SPIRou @CFHT: design of the instrument control system

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ABSTRACT

SPIRou is a near-IR (0.98-2.35µm), echelle spectropolarimeter / high precision velocimeter being designed as a next-generation instrument for the 3.6m Canada-France-Hawaii Telescope on Mauna Kea, Hawaii, with the main goals of detecting Earth-like planets around low-mass stars and magnetic fields of forming stars. The unique scientific and technical capabilities of SPIRou are described in a series of eight companion papers. In this paper, the means of controlling the instrument are discussed. Most of the instrument control is fairly normal, using off-the-shelf components where possible and reusing already available code for these components. Some aspects, however, are more challenging. In particular, the paper will focus on the challenges of doing fast (50 Hz) guiding with 30 mas repeatability using the object being observed as a reference and on thermally stabilizing a large optical bench to a very high precision (~1 mK).

Keywords: SPIRou, CFHT, spectropolarimetry, high precision velocimeter, near IR, control-command, view & tip-tilt, fast guiding, algorithm, thermal control

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1. INTRODUCTION

SPIRou (un SpectroPolarimètre Infra-Rouge in French; or Infrared spectropolarimeter in English) is a high resolution, near-IR spectropolarimeter being designed for the Canada-France-Hawaii Telescope on Mauna Kea. The spectrograph will deliver a full spectrum over the range of 0.98 – 2.35 μm in a single exposure at a resolving power of ~75,000. The polarimeter will be able to measure the circular and linear polarization in the line profiles of a source to a precision of better than 10 ppm, relative to the unpolarized continuum, with a relative accuracy of better than 2%. Finally, the system will be able to measure radial velocities (RVs) of sources to 1 m/s or better.

Obviously, with the ability to measure RVs to this level, one of the primary science goals for the instrument will be to find planets. In this case, the target population will be Earth-like planets around low-mass stars. An additional, important science goal for this instrument is to measure the magnetic fields of objects, especially in star forming regions where the access to the *K* band allows objects embedded in dust to be observed. For more on the science expected with SPIRou, see Doyon R. et al., Paper # 8446-61 in this Conference[3] and Bonfils, et al. (2011)[4].

Achieving the requirements for this instrument will present a number of challenges in all parts of the instrument design, including the control system. Where feasible, the control system will be designed using off-the-shelf components for the control hardware with preferences given to hardware similar to what is already in use at CFHT so that as much pre-existing code can be used as possible. However, as with any instrument of this complexity, some new, off-the-shelf and custom hardware will be required as will be some new or unusual methods of controlling the hardware. This paper will first give an overview of the instrument control system for all the various sub-systems in the instrument. The overview will be followed by more extensive descriptions of the guiding system and the thermal stabilization systems being designed for SPIRou as they present some particular challenges for the designers.

The SPIRou project is being developed by many institutions within the CFHT community and even by one institution outside of the CFHT community. The lead is being taken by Institut de Recherche en Astrophysique et Planétologie (IRAP) in Toulouse, France with substantial contributions from the Herzberg Institute of Astrophysics (HIA) in Victoria, B.C., Canada, the Université de Montréal (UdeM) in Montréal, Canada, the Université Laval (UL) in Québec the Laboratoire d'Astrophysique de Marseille (LAM) in Marseille, France, the Observatoire de Haute-Provence (OHP) in Provence, France, the Institut de Planétologie et d'Astrophysique de Grenoble (IPAG) in Grenoble, France, the Academia Sinica Inistitute of Astronomy and Astrophysics (ASIAA) in Taipei, Taiwan, and the Observatoire de Genève (OG) in Geneva, Switzerland.

2. OVERALL INSTRUMENT CONTROL

The SPIRou instrument is composed of four main sub-systems: the polarimeter/injection unit (Cassegrain unit) that is mounted at the Cassegrain focus of the CFH telescope, the fiber link, the spectrograph unit, and the calibration unit. The calibration unit has a further sub-system of a precision radial velocity source that couples into the main calibration unit using a fiber-optic link. Of these four sub-systems, all have the need of control systems with the exception of the fiber link. A block diagram of the instrument is shown in Figure 1.

The control software for the various sub-systems within SPIRou will be integrated as agents within the NEO/Director environment at CFHT. The NEO/Director environment is a flexible command line interface that manages control software (agents) providing parsing for input to the agents and a display area for output messages from the agent.

2.1 Cassegrain Unit Control

The Cassegrain unit is the system that receives the light from the telescope. Both the opto-mechanical structure and the control electronics (LCU; or local control unit) will be attached to the bottom of the telescope structure; the opto-mechanical structure on the Cassegrain instrument mounting interface (Cassegrain bonnette) and the electronics nearby on the Cassegrain rotation plate also known as the Cassegrain environment.

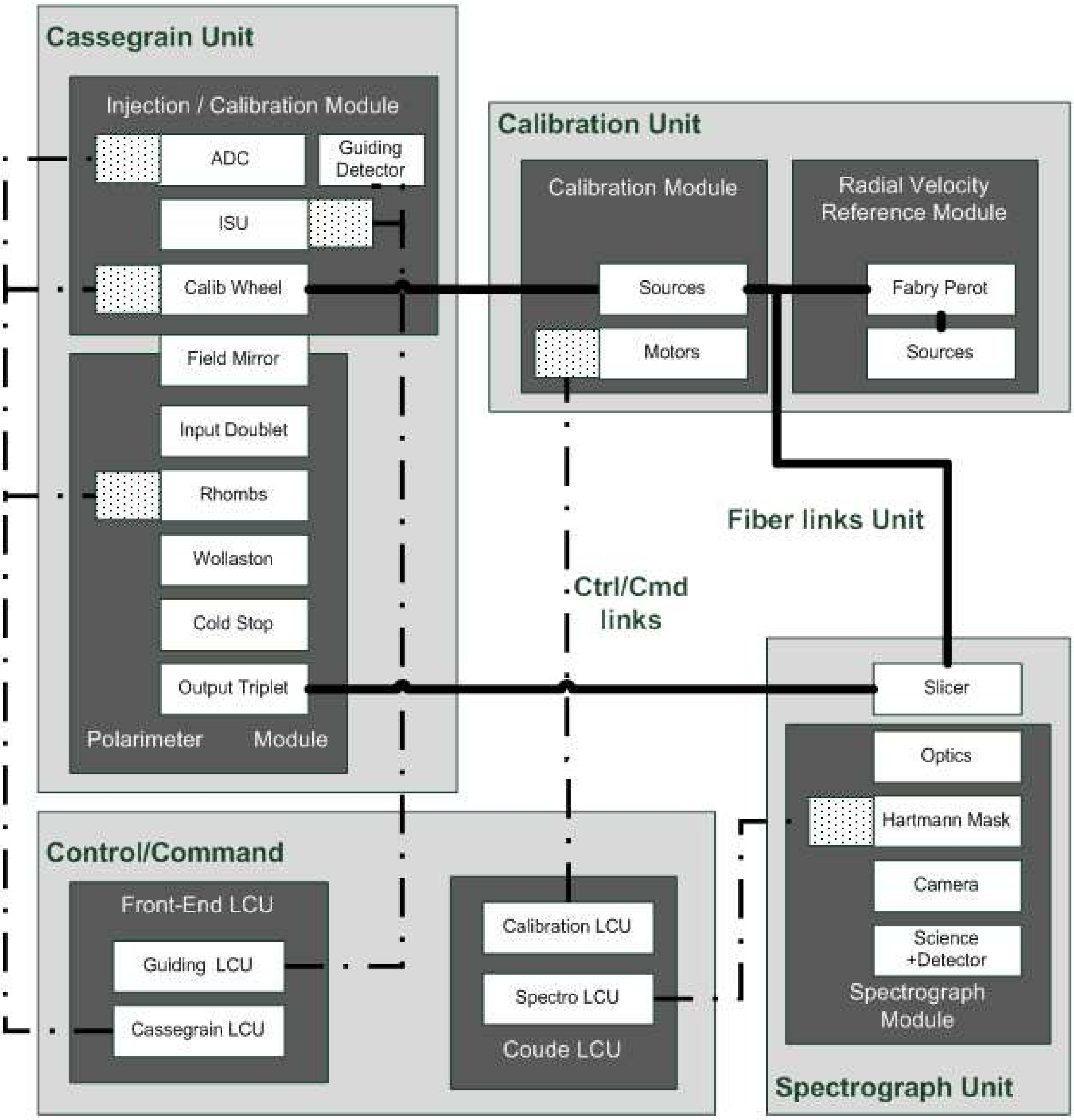

Figure 1: Block diagram of the SPIRou instrument control system. The boxes filled with dots indicate controlled devices. The solid lines indicate fiber optic links. The dash-dot lines indicate electrical connections.

The Cassegrain unit is composed of the injection unit and polarimeter unit. The controlled devices for this unit are:

- An atmospheric dispersion corrector (ADC) composed of 2 counter-rotating prism assemblies.
- An image stabilization unit (ISU), or fast guider, and its associated detector. (See section 3.)
- A neutral density filter wheel in the guide beam used to avoid guide detector saturation.
- A calibration/injection wheel used to allow the injection of various calibration sources into the instrument.
- Two rotating quarter-wave retarders to allow the determination of the polarization state of the light.

- A Peltier cooler (thermoelectric cooler, or TEC) to cool a cold stop which suppresses *K*-band radiation from the telescope structure.

The motion control will be done with a Galil controller, which can control up to 8 motors. Galil controllers are completely generic with interfaces to various motor types specified by daughter boards (4 motors per daughter board). The software that will be implemented to control the motors through the Galil controller will be an upgraded version of the software used in ESPaDOnS, a visible wavelength predecessor to SPIRou. In addition, the Cassegrain unit agent will have a direct interface with the telescope control system to determine the current pointing of the telescope, allowing the correct rotation of the ADC to be calculated.

2.2 Spectrograph Unit Control

The spectrograph unit is the portion of the instrument that receives the light from the fiber, disperses it, and images the spectrum on the detector. Since a major emphasis of SPIRou is high-precision RV measurements, it is essential that the spectrograph be as stable as possible. For this reason, any proposed remotely controllable devices were considered with great care and eliminated from the design. Doing this eliminated the possibilities of unwanted motions which can happen more easily with motorized devices as well as variable thermal loads on the cryostat resulting in the potential for relative deflections of various optical components.

As a result, there are only three controlled systems within the cryostat:

- A Hartmann mask to be used primarily for initial alignment and integration. It may be removed after a successful integration. It will at least be disconnected from the cryostat wall to remove the heat load of the motor and encoder wires.
- A Teledyne Hawaii 4RG detector for recording the spectrum. It will be controlled by a cold Teledyne ASIC and interfaced to a Linux detector control computer using the GigaBit Ethernet capabilities of the new Teledyne SAM card located outside the cryostat.
- A thermal control system capable of maintaining the cryostat optical bench at a constant temperature at a level of ~1 mK RMS[2]. See section 4 for more details.

There will also be various environmental monitoring devices external to the cryostat such as vibration sensors and external pressure monitors. The control of these systems will again be via a Galil controller with higher level agents running under Director for instrument control.

There will also be an Allen-Bradley PLC system for monitoring the health of the cryostat vacuum and controlling and monitoring the helium compressors for the two Cryomech PT90-UL single stage pulse tube cryo-coolers.

2.3 Calibration Subsystem Control

The calibration subsystem is a major contributor in allowing SPIRou to reach the expected overall performances by providing precision wavelength calibration capabilities and the possibility of allowing an RV reference source to be observed simultaneously during observations. It is composed of three items: the calibration module, the radial velocity reference unit (RV reference unit) and two calibration fiber links.

2.3.1 Calibration Module

The calibration module provides light from different selectable sources to feed two calibration fibers, one linked to the Cassegrain unit (the calibration beams follow the same optical path as the stellar beams) and the other to the spectrometer (links directly the calibration module to the spectrometer through the slicer unit to monitor RV drift throughout the night). The calibration module is composed of four main subsystems shown in Figure 2:

- The light sources module: This module includes the calibrations lamps, collimating and filtering optics, the lamps power supply and mechanical supports. We plan to use 5 slots to meet the scientific requirements for instrument calibration. The 5 slots of the module will be occupied by: one continuum lamp, two hollow cathode lamps, one fiber link for the RV reference unit (based on a Fabry Perot) and one spare.
- The reference fiber module and the Cassegrain fiber module: These modules are moving slides that select the light source to be injected into each of the two calibration fiber links (Cassegrain or Reference) providing for all

of the anticipated SPIRou calibration modes. These modules include two short fibers, optics, and two actuators (linear stages, sensors, motors, encoders and a motion controller) to independently position with precision and accuracy the Cassegrain and reference fiber injection systems in front of the selected calibration lamp or lamps.

- The flux balance module: The output flux of the reference channel needs to be controlled in intensity so that an appropriate signal-to-noise ratio is achieved on the reference spectrum regardless of the exposure time needed for the target object. To achieve this requirement, a variable neutral density system will be used. This system will include a variable neutral density wheel placed between the output of the reference module fiber and the reference fiber, a motion controller, an encoder and a motor.
- Control Command part: The calibration module will be completely remote controlled. We will monitor critical parameters to ensure the smooth running of the unit, to help anticipate maintenance needs, and to detect component failures. To manage all the hardware of the calibration module, we use a Galil controller. The main functions of the controller are: communication with the "calibration agent", three axis motion controller (Cassegrain trolley axis, Reference trolley axis, and a density wheel axis), temperature acquisition (analogue input), and dedicated inputs and outputs to provide remote control of the non-motorized devices (*i.e.* commanding lamp power supplies and reading status and limit sensors).

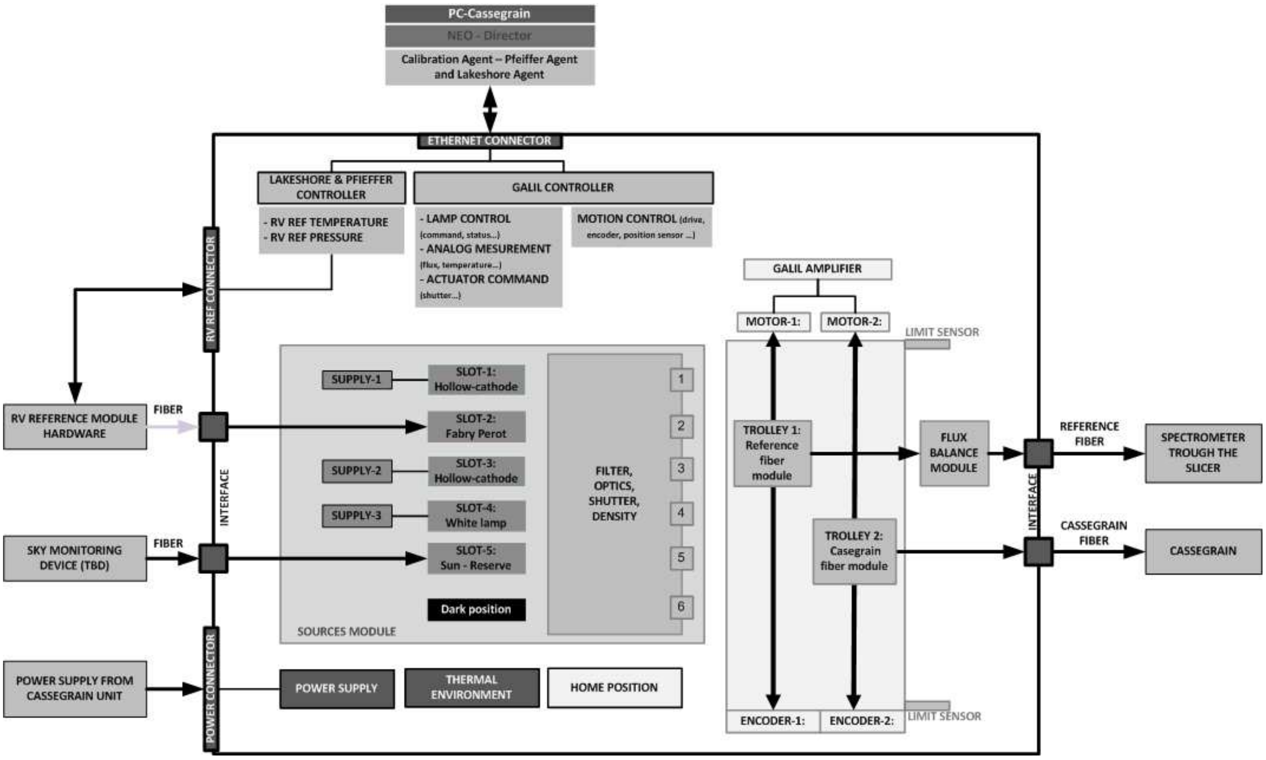

Figure 2: Block diagram of the calibration subsystem.

2.3.2 High-precision Radial Velocity Source

SPIRou is designed to be stable at the level of 1m/s within any period of ~24 hours like HARPS. If such stability is reached the daytime calibrations will be sufficient and supplementary nighttime calibrations will not be needed to reach 1m/s accuracy. However, the instrument will be provided with an RV reference source that can be observed simultaneously with an astronomical target (1) for programs requiring very high RV accuracy and (2) to reduce the impact if the 1m/s stability is not reached in all observational configurations.

The preferred solution for this source is a thermally stabilized Fabry-Perot source. A Fabry-Perot source is desirable since it provides a great many, evenly-spaced lines in each order with approximately the same intensity. This is contrasted to a hollow cathode lamp that has randomly positioned lines, many of which are blended, with a huge range in brightness. The bright lines are particularly problematic since they introduce scattered light into the spectrograph and can cause persistence on the detector. Unfortunately, the position of the lines in a Fabry-Perot source is typically sensitive to temperature variations, even if the Fabry-Perot etalon is athermalized, hence the source will be thermally stabilized.

The control of the radial velocity reference is quite straightforward. Control of the input light source, a halogen lamp, is needed, though in normal operation the lamp will remain on so that it does not disturb the temperature stability of the system. The pressure of the reference needs to be monitored since the mechanism will be evacuated to provide thermal insulation from the environment. The vacuum vessel may be continuously pumped depending on the hold time possible with the vessel.

Finally, the temperature of the components inside the vacuum vessel will be stabilized to a temperature somewhat above the ambient temperature of the environment. In the case of the RV reference, the environment will be the CFHT coudé room with an ambient temperature of ~14°C with yearly variations of <10°C and daily variations of <1°C. The temperature will be controlled using a LakeShore temperature controller.

A block diagram of the RV reference system is shown in Figure 3.

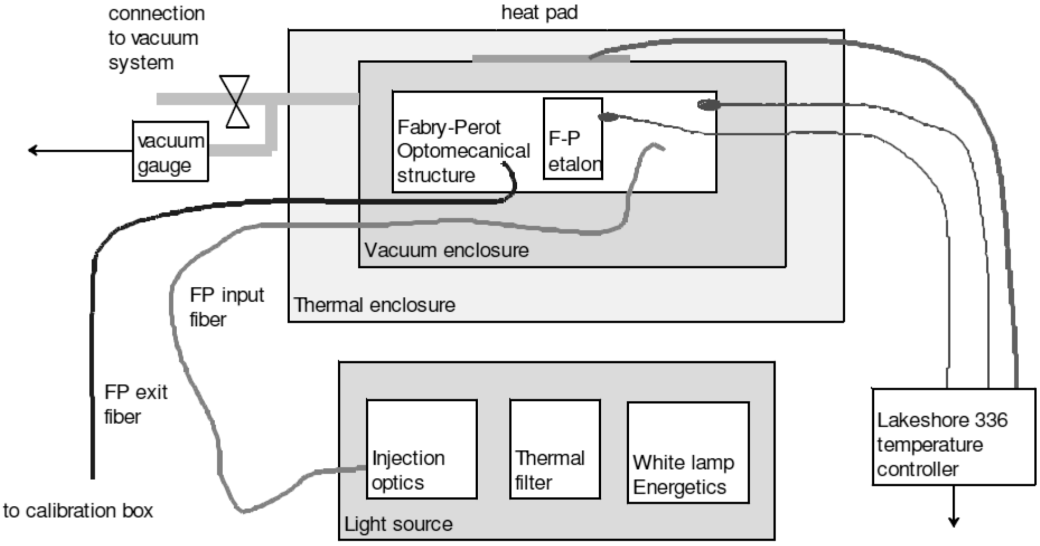

Figure 3: Block diagram of the RV reference source.

3. GUIDING WITH SPIROU

To achieve the 1 m/s RV precision required by SPIRou, it is necessary that the light from an observed object fill the fiber in the same way on each return visit to the object (many visits per object are needed to determine the RV curve of the object and find planets). Mainly, it is necessary that the center of the star image falls on same place on the fiber to high precision. The requirement placed on the guiding for SPIRou is that the center of the star image falls on the same spot on the fiber to within 30 mas on each return visit.

The stability of the illumination of the spectrograph is critical for obtaining very accurate radial velocity measurements. The centering of the stars at the entrance of the fiber has important consequences for the light distribution at the fiber output. This illumination variation directly translates into the spectrum on the detector and therefore into spurious RV variations[5,6] caused by the spectrograph geometrical field and aperture aberrations. To limit this effect, SPIRou will be equipped with a fiber link using an octagonal fiber[7] which scrambles the light in a ratio of a few hundred up to a thousand to one. Despite this very good scrambling it is necessary to place a tight requirement on the guiding in order to minimize this important source of error in the RV error budget.

In using results obtained on SOPHIE[7] (an optical, radial velocity spectrograph with 2m/s accuracy at Observatoire de Haute Provence, France) we show that, if the star is centered on the fiber with an accuracy of 30 mas and maintains this center, on average, to a precision of 30 mas RMS, the guiding contributes an error of about 0.17 m/s. Because of the different optical configuration of SPIRou, this same level of guiding error should contribute about 0.11 m/s to the RV error. This is significantly smaller than the 0.3 m/s allowed in the SPIRou RV error budget, allowing plenty of margin.

If long integration times are possible (>5-10 minutes), this level of centering repeatability can nearly be achieved with on-object telescope guiding as has been seen using the ESPaDOnS spectrograph at CFHT (~50 mas for 5 minute exposures). However, many of the SPIRou objects desired for high-precision RV measurements will be quite bright. To meet the requirements of the science goals for SPIRou, it is necessary to achieve the 30 mas centering repeatability for observations as short as 10 seconds, which will require fast steering of the input star image.

There are a variety of sources within the telescope system that contribute to the wander of the star image during observations. Most are fairly low frequency, but one major contributor, windshake, occurs at the lowest natural frequency of the telescope which is around 3 Hz. To well correct this perturbation, it will be necessary to sample and correct at a frequency of at least 30 Hz, and 50 Hz would be better. Removing atmospheric tip/tilt would also be beneficial in improving the seeing, but removing the seeing is not necessary to achieve the re-centering requirements and so will be a secondary consideration.

Fast guiding, while not trivial, is something that has been done before. The challenge with SPIRou, however, is that, ideally, guiding would take place using the object to be observed as a reference. However, this light is also needed in the spectrograph to do science.

Alternately, a star near the science object could be used, but needs to be fairly bright to provide the photons needed for fast guiding and also needs to be fairly close to the object since the guider field-of-view will be limited. Typically, the objects observed with SPIRou will be the brightest object in the neighborhood, so offset guiding will not always be possible.

The solution settled on for SPIRou is to use, like HARPS and SOPHIE, the object star as a reference by picking off ~4% of the light using a plate of glass that is uncoated on one side. A diagram of the pickoff mirror is shown in Figure 4.With this solution, we will be able to achieve full correction to 50 Hz or more on brighter stars that will have short integration times. On dimmer stars, full 50 Hz correction will not be possible, but these stars will require a much longer integration time still allowing the system to meet the repeatability requirement. Offset guiding will only be used for very faint objects for which high-precision RV measurements are not possible.

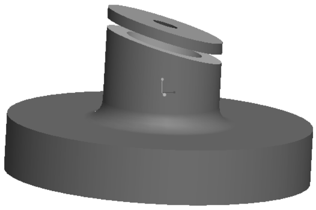

Figure 4: Field stop and guiding pickoff. The dark area in the middle represents the uncoated portion of the mirrored surface. This section is shown on top for clarity but will actually be pointed down to protect the mirror coating.

Since the guiding optics and detector will need to be off of the telescope axis, it is also necessary to ensure that the guiding system has not drifted with respect to the fiber input. While all efforts will be made to make the structure mechanically stiff so that drifts at the 30 mas level (4 µm at the f/8 focus of the CFH telescope) do not occur, for an instrument with the stability goals of SPIRou this will need to be verified. The guiding software will estimate from the image the position of the hole at the beginning of the exposure.

Ideally an image of the star on the fiber would be used for this verification, but that image is not readily available without making other parts of the instrument much more complex. In the case of SPIRou, the next most obvious place to verify the centering of the guiding is at the field stop, which is necessary to limit the amount of structure and sky seen by the fiber. The field stop is co-axial, mechanically, with the fiber, so it should be less susceptible to motion relative to the fiber in a stiff mechanical system.

In view of the added expense required for a totally separate viewing channel (especially the detector) and the added complexity of two separate viewing channels on the same detector, the two functions have been combined for SPIRou. The field stop will be a mirrored, plane-parallel glass plate with a pinhole in the center the size of the fiber projected back to the f/8 focus. The other side of the plate (facing up) will be anti-reflection coated to reduce ghosting and improve throughput. The areas of the field stop outside the aperture will be used for object acquisition.

This solution provides the complication that the core of the star image will be fairly dim at ~4% reflectivity while the edges of the star image will be brighter at >98% reflectivity. Section 3.1 will give more details on the fast guiding image acquisition, correction and control loop, including centroid measurements using these odd images while section 3.2 will give more details on the centering verification and slow guiding with SPIRou.

3.1 Fast Guiding

At the beginning of an observation, the whole field-of-view of the guider camera will be read for target star acquisition. After centering the target star, the window size will be reduced to a 32×32 area around the target star that will be used for the image stabilization and centroid estimation. The guider window will be continuously read and reset only when the pixel signal reaches about half of the saturation level. The window will be sampled every 2.5ms using a pixel rate of 500 kHz. The image used for the tip-tilt correction is obtained by differencing two adjacent co-added frames composed of the 4 frames taken over a 10ms interval. This technique is called the Differential Multi-Accumulate Mode[1]. See figure 5 for a simple timing diagram.

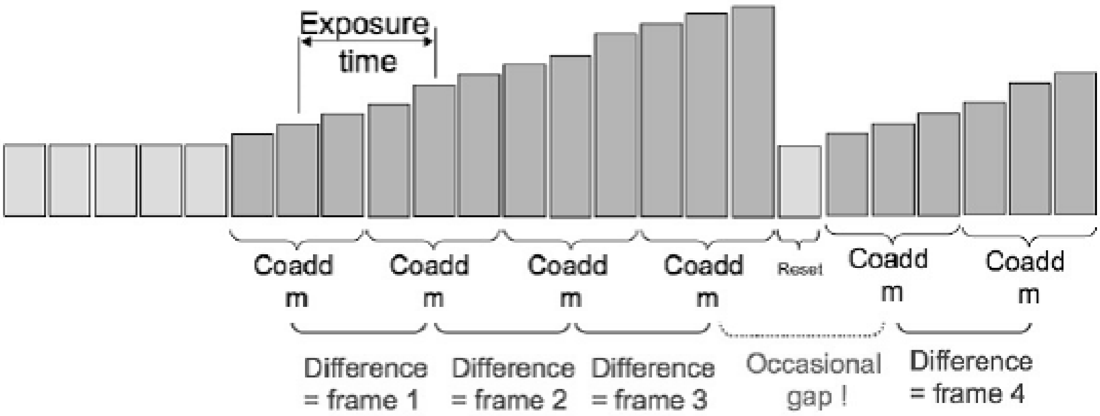

Figure 5: Simplified timing diagram for the guider readout. Resets occur when the signal in the 32×32 window reaches half the saturation value. This graph describes the Differential Multi-Accumulate Mode[1].

For fainter stars, the flux is not enough for 100Hz sampling. More frames are needed for the co-add frames with a total integration time of 80 ms interval needed for the faintest RV target stars with H=11.5 magnitude. The co-add function will be handled by the array controller. The co-added frames will be saved for troubleshooting and for possible use in correcting the RV measurements. All frames before the reset will be saved and stacked to determine the centroid stability of the target star, the possible motion of the field stop relative to the guider, and the seeing condition for the observation.

The centroid algorithm of the tip-tilt image is critical to the tip-tilt correction. With 100Hz images, the centroid needs to be calculated quickly in order to minimize the latency of the servo loop. Typically, curve fitting (Gaussian or Lorentzian) gives better centroid estimations but with the possibility that the fitting could fail to converge and a variable calculation latency. A centroiding algorithm based on a center-of-mass calculation feeding a Gaussian curve fitting routine to find the point spread function of the image is under development with simulated images. Examples of simulated images are given in Figure 6 for different seeing conditions.

The detector, currently designed to be an engineering-grade Hawaii 2RG, will be read using either a cold Teledyne ASIC controller or an Astronomical Research Corporation controller depending on which one provides the best noise performance. The pixel data will be sent to a Linux-based PC (guiding PC) where the centroiding calculations will take place.

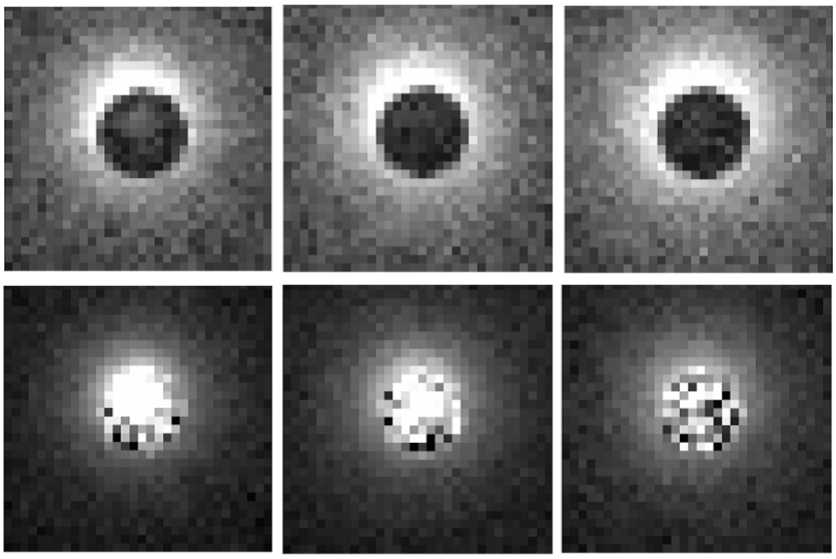

Figure 6: Simulated SPIRou guider images for an H=10.5 star with an 80ms integration time and three different seeing conditions (0.65”, 1.05”, 1.45”). The top row are the images as observed, the bottom row are the images after correcting for the differences in reflectivity between the hole and the mirrored areas. The noise is amplified for the center section of the bottom row since there is less flux.

The fast steering mechanism (ISU or image stabilizing unit) will be operated through a servo loop to maintain a stabilized image at the input of the polarimeter. Figure 7 shows a block diagram of the ISU control loop.

The mechanism, from Left Hand Design Corporation, is capable of tilting the optical correction plate, a 20 mm thick fused silica window, about two perpendicular axes. The mechanical assembly contains position sensors and actuators needed to accurately drive the plate to a given tilt.

The control of the ISU is done using the servo control electronics chassis (SCEC), also provided by Left Hand Design, and is contained in a VME-6U 19 inch (483mm) wide mountable rack. The SCEC contains the position servo control board (SCB), the sensor demodulation electronics (SDE) and the power supplies needed to drive the mechanism.

The guiding PC will be used to compute the centering errors from the guide images, determine the tip-tilt correction needed on the ISU, and send the necessary corrections to the SCEC. It will also keep track of the position of the ISU. The guiding PC will use a PowerDAQ PCI board to interface with the SCEC. The PowerDAQ board will command the SCEC by providing analog voltages proportional to the desired correction on each axis. The PowerDAQ board is also capable of reading the outputs of the SCEC to determine the current ISU tilts.

3.2 Slow Corrections

For SPIRou, it is important that not only does the guiding system correct for telescope drift and positioning, but that it also keeps the star well centered on the fiber. Unfortunately, an image of the fiber with the star is not practically available for viewing. The next best thing is an image of the field stop which is what will be viewed with the guide camera.

It is probable that the center of the field stop with respect to the guide camera will not change much with time, or at a very rapid rate. The changes that do take place will be due to flexure in the instrument and temperature changes primarily. Obviously, the position of the field stop relative to the fiber is not immune to these effects, but it is expected that they will be smaller since the field stop is closer to the fiber than the guider and is also coaxial with the guider.

Since the rate of change of position is likely to be small and slow, it is not necessary to determine the center at the full ISU loop rate. This means that many of the ISU image can be stacked together, greatly increasing the signal-to-noise on the images. By allowing the center of the “hole” in the image to be a free parameter in a Gaussian fit, it should be possible to very accurately determine the center of the hole and the position of the star in the hole at a rate of around 1 Hz.

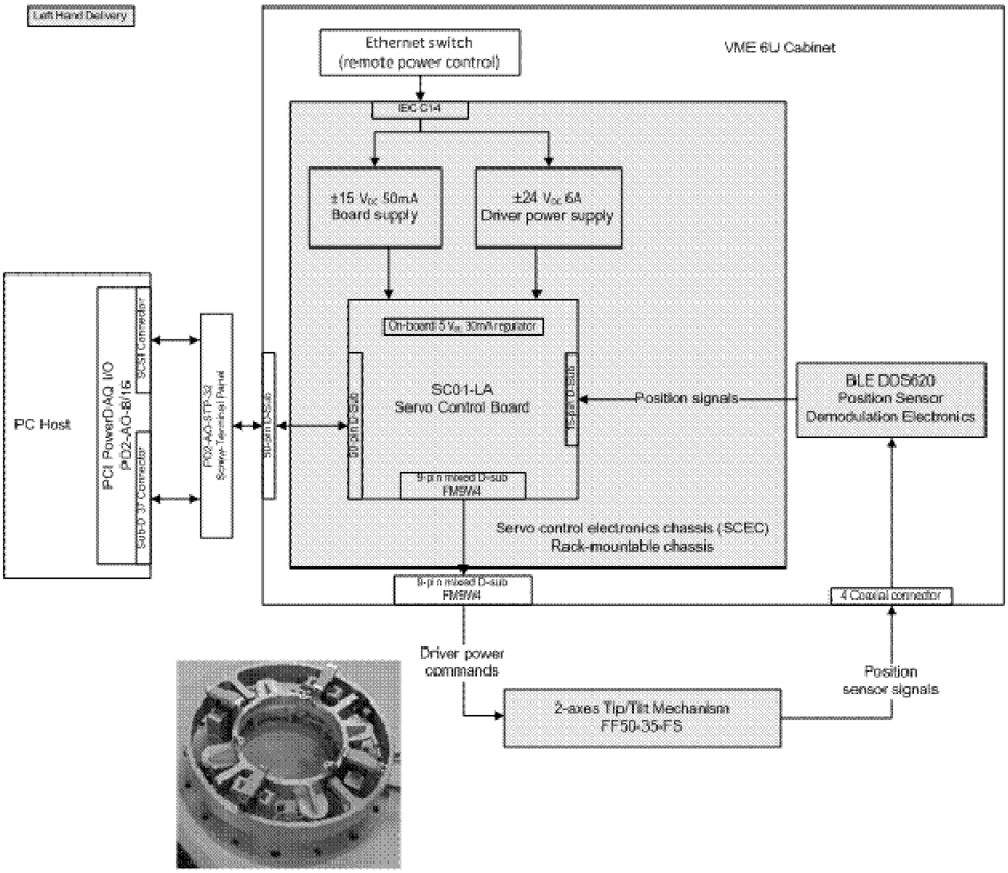

Figure 7: Block diagram of the Left Hand Design Corporation servo control system for the fast steering mechanism.

If it is found that the center of the hole has moved beyond a certain threshold, this information can be fed back into the fast-guiding loop to improve the centering of the star. In addition, these 1 Hz images from throughout a given exposure can be stacked to provide information about the centering of the star throughout the image and the overall seeing during the observation.

Finally, it will be necessary to periodically update the telescope position to ensure that the ISU does not exceed its range of motion. The position feedback from the ISU will be used to determine the average tilt of the ISU over periods of 1 second. This average tilt, properly scaled, will then be sent to the telescope control system to move the telescope and allow the ISU to remain near the center of its travel.

The overall control loop for the guiding is summarized in the flowchart in Figure 8. The basic idea is: 1) Take an image. 2) Find the centroid of the star. 3) Send guiding errors to the ISU. 4) Find the center of the star and hole if the signal-to-noise ratio is sufficient. 4) If the hole center has moved appreciably, update the reference position for the fast-guiding loop. 5) Once per second, calculate the average position of the ISU and send this as a correction to the telescope.

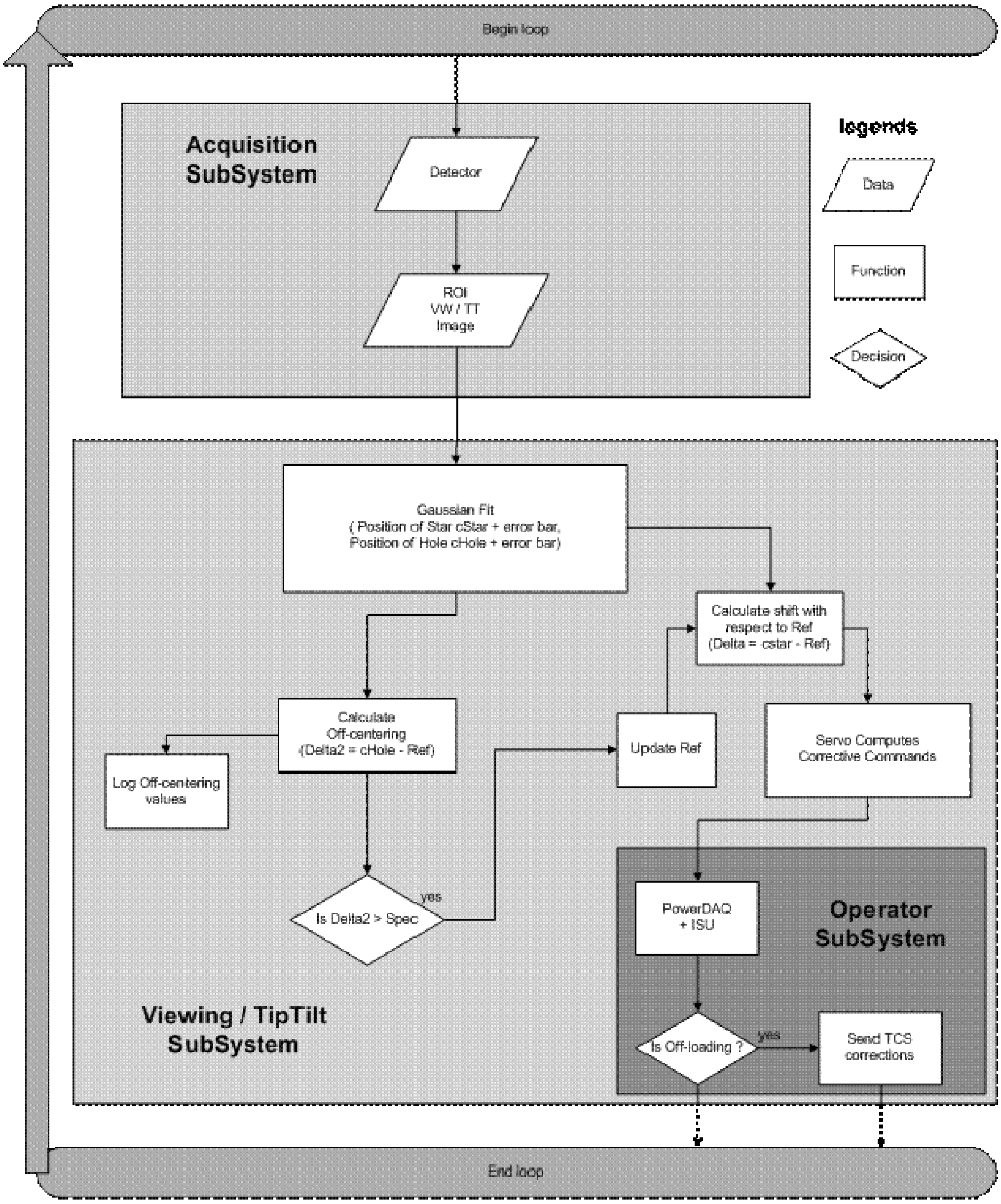

Figure 8: Flowchart outlining the control loop for guiding with SPIRou.

Figure 9 shows some results of a simulation done to determine the performance of the guiding system. The upper set of plots show that, with wind shake, the tip-tilt system is not able to keep the RMS center of the star in the hole to within the 30 mas requirement for dimmer stars. This is expected since the necessary integration times with dimmer stars will not allow sufficiently fast correction to correct for the wind. The lower set of plots in the figure show, however, that averaging the center over a longer period, 30 seconds in this case, does bring the center of the star onto the center of the hole to the necessary precision. Since dimmer stars will require longer exposures, this indicates that the guiding system will easily meet the requirements.

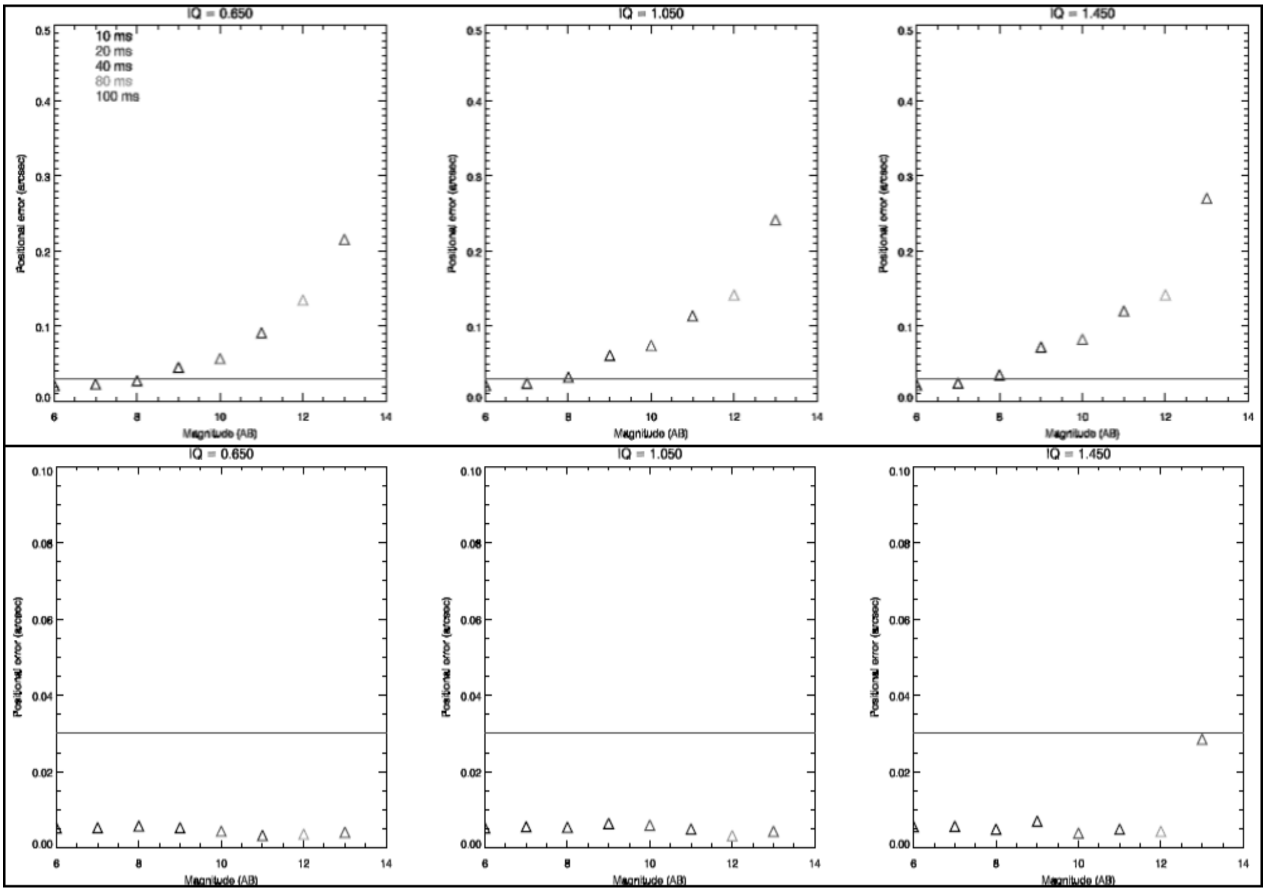

Figure 9: Results of a simulation of the guider performance. The upper set of plots show the RMS error of the tip-tilt measurements for different stellar magnitudes. The lower set of plots show the RMS error of the star center, as measured by the 1 second stacked images, relative to the hole center for 30 seconds of images. The magnitude is AB magnitude which is about 1.5 magnitude higher than H magnitude (*e.g.* an AB magnitude of 13 corresponds to an H magnitude of 11.5). Wind shake is present in all of the simulations.

4. SPECTROGRAPH THERMAL STABILITY

Even more important to allowing SPIRou to achieve 1 m/s RV precision is the stability of the spectrograph. One key requirement necessary to achieve this precision is that the motion of the spectral lines on the detector must cause an error of <0.5 m/s which corresponds to ~1/3000 of a pixel in the dispersion direction and ~1/300 of a pixel perpendicular to dispersion. For thermal control this equates to reducing temperature variations on the spectrograph optical bench to a level of ~1 mK RMS during a night of observations.

The basic concept for the spectrograph thermal control is to stabilize the temperature at a variety of locations in the spectrograph with increased stability as you get closer to the optical bench.

The first level of thermal stability was achieved by placing the spectrograph in the CFHT coudé room instead of on the observing floor of the telescope. The observing floor has day to night temperature variations of 4-5°C and yearly variations of 10-15°C while the coudé room, which is in the center of the observatory building under the telescope pier, has daily temperature variations of <1°C and yearly variations of <10°C. This will keep the heat load on the cryostat fairly constant.

The next level of stability comes from a passive heat shield around the optical bench within the cryostat. This shield is loosely coupled to the cooling system and is allowed to float with varying heat loads. This improves stability by passively compensating for the heat loads on the spectrograph from the environment.

The third level of stability is an active heat shield inside the passive heat shield. This heat shield will be strapped to the cold buss of the system, and the temperature of this heat shield will be actively controlled to a level of ~10 mK in three locations.

The final level of stabilization comes on the optical bench itself. The bench will be strapped to the cold buss and the temperature of the bench will be actively controlled in 3 locations to a level of ~1 mK. In addition, the detector package will be coupled to the optical bench using a copper strap, and its temperature will also be controlled to a level of ~1 mK. This last control point is necessary since the detector is the one internal heat load that will be used during observations, and it is also a variable heat load.

Figures 10 and 11 show a diagram of the spectrograph with the locations of the cold straps and the measurement/control points within the spectrograph, respectively.

This scheme will obviously not hold all parts of the optical bench at the same temperature. This is not required. It will, however, hold the variations in temperature of the bench to the required ~1 mK level.

This paper will cover the control aspects required for the temperature stability. For more on the overall aspects of the temperature stabilization, see “Cryogenic mechanical design: SPIROU spectrograph” which is Paper # 8446-171 in this conference[2].

Section 4.1 describes the solutions found for sensing temperatures to the needed precision. Section 4.2 describes the solutions found to hold the temperature of the optical bench to the necessary levels.

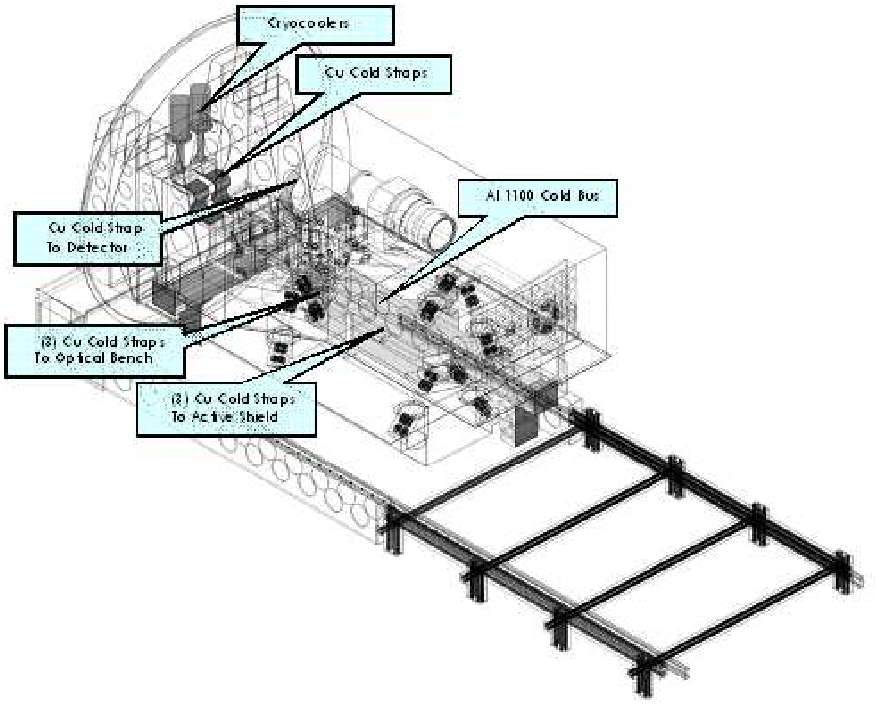

Figure 10: Drawing of the SPIRou cryostat indicating the approximate locations of the cold straps in the cryostat.

4.1 Temperature Sensing

In controlling temperatures, or anything else for that matter, it is necessary to measure the temperatures to a higher precision that the desired level of control. To do this, one needs not only temperature probes of sufficient quality, but, as the needed precision increases beyond normal temperature measurements, the readout electronics need to become more sophisticated.

The active heat shield temperature probes need to be moderately stable and be capable of measurements with precision < 10 mK. This level of precision and stability is present in many normal RTDs. The type chosen for SPIRou for use in three locations on the active shield are Omega ceramic wire-wound platinum RTDs.

For the optical bench, measurements with precisions < 1 mK are necessary. In addition, the sensors need to be stable with time and thermal cycling, so normal RTDs will not be sufficient. In this case, standard platinum RTDs (SPRT), which are specially made platinum RTDs typically used in temperature calibration labs, have the necessary precision and stability for the needs of SPIRou. The RTD chosen for use on the SPIRou optical bench is the Hart (Fluke) 25 Ω glass capsule SPRT.

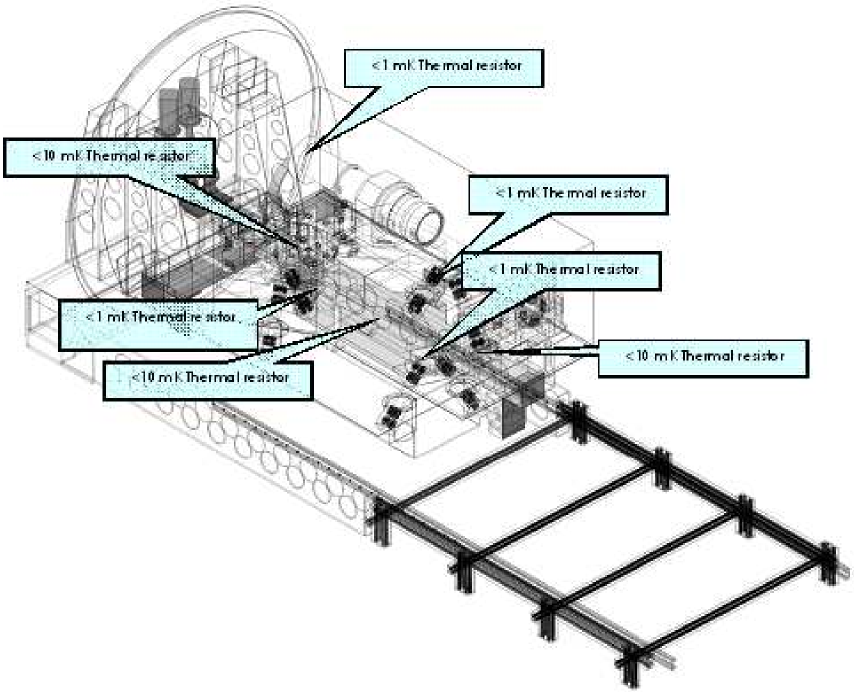

Figure 11: Drawing of the SPIRou cryostat with the locations of the temperature measurements indicated.

The precision of any of these sensors is mainly a function of the readout electronics. To achieve the necessary precision for the optical bench, special low noise and low drift electronics need to be used. The solution found to do the high precision temperature measurements is the IsoTech MicroK 500 thermometry bridge.

Even though the high precision is not necessary, the MicroK 500 will also be used to read the active shield RTDs as well as any other RTDs placed within the system, such as on the passive heat shield.

4.2 Temperature Control

The temperatures also need to be controlled, not just measured. The normal method for controlling temperatures is to raise the temperature at the control points above the normal base temperature by a few degrees using resistive heaters, then regulating the temperature by controlling the heater current based on feedback from the temperature measurements. PID-based controllers are quite good at handling the feedback loop for the temperature control.

The heaters chosen for SPIRou are all Minco polyamide Thermofoil heaters. 25 W heaters were chosen for the active shield since the mass of the shield will be moderately small. 50 W heaters will be used on the optical bench since the thermal mass of the bench is much greater. In all cases, the heaters will be placed near the location of the temperature sensor used to drive them.

The PID control of the temperature regulation is relatively straightforward and is well within the abilities of many common controllers. The biggest issue for SPIRou is the number of independent loops (7) that need to be controlled. The controller also needs to be able to read the data from the MicroK 500 which is able to communicate via RS-232 or Ethernet. The search for an appropriate solution for the PID controller continues.

5. SUMMARY

The design of the SPIRou control system is well advanced and is set to meet the challenges posed by an instrument required to measure radial velocity to a precision of < 1 m/s. There are some challenging aspects to the control system, such as the on-axis guiding with partial flexure compensation and the extreme thermal stability necessary for the spectrographic part of the instrument. Thanks to the hard work of the people in the many institutions contributing to the SPIRou consortium, all the challenges, from the mundane to the unusual, are being met to make SPIRou a one-of-a-kind instrument for the CFHT.

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