Report of the Preliminary Design Review Committee for the ARCON CCD Controller

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Summary

The ARCON design review committee conducted a thorough investigation of the capabilities and costs associated the ARCON controller. Information about ARCON was provided to the committee through a combination of a “live” demonstration of ARCON under both lab and real telescope conditions, a well prepared set of documents, and an informative session of questions and answers at the CTIO office. The ARCON team is to be commended for the quality of the demonstrations and documentation that was provided to the committee. The high quality of the documentation made it possible for the actual review meeting to be streamlined around detailed questions that provided the committee with valuable insight into the ARCON system architecture, future upgrade paths, and costs.

There was a clear consensus among the committee members that ARCON is an extremely well engineered and tested CCD controller. The quality of the construction no doubt is hard to beat at any existing observatory. The proven track record of ARCON at CTIO gave the committee confidence that the controller is a reliable system. ARCON, especially with the changes now underway, has a rich variety of internal diagnostics that make trouble shooting and maintenance relatively straightforward compared to other controllers. ARCON has also been thoroughly integrated into the IRAF data control/processing environment so that efficient data acquisition is supported. The real time display with data streaming as the array is readout was viewed as an attractive aspect of the design which was implemented particularly well.

While the committee was overall impressed with the current implementation of ARCON, there was great concern about how straightforward it will be to upgrade ARCON to perform to the level articulated in the Gemini Science CCD Requirements (see Appendix A). The largest single hardware concern expressed was the uncertainty associated with boosting the data rates up to the 250 Kp/s level specified by Gemini. Indeed, getting the system to perform at even the 200 Kp/s level will no doubt require significant modifications to the design and there was concern that meeting the 200 Kp/s rate had significant development risks associated with it. In essence, the committee felt that the same precise match of component performance that went into making ARCON an extremely reliable system at the current (~50 Kp/s) rate makes it difficult to upgrade the system by the factor of ~4-5 needed to meet the Gemini data throughput specification. Recommending in favor of adopting ARCON as the Gemini standard science CCD controller would have been much easier if the upgraded version proposed not only *met* but *beat* with a significant amount of margin the Gemini speed

requirement. In reality even the upgraded ~200 Kp/s version of ARCON does neither. In this key aspect, the committee concluded that the upgraded version of ARCON fails to meet one of the basic performance specifications for Gemini. To be clear, this is a specification that other controllers existing and planned for the near future can meet, hence it is not a fundamentally difficult or unrealistic one to meet given current electronics technology and current/near future CCD technology.

The other area in which the committee expressed tremendous concern was in the area of cost. Since the ARCON workpackage is identified as a Chilean managed project, under the Gemini international agreement Chile would be responsible for subsidizing the project for all indirect costs, which includes costs associated with development risks (contingency) and inflation. The Chilean representatives expressed great concern that they would not be able to subsidize the proposed workpackage to the level described. Even the unburdened costs of ARCONs were viewed as unacceptably high from the IGPO perspective. As a backup the IGPO completed just prior to the ARCON PDR a preliminary assessment of costs and capabilities of CCD controllers that will be available to Gemini on the timescales required. This assessment identified at least one alternative that is being designed to not only meet the basic speed requirement for science CCDs but also meets the all of the wavefront sensing requirements, likely will be easier to interface to the Gemini hardware environment, and will likely be *significantly* cheaper to buy. Since Gemini is operating under a clear mandate by its Board of Directors to find the most cost effective solutions to procuring major components in the telescope/instrument systems, the IGPO is compelled to see if it can find less costly solutions to its science CCD controller needs elsewhere.

The top level unanimous recommendation of the committee is therefore that the IGPO examine in detail the cost and performance of alternate controllers. The IGPO will continue to monitor the ARCON project with keen interest as the already initiated MOSAIC upgrade is carried out. To be clear this monitoring activity will be "passive" and is not intended to place any additional burden on the CTIO staff as they continue to work on the MOSAIC upgrades. Furthermore the IGPO would like to work through the ARCON cost estimates in greater detail with NOAO (Neil Gaughan) to try to resolve lingering questions about how they were derived. Upon completing its internal assessment of alternatives to ARCON the IGPO will make a selection of a controller for its science CCDs, most likely near the end of 1995.

Hardware

Multiple Channel Upgrade Path: One of the Gemini requirements is that system be modular so that it can support up to 16 separate data channels. For GMOS alone, assuming 2 port CCDs are used, a total of 6 data channels will be required to support GMOS. ARCON addresses the need for modularity to include more data channels through replication of additional ARCON controllers (each capable of handling 4 channels). The committee was unconvinced that this is a more cost effective approach than one requiring, for example, a single additional analog processor board as alternate controllers offer. For GMOS two separate ARCON controller boxes will have to be mounted near the GMOS dewar to support its 3 CCDs instead of a single box that will be possible with alternate designs in use today at major observatories. Concern was expressed about the lack of any in-house experience with the subtleties associated with actually running multiple CCDs in a dewar - ARCON has never been run in a mode that compares directly with the GMOS implementation. The ARCON team may have under estimated the problems they will encounter when they first attempt this in the MOSAIC project and it is not clear if the solutions proposed to synchronize read outs will be adequate to control excess noise. Also, due to the number of clocking signals that ARCON can support it may be necessary to in fact gang wires across CCDs in a common dewar to drive them all and this may lead to unexpected performance degradation (e.g., cross talk). To be sure these problems will need to be solved for the KPNO MOSAIC project before ARCONs are delivered to Gemini, but this was seen as having some technical risk at this time.

Increased Speed Upgrade: The single greatest concern expressed within the committee about ARCON is the complexity and risk associated with upgrading it to meet the Gemini speed requirement. There appears to be a major bottleneck in the design caused by the fiber link between transputers at each end of the data system. Even the upgrade of boosting data throughput to a peak value of 200 Kp/s requires a significant number of changes including changing the transputer link protocol from the byte-wise transputer standard to a custom packet-wise protocol, modifying the electronics to add clock drivers after the slope control (in an awkward location), changing the signal processing or at least the ADCs, adding more supply power for the additional clock drive and possibly changing the entire packaging for the increased volume now necessary. Boosting the data rate to one which actually meets the requirement would require most of the above, as well as a complete additional data link. All of this was seen as patches and modifications to the tidy and well-integrated original design, and which may well detract from its merits of a stable and reliable system. A clear and low-risk approach toward upgrading ARCON to deliver the 250 Kp/s speed requirement (or even 200 Kp/s) was not therefore presented - clearly some development work will be needed to make these changes. ARCON has been well engineered to meet the CTIO needs but the end result is design that is not very flexible in terms of upgradeability without significant investment of CTIO engineering resources to make the changes needed. Furthermore, while one of the main attributes of ARCON is its proven record of reliable performance, it is not clear that with the substantially *different* ARCON that would emerge at the end of the development phase needed to make Gemini’s version of ARCON, that Gemini would have a well tested product in the end, i.e., one of the most powerful arguments for adopting ARCON might go away. Again, as expressed in the summary statement, accepting ARCON even in its 200 Kp/s upgraded version carries considerable risk and would still mean relaxing Gemini specifications and the committee felt this was unacceptable.

As a corollary to the issue of speed, the CTIO staff raised the legitimate issue of relaxing the Gemini speed requirement by adopting CCDs that have 4 ports (the baseline envisioned now is for 2 readout ports for each CCD). Needless to say the number of ports assumed to be in the Gemini science CCDs was given considerable thought in the formulation of the requirements. Some of the concerns felt within Gemini about 4 port designs include:

- A number of vendors and foundries are currently developing two output 2K x 4K pixel CCDs and Gemini's baseline allows for the possibility of cost savings by making use of existing masks and designs, or possibly purchasing the CCDs.

- Since a foundry run will likely be used to procure the CCDs the yield should go up if only 2 high quality amplifiers are needed for each CCD, rather than 4

- Each additional port means low-level problems may creep into performance due to nonuniformities each output amplifier's gain, linearity, etc. While these in principle can be calibrated out, reducing the problem at the outset by reducing the number of separate data channels seems reasonable.

- An internal assessment of likely speed vs. noise performance of CCD amplifiers available in the near term suggests that high gain devices which relax noise requirements on controllers at high speed will likely be available soon.

- The 250 Kp/s requirement is one that can be met by several controllers available today hence this was not viewed as a fundamentally difficult requirement to meet given the state of the art.

Commonality in Gemini CCD Controllers: Having common systems to support similar needs has always been a fundamental goal for Gemini. The realization of cost savings and simpler long term operational support is self-evident with this model. With the variety of CCDs dedicated to wavefront sensing throughout Gemini's A&G and AO systems, the possibility of adopting a single controller for all CCD control applications within Gemini is a more compelling argument for commonality than sharing a science CCD controller with CTIO in Chile. Furthermore, while CTIO expertise could be tapped in supporting ARCONs at Gemini-South, the telescope on Mauna Kea would stand alone with ARCON, hence support at this site will certainly be more difficult.

Software

The opinion of the committee was that CTIO significantly under estimated the amount of work required to develop software for a Gemini-grade ARCON. It was understood by the committee that CTIO feels that the largest uncertainties in the software development estimates stem from CTIO's uncertainties about exactly what is required to link to EPICS. No in-house expertise at CTIO exists with EPICS though that will change in the future as new instruments (e.g., the NIRS) are commissioned at the CTIO 4 m, which will run under EPICS. However the committee felt that a major source of uncertainty lies in the changes required to take a user driven system such as ARCON and turn it into an ARCON kernel with an associated API and server. Creating client-server software from software that did not have this as an initial design goal can be problematic. As much as a 100% uncertainty was estimated to exist in estimates of software development needed to create an ARCON kernel.

Concern was expressed about the ability of the CTIO staff to support a broadly distributed kernel. If ARCON is the adopted standard at a large number of institutions there will no doubt be a load placed on the CTIO staff to support the core ARCON software to the satisfaction of all involved. The model proposed is for each institution to have membership on a change control committee in order to assure that all ARCON users have some level of representation/input into change control decisions. Currently the staffs at Kitt Peak and CTIO have representation on this committee and if Gemini adopts ARCON as its standard science CCD controller Gemini would also have membership. While CTIO will clearly push forward with software modifications and offer these upgrades at no charge to the ARCON user community, external members of this community will have to pay CTIO for future modifications. It is understood that CTIO cannot support future modifications to the kernel without resources (money) being injected into CTIO as non-CTIO ARCON users demand kernel modifications. The review committee expressed general concern though about whether CTIO had given adequate consideration to the long term staffing implications of this support model even with injection of money on a sporadic basis. More importantly, the committee was concerned about the responsiveness of this support model during Gemini commissioning and operations. For example, if Gemini decides to upgrade its Sparc workstations for any of a number of reasons, and they are delivered with a significant OS upgrade (which is often the case), how will Gemini operate ARCONs in the new OS environment? Coordinating the numerous internal changes to hardware and software within Gemini that occur quite naturally with infrastructure improvements must therefore be linked with an external change control committee and a CTIO staff that does not have clearly allocated resources to support an ARCON kernel. It is understood that this model is still in a formative state and will no doubt be streamlined after the change control committee begins to work together. Nonetheless, all of this suggests considerable risk in the long term maintenance of ARCON's kernel to Gemini, assuming an alternate model relying on in-house expertise to maintain CCD controller software (at all levels) is adopted by Gemini operations.

Management/Costs/Schedule

The cost of an ARCON controller is very high. Even the unburdened costs exceed the Gemini budget for these devices. The labor proposed to build 3 Gemini ARCONs seemed excessive at 11.4 PY's, since a significant fraction of this effort should be pure replication of an existing (developed) system. During the review the CTIO staff expressed that a rather conservative model was used to arrive at the unburdened cost, in essence this provided contingency in the cost estimates that in reality may or may not be needed in the actual development of the Gemini version of ARCON, but Gemini will pay in any event. As a specific example, the time required to make the MOSAIC upgrades for an ADC board from its current configuration to a final PCB was 40 man-weeks (note that some modifications to the board are factored into this estimate). Out of this an estimated 6 man-weeks will be needed to take the design from an *existing schematic* to a PCB layout - a process that should be substantially automated with modern PCB design software. The committee was rather puzzled by the 40 man-week figure in general and the 6 man-weeks needed go from an existing schematic to a PCB layout. Members on the committee with direct experience in this area were clearly disturbed by such manpower estimates and the question emerged within the committee if CTIO is using a very efficient technique for in-house PCB design.

The very conservative approach toward estimating direct costs of course propagates into indirect costs as well, since relatively simple multiplicative factors are used to scale between direct and indirect costs. As already stated in the summary, the (frankly) huge indirect costs associated with the project all but ruled out Chilean participation as workpackage manager. The whole issue of defining realistic overhead rates clearly lies beyond the scope of the review committee, other than to identify them as very high and will make it impossible for the development of ARCON, as proposed, to remain as a Chilean workpackage.

In terms of costs associated with new software development, there was no obvious difference between IGPO costs needed to incorporate ARCON into the Gemini control system and any other control system. There may be cost savings with software development if a single type of controller is used for all wavefront sensing and science CCD applications though.

Regarding management of the overall project, concern was expressed in the committee that the CTIO engineers and scientists have limited experience in terms of defining work schedules, cost estimates, etc., Since the CTIO staff has a primary function of supporting operations on Tololo, it was not clear that available resources to effectively manage ARCON development through the 200 Kp/s stage were available. The ARCON team found it difficult to express how the MOSAIC upgrade schedule meshes with the proposed Gemini upgrade plan, which was a bit disturbing because the MOSAIC upgrade feeds directly into the Gemini upgrade. The perceived difficulties of the CTIO staff to estimate labor and costs, even for an existing system, suggests potential risks in schedule and costs if the full 200 Kp/s upgrade path is pursued.

Final Conclusions and Recommendations

The primary conclusions reached by the review committee are:

- ARCON is a well designed compact system that meets the current CTIO requirements.

- ARCON does not and cannot without *significant* further development meet all of the Gemini performance requirements. Primary deficiencies are in the areas of speed and extendibility.

- Adopting ARCON as Gemini’s science instrument CCD controller commits Gemini in the near term operational future to fairly old and possibly obsolete technology (T8 series transputers). Gemini is still in the position to adopt a system with a newer (mid 90's) technology.

- The labor and cost estimates appear excessive and are well over what Gemini can afford within its instrumentation budget. There are likely other more cost effective suppliers available.

Actions within the IGPO should therefore include:

- Investigate other controllers in an effort to identify alternatives to ARCON.

- Investigate the possibility of one common CCD controller for science CCD and wavefront sensor CCDs.

- Track the progress of the NOAO mosaic program to assess the capability to meet schedule and the performance obtained when ARCONs are paralleled up.

- Investigate with the Chilean Project Office other means of supplying CCD controllers to Gemini as a Chilean Work Package.

Appendix A - Gemini Science CCD Controller Requirements

- Capable of reading/running Gemini science grade CCDs under development (probable baseline: 2x4k, 2 ports, 3-edge buttable)
- Programmable to support modes such as anti-blooming, on chip binning (up to 8x8) of serial and parallel pixels independently, and up to 4 independent selectable sub-array readouts
- Noise performance at least 2x below read noise specification on Gemini CCDs for a CCD amplifier gain of >5 µV/e- and 20 kohm output impedance
- Capable of supporting read rates from 25 Kp/s up to at least 250 Kp/s with a goal of 800 Kp/s through a single amp
- Designed for ease of maintenance and trouble-shooting in Gemini environment by Gemini staff
- Modular design capable of simple upgrades for mosaics, up to 16 channels
- User selectable gain from proper read noise sampling to full well depth encoding
- Full 16 bit ADC accuracy
- <50 W power dissipation into Cass environment - a Gemini provided heat-sink rack is available if required with up to 1 KW capacity
- Transfer the entire descrambled image to the Gemini DHS in a time no longer than 20% of the readout time or 5 sec, which ever is longer
- Capable of handling CCD temperature and shutter control
- Support control functions and interfaces per the document "Requirements for Gemini Detector Array Controllers"
- A "STOP" function should end a running exposure, read-out the array, and leave the system ready to begin a new exposure. The "ABORT" function should terminate a running exposure w/out readout and leave the system ready to begin a new exposure

Appendix B - Charge to the Design Review Committee

- Does the design meet the Gemini requirements as specified by Gemini? What level of performance has already been demonstrated and where are the significant technical and cost risks?
- Does the ARCON design meet the requirements of the Gemini facility instruments (GMOS & HROS)?
- Is the design compatible with Gemini standards and interfaces, including EPICS?
- Are the hardware and software likely to be reliable, maintainable, and upgradeable?
- Are the costs and schedules consistent with Gemini's requirements?