BUF 0.12

Cryogenic CMOS Buffer Amplifier

- Datasheet -

Version 2.0 / Dec. 2018

Features:

- **Precision Voltage Buffer DC…500kHz, max. range DC to 10MHz**
- **Wide Temperature Range T = 300K down to T = 4.2K**
- **Selectable Input Impedance**

Block Diagram

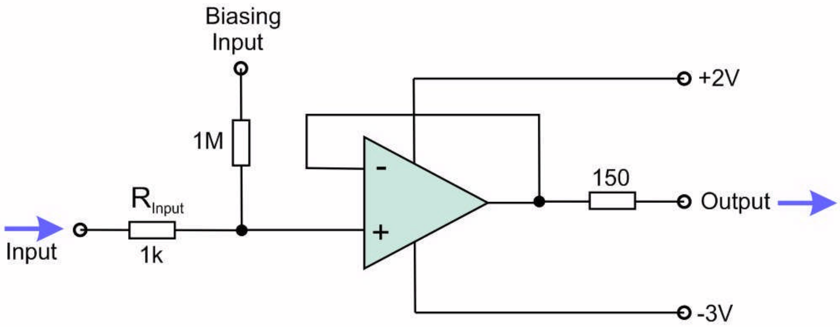


Figure 1: internal structure of the BUF 0.12

Introduction

The BUF 0.12 device is a CMOS-based precision buffer amplifier, operating in room temperature down to deep cryogenic environments (T = 4.2K, liquid Helium). The BUF 0.12 covers a frequency range from 0Hz to 0.5 MHz (in terms of max. 1% voltage deviation), features a very high input impedance and has an input voltage noise in the order of 10nV/√Hz. The output voltage follows precisely the input voltage, i.e. the amplification factor A is kept very well at unity (A = 1 V/V). The high input impedance of larger 1MΩ (vs. GND) is suited to sense signals originating from sources with very high source resistance, like STM/QPC tunneling signals as well as medium impedance signal sources like conductance measurements in the kOhm range. The device is based on highly-doped Silicon JFET/CMOS technology, which allows for operation over a very wide temperature range from room temperature to liquid Helium temperature, provided the device is located in a vacuum cryostat. Dipping the device into cryogenic liquids (Nitrogen, Helium) is not admissible, since in that case the internal regulation circuitry will not be able to stabilize the operating parameters.

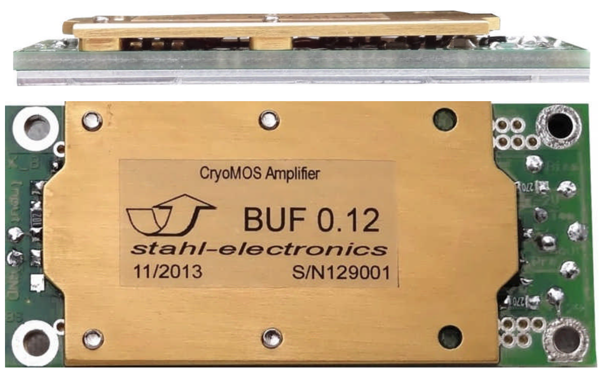
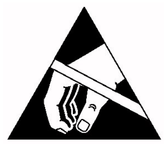


Figure 2: side and top view

Caution: Electrostatic Sensitivity



This device can be damaged by ESD (Electrostatic Discharge), especially the **input and output lines**. It is 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 Hint:

*In case 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 place of the device: Most important the destinations ground has to be on the same potential as the devices ground. Therefore connect both grounds first before making any other connection or changing the device position.*

Solder Pad Connections

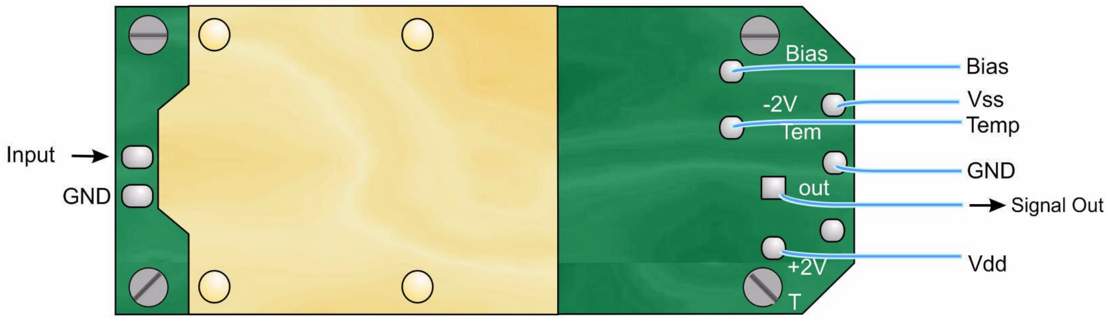


Figure 3: Location of solder pads

Front Side:	Remarks:
Input	high impedance input
GND	reference GND for input lines
Rear Side	Remarks:
Bias	Optional Bias Line, connected to input via 1MΩ
Vss, negative power supply line	apply typ. -3.6V, draws typically 4.1mA
Temp	connects to GND via uncalibrated temperature Silicon diode sensor, this pad is used for adjustment purposes only
GND	Ground line
Signal Out	Output signal
Vdd, positive power supply line	apply typ. +3.6V, draws typically 4.1mA

Absolute Maximum Ratings

Note: Stress above these ratings may cause permanent damage or degradation of device performance. Exposure to absolute maximum conditions for extended periods may degrade device performance and reliability.

Quantity	Limits		Remarks
	min.	max.	
pos. Supply Voltage Vdd vs. GND	0	+6.0	
neg. Supply Voltage Vss vs. GND	-6.0V	0V	
Input Current		1.5mA 3mA	continuous current through input short term (< 1ms) current through input
Input Voltage	Vss - 0.3V	Vdd + 0.3V	
Output Voltage	Under normal conditions no voltage source must be applied to the outputs.		
Storage Temperature, Baking	1 K	125°C	Baking is possible up to 125°C, max. for 24 hours
Temperature changes	-	+/-20 degrees Kelvin per minute	exceeding this temperature slew/fall rate may damage the device due to formation of mechanical cracks
Storage Humidity		70% @ 40°C	

Table 1: Absolute Maximum Ratings

Characteristic Data and Operating Parameters

Parameter	typical Value	Remarks/Conditions
Freq. Range for amplification deviation of better (less) than 1% 6dB roll-off	DC ... 120 kHz 10 MHz	output connected to high impedance load (oscilloscope) through 1m of coaxial cable Vdd = +3.6V, Vss = -3.6V
Offset	typ. +/-200µV max. +/-500µV	T = 4.2K to 300K, see graph
Voltage gain @ f = 10 kHz	1.00 V/V	T = 4.2K to 300K
Input Impedance vs. GND	> 100MΩ	$\lvert V_{input} \rvert$ < 3.6V at +/-3.6V supply
Input Resistance to Bias input	1MΩ	defined by thin film resistor inside amplifier
Input Capacitance vs. GND	12 pF	f_{test} = 10 kHz
Input Offset	typ. +/- 0.4mV	T = 4.2K to 77K
Input Offset TC	+/-2.5µV/K	T = 4.2K to 77K
Output Impedance	150 Ω	T = 4.2K to 300K
Output Slew rate	4 V/µs	T = 4.2K to 77K
Output Power	≤ 10mW	
Input Noise voltage noise density current noise density	10 nV/√Hz approx. 100 fA/√Hz (depending on R_{input}, see text)	f = 10kHz, T = 4.2K to 77K, see also graphs below
Operating voltages V_{DD}, positive supply voltage V_{SS}, negative supply voltage	+3.6 V -3.6 V	T = 300K down to 4.2K
Supply Currents I_{DD}, positive supply = $-I_{SS}$, negative supply	4.1mA+/-0.4mA	T = 4.2K to 110K
Temperature Diode (pad T) forward voltage	U_F = 0,79 V , T = 300K 1,59V , T =4.2K	I = 5µA measurement current to GND
Power Consumption	29mW	T = 4.2K to 110K
General Operating Temperature	T = 4.2 K … 300 K	Attention: Temperature variations max. +/-20 degrees Kelvin per minute
External magnetic field	B = 0 … 5T	
Geometrical Size	24.6mm x 7.8mm x 55 mm	
Outgassing	(to be determined)	
Remark: This table represents typical values at low magnetic fields B < 2T. Parameters may vary at higher B-fields.		

Table 2: Characteristic Data

Voltage Supply

In order to bring the device into operation a positive supply voltage (connected to pad Vdd) is required as well as a negative supply (apply to pad Vss). Typically voltages of +3.6V should be applied to Vdd and -3.6V to Vss. A current of typically 4.1 mA is drawn through both lines, resulting in approx. 29mW of heat dissipation. The manufacturer provides a low noise power supply, to which the amplifier may be connected. Even though the standard supply voltage is +/-3.6V, one may vary it to some degree, e.g. increase somewhat in case larger signal are being amplied

Biasing Line

For certain applications like conductance measurements a biasing line is provided, which can be used to apply a bias voltage or current to the input. This line is internally filtered by a low pass and then connected by 1MΩ (thin film resistor) to the input. For details see also next figure. The input pad “bias” may be left open in case this function is not needed.

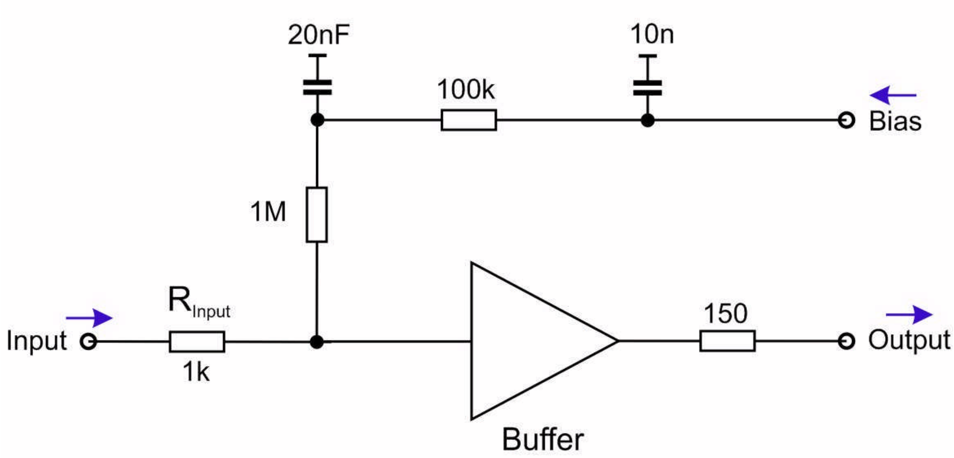


Figure 4: Internal circuitry of biasing line.

Input Serial Resistor R_{Input}

As depicted in the diagram above, the Input of the device is connected to the internal input of the buffer through a defined resistor, called R_{Input}. The latter’s value is 1kOhm or 100 Ohm by default but can also be altered later and ordered for a different value from the manufacturer (e.g. 100 Ohm for devices of serial numbers 128002, 129003, 129004). The reason for its existence is not only the protection of the internal buffer against accidental overvoltages at the input but also a kind of isolation of the internal buffers input capacitance (approx. 10pF) towards the input. For instance a value of 150kOhm is well suited to operate this device in conjunction with a RF high-input-impedance amplifier to perform shot noise measurements in the range between 0.5 to 5MHz, since such a value of R_{Input} delivers an effective input capacitance of less than 1.5pF and low input capacitances are crucial for sensitive high-frequency shot noise measurements.

Bias Filtering and Shielding

Grounding and Shielding at the input and output side are important matters of concern. A proper grounding and shielding is essential to maintain good device performance and low noise characteristics. To ensure a “clean” electrical environment, provide good ground connections especially around the amplifier input. All lines from a signal source to the amplifiers inputs should be kept as short as possible. The connections may be implemented as coaxial lines for shielding reasons. Please note that insufficient grounding or shielding around the signal source, which connects to the device input, may lead to a considerably increased noise level, specially in noisy environments.

For optimum noise performance the supply lines (Vdd, Vss) may be supplied from a well-stabilized power supply and additionally filtered. Standard blocking capacitors of 100nF from the biasing supply lines to a local ground may support power supply stabilization, or in noisy environments the use of filter banks at the vacuum feedthroughs of the cryostat may be desirable.

In this way the vacuum vessel may be kept inside free of disturbing noise interference. The subsequent graph depicts a possible arrangement of a simple and inexpensive RC-low pass filter set, which usually does a good job to establish a noiseless environment. DC supply signals come from the left and should enter the (shielded) vacuum setup right after this filter bank at the right.

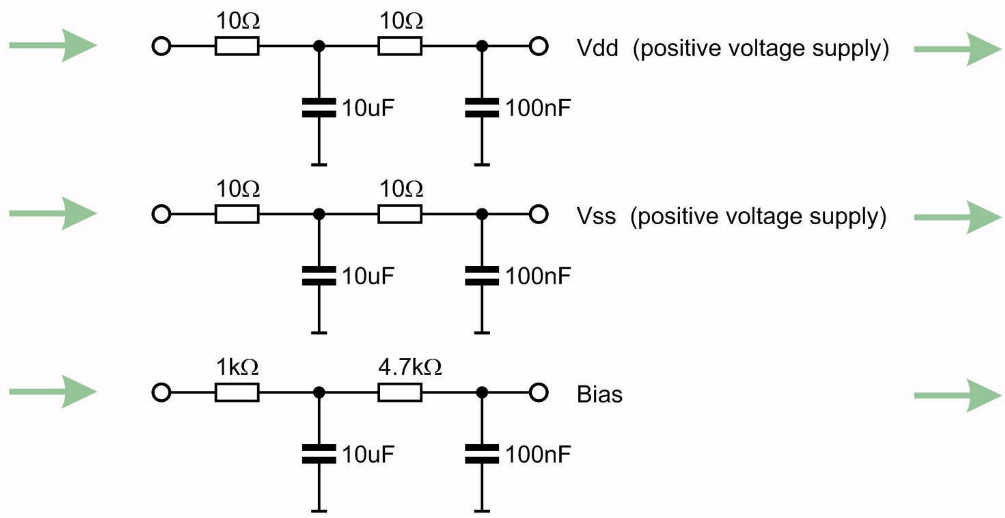


Figure 5: Inexpensive RC filter can establish a low-noise environment. Supply voltages should enter the vacuum setup in which the device is mounted through such a filter bank, located directly at the vacuum feedthroughs.

Thermal Anchoring

In a vacuum cryostat a good thermal coupling to the cold reservoir (cold finger, Helium cryostat cold plate) is required to ensure proper operation and low noise. Thermal connection may be established using the mounting screw holes in the base plate of the amplifier, e.g. using brass screws. Brass metal contracts stronger when getting cold compared to most other metals and printboard substrate, therefore tightening the thermal connection upon being cooled down. Note that a thermally conducting agent like “Apiezon N” grease between the metal pieces of different temperatures also significantly increases the thermal heat flow. Use primarily the front side holes for mounting, use rear holes only if there is no access to the front side holes.

Commissioning in a Vacuum or Cryogenic Setup

After wiring the device and mounting into a cryogenic dewar or vacuum chamber (always connect ground lines first for ESD reasons), the device may be checked and eventually powered up with appropriate supply voltages. *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. Essentially all lines (Vdd, Vss, Output) show a resistance which is > 10MΩ to GND in case the room temperature electronics (like power supply) are not attached yet. The temperature sensor should show approx. 0.84V in diode mode of a DMM versus GND.

Cool-Down Procedure and Power-Up

Once mounted inside a vacuum or cryostat setup, it is recommended to re-check the cabling (using a DMM in Ω-Mode) as mentioned before. In case the latter is correct, one may power-up the device. A typical consumption current of +/-4mA will be drawn from Vdd / Vss pads.

It is recommended to keep the supply voltage turned on during cool down in a cryostat. In case the supply voltages are accidentally or intentionally turned off and the temperature drops below 100K, it is recommended to wait approx. 10 minutes after powering on, to achieve stable operating condition. Note that during this stabilisation time the value of amplification may be significantly smaller. Apart from this “wake-up” procedure, which is necessary in case the device temperature drops below 100K, the device is generally operational over the complete range from 300K to 4.2K or below.

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 and never dip it directly into cryogenic liquids.**

Warming up

There are no special constrainsts when warming the device up, it may happen with or without electrical power supply. Make sure to maintain a temperature rise of no more than 20 degrees Kelvin per minute as mentioned above and ensure that the device is exposed to ambient air only if it has well reached ambient temperature inside the cryostat for at least 20 minutes. Otherwise air humidity may easily condensate on it and cause severe corrosive damage.

Typical Performance Data:

Amplification Frequency Response

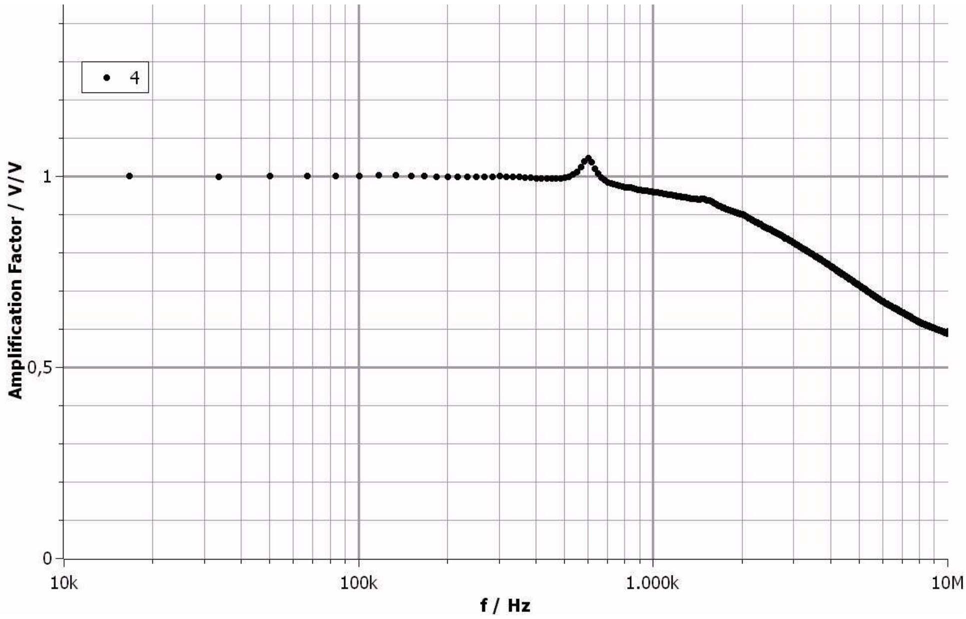


Figure 6: Amplification in V/V versus frequency at T = 4.2K to 77K at supply voltage Vdd/ss = +/-3.6V
Note that the bump at 600 kHz is mainly a measurement artefact.

Amplifier Saturation

The input voltage should maintain a voltage difference ("headroom") of approx. 1.0V to the positive supply and of approx. 600mV to the negative supply. Driving the amplifier input with larger signals will lead to saturation effects. The subsequent figure shows the onset of saturation while driving the input with a sine curve of 6Vpp and 10kHz. Overdriving the input does not harm the device as long as the input voltage stay within the supply lines limits (Vdd to Vss), or at most exceeds them by 0.3V.

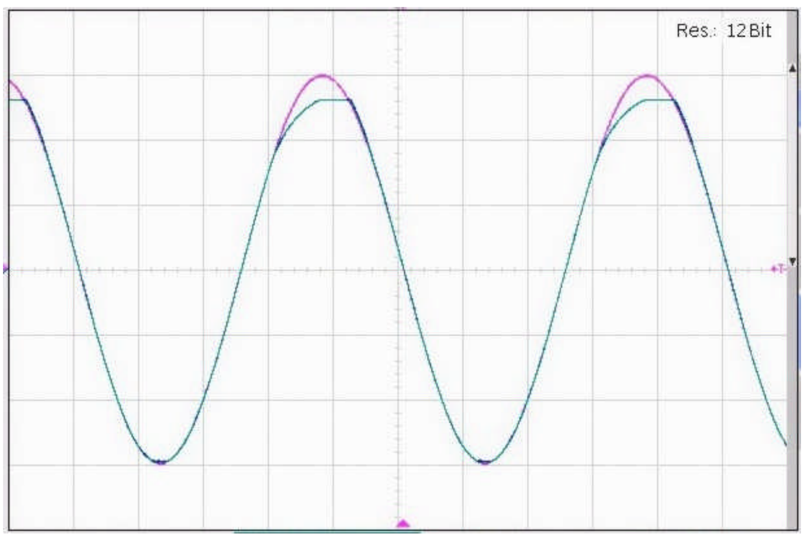


Figure 7: **1V/div, 20µs/div**
Typical oscilloscope traces showing overdriving the input (6Vpp sine wave).

Pink trace: input signal, blue trace: output signal. Vdd/ss = +/-3.6V

Pulse Response

The subsequent figures show the typical behaviour of the BUF 0.12 buffer on pulse-type input signals at temperatures of 77K and below. The first graph shows the small signal behaviour (100mV steps), the following graph large signal response (2V steps up and down).

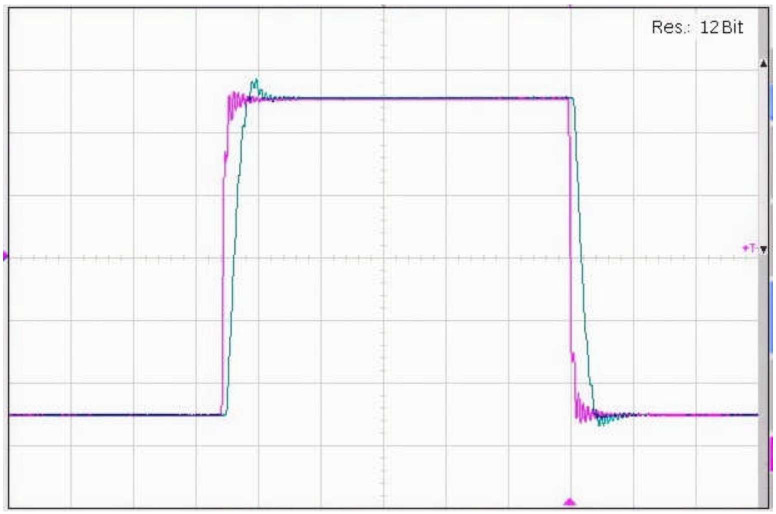


Figure 8: **20mV/div, 500ns/div**
Small signal step response (100mV step) at T = 4.2K to 77K .
Pink trace: input signal, blue trace: output signal. Vdd/ss = +/-3.6V

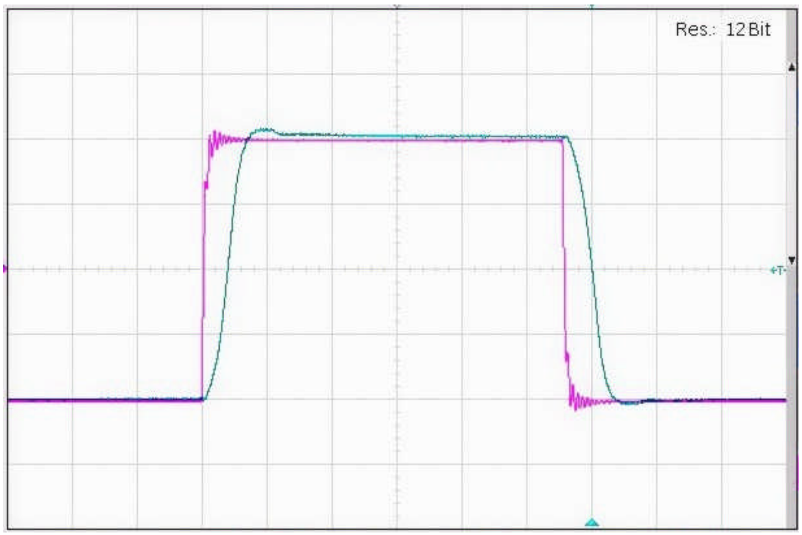


Figure 9: **500mV/div, 500ns/div**
Large signal step response (2V step) at T = 4.2K to 77K .
Pink trace: input signal, blue trace: output signal. Vdd/ss = +/-3.6V

Offset versus Temperature

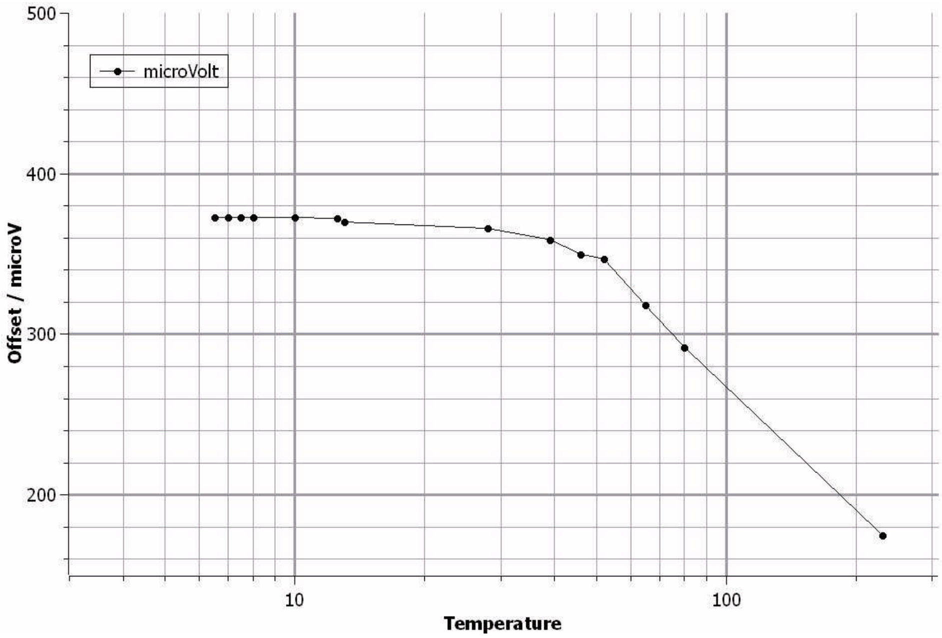


Figure 10: Typical input offset versus environmental temperature. Operating parameters: Vdd/ss = +/-3.6V

Offset Fluctuations

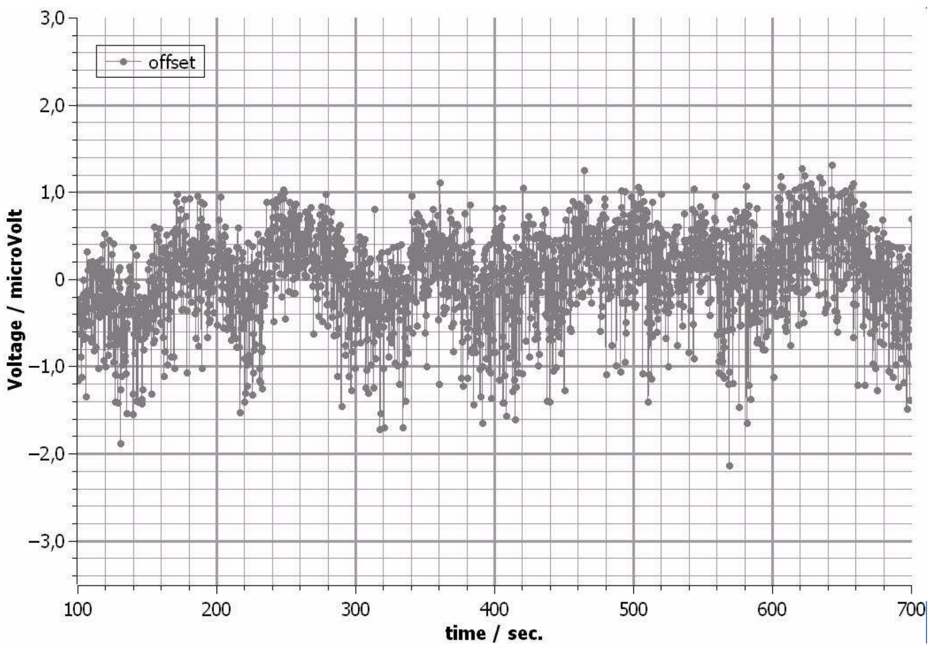


Figure 11: Typical input offset fluctuations at T = 5K, operating parameters: Vdd/ss = +/-3.6V
4 measurement points were taken each second. RMS value is only around 550 nV_{rms}

Noise Data

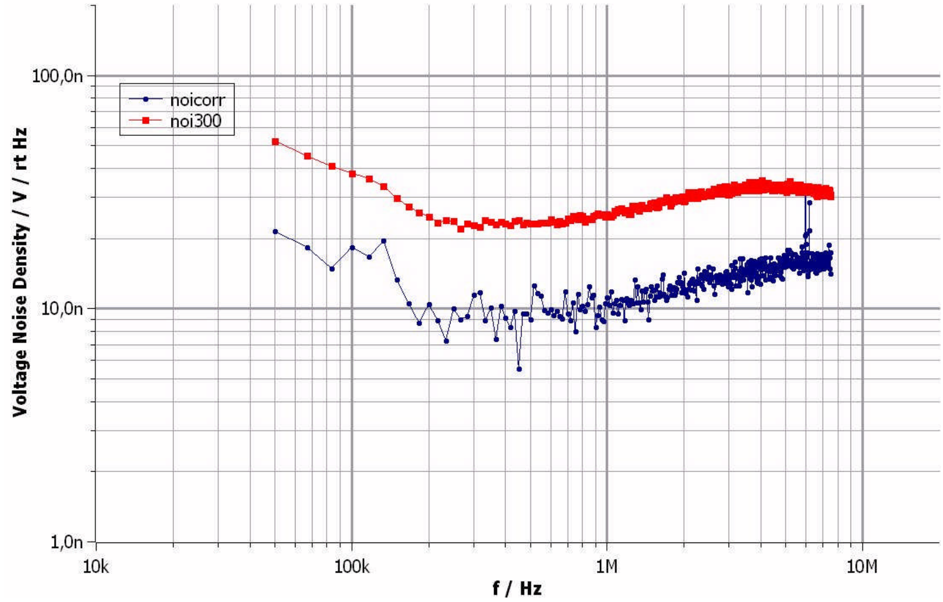


Figure 12: Typical input voltage noise density (V/ √Hz) at temperatures T = 5K (lower trace) and 300K (upper trace); Operating supply voltage: Vdd/ss = +/-3.6V

Case Outline (Type 1a Case)

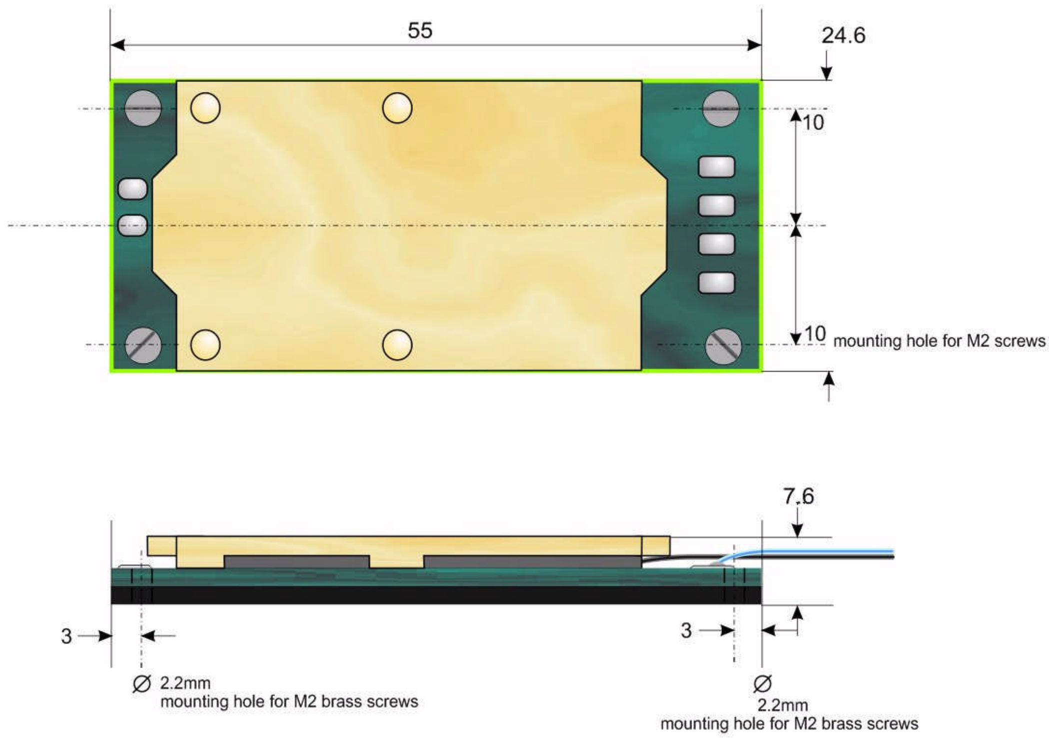


Figure 13: Case outline. Dimension in Millimeters