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Evaluation of Cryogenic Preamplifiers for Infrared Focal Plane Array Detectors

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Summary:
Infrared focal plane array detectors for instrumentation of ground-based telescopes such as the VLT are operated at cryogenic temperatures to minimize dark current and reduce cosmetics. To achieve high signal integrity, the analogue video outputs of MCT type sensors from Teledyne, Raytheon or Leonardo are typically amplified inside the cryo-environment close to the detector and which requires highly efficient preamplifier designs and devices. Within the scope of this paper, three design concepts built from commercial products are compared and simulated regarding power consumption, bandwidth, and noise.

Keywords: Infrared Detector, Simulation, Preamplifier, Cryogenics, low noise

Motivation

Ground-based infrared telescope instruments translate infrared light of observed objects to digital values (see Fig. 1). The photoelectric effect inside the focal plane array pixels converts photons to electrons and thence to an electrical voltage via a capacitor.

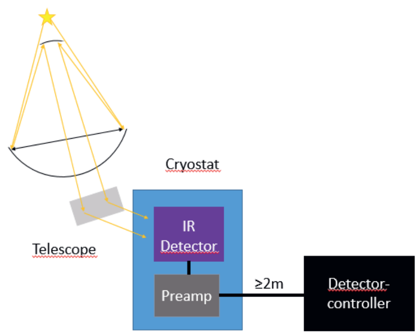

Fig. 1. signal chain of ground-based telescope; from the light of stars to digital units

State of the art infrared focal plane arrays for near- up to mid-infrared astronomy are usually operated at temperatures between 4K to 80K with a readout frequency varying from 100 kHz up to 5 MHz per video channel [1], dependent on the wavelength range. However newly developed detectors are specified to operate at pixel speeds in excess of 10MHz. Preamplifiers allow the detectors to drive longer cables of 2m or more at high speeds, by applying electronic gain they can increase the signal above external noise sources and by converting single-ended video signals to differential signaling they greatly improve the common mode rejection. Due to these benefits but also to minimize the external capacitive load, the preamplifiers are operated in the cryo-environment close to the detectors.

The requirements of cryogenic preamplifiers for scientific infrared detectors are typically a noise of less than 72µVrms, a bandwidth of greater than two times the signal frequency and static power of less than 100mW per channel.

Not all technologies can be used in cryo-environment, for example, ordinary silicon bipolar transistors suffer from low-emitter-base efficiency, making them unusable at temperatures below 100K [2]. GaAs or SiGe compound semiconductor devices, JFETs and MOSFETs are compatible with the cryo-environment and some can even work down to very low-temperature levels [2].

Cryogenic Preamplifier

Cryogenic preamplifiers for infrared detectors have been utilized and developed at ESO for many years [3]. Besides the standard ESO preamplifier design [1] two additional designs are analyzed: a J-FET Source Follower Preamplifier and a 2 Stage Preamplifier.

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In the J-FET Source Follower design, a J-FET in a Source Follower configuration is utilized to buffer the high impedance of the detector video output with unity gain. In this design, a single-ended video signal is amplified and routed in parallel with a corresponding reference voltage which is buffered by a second J-FET to form a pseudo-differential signal.

The 2 Stage Preamplifier design combines a non-inverting cryogenic operational amplifier that buffers the video signal with a differential amplifier which can be realized by the standard ESO Preamplifier. This configuration only needs one operational amplifier with unity gain in the cryo-environment.

Results

To compare all three designs a simulation with SIMetrix was conducted. For this simulation, a total cable length of 2m is assumed. The spacing between the first and second stage of the 2 Stage Preamplifier Design is set to 1m.

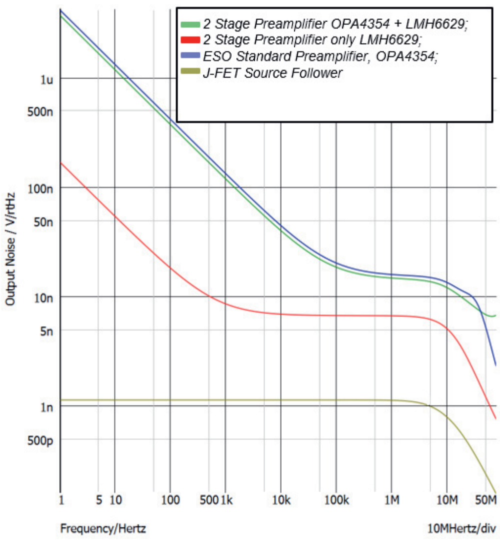

Fig. 5. Output Noise

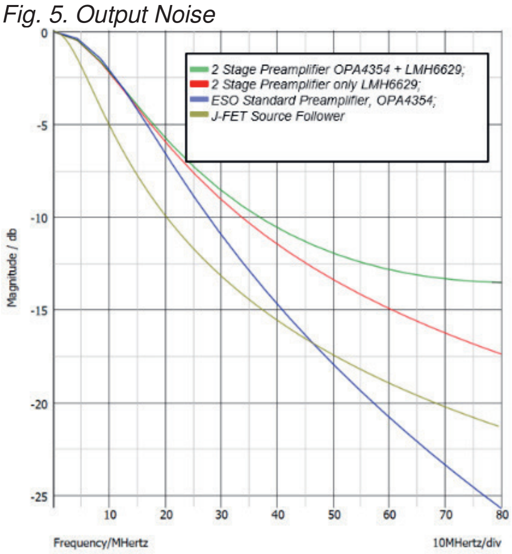

Fig. 6. Bandwidth

An overview of all designs and their simulation results are listed in Tab. 1.

Tab. 1: Overview of Designs and Results

	ESO Pre-amp	J-FET design	2 Stage Pre-amp
Amplifier	OPA4354	J309	1st stage: LMH6629 or OPA4354 2nd stage: OPA4354
Static power (mW)	47mW	50mW	Only 1st stage: 77.5 or 23.5
Gain	3	1	3
noise (µVrms)	~61.9	~3.9	~23 or ~56
BW (MHz)	11.3	6.476	11.3

Conclusion

All designs are less than 100mW static power per channel and are also less than a total noise 72µVrms. For slow read-out frequencies, a J-FET Source Follower Amplifier Design is favorable up to frequencies of 2 to 3 MHz due to the small number of required components, low power consumption, and noise. For higher frequencies, the 2 stage Preamplifier Design seems more favorable as only one operational amplifier with unity gain is required in a cryo-environment. The flexibility to utilize any conventional differential amplifier including bipolar technology as a second stage is an additional advantage that could increase the current Bandwidth to support faster detectors and longer instrument cables. The next step is a dedicated cryogenic test of the two new designs to analyze the actual performance when operated cold.

References

[1] Ackermann, Jörg & Azman, Suleyman & Gheorghe, Codin & Meier, Dirk & Maehlum, Gunnar. (2018). Multi-Channel Preamplifier IC for IR-Sensor and FPA Readout. 10.13140/RG.2.2.27382.65607.

[2] Device and Circuit Cryogenic Operation for Low Temperature Electronics, eds. F. Balestra and G. Ghibaudo, Kluwer Academic Publishers, 2001, ISBN 0-7923-7377-4

[3] D.Ives et al., Performance evaluation of 5 um cut-off Hawaii-2RG detectors using the fast readout amplifiers, *High Energy, Optical, and Infrared Detectors for Astronomy IV (2010), Proc. of SPIE Vol. 7742 77421S-3;* · doi: 10.1117/12.8