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CX-4 *- 30MHz*

Cryogenic *Super Low Noise* Amplifier

- Datasheet -

V. 2.5, June 2024

Features:

- **Frequency Range approx. 14kHz to approx. 30MHz**
- **Very High Input Impedance**
- **Super Low Noise (< 0.4nV/√Hz @ 1MHz, ~4pF=C_{IN})**
- **Operation in strong magnetic fields (6T) and low temperatures down to 4.2 K and even lower (options)**

Applications:

- **Quantum State Readout**
- **Single Ion FT-ICR**
- **Tuning Forks**
- **Schottky Noise Measurements**

Attention: Electrostatic Sensitive Device (see hints)

Introduction

The CX-4 is a highly sensitive voltage preamplifier, intended for low-temperature, low-noise applications. It comes in different versions, *this* datasheet describes the 2-channel version reaching from about 14kHz to about 30MHz in the frequency range. The circuit can be used directly inside a cryogenic vacuum setup. Cryogenic GaAs (Gallium-Arsenide)-FET technology allows for deep-cryogenic operation, even in strong magnetic fields up to several Tesla (optional), as they are present in NMR, FT-ICR or solid-state research applications. The amplifier features FET input and thus a very high input impedance. The ultra-low input voltage noise around 390pV/√Hz (at 1MHz) is outstanding in conjunction with a high-impedance input and represents state-of-the art technology.
The amplifier module is delivered as print board-stack with aluminum lids and comes together with a mating room temperature biasing controller. In contrast to preceding versions, no Bias lines are required, the device is self-biased through the 2 signal output lines (SMA sockets). Solder pads are used to connect the inputs. The device consumes only about 275µW per channel, easing cryogenic operation.

Application Example

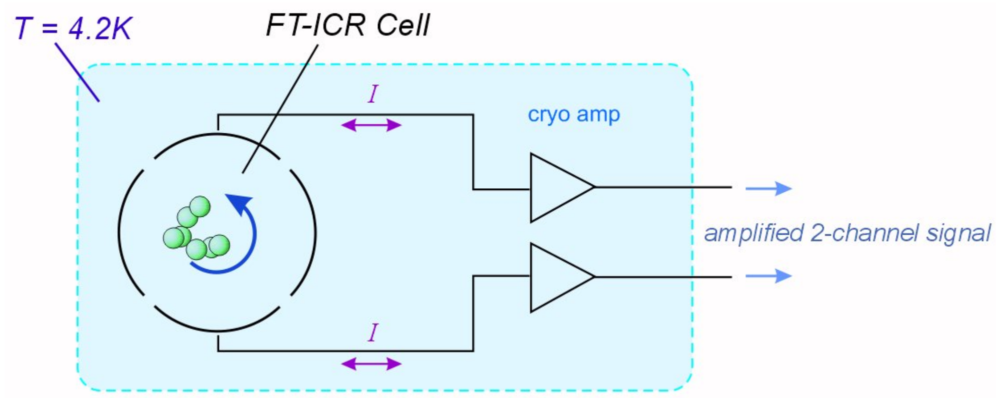

Fig. 1: Typical Application: High Impedance Signal Detection in FT-ICR Cells

Input Solder Connections and SMA Output

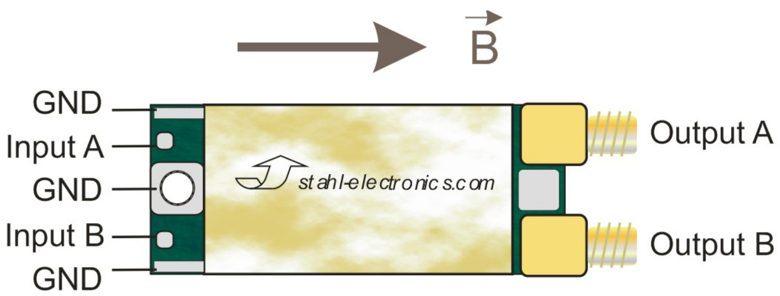

Fig. 2: Solder Pad Input Connections, SMA connectors

Electrostatic Sensitivity

This device can be **damaged** by ESD (Electrostatic Discharge). It is **strongly recommended** to handle the device with appropriate precaution. Failure to observe proper handling and installation procedures can cause serious damage. This ESD damage can range from subtle performance degradation to complete device failure.

Practical Hints:
*Whenever the device is picked up by hand, ensure that the ground pin or aluminium case is touched first before touching any other pin. Touching any other pin than ground first, **may destroy this device**. Similar precaution has to be applied when changing the location of the device: Most important the destinations ground has to be on the same potential as the devices ground (ground balancing). Therefore, connect both grounds first (using a resistor around 100kOhm, or simply by hand without gloves) before making any other connection or changing the amplifier position. Failure to perform ground balancing may easily lead to severe **irreversible damage** of the device. Always ensure to take thorough measures to avoid static charges building up in the vincinity of this device or laboratory equipment connected to it. Furthermore, **beware of non-grounded Soldering Irons**: Inexpensive Soldering Irons often have floating solder tips, which easily may **destroy** ESD-sensitive parts.*

Connection to Room Temperature Biasing Controller

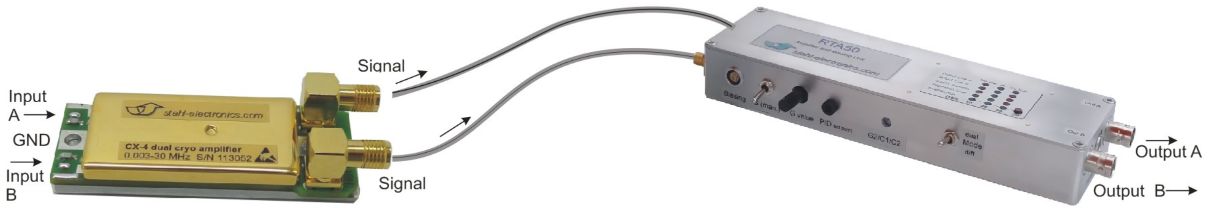

Fig. 3 Cabling to Room Temperature Biasing Controller Unit A3-5 (2-channel version)

As indicated in the picture above, the device is connected to its mating room temperature controller through two output signal lines A and B (SMA coaxial lines, 50Ω). They also provide power and biasing to the cryogenic amplifier.

Absolute Maximum Ratings

Note: Stress above these ratings may cause permanent damage or degradation of device performance. Exceeding these conditions for extended periods may also degrade device reliability.

Quantity	Limits		Remarks
	min.	max.	
Input Voltage absolute value (AC+DC) AC		100 V_{pk} vs. GND, 3V_{pp}, f = 0 ... 25MHz	derating inversely proportional with frequency above 25MHz
Input Current		25mA_{eff}	continuous current through protection circuitry
Output Voltage	-0.3V	+3V	Under normal conditions no voltage source must be applied to the outputs.
Storage Temperature	3.5K	125°C	
Storage Humidity		65% @ 40°C	
Cool-down Rate, Heating Rate		+/- 20K / minute	Care has to be taken during cool down and warm up phases. A sudden drop into cryogenic liquids may **destroy the device.**

Table 1: Absolute Maximum Ratings

Cleaning and Baking

The CX-4 device may be gently and carefully purged from organic attachments by rinsing with a mild solvent. Ethanol or isopropanol are acceptable. It may be also dipped for a while into these solvents. Stronger solvents like acetone are not recommended. Due to sensitive internal parts (thin bond wires of approx. only 40µm Gold thickness), in no case pressurised air or pressured solvents must be guided into the inner parts of the device. Ultrasound cleaning is not recommended. Baking is possible up to 125°C, and should not last longer than 48 hours prior to use at cryogenic temperatures.

Characteristic Data and Operating Parameters Cryogenic Amplifier CX-4 – 30MHz

in conjunction with mating Room Temperature Biasing Controller Unit A3-5

Parameter	typical Value	Remarks/Conditions
Freq. Range @ 4.2K for ±3dB deviation	14 kHz....35 MHz	±3dB range in conjunction with controller A3-5, customization possible
Gain linear voltage gain @ T = 4.2K, 4 steps (for elevated temperatures >4.2K see data at end of this document) Remark: linear voltage gain @ T = 300K	x 100 V/V ± 2.5% x 300 V/V ± 2.5% x 600 V/V ± 3% x 1200 V/V ± 3.5% approx. factor of 40 smaller than at 4.2K (low bias), or factor of 8 smaller than at 4.2K (high bias)	f = 1.5 MHz T = 4 K to 15 K over-all amplification including biasing controller, on 50 Ohm load 4 amplification steps are available.
Gain Mismatch between both cannels	typ. 1.5%	T = 4.2K, f = 30kHz ... 30MHz
Input Impedance vs. GND at either input DC, T = 4.2K … 300K AC, 300K AC, 4.2K input capacitance vs. GND	> 40MΩ capacitively coupled >100kΩ capacitively coupled ≥ 5MΩ 4.3pF ±1.0pF	f < 1kHz f < 1MHz T = 4.2K … 300K
Dynamic Output Impedance cryogenic stage @ 4.2K max. AC Output Power	4 kΩ ± 25% 3 mW	f = 1 MHz
Expected Impedance Biasing Conroller Unit	33 Ω ± 10%	max. AC Output Power 5mW
T = 4.2K voltage noise density *standard version* current noise density	1.0 nV/√Hz 0.47 nV/√Hz 0.43 nV/√Hz 0.39 nV/√Hz 0.46 nV/√Hz 6.8 fA/√Hz, T = 4.2K	f = 30 kHz 100 kHz 500 kHz 1 MHz 25 MHz f = 100 kHz
Operating voltages positive supply voltage on signal line	+0.275 V	Positive and negative supply should be provided by a room temperature biasing unit
Supply Currents @ 300K…4.2K positive supply on signal line	1.0 mA each channel	
Operating Temperatures	T = 4.2 K... 77K and 300 K	The device is primarily designed for low temperature applications

Applicable external magnetic field B	B = 0 to 100mT, optional to 6T (contact manufacturer)	external field must be in parallel to the long-side of the device (+/-3.5°) at fields above B = 0.1T and oriented like shown in fig. 2 (not reversed)
Magnetic Properties	Device consists mostly of non-magnetic materials. Spurious amounts of ferromagnetic substances < 5 x 10^{-3}gr. are possible	In conjunction with FT-ICR cells, it is recommended to locate the device min. 5cm away in order to avoid magnetic disturbance
size CX-4 2-ch. Room Temperature Biasing Unit	64.4mm x 23.9mm x 14.6mm Including SMA sockets approx. 210mm x 65mm x 34 mm	
Outgassing	(to be determined)	
Weight Cryogenic Unit Room Temperature Controller	approx. 25 gr. 400 gr.	
Power Supply for Room Temperature Biasing	Output +/-5V on Lemo Connector 3-pole 0B-style	**Attention: external B-field at location, the mains adaptor is placed, must not exceed B = 10mT to prevent damage or fire hazard.**

Table 2: Characteristic Data

Required External Circuitry

The mating room temperature controller (type A3-5), which is provided along with the cryogenic amplifier, regulates the bias voltage on the signal lines to be around 275mV. This voltage provides a stable biasing condition on each channel. For testing purposes one can also force a higher biasing (switch on case side of the room temperature controller) to allow for a higher voltage and current, e.g. to test functionality at room temperature.

The biasing controller A3-5 of the CX-4 serves also as a tool for error finding and debugging, see below. The controller provides further AC amplification in discrete steps, normally set to x 100 V/V, x 300 V/V, x 600 V/V or x 1200 V/V of voltage amplification at 50 Ohm load (about twice as much on high impedance load). It also supports a differential operation, by building the signal difference between the two channels (see also figure 7). In this mode, signals being common to both channels are suppressed by typically 2 orders of magnitude with respect to their amplitude. This could be regarded as a *quasi*-differential mode of the amplifier, since the actual voltage difference is being built at room temperature, and not at cryogenic temperature.

Note that channels A and B must not be interchanged, since the A3-5 controller provides some fine tuning on amplification factor and frequency response.

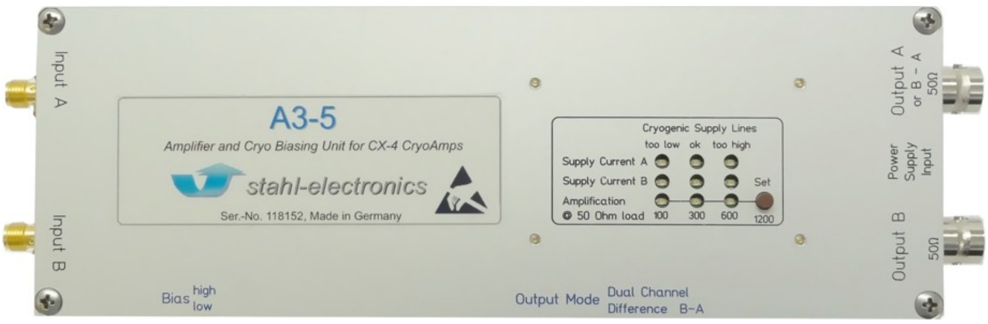

Figure: 4: the room temperature controller indicates the status of the cryo amplifier and allows for setting the overall-amplification factor. The stated values of amplification factors refer to cryogenic operation and 50 Ohm termination at the room temperature controller outputs.

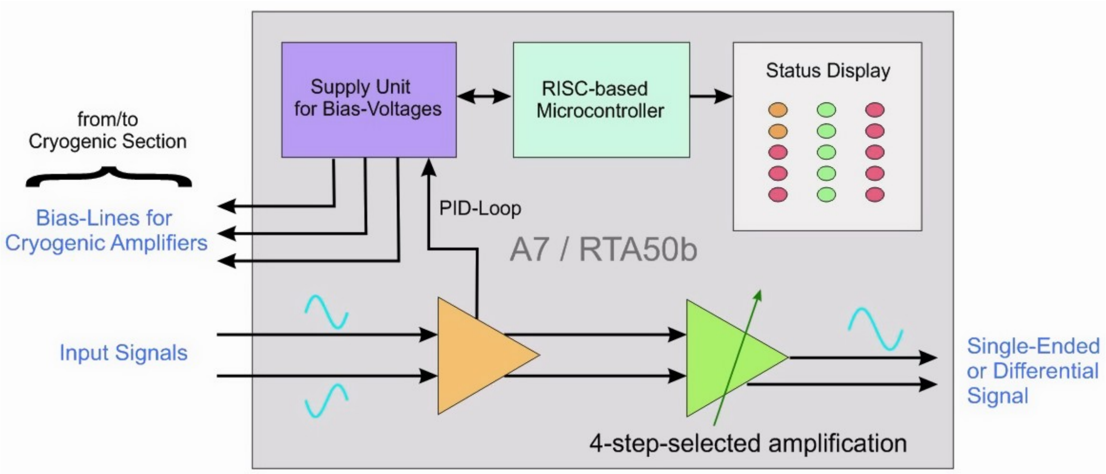

Figure 5: Block diagram of the 2-channel room temperature controller

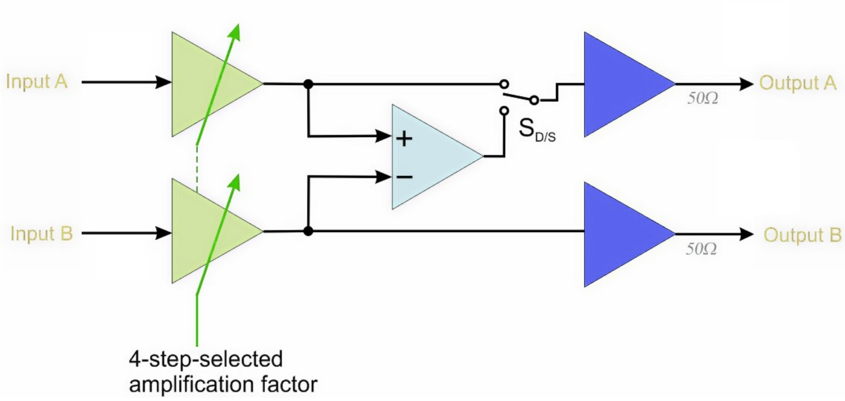

Figure 6: Schematic diagram of the analog signal amplifier circuitry inside the roomtemperature controller. The mode switch $S_{Dual/Differential}$ allows for choosing between dual-channel or differential operation

Monitoring section

This section consists mainly of a microcontroller and an attached LED (light emitting diode) status display. The microcontroller makes use of sensor amplifiers inside the A3-5 and observes the biasing currents and voltages once a cryogenic amplifier is connected. This information is processed and the results are displayed on a LED-display, such that an overview of the cryogenic amplifier's status is obtained. Eventual problems in the cryogenic region are therefore easier to locate. In case all LED are on 'green status', the left LED near the power supply plug will also lighten up green.

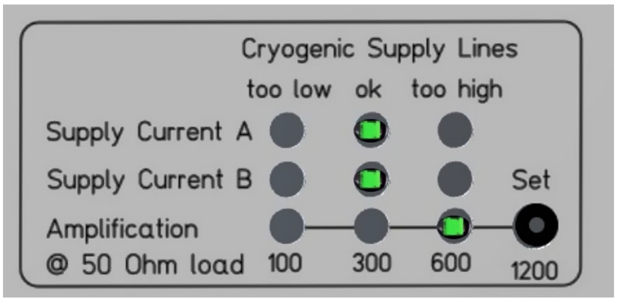

Figure 8:

LEDs indicate the status of biasing lines, assisting to find problems in the cryogenic region. The bottom row represents the amplification factor, and the amplification selection switch. Pressing the switch increases the amplification factor, a long press resets to the minimum value.

The threshold levels, upon which the LEDs change their status, are set by default (software programming) to the values stated in the Appendix. In normal operation all LED light up green.

Bias Switch

A switch at the side of the room temperature controller selects the bias condition of the attached CX-4 cryogenic amplifier. The regular position is 'low Bias', in which the amplifier draws only 1mA per channel of supply current, resulting in just 2x 275µW = 550µW of total power consumption. The accuracy and amplification specifications listed in table 2 refer to this low power mode. However, using the low power / low Bias mode at room temperature results in a rather poor amplification, which is about 1/40 of the cryogenic amplification (e.g. in the '300x' - setting the actual amplification factor is just about 7.5-fold at room temperature). Switching the Bias switch to 'high Bias' mode lifts the biasing points, which result in an amplification factor being about 8.5 times smaller than at cryogenic temperature. This 'high Bias' mode therefore may be used for a few room temperature tests, before running the system at a cryogenic temperature.

Before cooling the system down, please remember to put this switch into the 'low Bias' position, and, as described above always cool the amplifier only down, once the A3-5 power is turned off.

Note, that the current consumption LED indicators usually get red in the 'high Bias' mode. This is a normal behavior, as long as the LEDs will become green again, once returned to the the 'low Bias' mode.

Connections inside Vacuum

Attention: When mounting cables and lines to the CX-4 amplifier, always observe ESD handling hints (page 3)

AC connections to Room Temperature

The signal connection from cryogenic to room temperature (Output A, Output B) should be implemented as coaxial lines, in order to minimize external interference and the possibility of unwanted feedback from the output to the high-impedance input. A cryogenic 50 Ohm-cable (SMA connectors) is preferable. Note, that cables of channels A and B must not be interchanged, i.e. the CX-4 output A needs to be connected to input A of the A3-5 and correspondingly for channel B.

Input Connections and Grounding, Risk of Self-Oscillations

Using high impedance FET amplifiers, such as the CX-4, requires proper *Grounding and Shielding* at the input side. A thorough grounding and shielding is essential to maintain good device performance and low noise characteristics, and to avoid the creation of parasitic oscillations. Typical RF (radio frequency) -design rules for proper grounding and shielding apply here, even though the upper limit of the frequency range just barely reaches the HF (high frequency) regime. To ensure a "clean" electrical environment provide good ground connections especially around the amplifier input. The gounding hole at the input (see photo) may serve as central connection point, to which the signal ground may be connected. All lines from the signal source to the amplifier's inputs should be kept as short as possible and of low inductance-style (no large loops or spirals).

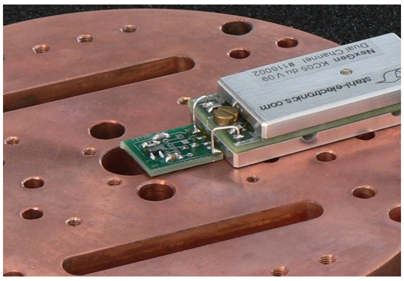

Figure 9: Illustration of connecting a sample to the amplifier's inputs. Very short silver-plated wires represent the electrical signal connection while a Brass or Aluminum screw establishes a tight mechanical GND contact to a well-conducting substrate. In the cold state, the Brass/Aluminum screw will stay tight, other material may not.

Please note that insufficient grounding or shielding around the signal source, may lead to a considerably increased noise level and furthermore increases the risk of self-oscillations. These uncontrollable oscillations appear typically at MHz- frequencies and are normally an indication of insufficient shielding at the input.

External Magnetic Field

In case a static external magnetic field is applied (e.g. FT-ICR or NMR/MRI setups) the CX-4 amplifier must be oriented like shown in figure 2, i.e. with the long side parallel to the external field, max. 3.5 degrees deviation. Also, the polarity is decisive and thus the field orientation matters. This applies for magnetic fields higher than about 0.1T. In case magnetic fields larger 0.1T are used, please contact manufacturer for special chip alignment. Figure 2 depicts the proper orientation and refers to the usual convention of polarity definition, i.e. the field line arrow points from a magnetic north pole to a magnetic south pole. For instance, earth's geographic North Pole is a magnetic south pole; a conventional mechanical compass or Smart Phone App may be therefore used, to determine the magnetic field direction at a given experimental setup, at safe distance from a strong magnet.

Input Circuitry

The subsequent figure illustrates the input protection circuitry for each input. DC blocking capacitors are provided in order to maintain a reasonable amount of admissible DC offset voltage being applied to the inputs without harm. These blocking capacitors $C_{blocking}$ are located outside the upper aluminium housing (see figure) and can be bridged / removed in favour of zero-ohm resistors for an optimised noise figure or in case a different coupling scheme is required. In case they are kept in place, the maximum allowed offset voltage at each input is +/-100V versus GND.

The limited pulse capability of maximum $1A_{pk}$ for less than 10ms duration has to be kept in mind, which is restricted by the maximum possible current through antiparallel protection diodes (see fig. 10a). This matters especially if attached circuitry is operated in a switched or pulsed mode, or, exposed to high-power radio frequency bursts (like in FT-ICR or NMR experiments).

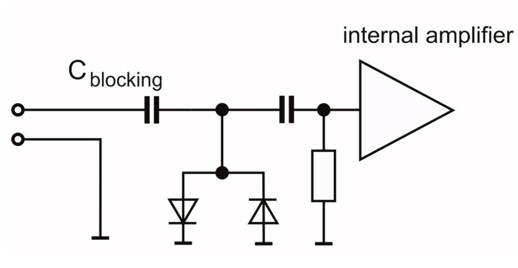

Figure: 10a
Input protection scheme (each channel)

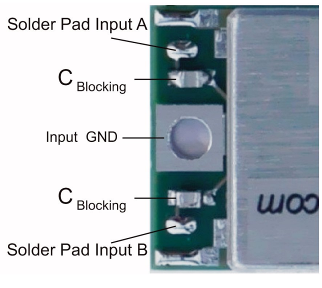

Figure: 10b
Location of removable blocking capacitors

In case the blocking capacitors are bridged, the input ESD-protection diodes limit the maximum voltage to about +/-750mV. Behind this protection circuitry the subsequent amplifier stages follow capacitively (AC) coupled.

Thermal Anchoring

Mounting the device into a cryogenic setup demands for a good thermal coupling, which is essential to achieve the specified performance of the CX-4 series amplifiers at low temperatures. The substrate, on which the circuitry is placed, should be connected by the user to an appropriate heat sink or cold finger. It is recommended to use a high conductance thermal agent like “**Apiezon N**” to provide a good heat flow between the adjacent surfaces (apply only as very *thin* layer, to bridge possible vacuum gaps). We recommend using one of the 3mm-holes for mounting with Brass or (preferably) Aluminum screws on a cold surface, or cold finger. Using Brass or Aluminum material (rather than other metals) is essential, since it will contract stronger than for instance steel or copper, which have a smaller thermal contraction when getting cold. Note that using stainless steel screws can drastically impair the thermal connection, due to thermal contraction mismatch (i.e. screws getting loose) and quite poor thermal conduction at cryogenic temperatures.

When mounting the thermal connection, ensure to avoid mechanical tension of the remaining parts of the amplifier or other kind of mechanical stress. It is recommended, not to connect both amplifier ends with screws, unless the substrate to connect shows a similar thermal expansion like the amplifier's Aluminum (AlMg alloy) housing. Copper or Aluminium substrates serve well in this respect.

Commissioning in a Vacuum or Cryogenic Setup

After cleaning and baking (in case required, see also page 4) the CX-4 device can be mounted and wired up in a cryogenic vacuum chamber. It is very important to connect ground lines first for **ESD reasons** (fatal damage may occur by Electrostatic Discharge). The device may be checked for obvious mounting problems and eventually powered up with an Biasing Controller (A3-5).

Before power is applied to the device, one should carefully check the cable connections in order to avoid damage or malfunction. With a standard multimeter (DMM) one can perform a quick check of resistances.

Line designator	**Resistance vs. GND**	**Remark**
SMA Output A, or B	approx. 144Ω ± 15Ω @ 300K approx. 134 Ω @ 4.2K	Since the device output features protection diodes, the value shown on a DMM display depends on the measurement current and voltage in resistance measuring mode.

Table 3: typical resistance values of lines versus GND, measured with standard multimeter.

Cool-Down Procedure and Readjustments

After a complete check of the cabling (using a DMM in Ω-Mode, table above) and in case the latter is correct, one may temporarily power-up the device. The biasing currents on the supply lines should be around 1mA, which will be indicated by green light on the room temperature controller display. Note, that during cool down in a cryostat the device **must** be switched off. The reason are strong offset shifts, which may cause temporary malfunctions otherwise. Please turn the power only on, once the final temperature is reached or temperature is already below 45K. After cooling down one may recheck the resistance of lines to be sure the device is operational.

Note:

During cool-down/warm-up procedures always maintain a temperature rise or decrease of no more than +/-20 degrees Kelvin per minute. Note that exceeding this temperature slew/fall rate may damage the device due to formation of mechanical cracks. **Never apply thermal shocks to the device like dipping into a cryogenic liquid**.

Cool-Down and Warm-Up Cycles

Care has to be taken in the cool down and warm up phases. A fast drop into cryogenic liquids can irreversibly **damage** the device because of excessive mechanical stress, caused by rapid thermal contractions or expansions. It is strongly recommended to keep the rate of temperature change below +/- 20K / minute. A complete cool down from room temperature into a cryogenic liquid like liquid Nitrogen or liquid Helium should take at least 20 minutes (liquid Helium) or 15 minutes (liquid Nitrogen).

Care has also to be taken, in case the device is brought from the cold state rapidly into normal air because of humidity condensing on the cold surfaces. In case the device is still powered up with supply voltages, a water film on the surfaces will lead to immediate destructive and possibly fatal galvanic corrosion. It is strongly recommended to let the device dry thoroughly before next operation, eventually using a conventional hair dryer, after the device was brought out of vacuum. Beware of overheating the device in this procedure. The use of so-called “hot air guns” is not admissible, since their air temperature may easily exceed 150 deg Celsius, which can lead to rapid overheating and substantial, non-reversible damage of the device. Even using conventional hair dryers, they should be set to minimum heat output and the device temperature carefully monitored in order to **never** exceed 150 deg. Celsius.

Performance Graphs

Amplification and Noise Data

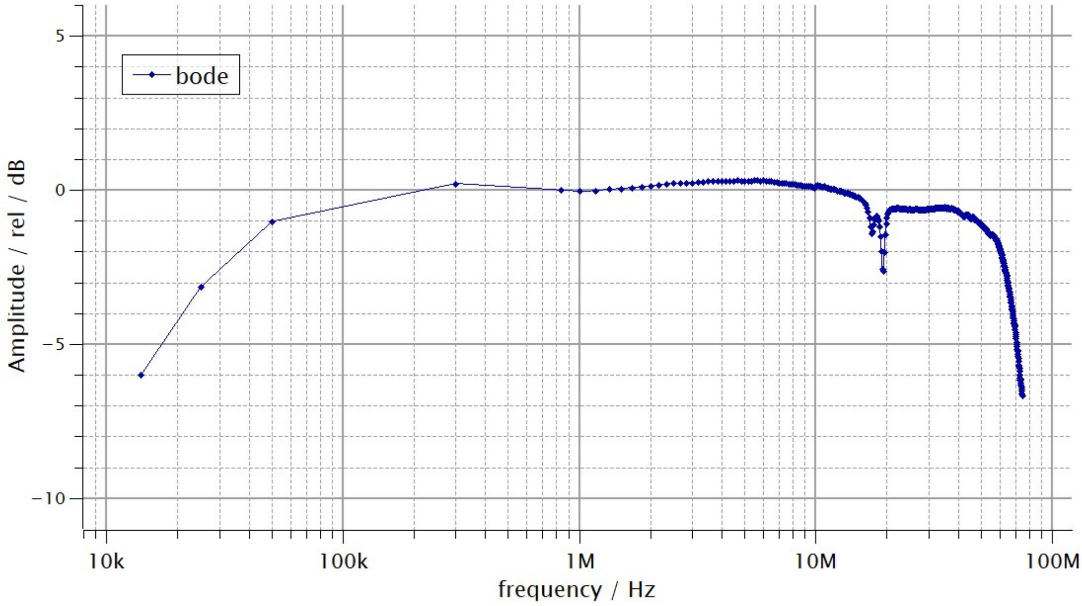

Fig. 11: Amplification at cryogenic temperature (6K) as function of frequency, expressed in dB relative to the amplification factor at f = 1MHz. The data set comprises the cryogenic amplifier (at 6K) including the biasing controller with 50 Ohm load.

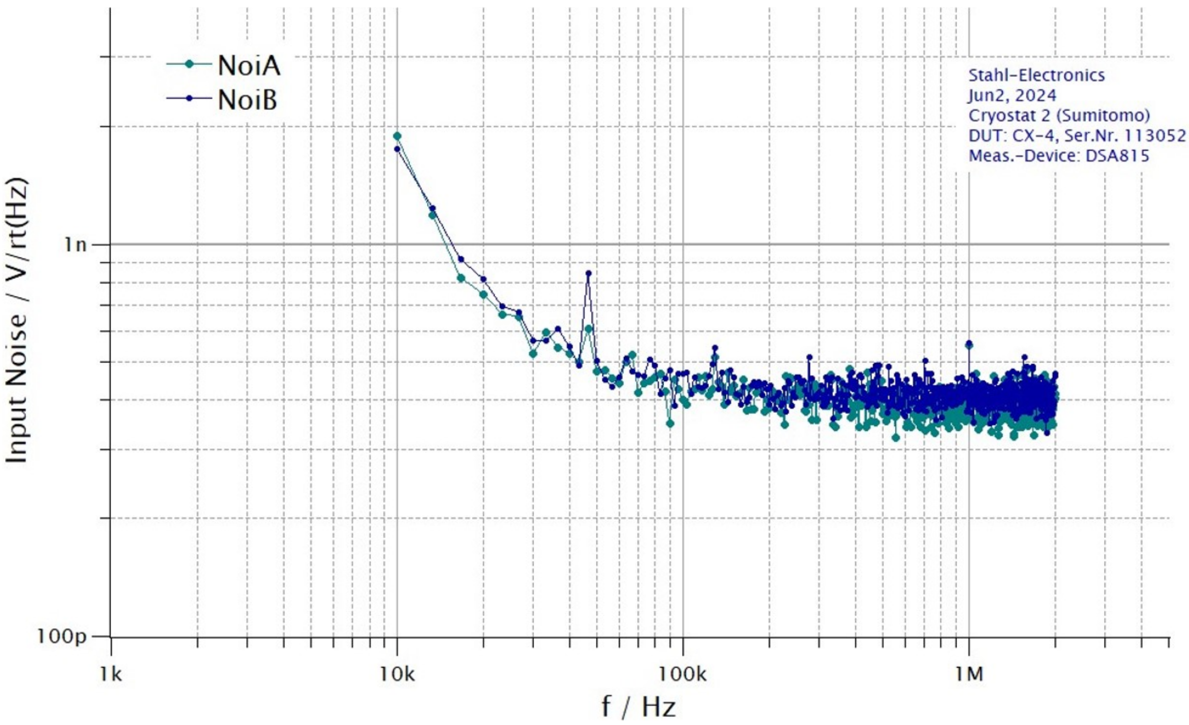

Fig. 12 : Input Voltage Noise Density at 6K for both amplifier channels, detailed lower frequency range 10kHz to 1MHz

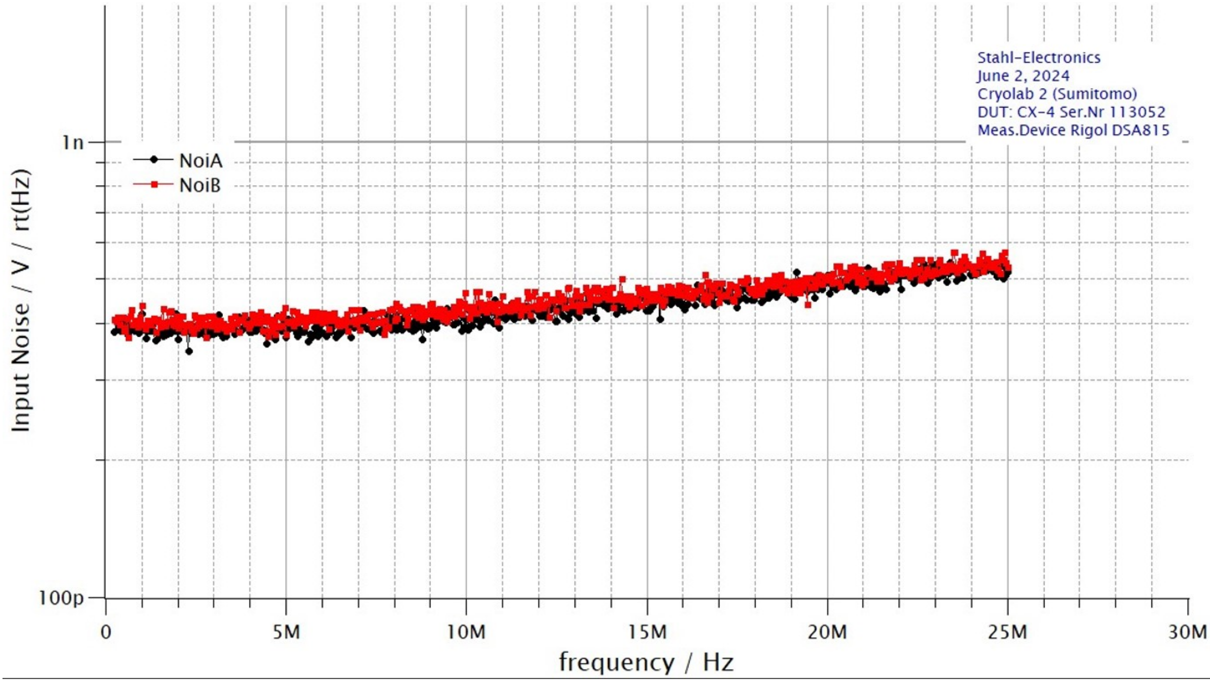

Fig. 13: Input Voltage Noise Density at 6K, frequency range 300 kHz to 25 MHz,

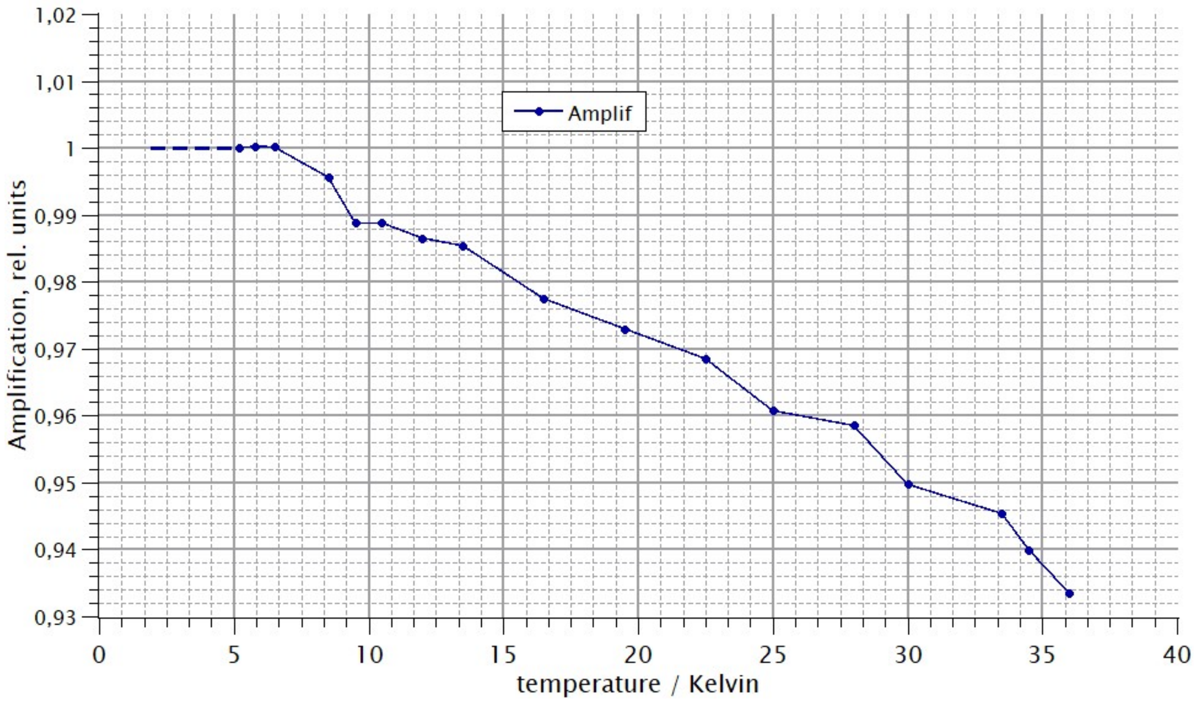

Fig. 14: Linear voltage amplification factor as function of ambient temperature, from ~4.2K to elevated cryogenic temperatures, value related to 4K operation.

Note that the decrease of amplification at elevated temperatures as shown above is not automatically being corrected, since the A3-5 room temperature controller is not aware of the real temperature of the cryogenic amplifier. The amplification factor settings (100x, 300x, 600x, 1200x) refer to the nominal operating temperature of 4.2K.

Dashed line in graph above: expected values below 4.2K.

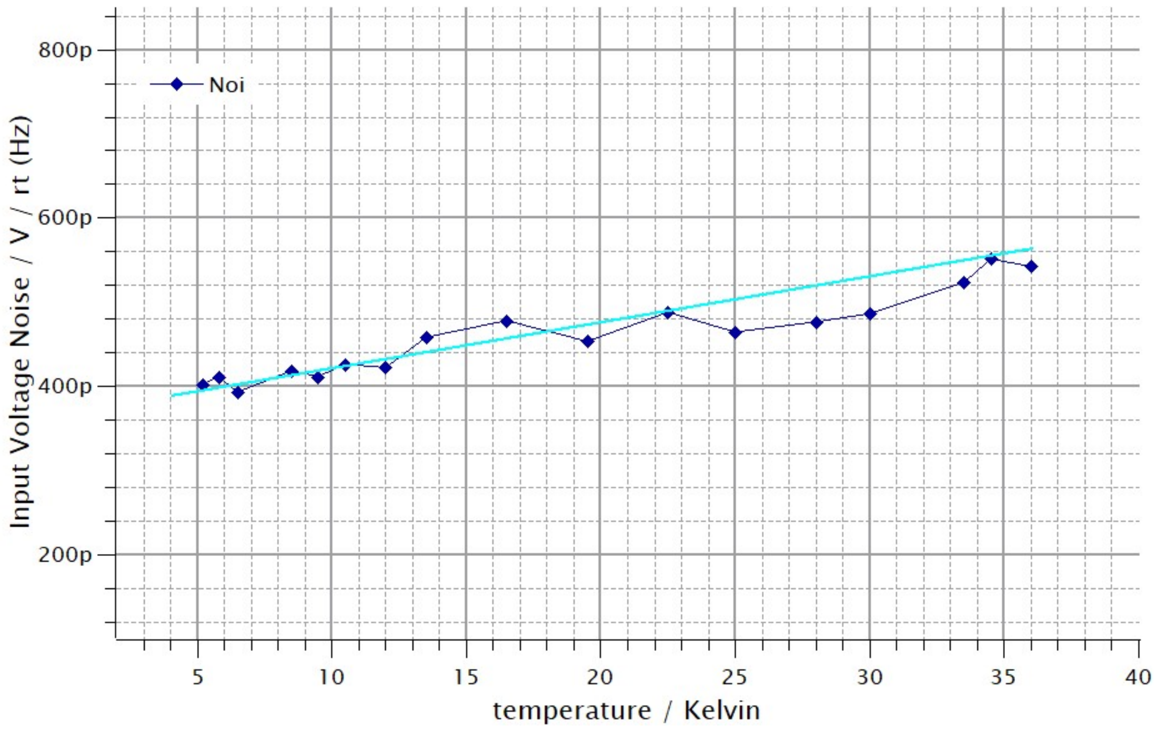

Fig. 15: Voltage input noise density at f = 1.5MHz as function of ambient temperature

Geometrical Outline

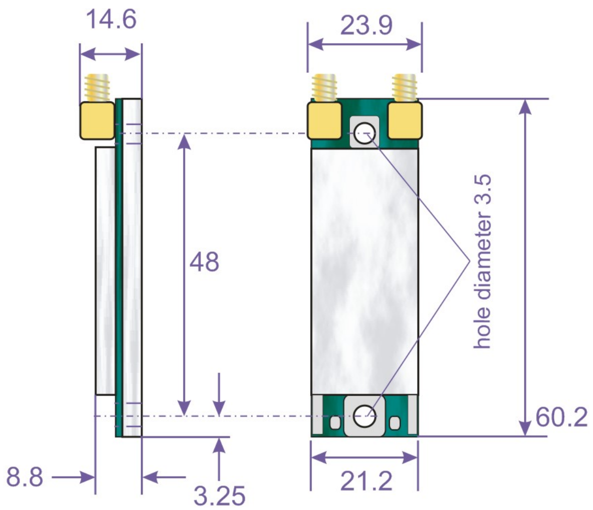

Figure 16: Outline dimensions 2-channel version with SMA output sockets (units: mm)

LED Indicator threshold values of A3-5 biasing controller

	too low	ok	too high	remark
Supply Currents	< 0.6mA	0.6mA … 2.0mA	>2.0 mA	currents flow through A3-5 inputs and CX-4 outputs

Table 4: typical DC threshold levels, defining the range in which individual LEDs will lighten up.

Trouble Shooting

In case not all LEDs show green light, there could be the following reasons.

DC Supply current too low (line A or B):

- missing GND connection or
- SMA cable not attached (300K to cryogenic)

Supply current too high:

- short cut from signal line to GND
  → disconnect cryogenic amplifier to prevent damage

If one of these error conditions occurs, check carefully all connections, eventually also the nominal resistances of the supply lines to the cryogenic amplifier according to the value listed above. Note that in case the cryogenic amplifier is operated at room temperature, the currents may become too high, if the Bias-switch is set to hi-Bias. For low temperature operation this switch should always be set to low-Bias.
A reason to set the switch temporarily to high could be to check general operation at room temperature, since the amplification factor at 300K will otherwise be too low.

In general, note that the amplifier must be **switched off during the cool-down process**, until final temperature is reached. f one assumes, that the power was accidentally turned on during cooling, one can restore the correct operating condition by warming up completely to 300K and starting again in the off-state (non-powered).