BUF 0.12

Cryogenic CMOS Buffer Amplifier

Features:

- Precision Voltage Buffer DC…500kHz, max. range DC to 10MHz
- Wide Temperature Range $T = 300K$ down to $T = 4.2K$
- Selectable Input Impedance
- 1-Channel and 2-Channel version available
**Introduction**

The BUF 0.12 device is a CMOS-based precision buffer amplifier (1- or 2-channel version), 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.

**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.

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**Block Diagram**

![Figure 1: internal structure of the BUF 0.12](image1)

**Figure 2: side and top view**
Solder Pad Connections

1-channel version

![Diagram of solder pad connections for 1-channel version]

**Input Side:**
- Input
- GND

**Remarks:**
- high impedance input
- reference GND for input lines

**Output Side**
- Bias
- Vss, negative power supply line
- Temp
- GND
- Signal Out
- Vdd, positive power supply line

**Remarks:**
- Optional Bias Line, connected to input via 1MΩ
- apply typ. -3.6V, draws typically 4.1mA
- connects to GND via uncalibrated temperature Silicon diode sensor, this pad is used for adjustment purposes only
- Ground line
- Output signal
- apply typ. +3.6V, draws typically 4.1mA

2-channel version

![Diagram of solder pad connections for 2-channel version]

**Input Side:**
- Input A, Input B
- GND

**Remarks:**
- high impedance inputs
- reference GND for input lines

**Output Side**
- Signal Out (Out A, Out B)
- Vdd, positive power supply line
- Vss, negative power supply line
- Bias Line
- n.c.
- GND

**Remarks:**
- Output signal Bias
- apply typ. +3.6V, draws typically 4.1mA
- apply typ. -3.6V, draws typically 4.1mA
- optionally connected to inputs via 1MΩ or other
- not connected
- Ground lines

The output pins are arranged in a standard 1/10" (= 2.54mm) pattern with 0.64mm x 0.64mm pin size
**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.

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Limits</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>pos. Supply Voltage Vdd vs. GND</td>
<td>0, +6.0</td>
<td></td>
</tr>
<tr>
<td>neg. Supply Voltage Vss vs. GND</td>
<td>-6.0V, 0V</td>
<td></td>
</tr>
<tr>
<td>Input Current</td>
<td>1.5mA, 3mA</td>
<td>continuous current through input short term (&lt; 1ms) current through input</td>
</tr>
<tr>
<td>Input Voltage</td>
<td>Vss - 0.3V, Vdd + 0.3V</td>
<td></td>
</tr>
</tbody>
</table>

**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**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>typical Value</th>
<th>Remarks/Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freq. Range for amplification deviation of better (less) than 1% 6dB roll-off</td>
<td>DC ... 120 kHz, 10 MHz</td>
<td>output connected to high impedance load (oscilloscope) through 1m of coaxial cable Vdd = +3.6V, Vss = -3.6V</td>
</tr>
<tr>
<td>Offset</td>
<td>typ. +/-200µV, max. +/-500µV</td>
<td>T = 4.2K to 300K, see graph</td>
</tr>
<tr>
<td>Voltage gain @ f = 10 kHz</td>
<td>1.00 V/V</td>
<td>T = 4.2K to 300K</td>
</tr>
<tr>
<td>Input Impedance vs. GND</td>
<td>&gt; 100MΩ</td>
<td></td>
</tr>
<tr>
<td>Input Resistance to Bias input</td>
<td>1MΩ</td>
<td>defined by thin film resistor inside amplifier</td>
</tr>
<tr>
<td>Input Capacitance vs. GND</td>
<td>12 pF</td>
<td>f_{test} = 10 kHz</td>
</tr>
<tr>
<td>Input Offset TC</td>
<td>+/-2.5µV/K</td>
<td>T = 4.2K to 77K</td>
</tr>
<tr>
<td>Output Impedance</td>
<td>150 Ω</td>
<td>T = 4.2K to 300K</td>
</tr>
<tr>
<td>Output Slew rate</td>
<td>4 V/µs</td>
<td>T = 4.2K to 77K</td>
</tr>
<tr>
<td>Output Power</td>
<td>≤ 10mW</td>
<td></td>
</tr>
<tr>
<td>Input Noise voltage noise density</td>
<td>10 nV/√Hz</td>
<td>f = 10kHz, T = 4.2K to 77K, see also graphs below depending on R_{input} and Biasing resistor</td>
</tr>
<tr>
<td>current noise density</td>
<td>approx. 100 fA/√Hz</td>
<td></td>
</tr>
</tbody>
</table>
Operating voltages
$V_{DD}$, positive supply voltage
$V_{SS}$, negative supply voltage

<table>
<thead>
<tr>
<th></th>
<th>+3.6 V</th>
<th>-3.6 V</th>
<th>T = 300K down to 4.2K</th>
</tr>
</thead>
</table>

Supply Currents
$I_{DD}$, positive supply
$= -I_{SS}$, negative supply

<table>
<thead>
<tr>
<th></th>
<th>4.1mA+/-.4mA</th>
<th>T = 4.2K to 110K</th>
</tr>
</thead>
</table>

Temperature Diode (pad T)
forward voltage

<table>
<thead>
<tr>
<th></th>
<th>$U_F = 0.79$ V, T = 300K</th>
<th>$1.59$ V, T = 4.2K</th>
</tr>
</thead>
</table>

Power Consumption

<table>
<thead>
<tr>
<th></th>
<th>29mW</th>
<th>T = 4.2K to 110K</th>
</tr>
</thead>
</table>

General Operating Temperature

<table>
<thead>
<tr>
<th></th>
<th>T = 4.2 K ... 300 K</th>
<th>Attention:</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Temperature variations max. +/-20 degrees Kelvin per minute</th>
</tr>
</thead>
</table>

External magnetic field

<table>
<thead>
<tr>
<th></th>
<th>B = 0 ... 5T</th>
</tr>
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</table>

Geometrical Size

<table>
<thead>
<tr>
<th></th>
<th>24.6mm x 7.8mm x 55 mm</th>
</tr>
</thead>
</table>

Outgassing

<table>
<thead>
<tr>
<th></th>
<th>(to be determined)</th>
</tr>
</thead>
</table>

Remark: This table represents typical values at low magnetic fields $B < 2T$. Parameters may vary at higher B-fields.

### Voltage Supply

In order to bring the device into operation a positive supply voltage (connected to pad $V_{DD}$) is required as well as a negative supply (apply to pad $V_{SS}$). Typically voltages of $+3.6V$ should be applied to $V_{DD}$ and $-3.6V$ to $V_{SS}$. 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 amplified. The supply currents (for $V_{DD}$ and $V_{SS}$) can be checked though shunt resistors and measurement sockets on the mains adapter.

### Biassing Line

For certain applications like conductance measurements a biassing 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 $1M\Omega$ (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.

![Biasing Line Diagram](image)

Figure 4: Internal circuitry of biasing line ($R_{input}$ is omitted in the 2-channel version).
**Input Serial Resistor $R_{\text{input}}$**

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 $R_{\text{input}}$. 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 $R_{\text{input}}$ delivers an effective input capacitance of less than 1.5pF and low input capacitances are crucial for sensitive high-frequency shot noise measurements. Note, that the 2-channel version does not feature this input resistor due to limited available space.

**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.

![Filter Diagram](image)

*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 (only 1-channel version) 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 constraints 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](image)

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 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](image)

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**

![Graph showing offset versus temperature](image)

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

**Offset Fluctuations**

![Graph showing offset fluctuations](image)

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 nVrms
Noise Data

Figure 12: Typical input voltage noise density ($V/\sqrt{Hz}$) at temperatures $T = 5K$ (lower trace) and 300K (upper trace); Operating supply voltage: $V_{dd/ss} = +/-3.6V$

Case Outline, Type 1a Case

Figure 13: Case outline. Dimension in Millimeters