Evaluation of the ARC Controller for the NASA IRTF

Anthony Denault, Charles Lockhart, Eric Warmbier, John Rayner

2012.01.24

TOC

1. About this document

This document discusses the potential use of the ARC Controller at the NASA IRTF. A brief description of the ARC controller will be given, some background on the controller's use at the IRTF and related organizations, and a description of the ARC controller's capabilities compared against the requirements of IRTF instrumentation.

1.1 Introduction

The NASA IRTF is currently upgrading two of it's instruments, SpeX and NSFCAM2, while also building a new third instrument, iSHELL. All three of these instruments use the HAWAII-2RG devices, with SpeX and iSHELL also both using Aladdin II/III devices. Effort is being made to capitalize on that commonality by using identical or similar controllers for all three cameras.

In reviewing the array controller requirements of the IRTF instruments, IRTF staff chose Astronomical Research Cameras, Inc.'s Gen III array controller as the most likely candidate to fit its needs. Based on input from users of ARC controllers in the community, as well as limited testing by IRTF personnel with both a Gen III ARC controller in isolation and a Gen III ARC controller based camera, this document will show that the ARC Gen III controller will meet the majority of the IRTF requirements in terms of noise, throughput, and reliability, and does match the performance limitations of the HAWAII-2RG as described by the manufacturer, Teledyne Scientific & Imaging, LLC (formerly Rockwell Scientific).

This paper recommends that the IRTF selects the ARC Gen III controller and begins development for those upcoming instruments.

2.0 Array Controller Needs for the IRTF

2.1 New Instrument: iSHELL

In 2008 the IRTF recieved funding for building a new instrument, iSHELL. This instrument would be similar to SpeX in that it would have a spectrograph and an imager/guider. The spectrograph would use a HAWAII2RG science grade array. The H2RG devices have very low readout noise compared to the Aladdin II/III devices used in SpeX, and require electronics with better noise performance, as well as the ability to handle data from a 2Kx2K pixel device (SpeX's electronics use Aladdin II/IIIs, which are 1Kx1K pixel devices). This generated the need for the IRTF to adopt a new set of electronics to meet this need.

2.2 Instrument Upgrades: SpeX and NSFCAM2

The IRTF has also received and dedicated funding towards upgrading the SpeX instrument with a H2RG for its spectrograph and a new array controller. As with ISHELL, this creates a need for a next generation of controller electronics that can take advantage of the H2RG's lower read noise and larger format.

For SpeX, this also meets the needs of the instrument's overall health. SpeX was commissioned in 2000, with the electronics having been designed in 1997. This makes the SpeX instruments electronics and support computers 15 years old. Towards the end of 2011 SpeX experienced a failure of it's SPARC VME CPU board. It is currently running with the IRTF's last spare. Attempts to acquire another spare CPU board have so far been unsuccessful.

NSFCAM2 will receive an upgrade for the controller electronics and have the current H2RG array replaced with a higher quality engineering grade array.

3.0 The ARC Controller

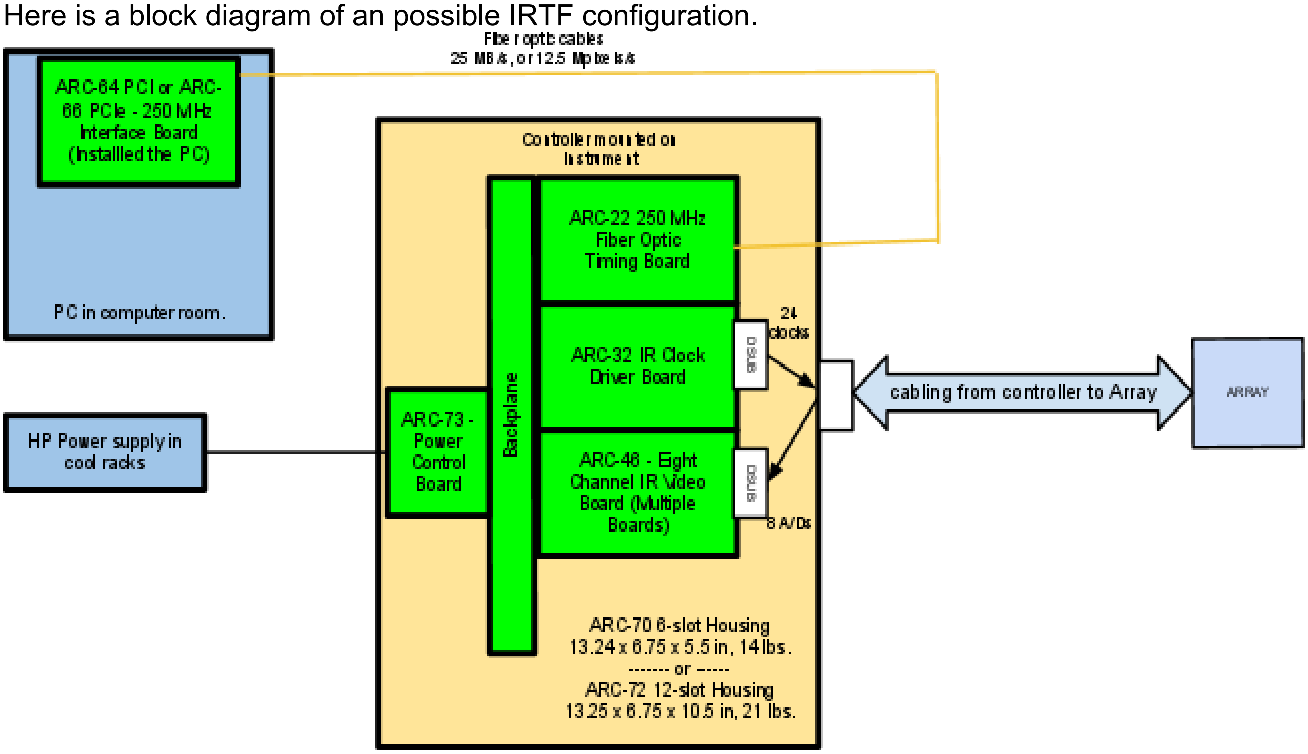
Background on Astronomical Research Cameras (ARC)

Astronomical Research Cameras (ARC, website at http://astro-cam.com)is a company run by Bob Leach which provides CCD and IR array controllers. Originally Bob Leach was with SDSU, and the ARC Controllers are often referred to as "Leach Controllers" or "SDSU Controllers." The current controller provided by ARC is the 3rd generation of their basic controller, which was mostly recently updated in 2007 with newer and better ADCs[1].

3.1 The ARC Hardware

The ARC Controller supports both H2RG arrays (1-output, 4-output, and 32-outputs) and Aladdin II/III arrays (8, 16, or 32 outputs) , both of which are used in the ongoing camera upgrades and development. Their website lists other infrared and CCD supported devices.

Here is a block diagram of an possible IRTF configuration.



This table summaries the possible configurations for NSFCam, SPEX, and IShell.

	Aladdin	**H2RG 32 ch**	**H2RG 32 ch + 8**	
ARC-70 6-slot housing with backplane	1	1		2K
ARC-72 12-slot housing with backplane			1	3K
ARC-73 Power Control Board	1	1	1	.4K
ARC-22 Fiber Optic timing board	1	1	1	2.5K
ARC-32. IR CLock Driver board.	1	1	1	2.5K
ARC-46 Eight channel IR Video board	1	4	5	6K. Configured with jumpers and components for each detector.
Arc-66 (PCIe) or Arc-46 (PCI) Interface board.	1	1	1	3K.
Approx Cost	$17K	$35K	$41K	

The H2RG "32 channels +" is a H2RG configured with 5 ARC-46 Video boards. Besides the 32 data input channels, the extra 8 channels of input could be used for the internal reference capacitors, windowing mode, and/or internal H2RG temperature monitoring.

The Aladdin 2 system uses a single video board (8 channels) for the 512x512 guiding array. Support for a full 1024x1024 would require 3 additional video boards (8 ch * 4 = 32 channels).

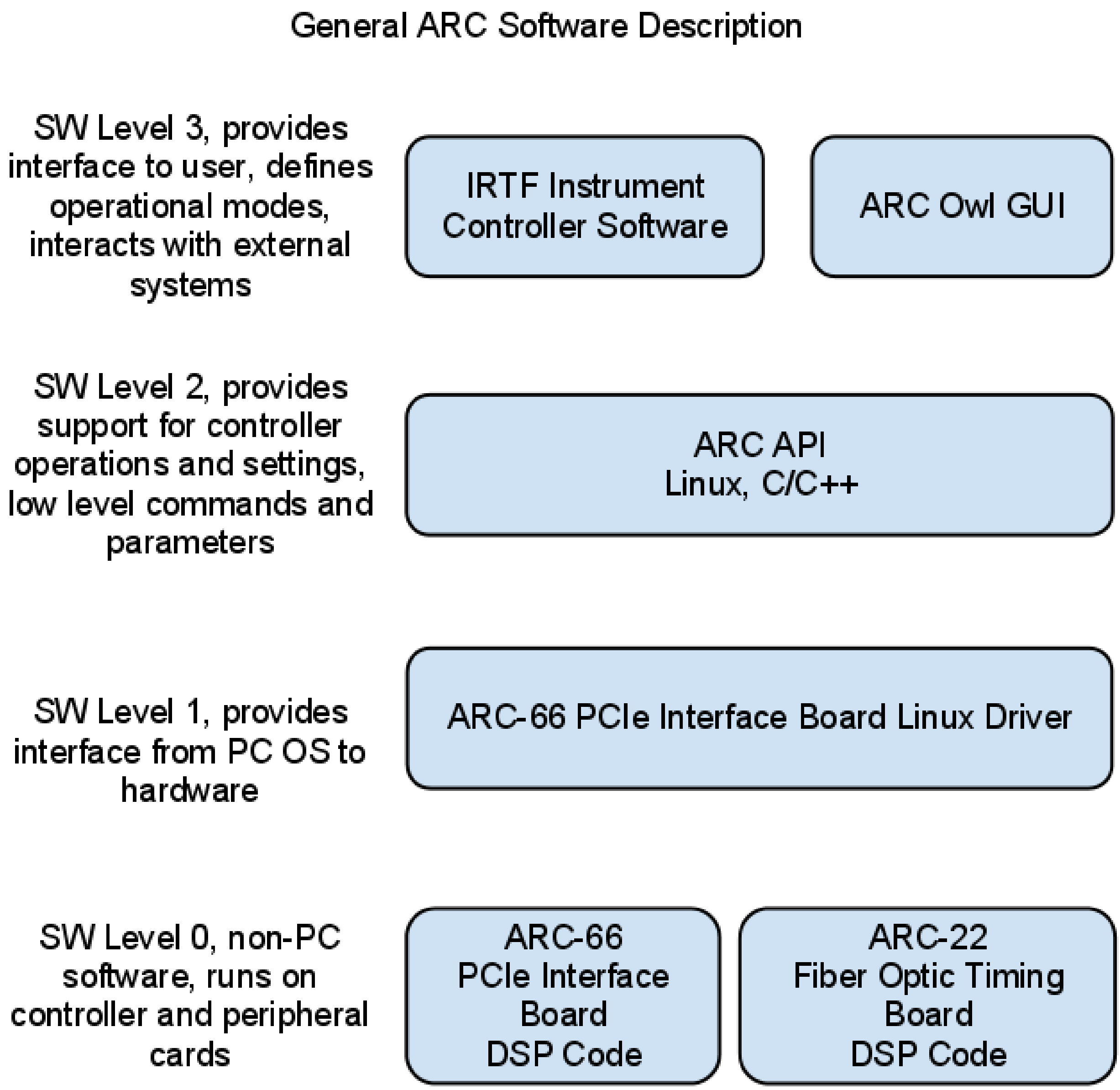
ARC controller component pricing:

Part Number	Description	Price	Comments
ARC-22	Gen III Fiber Optic Timing Board	$2,500	
ARC-32	IR Clock Driver Board	$2,500	
ARC-46	Eight Channel IR Video Board	$6,000	
ARC-50	Utility Board	$2,000	
ARC-66	Gen III PCI-Express Interface Board	$3,000	
ARC-70	Six Slot controller housing	$2,000	
ARC-72	Twelve Slot controller housing	$3,000	
ARC-80	Large Power Supply	$2,000	

3.2 The ARC Controller Software

The ARC software is free, and can be downloaded from the astro-cam web site. The code is a mix of custom and generic elements, and will require some customization by the IRTF. Full source code is provide. Shown here is a diagram of the ARC software needed by the IRTF, with an entry for where the IRTF instrument controller software would fit, replacing the ARC Owl software.

The source code at the API, device driver, and DSP level is written in a simple, straightforward matter that makes it easy to customize or add to. Basic operations and operational concepts are already largely supported.



1. Owl Imaging Acquisition Software - The vendor's acquisition software. The IRTF will use Owl for initial testing and checkout, then replace it with its in-house instrument software and GUI.

2. ARC API - A vendor supplied API for interfacing with the controller (AstroPCI or AstroPCIe and ARC-66 Fiber Optic Timing Board) via the interface board's device driver. Provides a generalized interface that allows for easy setup and readouts. This is used by Owl, and will be used by the IRTF instrument controller software.

3. AstroPCIe or PCI Board Device Driver - Software to communication with the PCI board. Used by the API software or custom application to communicate with the ARC controller.

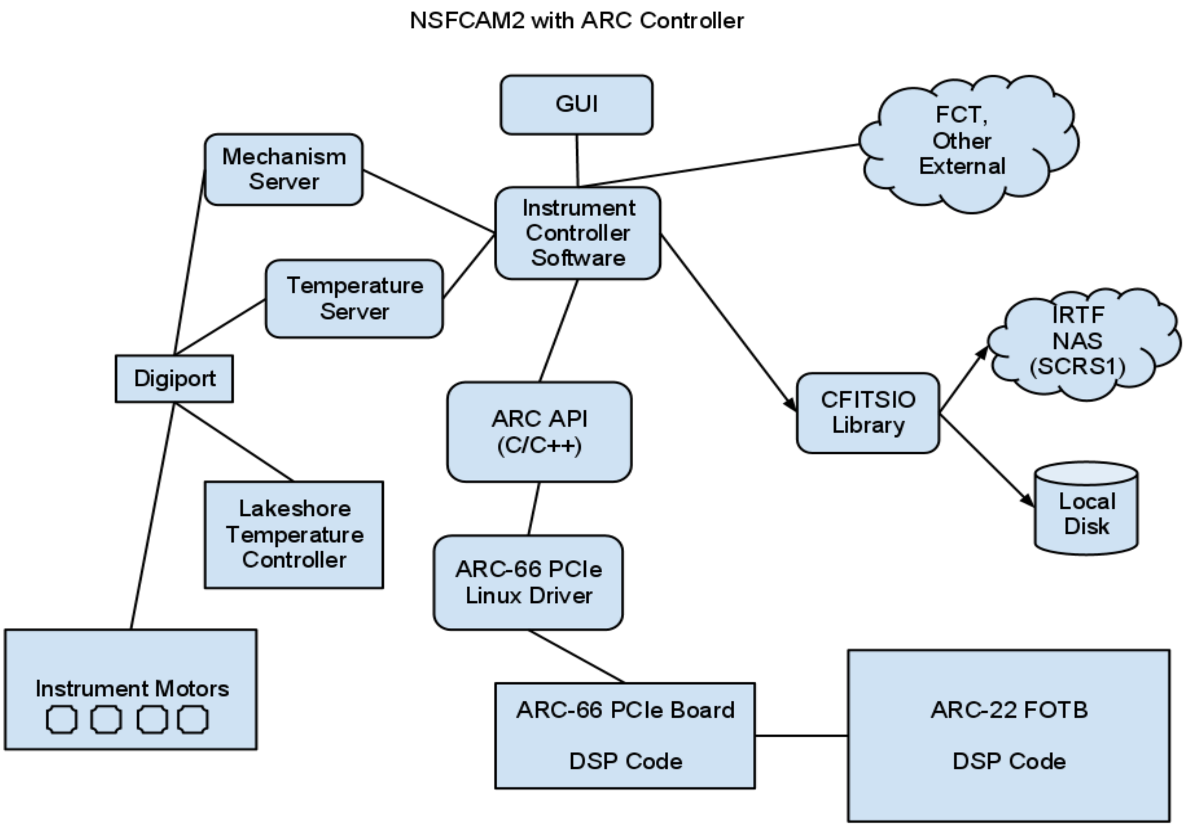
4. DSP Firmware - DSP code loaded loaded by the acquisition software to the ARC-22. Must modified based on array and desired array operations.

5 DSP Tool - Tools to compile the DSP Firmware.

Astro-cam software page is at: http://www.astro-cam.com/arcpage.php?txt=software.php

3.3 NSFCAM2 Software with ARC Controller

The following diagram illustrates the hardware and software components in the updated NSFCAM2.



4.0 ARC Systems in use

4.1 Current use of the ARC Controller at the NASA IRTF

MIRSI is the only IRTF instrument that currently uses an SDSU controller (the controller used in MIRSI is a generation II controller, the ARC controller under consideration is a generation III). The controller has a reputation at the IRTF as being unreliable and difficult to use, both software and hardware. (Iin 2006-2007 a more "IRTF standard" GUI was overlaid on top of the original software, and the original Sun workstation was replaced with a linux box, which made the camera more usable, but didn't affect some of MIRSI's more serious issues). However this is a 2nd generation controller, with boards dating back to 1997 (timing and utility board) and 2000 (video boards).

In addition to the main controller electronics, there is a PCI Interface Board. The PCI board that came with MIRSI was very problematic. The MIRSI upgrade team went through 8-10 different PCs when trying to find one that would work with the PCI board. Most would not boot with the PCI card installed. The current MIRSI pc had the best results, and even so has some very odd problems, including occasional system freezes, occasional reboot requirements, and a very odd start up procedure after the system has been de-energized.

The ARC Controller was briefly considered in 2008/2009 as a potential controller for upcoming IRTF instruments (NSFCAM2 upgrade, SPEX upgrade, ISHELL), but based on the negative experiences with the controller we have for MIRSI, it was quickly discarded as an option.

4.2 Use of the ARC Controller at other organizations

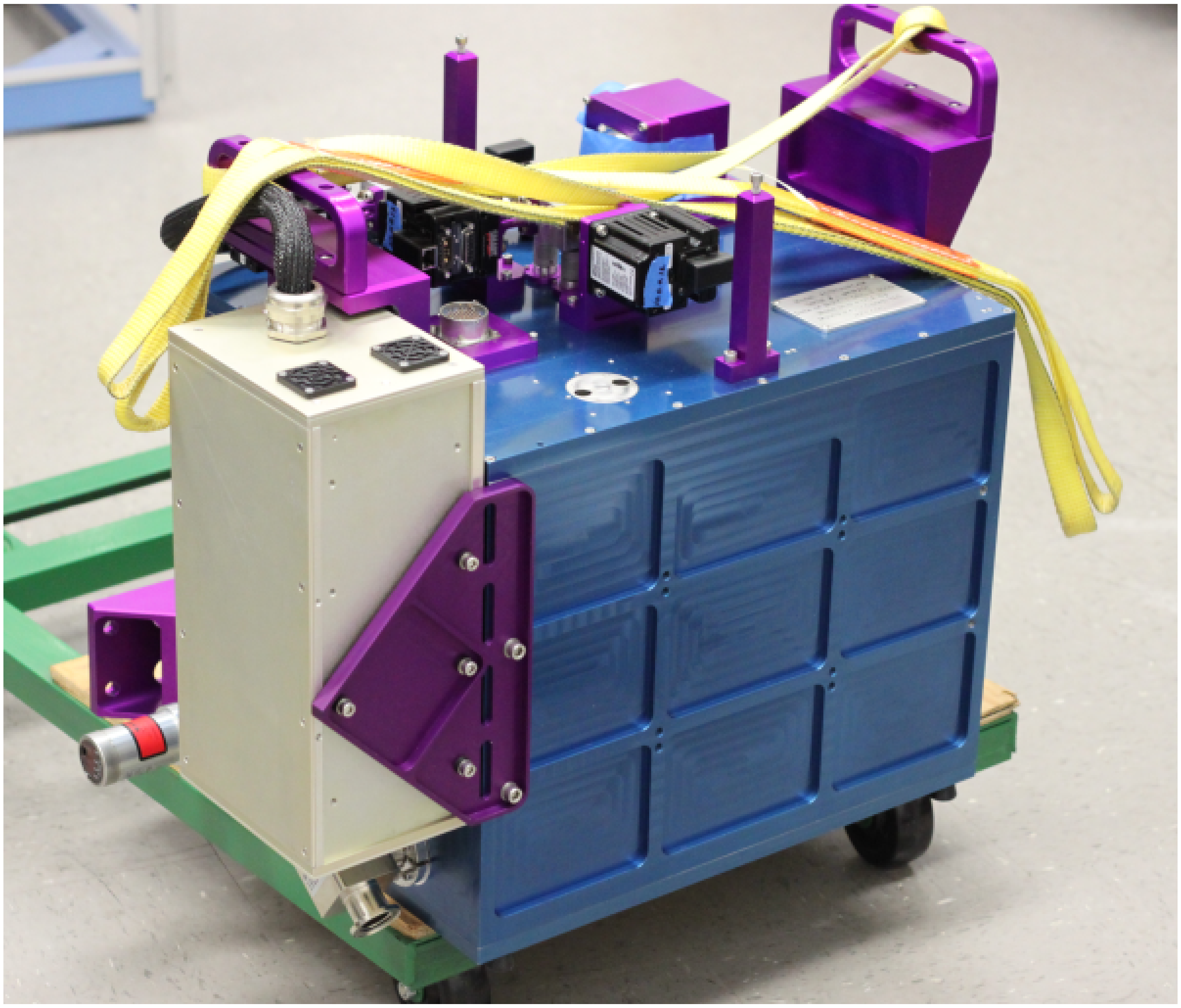
4.2.1 CFHT

Other Mauna Kea facilities known to use the ARC Controller include CFHT with it's WIRcam instrument. Jeff Ward, one of the primary engineers who worked on WIRcam, has reported noise levels in the range 15-20e- with the CFHT ARC Controllers.

4.2.2 MKIR

MKIR is also building an instrument called ASTRONIRCAM (ANC) that uses an ARC Controller and H2RG array. MKIR purchased an ARC Controller for ASTRONIRCAM mid-2011, and is currently up and running with that controller. Initial data indicates noise levels for a single coaded image are 2-3 ADU of noise, with a calculated e-/ADU conversion of 5, and a measured e-/ADU conversion of 6. The instrument responds well to the use of NDRs, with 16 NDRs giving a result of approximately 0.8 ADU of noise as measured in a 50 by 30 pixel box. Investment of personnel resources is under four months, and has primarily been matching the provided software with the needs of the instrument. The current pixel time for ANC is 5 µsecs. This would be a pixel rate of 200Khz. The target pixel time for ANC is 3 µsecs, which would provide a pixel rate of 300Khz, which is about as fast as recommended in the H2RG manual[2].

NOTE 1: Science requirements for IRTF are more rigorous than for ASRTONIRCAM and performance comparisons must take that into account.



ASTRONIRCAM with 6-slot ARC Controller mounted (courtesy of MKIR).

4.2.3 Community Feedback

As part of this investigation we interviewed several users given as references by Bob Leach who are using ARC controllers with the H2RG in 32 output mode.
Overall feedback was very supportive for using the ARC controller with the H2RG device in a manner identical to what is described in this document and required by the IRTF, and in fact it was reported that some users were using ARC / H2RG configurations that exceeded the probable requirements of the IRTF. Users indicated that they achieved a high degree of stability of operation and throughput with the ARC / H2RG pairing. Pixel readout rates in 32 output mode were reported to exceed 300 kHz.

Users noted that they were able to achieve a stable configuration where noise levels were device limited, though it was unclear if that condition was achieved in a lab environment or with working instrumentation in an environment similar to the IRTF.

It should also be noted that feedback included warnings regarding the need for a good grounding solution, and the possible requirement of additional filtering mods made to the board. This is a likely requirement of any array controller system.

Overall feedback from the community is highly supportive that the throughput and stability issues can be resolved by the IRTF.

4.3 Measured Performance of the ARC

4.3.1 Gain Testing

In order to determine other characteristics of the controller, it is necessary to calculate the system gain. The ARC Gen III controller has a software selectable gain option for selecting between low gain and high gain settings.

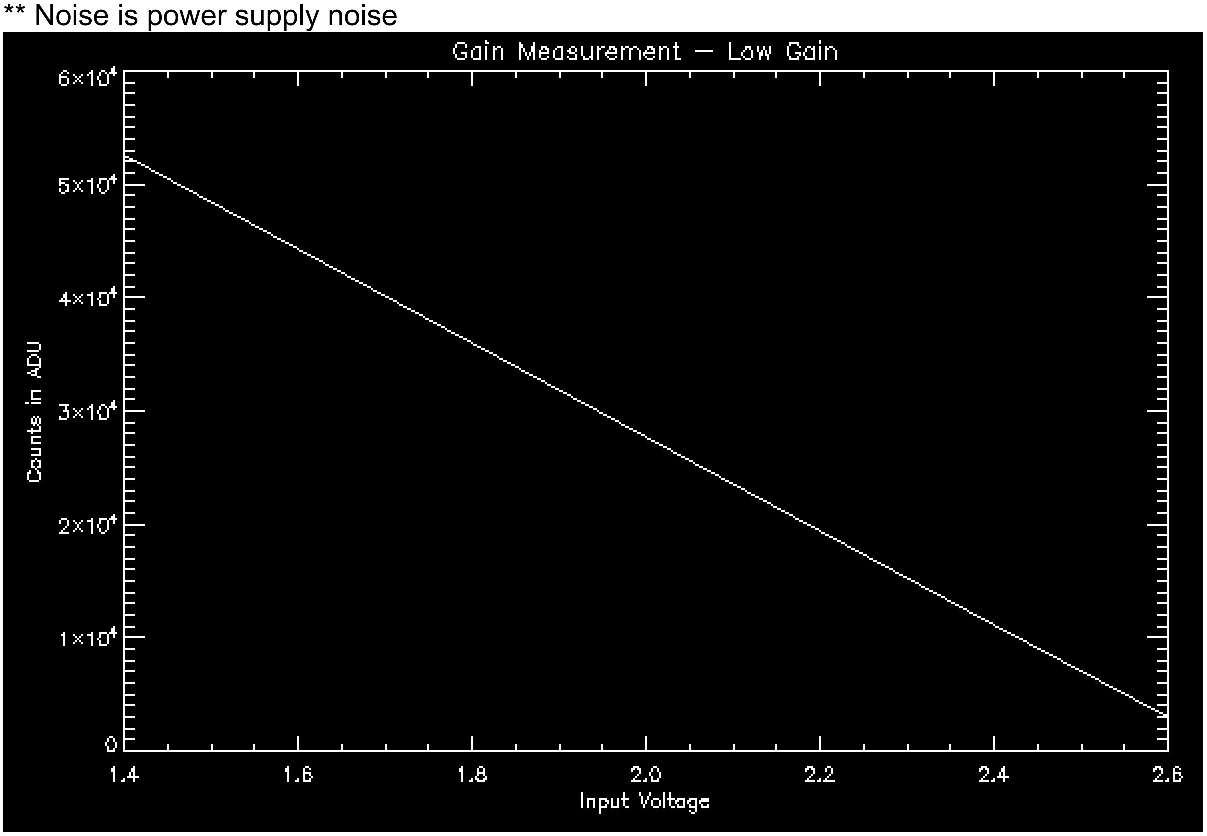
4.3.1.1 Gain Testing - Low gain

Using a power supply, a voltage of 2.0V was fed into one of the inputs of the ARC Controller. The value of 2.0 V was selected for being the approximate output value of the H2RG array. Offsets were modified to bring the read value near the center of the ARC-46 ADC input voltage. The input voltages were then varied above and below 2.0V in 0.2V increments, and the output values in ADU were measured and plotted against the input voltage.

The slope was calculated, resulting in a computed gain of the system of -24 uV/ADU.

Input Voltage:	**1.4V**	**1.6V**	**1.8V**	**2.0V**	**2.2V**	**2.4V**	**2.6V**
Mean in ADU	52,529	44,305	36,024	27,751	19,470	11,202	2,919
Noise in ADU**	5.91	5.94	5.89	5.91	5.92	5.94	5.96

** Noise is power supply noise



4.3.2 Gain Testing - High gain

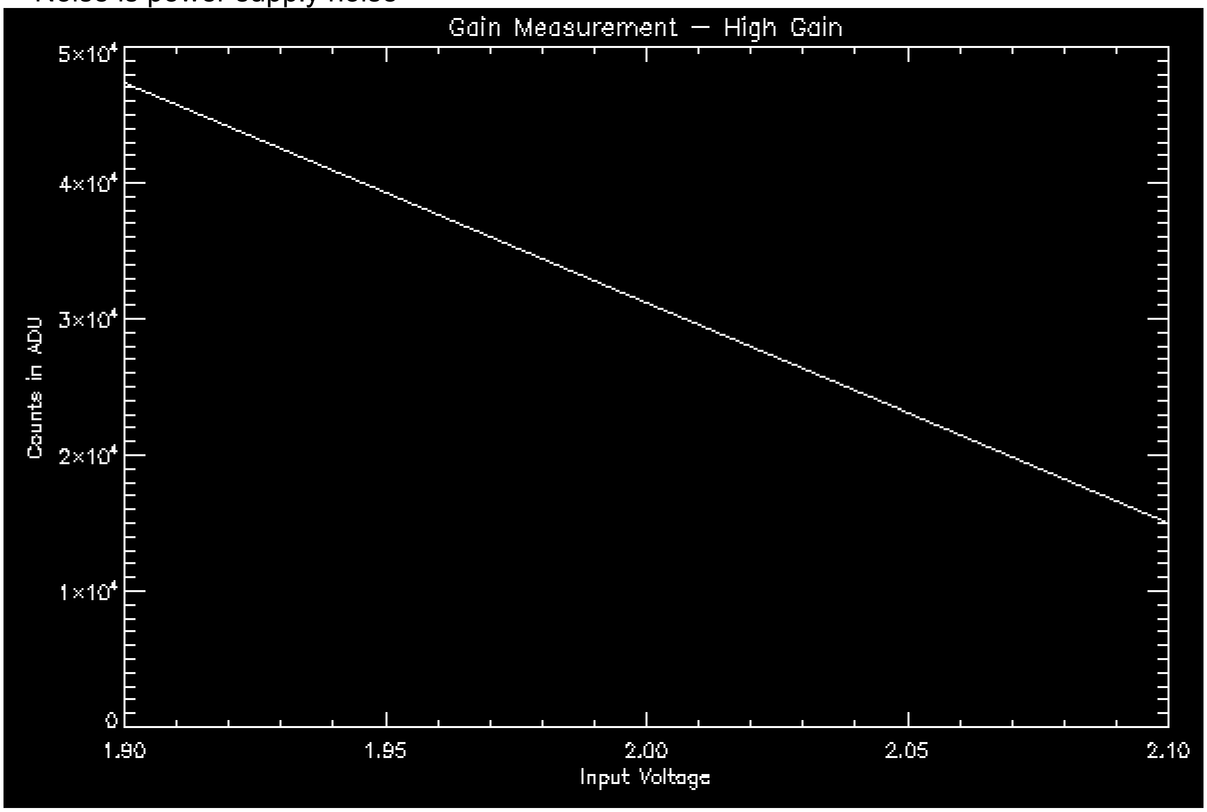
Using a power supply, a voltage of 2.0V was fed into one of the inputs of the ARC Controller.

The value of 2.0 V was selected for being the approximate output value of the H2RG array. Offsets were modified to bring the read value near the center of the ARC-46 ADC input voltage. The input voltages were then varied above and below 2.0V in 0.05V increments, and the output values in ADU were measured and plotted against the input voltage.

The slope was calculated, resulting in a computed gain of the system of -6.2 uV/ADU.

Input Voltage:	**1.90V**	**1.95V**	**2.0V**	**2.05V**	**2.1V**
Mean in ADU	47,288	39,326	31,176	23,149	14,994
Noise in ADU**	22.63	22.81	22.80	22.88	23.09

** Noise is power supply noise



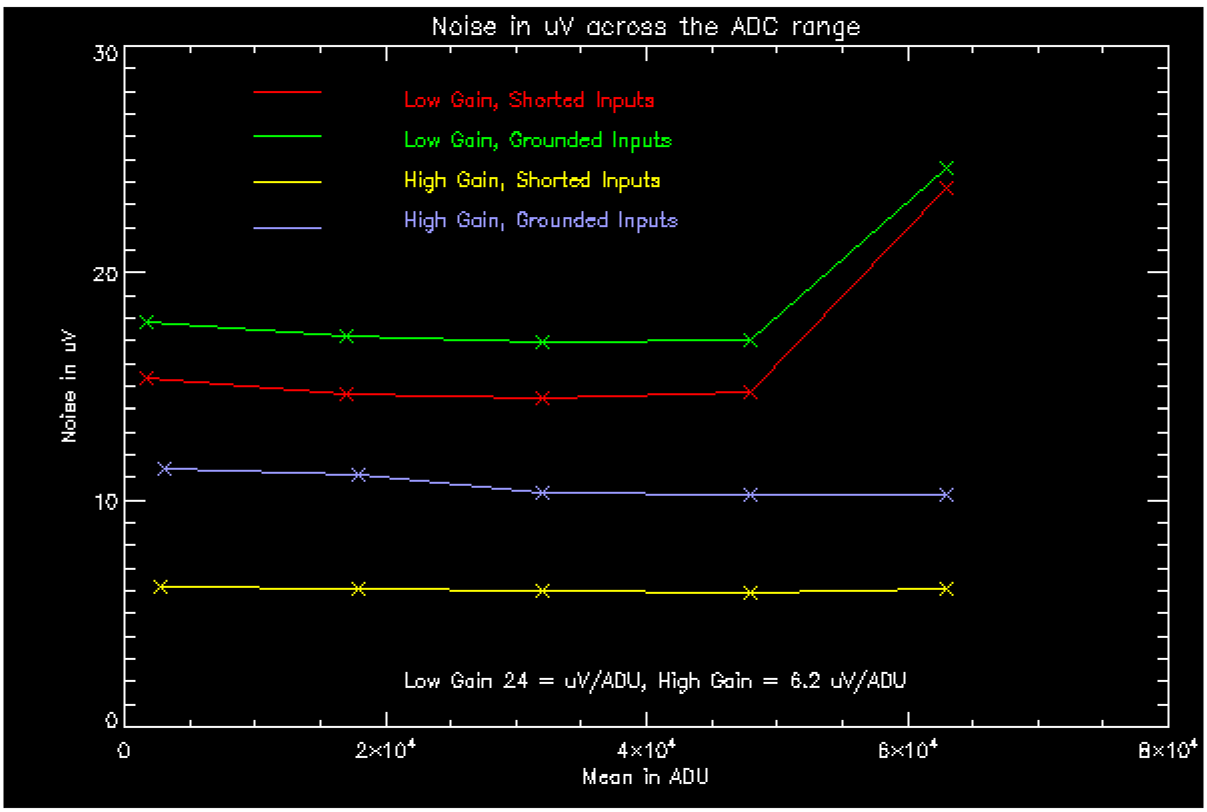
4.3.3 Noise Testing

We were able to perform a limited amount of noise testing with both an ARC Gen III controller in isolation and with an ARC Gen III based H2RG camera. The intent of testing the ARC Gen III controller in isolation was to determine array controller noise.

Noise tests with an ARC Gen III based H2RG camera allowed us to compare the array controller noise to overall system noise that includes an H2RG device. The results of this testing is outlined in section 4.4.

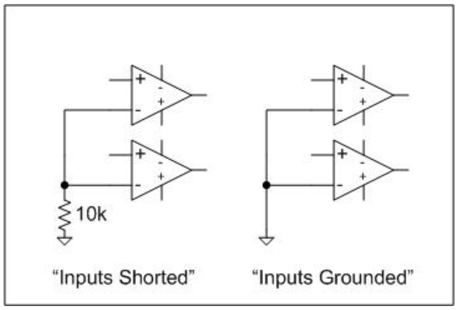
4.3.3.1 Noise testing of the ARC Gen III Controller with shorted and grounded inputs

Two test cases were used. The first had the differential inputs shorted together and connected to ground through a 10k resistor. The second had the inputs connected to ground directly. The internal offsets of the ARC controller were used to test the noise across the ADC range.



As can be seen for the Low Gain tests, near to 65K ADU there was an increase in noise. This sample may have fallen out of the range or reasonable operation for the ADC. There was not an opportunity to re-collect that data.

In low gain, 1 ADU = 24uV. The system noise in ADU was approximately 0.65-0.8 (See Appendix A). In high gain, 1 ADU = 6.2uV. The system noise in ADU was approximately 0.9-2 (See Appendix A). For both cases, system noise was low, which is good.



Resistor dummy load configurations.

4.4 Measured Performance of the ARC with ASTRONIRCAM

4.4.1 Darks taken with ASTRONIRCAM

Doug Toomey at MKIR allowed IRTF personnel access to data from ASTRONIRCAM. Looking at subtracted darks taken with Low Gain, we achieved the following results:

Test Conditions
Cold H2RG, held at 85K
Four output mode.
Pixel time is 3.33 usec / pixel
Total readout time was approximately 3.6 seconds
Array detector was blanked off with cold blank off.
Gain was low.
A CDS image was taken (1 NDR, Signal-Pedestal readout), and the standard deviation of selected regions was measured as noise.

Region	Noise in ADU	Noise in uV
Top 4 Rows (RR)	2.18 ADU	52.3 uV
Left 4 Cols (RR)	2.44 ADU	58.6 uV
Right 4 Cols (RR)	2.11 ADU	50.6 uV
Bottom 4 Rows (RR)	2.24 ADU	53.76
Full Array	6.39 ADU	153 uV
20x20 Pixel Subarray (58:77,9:28]	2.46 ADU	59.0 uV

Noise levels indicate that the array controller noise does not dominate over the H2RG readout noise.

4.4.1.1 NDR Evaluation

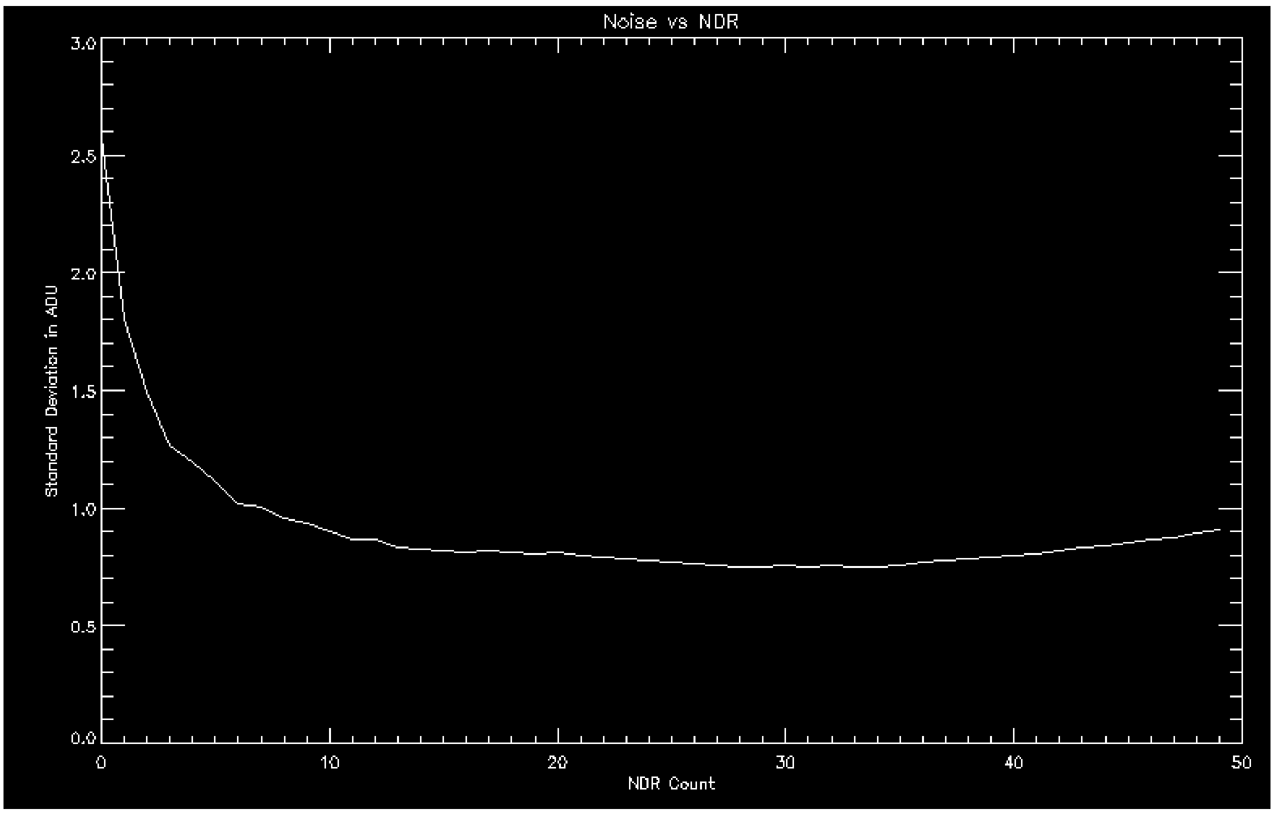
Test Conditions

Cold H2RG, held at 85K
Four output mode.
Pixel time is 3.33 usec / pixel
Total readout time was approximately 3.6 seconds
Array detector was blanked off with cold blank off.
Gain was low.

100 non-destructive reads were taken. From this data set, 50 CDS images were generated in the following way:

CDS image N=1 was the result of subtracting the second readout from the first.

For CDS image N>1, the CDS image was was generated by using the result of summing the first N readouts and dividing the results by N, and subtracting off the result of summing the second set of N readouts and dividing the results by N.



Looking at a subarray of 450 pixels, the standard deviation varied from 2.58 ADU down to 0.76 ADU, before starting to rise to 0.9 ADU. Other subarrays could be found that had standard deviations up to 10% lower.

5. Estimated Performance for IRTF Instruments

Requirements for the array controller have been detailed in the Array Controller Requirements document. They are derived from the science cases for the SpeX Upgrade and iSHELL projects. The most important design drivers are presented here.

To meet the sensitivity requirements the controller must not limit array read noise to more than 5 e RMS with multiple non-destructive reads (NDRs). Fast read out (~0.1-1s) is a requirement for several observing programs (e.g thermal imaging and spectroscopy of bright stars) and so the H2RG arrays will be wired for 32 outputs. For imaging of Jupiter at M’ with NSFCAM2 (0.04” per pixel) the integration time can be no longer than about 0.5 s to avoid saturation (assuming a well depth of 50,000 e). An integration time of 0.5 s imposes a brightness limit of J=6, H=5.5, K=5, L’=3.5, and M’=3 - about 0.5 magnitudes fainter than the current limit with SpeX (R=2000), although other measures can be taken to increase the limit (using an internal stop, and perhaps programmable gain).

Some observing programs require that frames be taken at a certain rate or cadence. For example, stellar occultations need to be sampled at a frequency dependent upon the geometry of the event (typically 0.1-1s). Extra-solar planet transits require cadences of typically about one minute. More general observations also have an effective cadence due to a variety of different observing requirements. To achieve a given cadence optimization of array size (i.e. use of sub-arrays) and read noise will be required.

Closely related to cadence is the implicit data rate, the rate at which data needs to be transferred and stored in order to keep up with the observations. Some programs, such as occultations, require relatively high data rates, whereas others, such as faint object spectroscopy (long integration times), require relatively low data rates. A critical requirement is the acceptable rate of any data loss and the timing of any data loss. A stellar occultation, for example, might require a cadence of one frame per second for a duration of one hour. During this period a system crash requiring a recovery of a minute or more would be unacceptable, whereas the loss of a few isolated data frames would have little effect. On the other hand, any data loss in a sequence of six 600 s integrations needed for faint object spectroscopy is unacceptable. Consequently an acceptable level of frame loss would be < 0.1% (one frame in 1000).

Both SpeX and iSHELL have infrared slit viewers for object acquisition, guiding, and scientific imaging and photometry. A fundamental requirement of the slit viewer is that the read out must operate independently of the spectrograph read out, i.e. with the exception of moving mechanisms and the telescope, there must be no mutual influence on the operation of the two arrays (no need to sequence integration times or read outs, no induced noise, independent computer operation, independent data transfer and storage etc.). This mode of operation is working extremely well in SpeX.

5.1 IRTF Array Controller Requirements

H2RG Controller Requirements

Requirement		**Can Meet?**
Array controller must fit on instrument.		Yes.
Read noise for slow readout	< 5e-RMS reqd, < 2 e- RMS goal	Yes.
Slow readout overhead	< 30s	Yes
Read noise for standard readout	< 15e- RMS reqd	Yes.
Standard readout overhead	< 1s	Yes.
Read noise for fast readout (< 0.1s overhead)	< 100 e- RMS reqd, < 30 e- RMS goal	NO, minimum readout speed 0.45 s
Fast readout overhead	< 0.1 s	NO**, fastest readout time would be ~0.45 s
Subarray	>= 3 boxes	Yes.
Cadence (Strictest Mode)	~ 6 frames per minute	Yes.

** See section 5.2.1 for details.

Aladdin II/III Controller Requirements

Requirement		Can Meet?
Array controller must fit on instrument.		Yes.
Read noise for slow readout (< 5.0s)	< 30e-RMS reqd, < 20 e- RMS goal	Yes.
Slow readout overhead	< 5s	Yes
Read noise for standard readout (< 1.0s)	< 70e- RMS reqd, < 20e- RMS goal	Yes.
Standard readout overhead	< 1s	Yes.
Read noise for fast readout (< 0.1s overhead)	< 100 e- RMS reqd, < 30 e- RMS goal	NO, minimum readout speed 0.11 s
Fast readout overhead	< 0.1 s	NO**, fastest readout time would be ~0.11 s
Subarray	>= 3 boxes	Yes.
Cadence (Strictest Mode)	~30 frames per minute	Yes.

5.2 The Gen 3 ARC Controller, limitations

5.2.1 Throughput limitations

The most likely greatest functional limitation for IRTF instruments is the data throughput of the controller. While the fiber line used for the controller is capable of 25 MBPS, or 12.5 Mpixels/sec, reported functional throughput rates vary. The ARC-46 manual indicates that the measured functional throughput was approximately 9 Mpixels/sec.

However, Bob Leach has indicated that information is dated, and that data rates have been increased to the full 12.5 Mpixels/sec. Still, a more conservative estimate is probably appropriate, and we estimate that 80% of max line rate is likely, giving a functional rate of 10 Mpixels/sec.

Summary of throughput rate limitation

Data Xfer Rate	Time for full readout	Full readouts per second	Time for 33 channel readout**	33 channel readouts per second**
9 Mpix/sec	0.467 sec	2.14 Hz	0.481 sec	2.08 Hz
10 Mpix/sec	0.419 sec	2.38 Hz	0.432 sec	2.31 Hz
12.5 Mpix/sec	0.336 sec	2.98 Hz	0.346 sec	2.89 Hz

** Includes H2RG reference output, essentially a 2048*2112 pixel image.

Using the 10Mpix/sec data transfer rate,frame per seconds estimates are provide for various array sizes.

SubArray Size	Transfer Time (seconds)
H2RG 2048 x 2112	0.432
H2RG 1500 x 2112	0. 317
H2RG 1024 x 2112	0.216
H2RG 512 x 2112	0.108
Aladin 512 x 512	0.026

5.2.2 Pixel Rate Limitations

The second most likely functional limitation for IRTF instruments is the rate at which pixels can be clocked. The ARC Video Board uses an integrator circuit which requires approximately 1.5 µsecs to integrate. The ADC requires 0.5 µsecs to sample. Minimum pixel time is most likely about 3 µsecs/pixel.

However, this pixel rate is well within the limitations of the H2RG when read out at stardard rates. The basic readout rate of the H2RG is 100khz, or 100 Kpixels/sec. Per the H2RG manual, and conversations with Don Hall, the H2RG can be run at 2-3 times this speed[5]. Reading the device faster than this can incur pixel transition error, as the output circuitry of the H2RG has not fully switched from the previously addressed pixels value to the newly addressed pixel’s value.

Summary of H2RG readout recommended rates

Pixel Rate	Single Pixel Time	Time for full readout in 32 output mode	Time for reading out a 512x1024 subarray in 32 output mode**
100Khz	10 usec	1.31 seconds	0.328 seconds
200Khz	5 usec	0.66 seconds	0.164 seconds
300Khz	3.33 usec	0.436 seconds	0.109 seconds

** Assumes that we are reading out a subarray that is 512 rows tall, 1024 pixels wide.

For the Aladdin Array, we estimate the pixel readout rate to be about 3.3 usec per conversion. The estimated minimum readout of the array would be: 3usec * 512 * 512 / 8 channels or 0.108 seconds. This nearly meets the desired readout rate of 0.1 seconds.

5.2.3 Channel Limitations

Known configurations for the H2RG/ARC Controller paired instruments are running 32 output mode, with most using four 8-channel video boards. Because the H2RG also has a reference output and a window output, as well as temperature sensors, it would be beneficial to add extra input channels.

Per the ARC documentation, the ARC controller should be able to handle up to eight 8-channel video boards, so this should not be a problem. However, it should be understood that this increases the amount of data that must be read, and decreases the overall rate at which readouts are taken.

5.3 The Gen 3 ARC Controller, problems

5.3.1 Software/System Crashes

A problem with the ARC controller used in ASTRONIRCAM is that it experiences occasional system failures where the PC freezes and needs to be rebooted. After the reboot it's found that the ARC-64 (PCI interface card) will not respond until reset (there is a reset button on the face plate of the ARC-64).

This is very similar to problems experienced at the IRTF with MIRSI, though to a lesser degree. For MIRSI, we were able to make fixes to the ARC-64 driver code to reduce the impact of these crashes.

However, for continued IRTF ARC controller development with the newer, better generation of controllers, it would be a high priority goal to diagnose and fix these problems completely. Bob Leach has indicated that moving to the ARC-66 (ARC's PCIe interface card) would likely reduce, or even remove the problem entirely. In addition, a review of the DSP code running on the controller, use of the more advanced and stable PCIe card, and the latest driver code would likely further improve controller reliability.

Other users of ARC controllers have indicated having similar problems to these, ie system crashes with the controller, and have indicated that they were able to develop their systems in a way which made them much more reliable, to the point of eliminating the problem entirely.

5.3.1.1 Impact of Software/System Crash

This problem is rare in occurrence with the newer generation of controllers. When it does happen the time lost is approximately 3-4 minutes to reboot and restart the electronics/software.

For most observing this would not prevent observation. However sytsem crashes would be a problem for occultation programs.

5.4 Long Term Support

Eventually the ARC Controller will become outdated and difficult to support. Electronics can and do fail over time. The components used for the ARC Controller boards are currently available, though some are no longer in production.

ARC has been providing controllers for more than 15 years. They provided extensive support to the IRTF with MIRSI in 2006, despite the controller for MIRSI being an obsolete generation from over six years earlier. If the IRTF experiences issues with the electronics, we can expected vendor support (Bob Leach), he has provided excellent support in the past.

At the same time, the IRTF should ensure that they have a reasonable supply of working spares in inventory. Should ARC as a company fail suddenly, the IRTF should have the resources to continue maintaining the controllers.

Finally, ARC provides schematics and layout for all of their boards. If necessary, the IRTF could design and build replacement boards for the controllers.

The ARC controller status should be reviewed by IRTF personnel within five years of going to the mountain. The status should be reviewed every two years after that five year review, and at any time that a board fails and needs to be replaced.
Based on experiences with Spex and NSFCAM2, we should expect to upgrade the electronics within ten years of going on the telescope. We should begin planning for a next generation upgrade after the eighth years of going to the telescope.

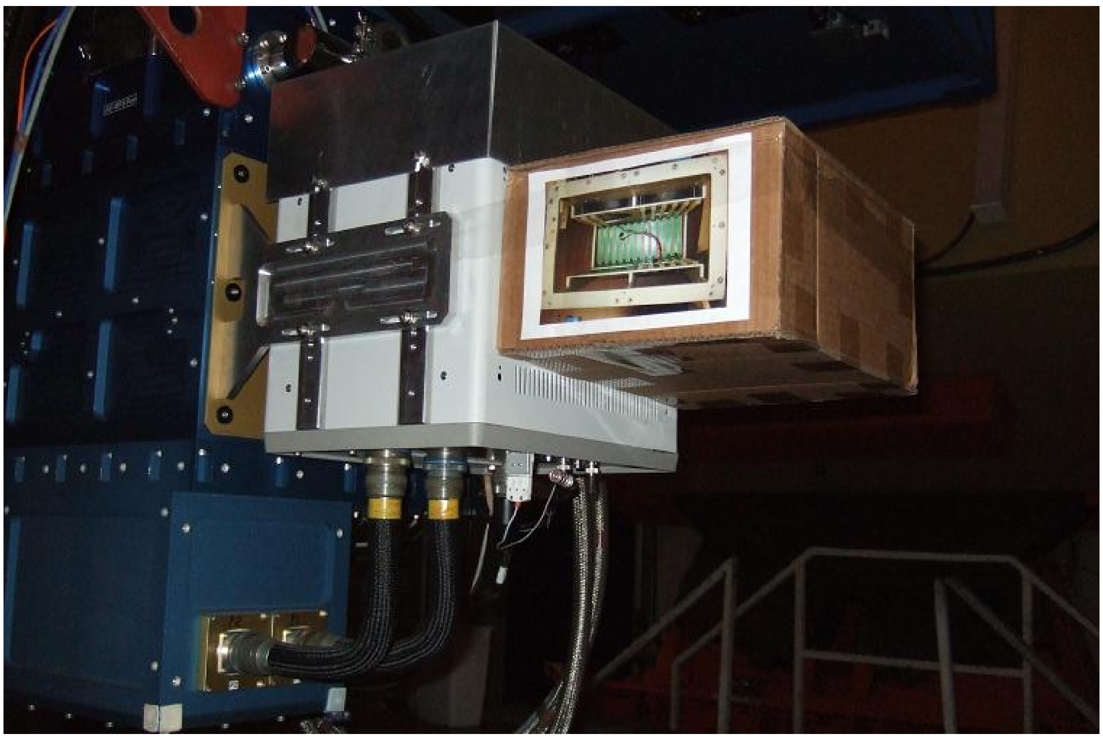
6.0 ARC Controller Mounting & Cabling

The cable designs need to be determined. The following sections will present the current configuration of NSFCAM2 and SPEX, where the ARC controllers could be mounted, and other information pertaining to tested cable configurations.

6.1 Suggested ARC Mounting for IRTF Instruments

6.1.1 NSFCAM2

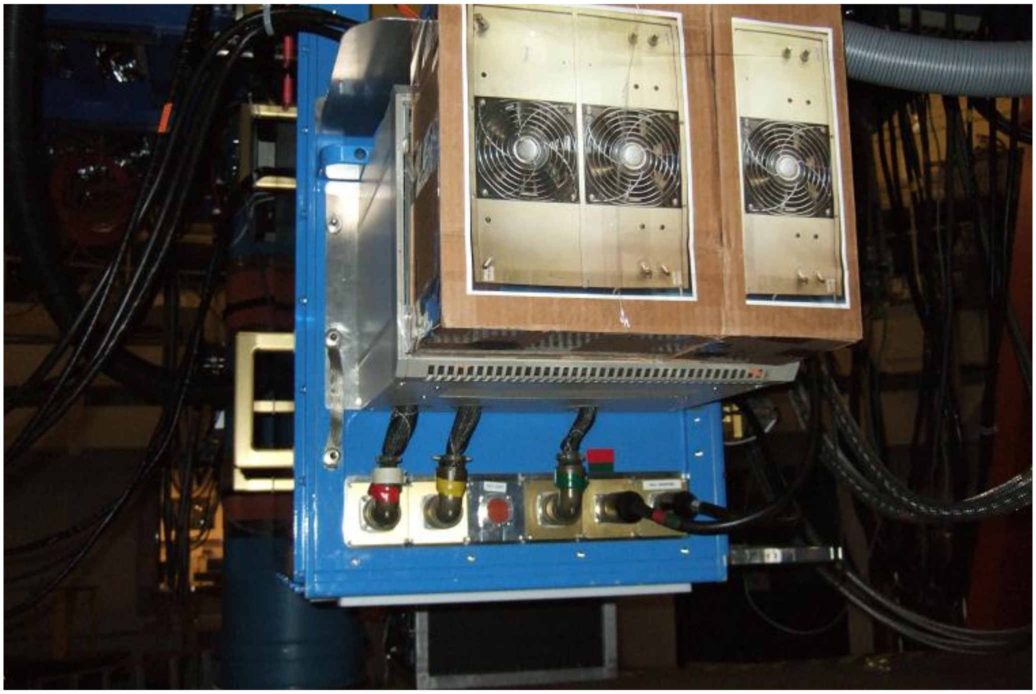
The ARC controller will fit comfortably in the space occupied by the current controller. The cardboard box represents the ARC Controller.



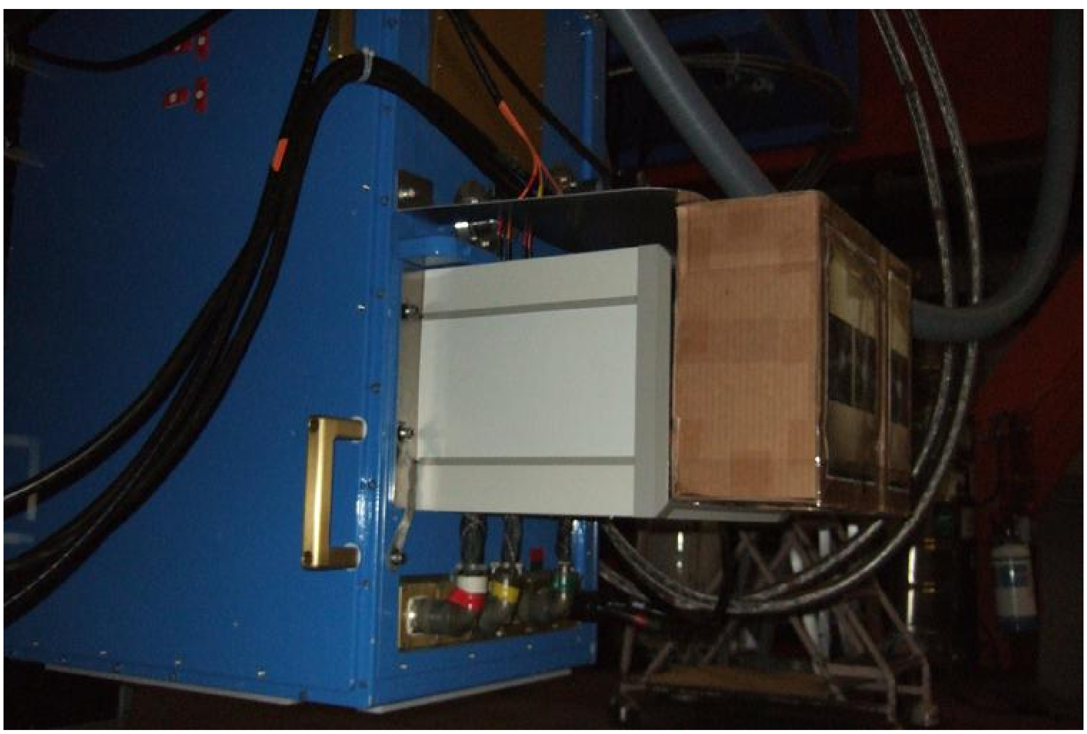
Current controller on NSFCAM2 with space model of ARC controller for comparison.

6.1.2 SpeX

There isn't enough clearance for the ARC controller on the bottom of SPEX either. Therefore, the ARC Controllers would have to be mounted where the present controllers reside or possibly one of the other sides. The cardboard boxes represent ARC Controllers.



Current controller SpeX with a space model of the ARC controllers shown for comparison on (12 slot for H2RG and 6 slot for Aladdin).

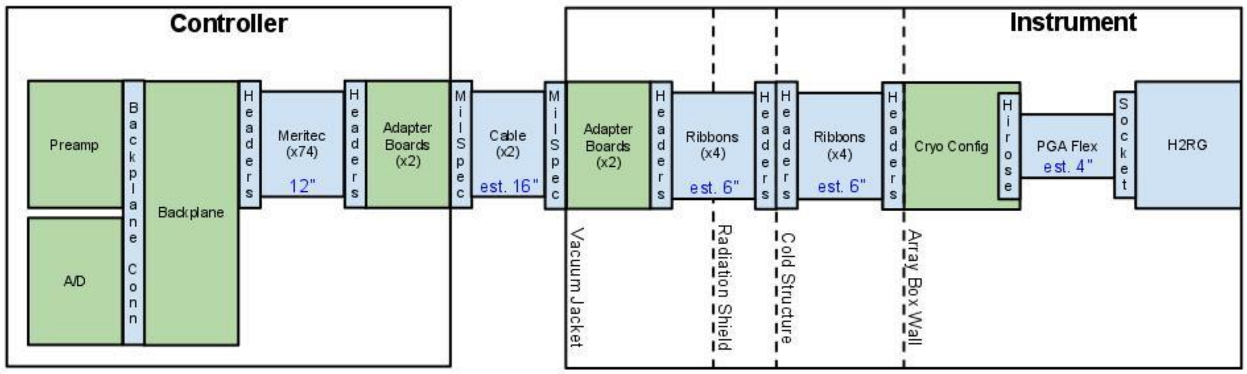


Side view of ARC controller mounted on SpeX.

6.2 Current IRTF Cabling

6.2.1 NSFCAM2

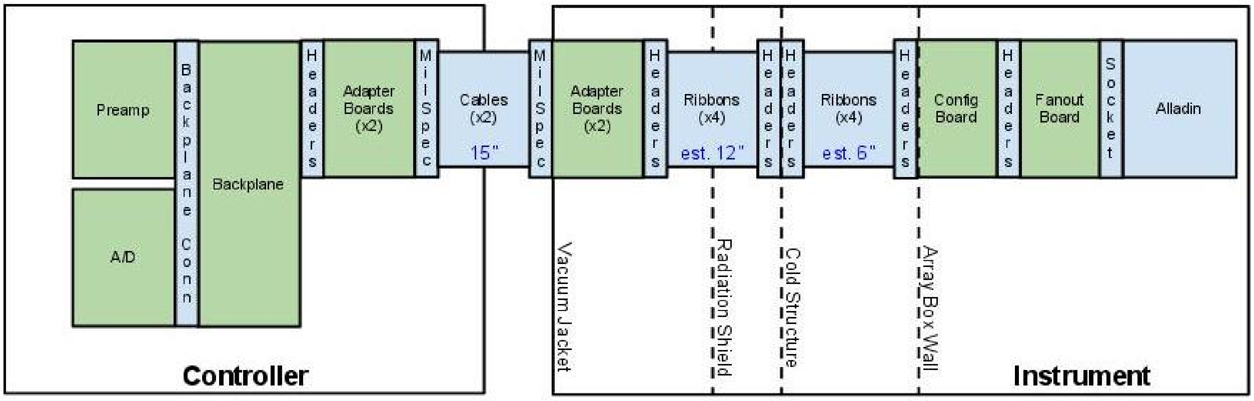
NSFCAM2 has a cable configuration as shown below. Total length of cable is estimated to be around 44”. This is an *estimation* based on photos and some measurements.



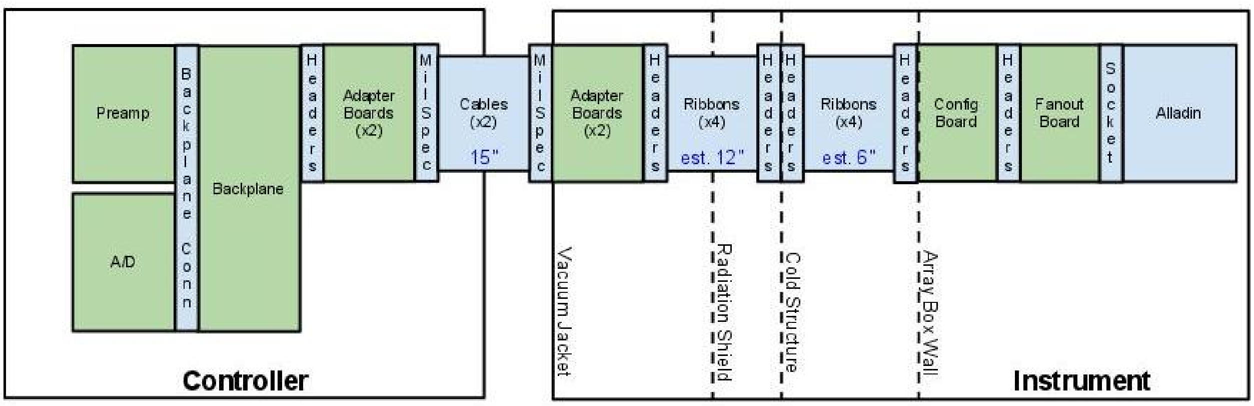
NSFCAM2

6.2.2 SPEX

SPEX has a cable configuration as shown below. Estimated cable length is around 33”. This is an *estimation* based on photos and some measurements. There may be some cable length differences between the spectrograph and guider array, however, without measuring or dimensioned drawings, they are assumed to be similar.



SpeX Spectrograph Array



SpeX Guider Array

6.3 Cabling

6.3.1 Cable Length

Cabling length is a concern as it can impact performance. The primary concern of a longer cable is drive impedance. The H2RG or Alladin will have to drive any addition impedance and it could affect settling time or stability which will appear as noise when sampled. Beyond some length of length of cable and at some pixel rate, there will be issues. Admittedly, hard numbers are difficult to come by and we do not have those.

Unfortunately, there is not a convenient way to simulate or calculate this. There is not an individual cable test that can be performed easily. The most accurate way is to simply test a cable configuration with the test dewar in the lab that is as close to the instrument cabling as possible. Any other configurations of interest could be tested also.

As a secondary concern, longer cables may also increase susceptibility to radiated emissions.

However, proper shielding and signal separation should reduce these issues.

To sum it up, “shorter is better”, but how short is the question.

6.3.2 ARC Controller Placement Limitations

The controllers have very few mounting options. Essentially they would probably be mounted were the present controllers are mounted. This sets the minimum cable length.

6.3.3 Cabling Design and Material

What material and design should be used is a question. Should the design be a flex? Should it be discrete wire? Should constantan or manganin be used due to thermal load? Manganin wire and a copper flex have both been tested and shown to provide an acceptable thermal load.

6.3.4 Connectors

Physically rugged connectors are desirable on the main body of the instrument. If a connector is damaged, there could be considerable down time to repair it. Minimizing the number of connectors is also desirable.

6.3.5 Forming Cables

The bend radius could be an issue depending on the mounting configuration. If a smaller radius bend is required, we could form the cables. That is, we could build the cables with a natural bend in them by building them on a simple jig. The only issue is that in order to do so, wires will be of various lengths in order to create the natural bend (outer longer, inner shorter). Length variations can be an issue with digital signals. DC signals would most likely be unaffected by length variations. Channel signals would have slightly different impedances, which may or may not matter. This is a potential issue since the cable designs have not been determined.

6.3.6 Cable Exit from ARC Controller

The ARC Controller does not have a predetermined side for the cable to exit. Usually it is through the front/back (the surface looking into the D-sub connectors on the cards). However, it could come through either of the other 4 sides. For instance, a 90 degree connector off the cards could be used if a tight radius bend in the cable isn’t desired.

6.3.7 Other Observatory Cable Designs

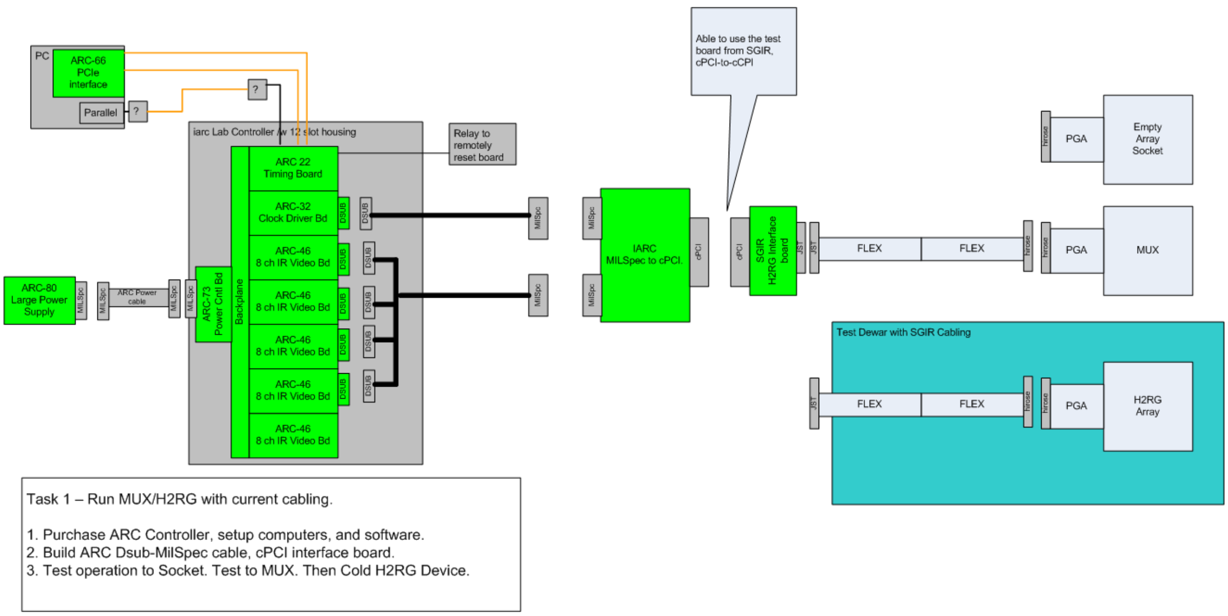
As mentioned earlier in this document, other observatories and organizations are successfully using the ARC Controller. Their cable designs and results provide good reference points from which we can base our designs on.

Organization	Instrument	Cable Length	Construction	Comments
MKIR	ASTRONIRCAM	~42”	Discrete wire and manganin ribbon. Mil-spec round, D-sub, headers.	Similar to portions of NSFCAM2 design.
CFHT	WIRcam	~35”	8” controller unshielded, 19” cable, 8” flex, D-SUB, Mil-spec round, other connectors	

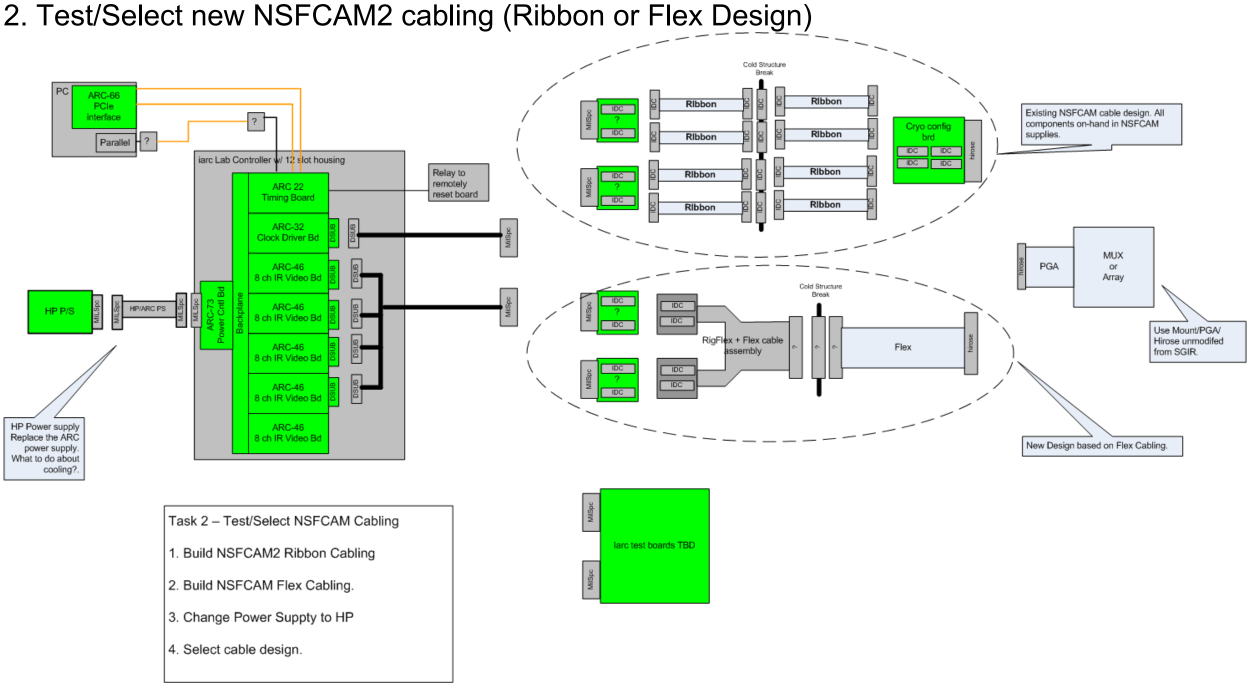
7.0 Tasks, Schedules, Costs

7.1 Tasks

1. Run Mux/H2RG with current SGIR cabling.



2. Test/Select new NSFCAM2 cabling (Ribbon or Flex Design)



3. Testing and Optimization

4. Start NSFCAM2 update.

5. Run Aladdin MUX with ARC Controller.

7.2 Schedule

The following assumes a high level of resource assignment in terms of personnel and resources. Diverting personnel to other projects would stretch or shift this schedule. Time off will affect this schedule.

Estimate time Frame	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	
1. Run Mux/H2RG with current cabling										
Purchase ARC & computer/controller	CL									
Design/Build MilSpec Cable, cPCI boards	EW, DW									
Test to Socket, then MUX, then Cold H2RG			CL,EW	*mux, and cold array images.						
Transport test dewar Hilo & Scope any mods	DW									
2. Test/Select NSFCAM Cabling										
Build NSFCAM2 Ribbon cabling	EW/DW			Test ribbon						
Build NSFCAM2 Flex cabling.		EW (design)	EW,DW	and Flex	*evaluate images from Ribbon and flex designs					
HP Power supply			EW,DW							
3. Testing and Optimization										
Select NSFCAM Cable Design					*					
Noise measurement and optimization.					CL,EW	MC				
							* acceptable Images for nsfcam2			
Possible testing of new H2RG										
4. NSFCAM2 Upgrade										
Upgrade to NSFCAM begins								MC, CL	EW ,DW	
							*purchase nsfcam2 controller			
5. Run Aladdin Mux with ARC controller										
Purchase ARC controller & computer			TD							
Design Build cabling to mux, test boards					EW,DW					
Image the Aladdin and verify operations							TD,EW			
									*1st aladdin mux image	
Equipment Cost										
ARC Controllers	43000	h2rg cntl	25000	aladdin cntl			47000	nsfcam cntl		115000
PC			2000				2000	nsfcam pc		4000
Electronic Fab	3000	cPCI supply	7000	flex cbl, test brds						10000
Machine Shop										0
										0
										0
									Total =	129000

Schedule as a table. H2RG and Aladdin task are separated

Months	H2RG	Aladdin	Others
1. Jan			Evaluate ARC
2. Feb	Start Project Order Lab ARC controller Design cPCI interface to SGIR Build NSFCAM2 Ribbon cabling. Test Dewar transported to Hilo		
3. Mar	Build test boards, cabling Controller Arrives, test basic software operations. Design NSFCAM2 Flex Cabling		CL Vac 2 wks
4. Apr	Test and Image with SGIR Cabling. Build NSFCAM2 Flex cabling. Switch to HP Power Supply.	Purchase Lab ARC controller Purchase PC.	
5. May	Test Ribbon cabling. Take test data. Test Flex cabling. Take test data.	Design/Build Mux cables, Aladdin test boards.	TD Vac 2 wk.
6. June	Select NFCAM cabling design. Begin Noise test/optimization .		
7. July	Noise test/optimization continues.		
8. Aug	Noise test/optimization continues. Purchase NSFCAM2 ARC Controller	Verify Controller signal logic and voltages	
9. Sept	NSFCAM Upgrade begins. Possible testing of new H2RGs.	MUX imaging	
10. Oct			

8.0 Executive Summary

8.1 Pros and Cons of the ARC Controller

This is a general summary of the positive and negative aspects of the ARC Controller.

Pros	Cons
Price: ARC Controllers are very reasonably priced when compared to other controllers in use, and should fit within IRTF budgetary needs.	Risk: As with any controller solution, there is a level of risk that the controller will not meet the needs of IRTF instrumentation, though this is very low (see section 7.2 for more information on the risks of selecting the ARC controller, or sections 4.1 or 4.2 for more detailed information).
Noise Performance: Noise performance has tested out to be good, and meets instrument requirements.	Throughput rate is limited. The throughput rate is faster than the recommended rates for reading the H2RG, but this is still a limitation.
Timely, Available, Responsive: ARC Controllers are received within 30 days of order. Bob Leach provides a high level of support for assisting in development and troubleshooting.	
Community Support: The ARC Controllers, being in wide use, have a large community of users when compared to other options, with groups and individuals willing to provide advice and guidance.	
H2RG Support: The ARC Controllers come with H2RG support, and there is a significant amount of developed software available for the IRTF to use.	
Aladdin II/III Support: The ARC Controllers come with Aladdin II/III support, and there is a significant amount of developed software available for the IRTF to use.	

Accessible: The ARC Controllers are fairly simple and straightforward, with both software source code and hardware schematics available. It will be easy for IRTF personnel to come up to speed on how the systems work and are built, leading to a high degree of “ownership” by IRTF staff.	
Personnel: All personnel required for working on the array controller are available in Hilo: Tony Denault, Warmbier, Darryl Watanabe, and Charles Lockhart	

8.2 Risk Assessment

The overall risk is very low. We know of cameras that are using the H2RG/ARC Controller configurations that are successful despite having more radical configurations than would be used by the IRTF (the IRTF configuration would be very straight forward).

8.2.1 Technical Risks

There are three areas of technical risk: noise performance, throughput performance, and reliability.

8.2.1.1 Noise Performance

In the area of noise performance, tests performed by IRTF personnel on ARC controllers have indicated that the ARC Controller meets or exceeds the requirements of the IRTF for all three cameras in development. This indicates a very low level of risk.

8.2.1.2 Throughput Performance

In the area of throughput performance, the ARC controller does not meet the strictest requirements put forth in the science requirements document presented by John Rayner. However, the ARC controller does meet or exceed the throughput rates specified for the H2RG in use recommended by the manufacturer. Conversations with John Rayner regarding the flexibility of this requirement indicate that the requirement may be adjusted, which would indicate a very low level of risk.

8.2.1.3 Reliability

In the area of reliability, there is one known problem with the controller, related to intermittent system hangs. Experiences of IRTF staff with the Gen 3 controllers indicate that this is a rare event, and experience with the Gen 2 controllers indicate that the problem may be minimized or even completely removed. Discussions on controller performance with other facilities indicate that the problem is solvable.

However, if this problem were unsolvable, the occasional system freeze would require a reboot, and a loss of time around 3-5 minutes. The greatest risk would be to observers taking long integrations, where the observation may be interrupted during a system freeze. This would possibly affect about 3% of observations.

8.2.2 Management Risks

In terms of management, the risk component is scheduling and meeting an appropriate time table. In this area, the ARC Controller is low risk. As shown in section 6.2, assuming appropriate allocation of personnel resources to the project, the ARC Controller would be ready for NSFCAM2 within six months of the start date. As this would be the same controller configuration as for Spex2 and ISHELL. Half way through the six month period work would begin on customizing software for the Aladdin II/III arrays for the Spex2 and ISHELL guiders.

The schedule presented assume a full time FTE effort of the technical staff. Telescope opeation, other IRTF project (2nd fix) will have a negative impact.

8.3 Recommendations

We recommend the ARC Controller for use at the IRTF for IRTF instruments. Specifically, we recommend using the ARC Controller for the building of ISHELL, and for upgrading SpeX and NSFCAM2.

Appendix A: Noise Data

Noise Testing - Low Gain - Shorted Inputs

For this test case the differential inputs of the ARC Controller were shorted together, resulting in a 10K Ohm to ground.

Mean=1.7K	Ch 0	Ch 1	Ch 2	Ch 3
Noise in ADU	0.648	0.642	0.645	0.638
Noise in uV	15.55	15.40	15.47	15.13

MEAN=17K	Ch 0	Ch 1	Ch 2	Ch 3
Noise in ADU	0.601	0.621	0.613	0.603
Noise in uV	14.44	14.91	14.71	14.48

Mean=32K	Ch 0	Ch 1	Ch 2	Ch 3
Noise in ADU	0.604	0.608	0.601	0.594
Noise in uV	14.50	14.60	14.41	14.25

Mean=48K	Ch 0	Ch 1	Ch 2	Ch 3
Noise in ADU	0.606	0.607	0.621	0.617
Noise in uV	14.54	14.58	14.91	14.80

Mean=63K	Ch 0	Ch 1	Ch 2	Ch 3
Noise in ADU	0.97	0.93	1.00	1.04
Noise in uV	23.3	22.5	24.09	24.99

Noise Testing - Low Gain - Grounded Inputs
For this test case the differential inputs of the ARC Controller were shorted to ground.

Mean=1.7K	Ch 0	Ch 1	Ch 2	Ch 3
Noise in ADU	0.730	0.772	0.736	0.727
Noise in uV	17.53	18.53	17.67	17.44

Mean=17K	Ch 0	Ch 1	Ch 2	Ch 3
Noise in ADU	0.707	0.737	0.712	0.709
Noise in uV	16.97	17.69	17.10	17.02

Mean=32K	Ch 0	Ch 1	Ch 2	Ch 3
Noise in ADU	0.704	0.716	0.699	0.701
Noise in uV	16.89	17.17	16.78	16.83

Mean=48K	Ch 0	Ch 1	Ch 2	Ch 3
Noise in ADU	0.704	0.719	0.702	0.710
Noise in uV	16.89	17.26	16.86	17.04

Mean=63K	Ch 0	Ch 1	Ch 2	Ch 3
Noise in ADU	1.04	1.02	1.04	1.001
Noise in uV	24.85	24.47	24.97	24.21

Noise Testing - High Gain - Shorted Inputs
For this test case the differential inputs of the ARC Controller were shorted together, resulting in a 10K Ohm to ground.

Mean=2.8K	Ch 0	Ch 1	Ch 2	Ch 3
Noise in ADU	0.965	1.01	0.992	0.984
Noise in uV	5.99	6.31	6.15	6.10

Mean=18K	Ch 0	Ch 1	Ch 2	Ch 3
Noise in ADU	0.976	1.01	0.953	0.988
Noise in uV	6.05	6.25	5.91	6.12

Mean=32K	Ch 0	Ch 1	Ch 2	Ch 3
Noise in ADU	0.956	0.979	0.969	0.983
Noise in uV	5.93	6.07	6.01	6.10

Mean=48K	Ch 0	Ch 1	Ch 2	Ch 3
Noise in ADU	0.964	0.930	0.929	0.984
Noise in uV	5.98	5.77	5.76	6.10

Mean=63K	Ch 0	Ch 1	Ch 2	Ch 3
Noise in ADU	0.949	0.995	0.991	1.01
Noise in uV	5.89	6.17	6.14	6.29

Noise Testing - High Gain - Grounded Inputs
For this test case the differential inputs of the ARC Controller were shorted to ground.

Mean=3K	Ch 0	Ch 1	Ch 2	Ch 3
Noise in ADU	1.80	01.92	1.81	1.84
Noise in uV	11.14	11.91	11.22	11.40

Mean=18K	Ch 0	Ch 1	Ch 2	Ch 3
Noise in ADU	1.80	1.85	1.74	1.79
Noise in uV	11.18	11.49	10.77	11.10

Mean=32K	Ch 0	Ch 1	Ch 2	Ch 3
Noise in ADU	1.68	1.74	1.63	1.62
Noise in uV	10.43	10.81	10.09	10.05

Mean=48K	Ch 0	Ch 1	Ch 2	Ch 3
Noise in ADU	1.62	1.72	1.64	1.62
Noise in uV	10.05	10.70	10.14	10.07

Mean=63K	Ch 0	Ch 1	Ch 2	Ch 3
Noise in ADU	1.64	1.69	1.62	1.64
Noise in uV	10.16	10.50	10.07	10.15

Footnotes

1. ARC-46: 8 Channel IR Video Processor (ARC46_UsersManual.pdf), found on http://astro-cam.com, pg 1.
2. HAWAII-2RG Technical Documentation Version 1.1a, Rockwell Scientific, pg 26.
3. ARC-46: 8 Channel IR Video Processor (ARC46_UsersManual.pdf Updated July 8, 2011), found on http://astro-cam.com, pg 7.
4. ARC-46: 8 Channel IR Video Processor (ARC46_UsersManual.pdf), found on http://astro-cam.com, pg 1.
5. HAWAII-2RG Technical Documentation Version 1.1a, Rockwell Scientific, pg 26.