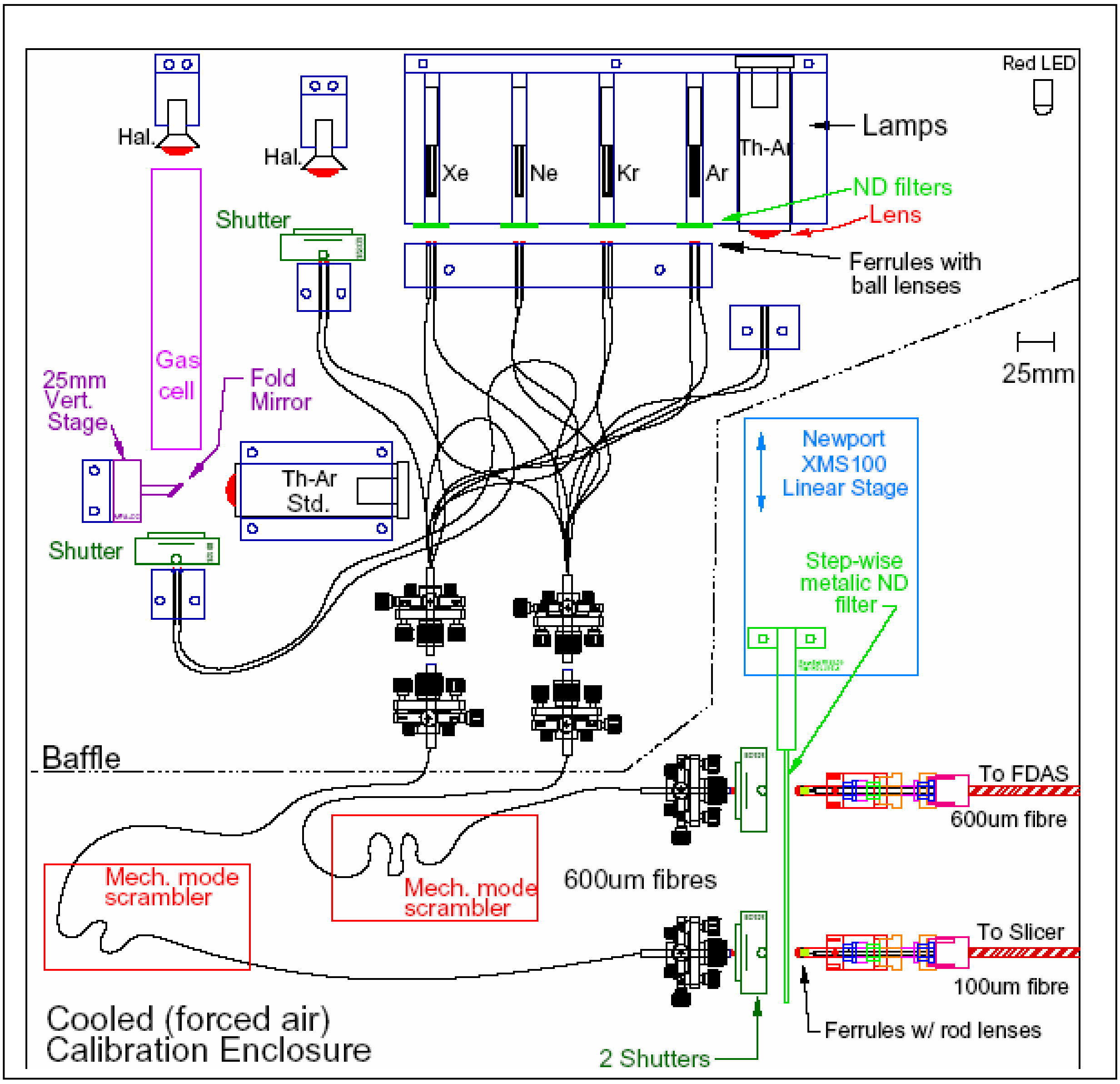

Figure 5: Conceptual schematic of the PRVS calibration system

The two separate integrating fibres will each undergo mechanical modal scrambling to assure that all the lamp signals are mixed at the output as well as assuring a stable distribution of modes. One of the integrating fibre outputs will be imaged onto the 100 micron core reference fibre to goes to the spectrograph as discussed in the *Fore-Optics and Fibre Assembly* document (PRVS-TRE-00002-0001). A TBC f/4 collimating lens is immediately after the filter. This beam is then re-imaged with a similar f/4.

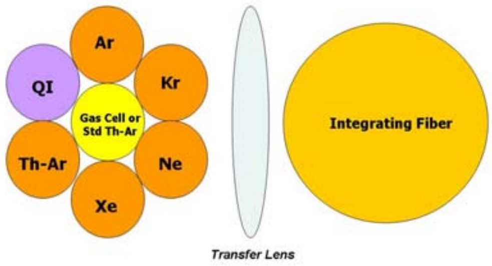

Figure 6: Illustration of integrating fibre

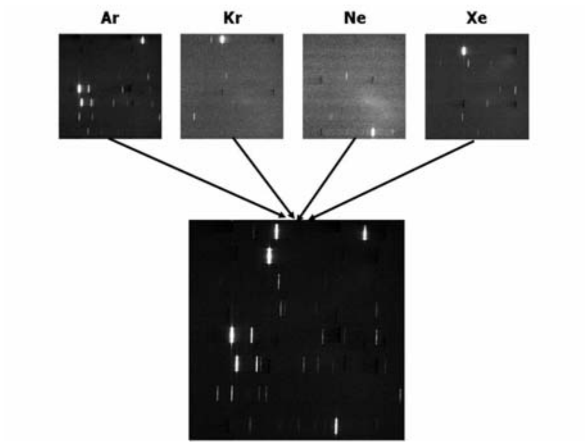

Figure 7: Example of integrated spectra concept

lens. In the collimated beam of the integrating fibres we will have a linear stepped metallic neutral density filter. This is required as we are exposing the emission lines alongside the stellar spectra and the latter can have a large range of exposure times. Any density variation over the beam will weight the modal distribution in down-stream fibres. We will use rod lenses cemented to the fibre ends so the collimated beam will be small and allowing for a less complex alignment. The second integrating fibre output is also collimated and transferred onto a TBC 600 micron core fibre that takes the calibration signals up to the FDAS where they can be re-imaged onto to the object fibre as discussed in PRVS-TRE-00007-0001.

3.5.2 Optical Design

The optics for the calibration system are of two types; transferring from a light source to an optical fibre and transferring between optical fibres.

The light source to fibre transfer also has several approaches depending on the source. The pen lamps are long ribbons of gas and we maximize the amount of light gathered by the fibre by using a ball lens. Our concept design uses a 2.5 mm LaSFN9 ball lens epoxied onto the end of a 200 micron core fibre with the fibre placed ~5 mm from the lamp. Preliminary ray-tracing shows that we get an un-vignetted six degree field of view and excite all the available modes in this NA= 0.22 fibre. We will use these ball lenses on the fibre pairs that look at the Ar, Kr, Ne and Xe lamps. For the QI flat field lamp, a fast condensing lens will image a slightly de-focused and de-magnified lamp ribbon onto the end of the fibre; again at maximum NA so all the modes are excited. For the gas cell, the QI lamp will be collimated through the cell and re-imaged onto the fibre at the maximum NA. The hollow cathode tubes have an emission source that is a cylindrical volume a few mm in diameter. We have found that we can maximize the light into a fibre by attaching a plan-convex aspherical condensing lens to the end of the hollow cathode tube that images ~3x de-magnified image of the diffuse emission onto the end of the fibre. This is our baseline approach.

The fibre-to-fibre transfer between bundle of fibres from the lamps and the integrating fibres will be done using ball lenses again. Both the fibre bundle and the integrating fibre will have the same size ball lenses but the index of refraction for the lens on the bundle will be less (TBC ~1.5) than for the integrating fibre (TBC ~ 1.85). This yields the desired ~0.8 magnification. We will do a trade study on using 100 micron fibres in the bundle as this will lead to a smaller integrating fibre and more efficient transfer to the spectrograph cable discussed below. The concern here is the low number of modes in 100 micron core fibres.

The transfer from the integrating fibre to the fibre cable which goes to the FDAS or the spectrograph directly is more complex since we need to place a shutter and filter between them. This will be done using rod (or drum) lenses that can be epoxied directly to the end of the fibres to assure illumination stability. The rod lenses on the integrating fibres will roughly collimate the fibre output for transmission through the neutral density filter. An imaging lens will be used on the fibre cable end. In the case of the FDAS cable, the imaging les will be identical. If we use a 100 micron fibre in the spectrograph cable, which is the baseline, we will have a faster lens to assure that all the modes are excited. We intend to look at the benefit of using a large fibre in this cable to lower the potential for modal noise.

3.5.3 Mechanical Design

The Calibration System will be built up on a standard TBD size optical bench and to maximise the use of off-the-shelf hardware. This unit will be housed in a thermal and light tight enclosure that is easily opened for replacement of lamps or removal of the fibre cable that goes to the FDAS. The whole calibration unit will be temperature-controlled to better than ±1C with a goal of ±0.5C. Sufficient cooling is required for the arc lamps to maintain relatively low temperature and maximise lifespan.

The gas cell will be temperature-controlled to better than ±0.5C with a goal of ±0.1C. The baseline concept uses a commercial unit optimized for this purpose.

3.5.4 Electrical Design

The calibration system electronics is straightforward. A concept breakdown is illustrated in Figure 8 that shows seven basic modules. The control system is the major interface and a detailed signal breakout is given in Table 2 in section 3.6 below. There will also be a power supply module That will provide voltage and current needed for the following five modules. At present we envision +5 and +/- 12. The solid state switch module will be a simple board with the 8 relays noted in Table 2 below as well as (TBC) two spares. At present we have only called out one analog and this module will be an even simpler board with a precision voltage reference and the sensor interface. The actuator drive module will provided the DC or stepper motor amplifier and signal interface. The baseline concept has four Vincent Associates MM-D1 shutter controllers and this module will consist of a mount for those and the cabling control system interface. The most complex module will be the lamp controls. There are three types of lamps, QI, gas pen lights and Th-Ar hollow cathode. Each will require a control circuit. The QI lamps will have a current servo to maintain constant intensity (and presumably colour temperature). Commercial options will be used if possible. The pen-lamps will have a high voltage supply with current control to maintain a preset intensity. The Th-Ar lamps also require a high voltage supply but have 2-3 times the current requirement of the pen-lamps. We have a baseline supply (EMCO HC2012R) for the Th-Ar lamps with which we have experience. Several vendors supply pen-lamp power supplies and we have these off-the shelf units in our baseline design.

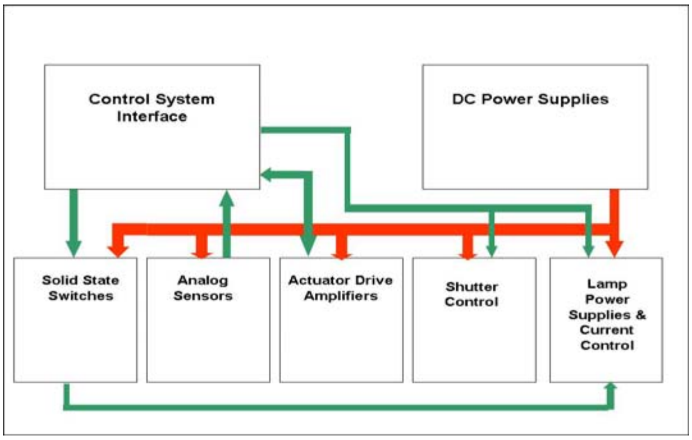

Figure 8: Calibration System Electronics concept breakdown

3.6 CONTROL SYSTEM INTERFACES

The calibration system has a substantial number of digital I/O control interfaces and a few analog ones. At present we show only one temperature monitoring output from the calibration system. During the preliminary design phase it is likely we will add more. For example, it is likely that we will monitor the temperature of the gas cell. The control lines listed in Table 2 below are at this concept phase known to be essential.

Table 2: List of control signals

Function Description	***Type***	***Voltage***	***baseline unit***	***Comments***
Inputs				
Flat Field Halogen Lamp on/off	Digital	5 VDC	Solid State Relay	Switches A/C power to power supply
Gas Cell Halogen Lamp on/off	Digital	5 VDC	Solid State Relay	Switches A/C power to power supply
Argon lamp on/off	Digital	5 VDC	Solid State Relay	Switches A/C power to power supply
Krypton lamp on/off	Digital	5 VDC	Solid State Relay	Switches A/C power to power supply
Neon lamp on/off	Digital	5 VDC	Solid State Relay	Switches A/C power to power supply
Xeon lamp on/off	Digital	5 VDC	Solid State Relay	Switches A/C power to power supply
ThAr lamp on/off	Digital	5 VDC	Solid State Relay	Switches A/C power to power supply
ThAr lamp current set	Analog	4-5VDC		Controls lamp intensity
Standard ThAr lamp on/off	Digital	5 VDC	Solid State Relay	Switches A/C power to power supply
Standard ThAr lamp current set	Analog	4-5VDC		Controls lamp intensity
Flat Field Halogen Lamp shutter	Digital	5 VDC	Uniblitz VMM-D1	Synced with detector shutter
Gas Cell Halogen Lamp shutter	Digital	5 VDC	Uniblitz VMM-D1	Synced with detector shutter
Slicer cable shutter	Digital	5 VDC	Uniblitz VMM-D1	Synced with detector shutte
FDAS cable shutter	Digital	5 VDC	Uniblitz VMM-D1	Synced with detector shutter
Lamp Intensity	Analog	0-10VDC	75 mm stage	Drive linear Variable ND filter.
Flip mirror in/out	Analog	0-10VDC	25 mm stage	Select either Gas cell of Standard Th-Ar lamp
Detector flood LED	Digital	5 VDC	Solid State Relay	Inside spectrograph to provide spatial flats
Outputs				
Temperature	Analog	5 VDC	AD590	monitor temperature in cal unit; ~280μA +/- 30
Flip Mirror Stage Position Feedback	Digital	5 VDC		Incremental encoder signal
Flip Mirror Stage + limit	Digital	5 VDC		
Flip Mirror Stage - limit/home	Digital	5 VDC		
Filter Stage Position Feedback	Digital	5 VDC		Incremental encoder signal
Filter Stage + limit	Digital	5 VDC		
Filter Stage - limit/home	Digital	5 VDC		

3.7 RISKS

The key risks with the calibration approach taken are as follows:

1. Large dynamic range in emission line sources

    a. Variable readout rates in sub-arrays complex or strong lines too numerous
    b. Scattered light in spectrograph

2. Inadequate number of lines in all orders to carry out wavelength calibrations.

3. Too few strong lines in the reference gas cell to monitor wavelength stability of emission line lamps.

In principle all these risks can be retired via analysis and/or experiment during the preliminary design phase. We discuss each of these the above risks and how we plan to address them.

Risk 1 is discussed in the PRVS Detector Sub-System document (PRVS-TRE-00003-0002). From experiments done at ATC with a H1RG and expected properties of H2RG's, it should be possible to accommodate up to 256 sub-array readouts on each detector or 512 total. This is more than the total number of lines we presently expect from Ar, Kr and Xe lamps (see Figure 3). During the preliminary design phase we will use the PRVS pathfinder to acquire a low sensitivity survey of the PRVS bandpass to map the stronger lines in the Ar, Kr, Ne, Xe and Th-Ar lamps and acquire estimate the contrast range. Scatted light estimates are contained in PRVS-TRE-00003-0001. The results of our survey will allow us to refine the impact of scattered light from the emission line spectrum.

Risk 2 is the most worrisome at present. While in principle we have enough lines at present to achieve the radial velocity precision needed as discussed in section 3.2.2 above, several orders have minimal lines to properly set a wavelength scale. We do not know at what level this will effect our radial velocity error budget yet nor do we understand the long term stability of the emission lines due to the noble gases which constitute a majority of the planned lines. Some of the wavelength stability risk is addressed with the gas cell and the Thorium lines in the standard Th-Ar lamp which provide for long term stability monitoring. We are also encourage by recent results from the PRVS pathfinder where the use of a Th-Ar lamp in our Y band sample region (see Figure 4) increased by more than 3 times the number of emission lines visible. Figure 9 compares the combined Ar, Kr, Ne and Xe spectra with Th-Ar in our sample region.

Risk 3, while deemed low at this time, will be addressed by experimenting with some gas cells in the preliminary design phase. Figure 10 shows a brass board calibration system currently being used with the PRVS pathfinder which can easily be modified to incorporate a gas cell.

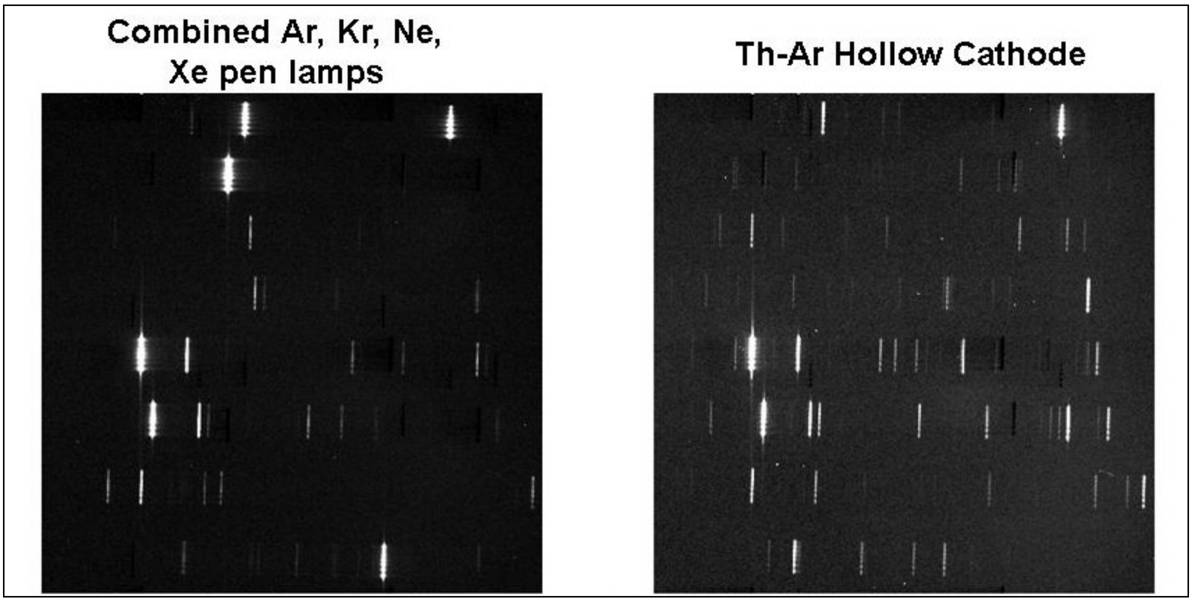

Figure 9: Comparison of combined Ar, Kr, Ne & Xe lamps to Th-Ar in test Y band region

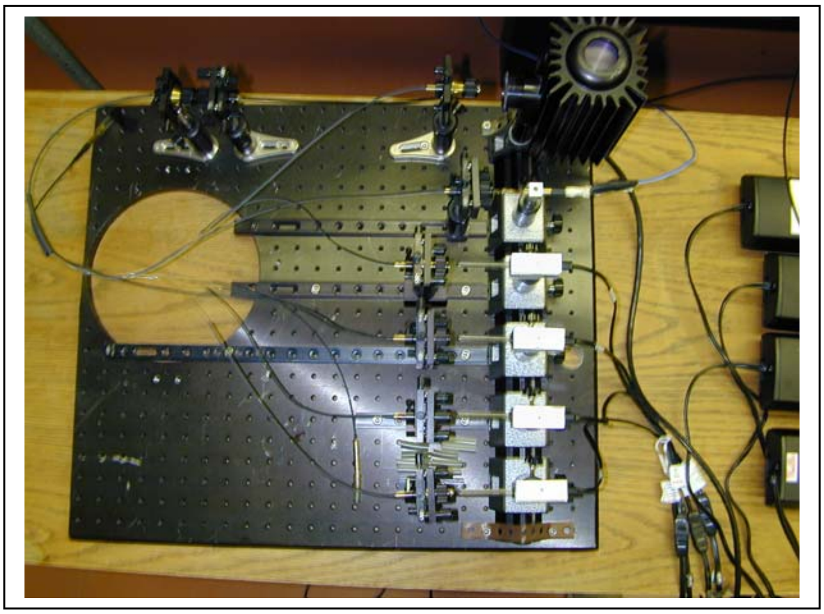

Figure 10: Prototype calibration system