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Cryogenic Detector Preamplifier Developments at the ANU

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ABSTRACT

We present a summary of the cryogenic detector preamplifier development programme under way at the ANU. Cryogenic preamplifiers have been demonstrated for both near-infrared detectors (Teledyne HIRG and Leonardo SAPHIRA eAPD as part of development for the GMTIFS instrument) and optical CCDs (e2v CCD231-84 for use with the AAT/Veloce spectrograph). This approach to detector signal conditioning allows low-noise instrument amplifiers to be placed very close to an infra-red detector or optical CCD, isolating the readout path from external interference noise sources. Laboratory results demonstrate effective isolation of the readout path from external interference noise sources. Recent progress has focussed on the first on-sky deployment of four cryogenic preamp channels for the Veloce Rosso precision radial velocity spectrograph. We also outline future evolution of the current design, allowing higher speeds and further enhanced performance for the demanding applications required for the on instrument wavefront sensor on the Giant Magellan Integral Field Spectrograph (GMTIFS).

Keywords: Cryogenic preamplifier, near-infrared, lucky imaging, CCD.

1. INTRODUCTION

The Australian National University (ANU), has embarked on a programme to develop cryogenic preamplifier system for both infra red and optical CCDs. The use of cryogenic preamplifiers is beneficial in systems with long cable runs in the readout out chain. The initial test for the cryogenic preamplifiers is the a *Lucky Imaging* instrument to be deployed on the 2.3 m telescope at Siding Springs using a Leonardo SAPHIRA near-infrared electron Avalanche Photo-Diode (eAPD) array, capable of high cadence imaging with frame rates of 10 - 5,000 Hz over the wavelength range of 0.8 μm to 2.5 μm . The controller for the initial development phase of the project will be an ARC SDSU Series III. A demountable cryostat for telescope operations will be developed in-house at ANU based on a design adaptation of the ANU/WiFeS instrument cryostat.²

As well as preamplifiers for infra red detectors, the ANU has also developed cryogenic preamplifiers for optical CCDs, in particular the e2v CCD231-84 used for the Veloce Rosso, the red arm of an ultra-stable fibre-fed R4 echelle spectrograph for the 3.9 m Anglo-Australian Telescope.

2. LEONARDO SAPHIRA APD SYSTEM

To overcome the perennial problem of pickup noise in long control leads between cryogenic near-infrared detectors and external control electronics, we have developed a cryogenic preamplification circuit for use with the Leonardo SAPHIRA eAPD detector and the large format science arrays (e.g., the Teledyne HxRG detector series to be used with the GMTIFS instrument, Sharp et al. 2016). Indeed, the *Lucky Imager* program provides the perfect test bed for such developments.

The readout electronics will consist of a detector PCB carrying the Leonardo SAPHIRA APD and cryogenic preamplifiers interfacing to a 32 channel ARC SDSU III detector controller.

Care has been taken to ensure that the circuits have been designed to minimise the noise in the readout chain. The ground planes are cut out around high impedance pins to avoid coupling between the signal pins and the ground plane. This is particularly significant for the input pins on the operational amplifiers on the cryogenic preamplifier circuit. The circuit boards all have internal ground planes to separate the analogue and digital signals as well as the differential and single

ended signals. The clocks, biases and power signals are laid out over their own independent ground plane linked up to either the digital or analogue grounds. All differential pairs are balanced with equal length tracks and chamfered corners.

The venerable ARC SDSU III has been identified as the initial test controller due to our existing in-house experience with this devices (e.g., NIFS, GSAOI, WiFeS^{2,4,5}); however it is envisaged that alternative controllers will be interfaced to the system in the future. The in-house expertise with programming the SDSU lends itself well to this project as it will allow us to test the full suite of features available on the ME1000 readout integrated circuit (ROIC) allowing us to take full advantage of the new technology in future applications

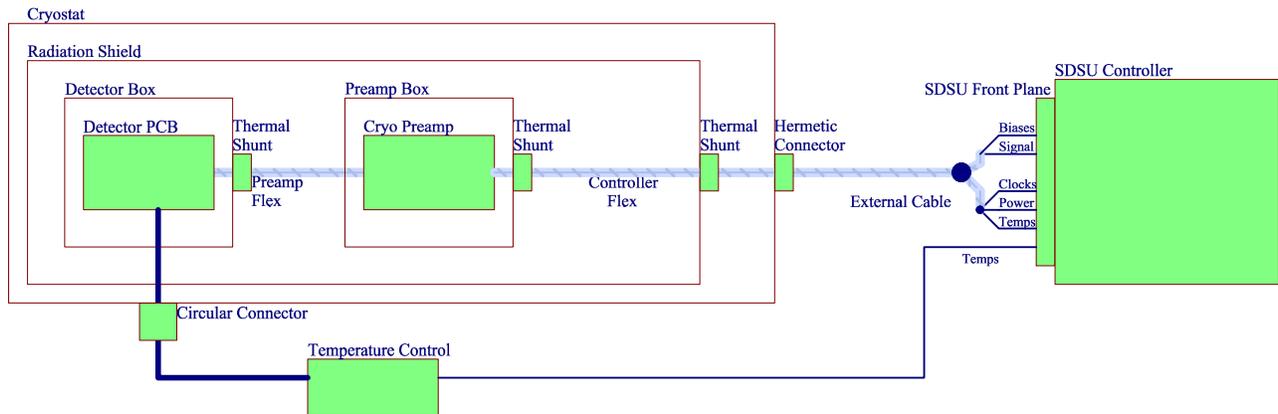


Figure 1. High level system overview for the ANU Lucky Imager.

2.1 Detector PCB

The detector PCB is primarily designed to carry the APD which is packaged in a 68-pin Leadless Chip Carrier (LCC) package. However due to space constraints on the preamplifier circuit the bias filtering has been added to the underside of the detector PCB. The biases do not vary with increasing readout speeds, and so the heat produced by the filtering circuits will remain constant regardless of the readout speed. A middle ground layer in the PCB will be connected to the second stage cold head and cooled to the same temperature as the detector, which will provide additional radiation isolation between the filtering circuits and the detector.

The APD is cooled by a spring-loaded copper block in contact with the back of the LCC package. The copper block will then be connected to the second stage cold head via two copper straps. To accommodate cooling, the SAPHIRA APD will be mounted to the detector PCB in an off-the-shelf 68-pin LCC socket with the bottom cover removed. The PCB has a square cutout that matches the square cutout of the PLCC socket, as shown in Fig. 2.

The flex cable connecting the detector PCB to the preamplifier circuit passes through a thermal shunt as it exits the detector box to isolate heat transfer between the two circuit boards. The flex cable has been kept to a length of 32 mm.

2.2 Cryogenic Preamplifier

The cryogenic preamplifier is a 32 channel instrument amplifier which is an extension of an existing 6 channel cryogenic preamplifier circuit designed and tested at the ANU to interface the Teledyne H1RG/H2RG detectors to the ARC SDSU III controller. The instrument amplifier circuit consists of two OPA2354 op-amps which have proven to be robust in cryogenic environments. The cryogenic preamplifiers have been repeatedly power cycled at 50K with no measurable degradation of performance.

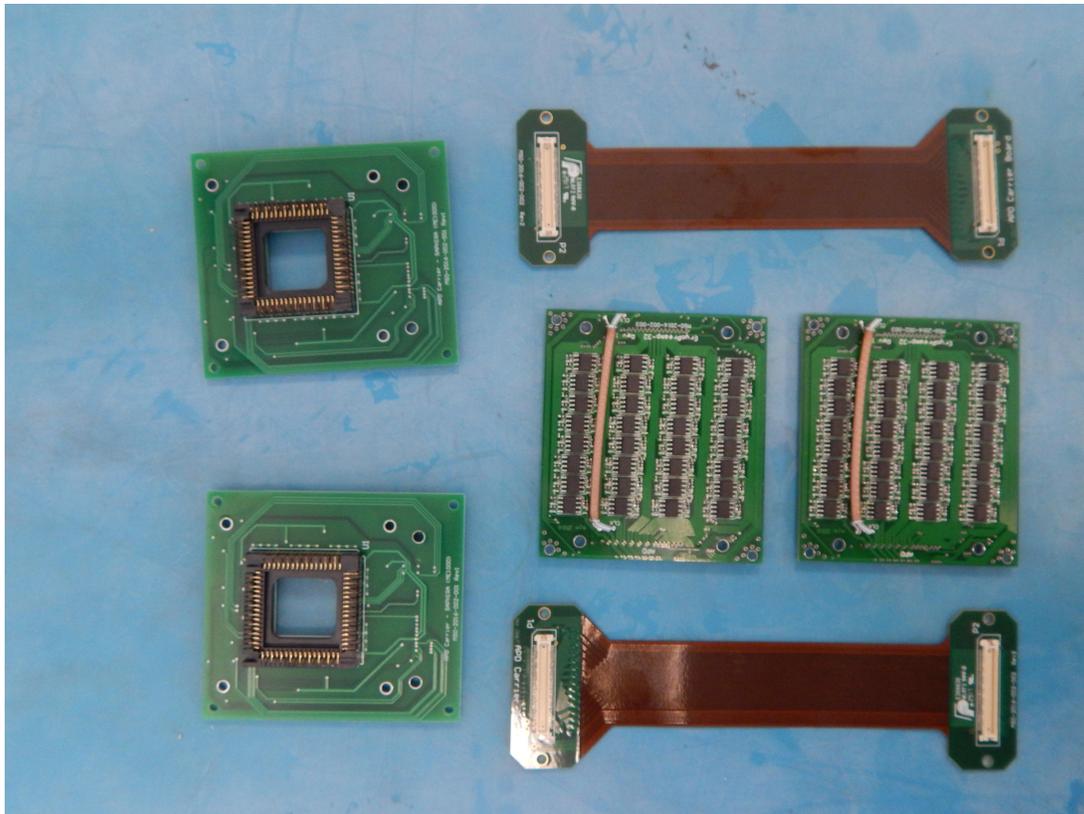


Figure 2. Two complete sets of detector carrier boards, 32 channel cryogenic preamplifiers and flex cables. The carrier board has all the components for filtering mounted on the bottom layer. The open space in the centre of the PLCC socket is for the detector cooling finger to contact the back of the detector.

The cryogenic preamplifier circuit is separated from the detector PCB and separated by a radiation shield and thermal shunt to reduce the risk of glow from the op amps at the highest readout speeds. The cryogenic preamp circuit when operating at the highest frame rates will dissipate up to 340 mW of power. Maintaining the cryogenic preamp circuit at a higher temperature than the detector will reduce the load on the cooling system. The op-amps are actively cooled through the ground plane through the 4 mounting holes at each corner of the PCB.

In the ANU Lucky Imager cryostat the cryogenic preamplifier and cooling interface are enclosed within an aluminium box which is cooled to the same temperature as the cryogenic preamplifier which acts as an active radiation shield, baffle and filter housing a 36mm filter. The cryogenic preamplifier box has 4 small copper cold straps that are screwed onto the top face of the preamplifier at the edges via holes. The cold straps then go around the rear preamplifier box and join to a copper block which is directly connected to the cold head of the cryostat.

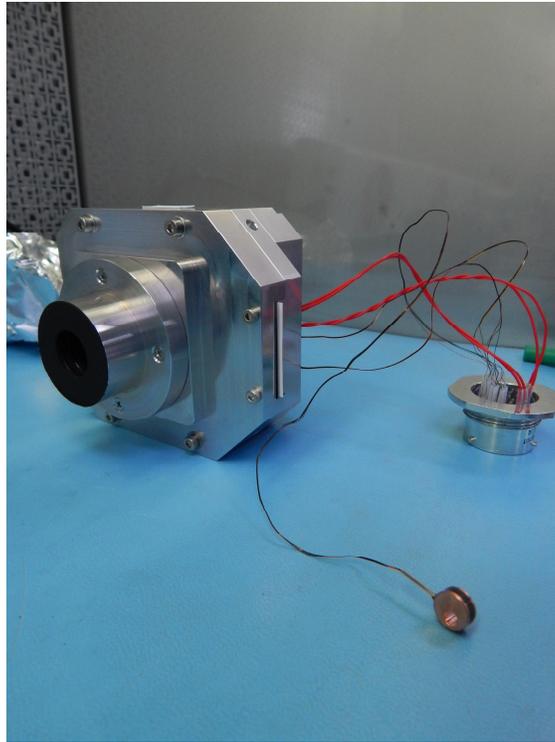


Figure 3. Aluminium housing for the cryogenic preamplifier detector, baffles and filter which also acts as an active radiation shield. A thermal shunt is clamped onto the flex cable between the preamplifier and carrier board.

Below is an image of a lens barrel taken through a pin hole using an engineering grade Leonardo SPAHIRA APD mounted in the ANU Lucky Imager cryostat. The filter in the cryostat is a H band filter with medium avalanche gain on the APD.

The ANU Lucky Imager is scheduled for first light on the ANU 2.3 metre telescope in October 2018. The first test runs will be the H band filter and the SDSU controller operating at a maximum cadence of 100 frames per second.

Several complete cryogenic preamplifier system have been shipped to several institutions which have reported favourable results in mitigating external interference noise.

The ANU cryogenic preamplifiers have been tested extensively in the lab and on site at SUBARU SCEAO and shown to be effective at reducing induced noise in demanding environments.⁸

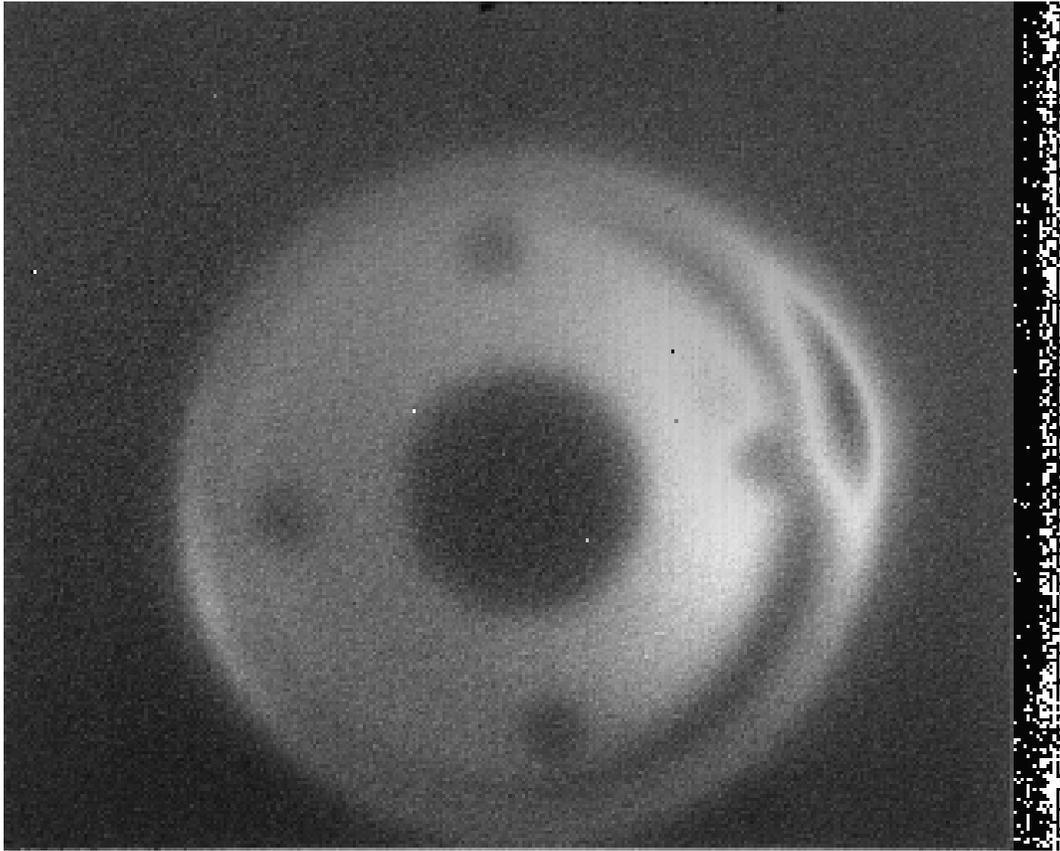


Figure 4. An image of a lens barrel taken with an engineering grade Leonardo SAPHIRA APD mounted in the ANU Lucky Imager Cryostat a readout through the ANU cryogenic preamplifier circuit to a SDSU controller.

3. CRYOGENIC PREAMPLIFIER FOR OPTICAL CCDS

The ANU has also been developing cryogenic preamplifiers for optical CCD systems, in particular to interface to the e2v CCD231-84, 4kx4k quad amp CCD. The ANU recently deployed Veloce Rosso, the red arm of an ultra-stable fibre-fed R4 echelle spectrograph for the 3.9 m Anglo-Australian Telescope. The design of Veloce Rosso required a long cable length from the detector to the controller in excess of 1 metre operating in a noisy environment. Cryogenic preamplifiers were tested to mitigate the risk external interference noise in the long cable runs. The existing infra red cryogenic preamplifiers were adapted to work with e2v CCD. An AC coupling stage was added ahead of the preamplifier stage to remove the high DC offset inherent in optical CCDs. The circuitry was integrated into a single flex cable due to space constraints of the cryostat design. A number of different amplifier designs were trialled including the OPA2354 layout used in the infra red system. An alternative design using the Maxim Integrated Max44206 integrated amplifier was also trialled with a view to adopting the Maxim devices longer term. Production of the Maxim Integrated MAX44206 has since ceased since the initial design and any further development on this design for the cryogenic preamplifier has also stopped.

The cryogenic preamplifier for optical CCDs has not matched the low noise performance achieved by the cryogenic preamplifiers for both the Maxim Integrated Max44206 and OPA2354 layouts has not matched that of the infra red systems and our investigations into the culprit is now focused on the AC coupling circuit as this is the only variation between the two systems.

The preamplifier circuit also includes bias filtering to remove high frequency noise induced in the bias supply lines from external sources. The bias, clocks and video signals are all laid out over separate ground planes to reduce the risk of coupling between the signals.

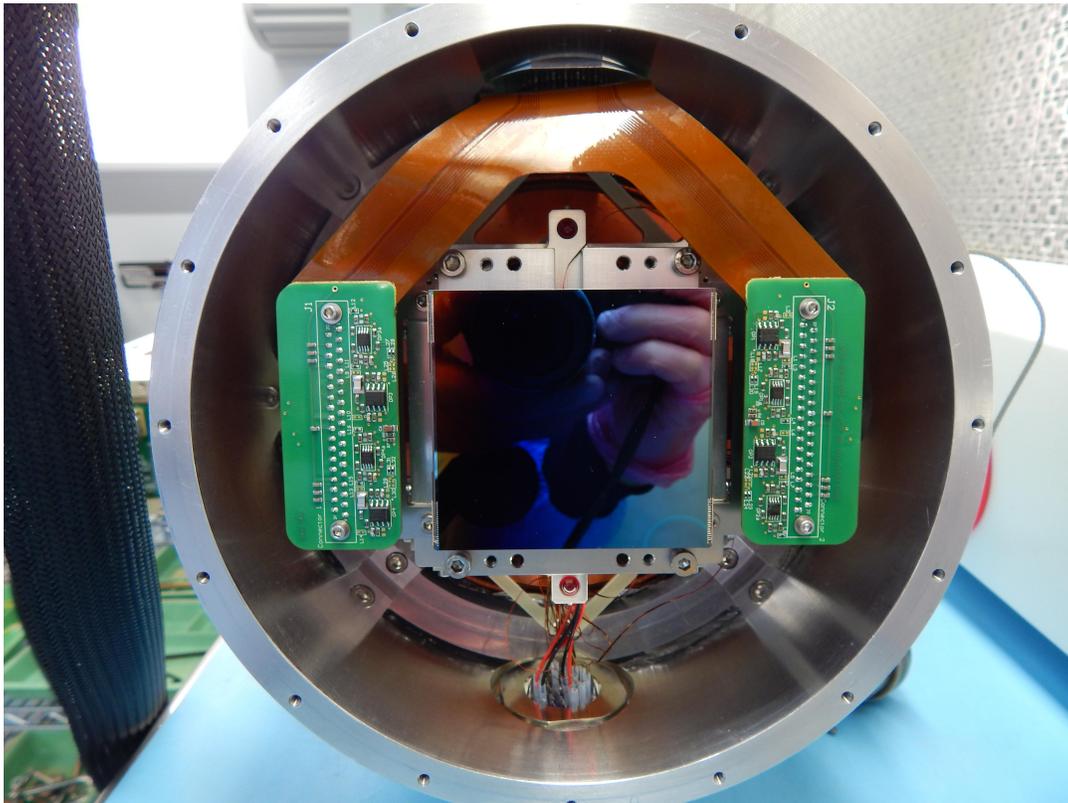


Figure 5. Cryogenic preamplifier circuit integrated into the flex cable for the e2v CCD231-84.

4. FUTURE DEVELOPMENTS

Future developments for the ANU cryogenic preamplifiers involve developing a 66 channel system to interface to the Teledyne H4RG-15 which is the default detector for the GMTIFS imager and integral field spectrograph.

Redesigning the Leonardo SAPHIRA system to accommodate more robust connectors capable of handling higher frame rates and reducing the risk of connector failures post deployment.

The ANU will also continue to development of the optical CCD cryogenic preamplifiers for instruments operating in demanding environments.

5. CONCLUSION

The cryogenic preamplifiers have proven effective at mitigating external interference noise particularly for infra red detector systems. Several systems have been installed in instruments at various observatories around the world returning positive results for mitigating external interference noise.

ACKNOWLEDGEMENTS

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