
# PD200X4 – Four Channel Power Amplifier

# Manual and Specifications

Hardware Version 2

## Revision History

| Date | Revision | By | Changes |
|---|---|---|---|
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# 1 Introduction

The PD200X4 is a four-channel linear amplifier for driving piezoelectric actuators and other loads. The output voltage range can be unipolar, bipolar, or asymmetric from 50V to 200V. Up to +/-200V can be achieved using two channels with a bridged load. Refer to the specifications table for the available output voltage ranges. Front panel switches and dedicated connectors for independent and bridged loads make it easy to switch between four independent channels and two bridged channels with double the voltage range.

The PD200X4 can drive any load impedance including unlimited capacitive loads such as stack actuators; standard piezoelectric actuators; two wire benders; and three-wire piezoelectric benders requiring a bias voltage. Bias voltages can be generated using two auxiliary outputs linked to the power supply voltages, or by using an amplifier channel with a constant DC offset.

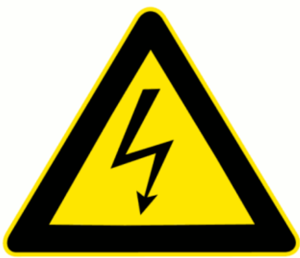
A range of user controls and ordering options are available to provide maximum application flexibility. The DC offset of each channel can be controlled by a front panel potentiometer, or can be fixed to zero as an option. The maximum positive and negative output voltages can be restricted using two front panel potentiometers. A 15-pin DSUB connector on the front panel includes signals for inputs, voltage monitors, current monitors, temperature measurement, a digital status output, and a digital shutdown input.

The output connectors include BNC for independent channels, LEMO 0B for bridged channels, and a plug-in screw terminal. The PD200X4 is suited to a wide range of applications including electro-optics, ultrasonics, vibration control, nanopositioning systems, and piezoelectric motors.

| **Compatible Actuators** | |
|---|---|
| Stack Actuators | Up to +200V (4 Channels) |
| Plates and Tubes | +/-100V or +200V with a grounded load (4 Channels)<br>+/-200V with a bridged load (2 Channels) |
| Two Wire Benders | +/-100V or +200V with a grounded load (4 Channels)<br>+/-200V with a bridged load (2 Channels) |
| Three Wire Benders | Up to +200V with +200V bias (4 Channels + Bias source)<br>+/-100V with +/-100V bias (4 Channels + 2 Bias sources) |

# 2 Warnings / Notes

This device produces hazardous potentials and requires suitably qualified personnel with an observer trained in first-aid training. Do not operate the device when there are exposed conductors.



# 3 Output Voltage Ranges

The desired output voltage range is specified when ordering. The output voltage ranges and associated current limits are listed below. A voltage range equal to, or greater than, the load requirements is recommended as the maximum and minimum output voltages can be reduced using the front panel controls.

| **Output Voltage** | **Bridge Mode** | **Peak to Peak Voltage** | **RMS Current** | **Peak Current** | **Order Code** |
|---|---|---|---|---|---|
| 0 to +200 V | | 200 V | 0.57 A | 2 A | PD200X4-V0,200 |
| 0 to +150 V | | 150 V | 0.91 A | 2 A | PD200X4-V0,150 |
| 0 to +100 V | | 100 V | 1.20 A | 2 A | PD200X4-V0,100 |
| -50 to +150 V | | 200V | 0.57 A | 2 A | PD200X4-V50,150 |
| -50 to +100 V | | 150 V | 0.91 A | 2 A | PD200X4-V50,100 |
| -50 to +50 V | +/-100 V | 100 V | 1.20 A | 2 A | PD200X4-V50,50 |
| -100 to +100 V | +/-200 V | 200V | 0.57 A | 2 A | PD200X4-V100,100 |
| -100 to +50 V | | 150 V | 0.91 A | 2 A | PD200X4-V100,50 |

**Table 1. Voltage range configurations.**

# 4 Output Current

The peak and average output current of each channel is listed in Table 1. The RMS current limit defines the maximum frequency that is achievable with a capacitive load. Numerical values and an online calculator can be found in Section 10.

In addition to the current limits on each channel, the total RMS current is limited to 2.6 Arms. Exceeding this limit will result in an overload condition on all channels, or a temporary reduction in output voltage.

During short circuit, the output current is limited to the rated maximum. The peak current can be drawn for up to five milliseconds before the output is disabled for approximately three seconds. The average current limit has a time-constant of 30 milliseconds and is reset 100 milliseconds after a previous current pulse.

High peak currents are available using the –PULSE option, which is described in Section 9.

# 5 Specifications

The amplifier specifications depend on the peak-to-peak output voltage listed in Table 1.

**Electrical Specifications (per Channel)**

| Output Voltage (Peak to Peak) | **100 Vp-p** | **150 Vp-p** | **200 Vp-p** |
|---|---|---|---|
| Peak Current | 2 A | 2 A | 2 A |
| RMS Current* | 1.2 A | 0.91 A | 0.57 A |
| Pulse Current (optional) | 10.0 A | 10.0 A | 10.0 A |
| Power Bandwidth | 470 kHz | 310 kHz | 230 kHz |
| Gain | 20 V/V (Custom gain available) | | |
| Slew Rate | 150 V/us | | |
| Signal Bandwidth | 680 kHz | | |
| Load | Any | | |
| Noise | 714 uV RMS (10uF Load, 0.03 Hz to 1 MHz) | | |
| Protection | Continuous short-circuit, thermal | | |
| Voltage Monitor | 1/20 V/V | | |
| Current Monitor | 1 V/A | | |
| Analog Input | +/-10 V , Zin = 100k, protected up to +/-20V | | |
| Output Connectors | BNC, Screw Terminals, LEMO 0B | | |
| Power Supply | 90 Vac to 250 Vac | | |

**Mechanical Specifications**

| | |
|---|---|
| Environment | 0-40 C (32-104 F) Non-condensing humidity |
| Dimensions** | 212 x 304.8 x 88 mm (8.35 x 12 x 3.46 in) |
| Weight | 2 kg (4.4 lb) |

* For AC signals greater than 100 Hz. The total RMS current limit for all four channels is 2.6 Arms, which can occur with 100 Vp-p and 150 Vp-p models, or with large load capacitances with a power bandwidth less than 100 Hz.

**A 3D Model is available at [www.piezodrive.com](http://www.piezodrive.com)

# 6 Signal Path

The signal paths for channels 1 and 2 are shown in Figure 1, which are identical to channels 3 and 4. The signal path includes a DC offset and voltage limit, which are set by front panel controls. The DC offset function can be disabled with the –OSD option, e.g. order code PD200X4-V100,100-OSD.

Channels 1 (and 3) have a fixed non-inverting gain; however, channels 2 (and 4) can be switched between independent non-inverting channels, or inverting channels that are connected to channel 1 (or 3). This function is useful for driving bridged loads, which is discussed in the following section.

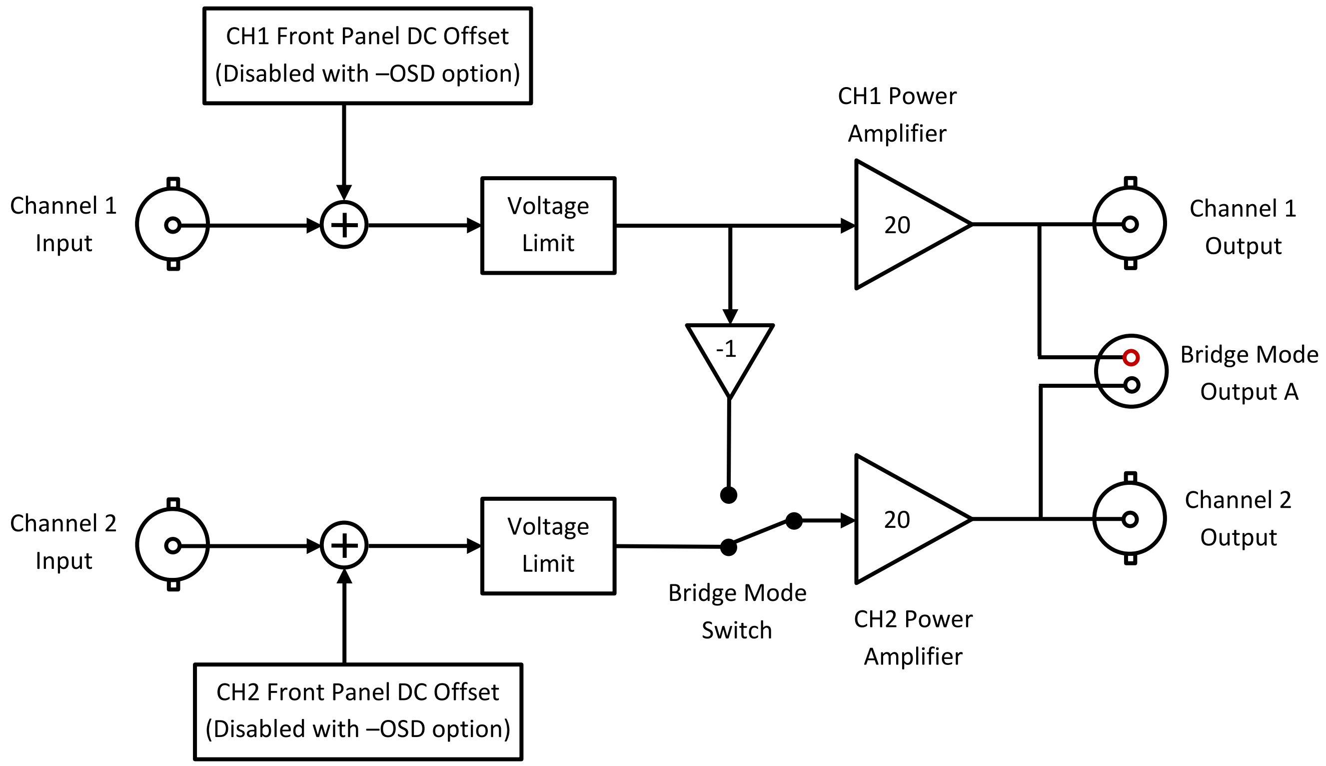



**Figure 1. Signal path for channels 1 and 2, which is identical to channels 3 and 4.**

# 7 Bridged Mode

In bridged mode, two channels are connected in series to double the output voltage range and power. For example, the PD200X4-V100,100 has four independent channels with a range of +/-100 V. When the Bridge Mode switch is enabled, channel 2 is inverting, which results in +/-200 V across the load. Therefore, the effective voltage gain is doubled to 40.

In bridged mode, the load is connected between the outputs of two channels and is not connected to ground. Grounded loads cannot be driven using bridged mode. Care should be taken not to connect the negative side (channel 2 and 4) to ground accidentally, for example, by using a grounded oscilloscope probe.

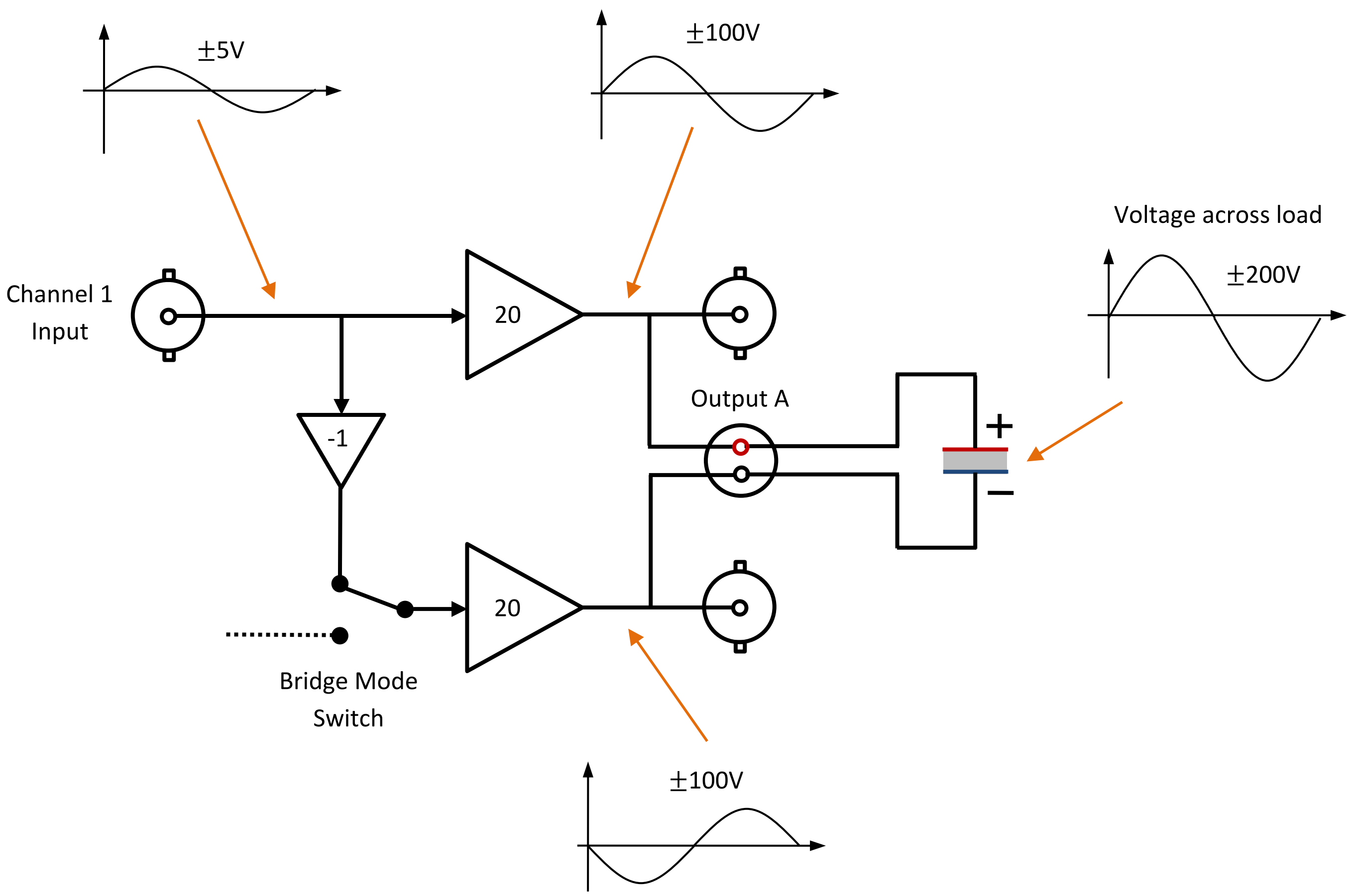



**Figure 2. Bridged load configuration to obtain +/-200 V using two +/-100 V channels. Note that the inputs to channel 2 (and 4) are not used. The offset and voltage limit is not shown for simplicity.**

In bridged mode, the overload conditions for both channels are linked. For example, if channels 1 and 2 are operated in bridged mode, an overload condition in either channel will trigger a shutdown in both channels.

The current limits in bridge mode are identical to the single channel limits. The power bandwidth calculator in Section 10 can also be used for predicting bridge-mode performance; however, the load capacitance used in the calculator must be doubled, and all of the voltages refer to a single channel. For example, consider a PD200X4-V100,100 used to drive a 1uF load with +/-200V in bridged mode. The correct calculator inputs are shown in Figure 3.

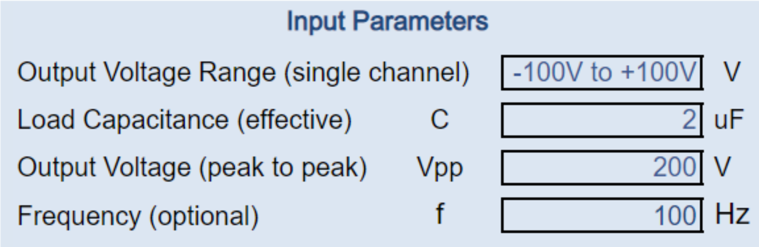



**Figure 3. Calculator inputs for driving a bridged 1uF load with +/-200V.**

The recommended order codes for bridge-mode operation are listed in Table 2. Note that any PD200X4 amplifier can be operated with a bridged load; however, asymmetric voltage ranges (e.g. 0V to +200V) require the inversion function to be implemented externally. That is, the channels are operated as single channels. For simplicity with bridged loads, it is recommend to set the DC Offset of all channels to zero using the –OSD option.

| Bridge Mode Output | Single Channel Output | RMS Current | Peak Current | Recommended Order Code |
|---|---|---|---|---|
| +/-100 V | -50 to +50 V | 1.20 A | 2 A | PD200X4-V50,50-OSD |
| +/-200 V | -100 to +100 V | 0.57 A | 2 A | PD200X4-V100,100-OSD |

**Table 2. Recommended amplifier configurations for bridged mode operation.**

# 8 Overload and Shutdown

Each channel is protected against short-circuit, over-current, and over-temperature. During these conditions, the effected outputs are disabled and the overload indicator will illuminate. An overload on any channel is also reported by a logic high on the FAULT signal, located on the auxiliary signals connector.

At turn-on, some or all of the overload indicators may illuminate briefly.

An over-temperature condition will disable all channels for a few seconds until the temperature returns to a safe level. If this occurs, ensure the air intake and exhaust are not obstructed.

The amplifier can be shut down by an external source by applying a voltage of between +3V and +24V to the DISABLE signal on the auxiliary signals connector. The input impedance of the shutdown input is approximately 10 kΩ.

# 9 Pulse Current Option

For applications that require a high peak current, the peak current limit can be increased to 10 Amps by appending the order code with “-PULSE”, e.g. “PD200X4-V0,200-PULSE”. In this configuration, the average current limit remains the same; however, the peak current limit is increased to 10 Amps and the maximum pulse duration is reduced to the time listed in Table 3. The peak-to-peak output voltage range is listed in Table 1.

| Peak-to-Peak Output Voltage | Pulse Current | Pulse Time |
|---|---|---|
| 200 V | 10 A | 100 us |
| 150 V | 10 A | 150 us |
| 100 V | 10 A | 400 us |
| 50 V | 10 A | 400 us |

**Table 3. Maximum peak current duration in the pulse configuration**

For a current pulse less than the peak current limit, the increased duration is described in Figure 4.

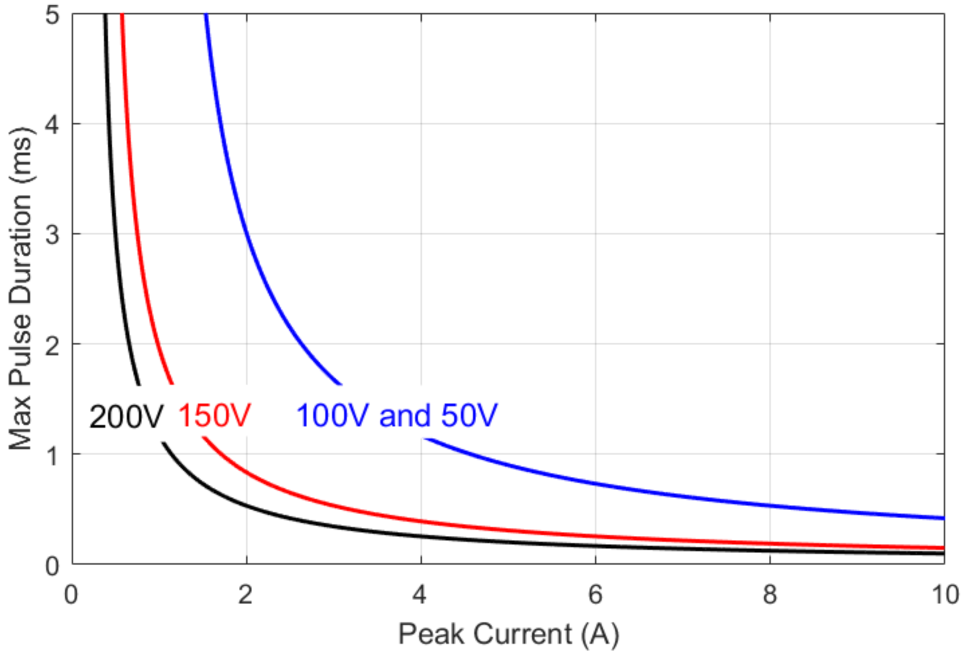



**Figure 4. Maximum pulse duration versus peak current and peak-to-peak output voltage range**

# 10 Power Bandwidth

Launch Online Power Bandwidth Calculator

The online power bandwidth calculator takes into account the current limit, slew-rate, output impedance, and small-signal bandwidth.

With a capacitive load, the RMS current for a sine-wave is

$$I_{rms} = \frac{V_{pp} C \pi f}{\sqrt{2}}$$

where $V_{pp}$ is the peak-to-peak output voltage, $C$ is the load capacitance and $f$ is the frequency. Therefore the maximum frequency for a given RMS current limit $(I_{rms})$, capacitance, and voltage is

$$f_{max} = \frac{I_{rms}\sqrt{2}}{V_{pp} C \pi} \ ,$$

The above equation is also true for any periodic waveform, including triangle waves and square waves.

The 'power bandwidth' is the maximum frequency at full output voltage. When the amplifier output is open-circuit, the power bandwidth is limited by the slew-rate; however, with a capacitive load, the maximum frequency is limited by the RMS current and load capacitance. The power bandwidth for a range of capacitive loads is listed below.

| Load Capacitance | 100V Range | 150V Range | 200V Range |
|---|---|---|---|
| No Load | 470 kHz* | 310 kHz* | 230 kHz* |
| 10 nF | 470 kHz* | 270 kHz | 130 kHz |
| 30 nF | 180 kHz | 91 kHz | 43 kHz |
| 100 nF | 56 kHz | 27 kHz | 13 kHz |
| 300 nF | 18 kHz | 9.1 kHz | 4.3 kHz |
| 1 uF | 5.6 kHz | 2.7 kHz | 1.3 kHz |
| 3 uF | 1.8 kHz | 910 Hz | 430 Hz |
| 10 uF | 560 Hz | 270 Hz | 130 Hz |

**Table 4. Power bandwidth versus load capacitance and output voltage span**

In the above table, the frequencies limited by slew-rate are marked with an asterisk, and the frequencies limited by small-signal bandwidth are marked with a double asterisk. The slew-rate is approximately 150 V/uS which implies a maximum frequency of

$$f^{max} = \frac{150 \times 10^{6}}{\pi V_{pp}}$$

The maximum peak-to-peak voltage is plotted against frequency in Figure 5.

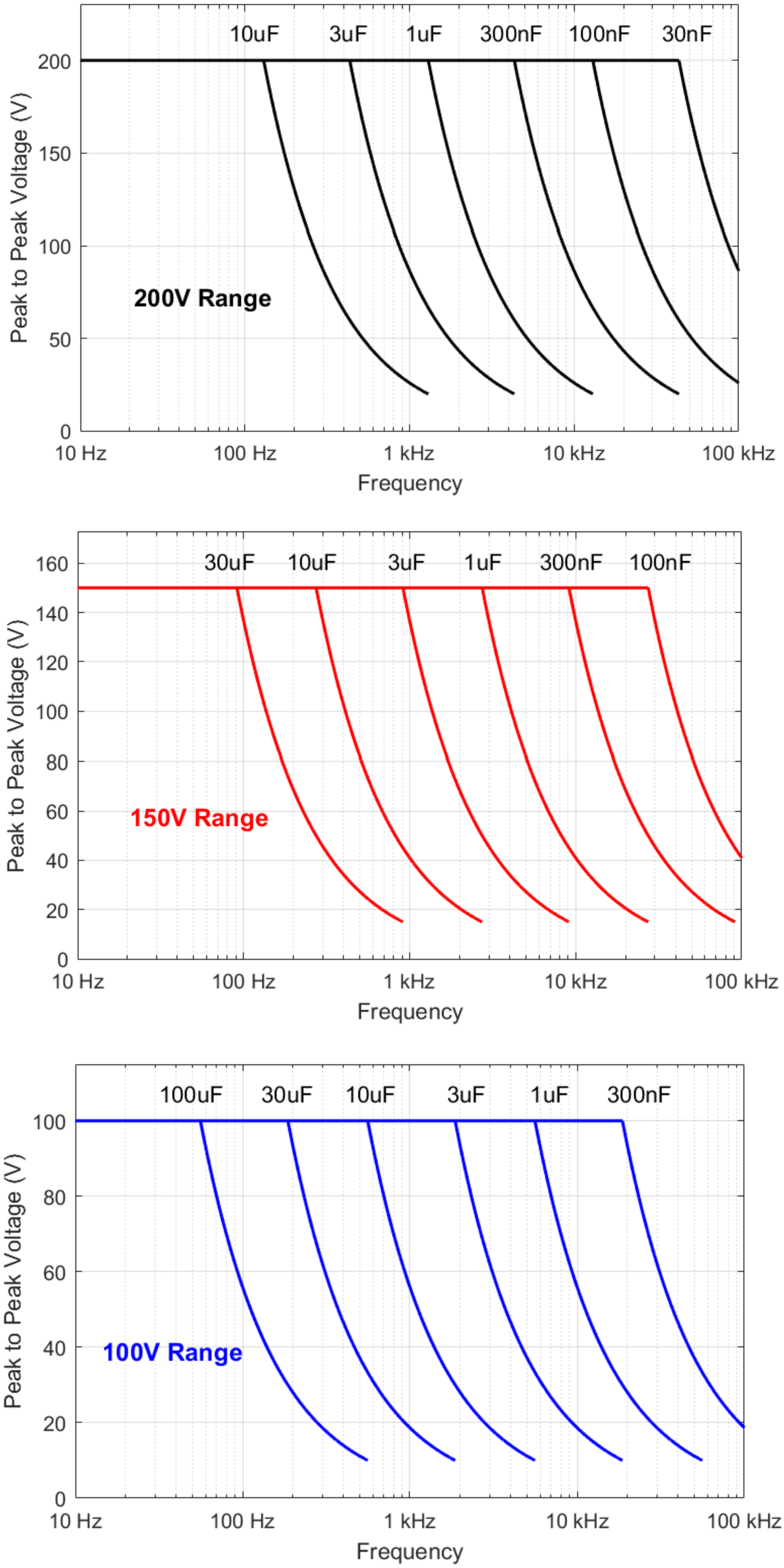



**Figure 5. Maximum peak-to-peak voltage versus frequency and load capacitance**

# 11 Small Signal Bandwidth

The small-signal frequency response and -3 dB bandwidth is described in Figure 6 and Table 5.

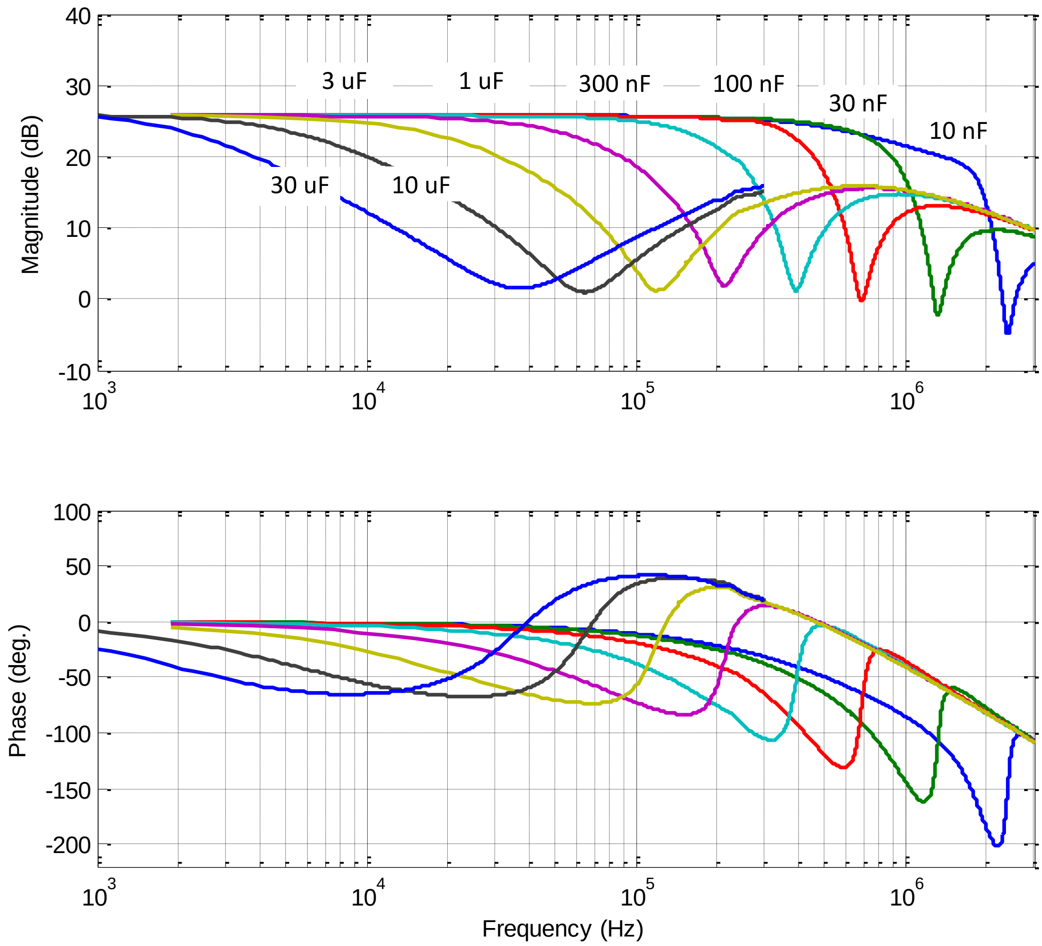



**Figure 6. Small signal frequency response for a range of load capacitances.**

| Load Capacitance | Bandwidth |
|---|---|
| No Load | 684 kHz |
| 10 nF | 759 kHz |
| 30 nF | 720 kHz |
| 100 nF | 388 kHz |
| 300 nF | 172 kHz |
| 1 uF | 60 kHz |
| 3 uF | 21 kHz |
| 10 uF | 6.4 kHz |
| 30 uF | 2.4 kHz |
| 110 uF | 940 Hz |

**Table 5. Small signal bandwidth versus load capacitance (-3dB)**

# 12 Noise

The output noise contains a low frequency component (0.03 Hz to 20 Hz) that is independent of the load capacitance; and a high frequency (20 Hz to 1 MHz) component that is approximately inversely proportional to the load capacitance.

The noise is measured with a preamplifier with a gain of 1000, an oscilloscope, and Agilent 34461A Voltmeter. The low-frequency noise is plotted in Figure 7. The RMS value is 650 uV with a peak-to-peak voltage of 4.3 mV.

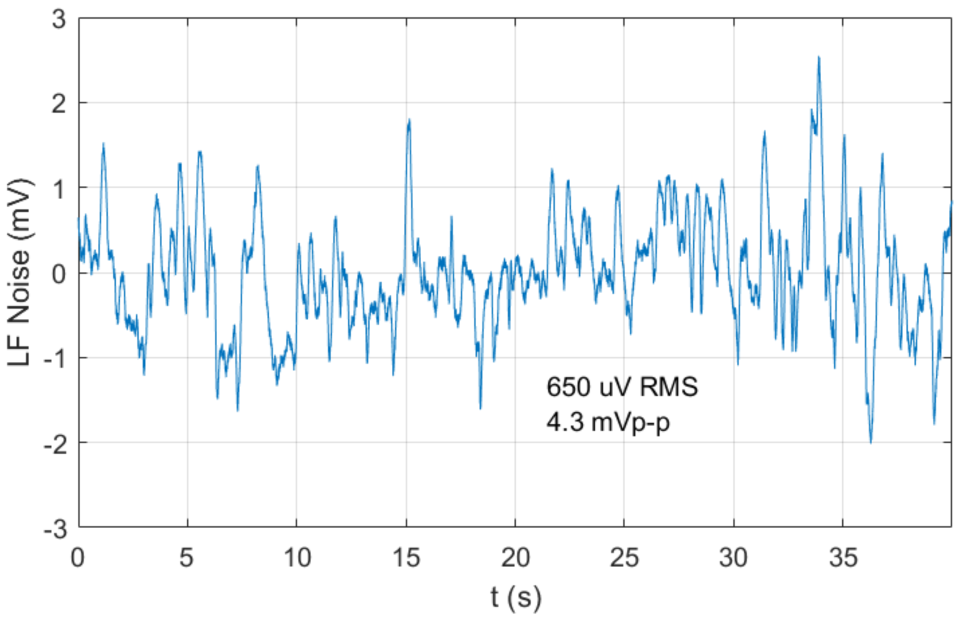


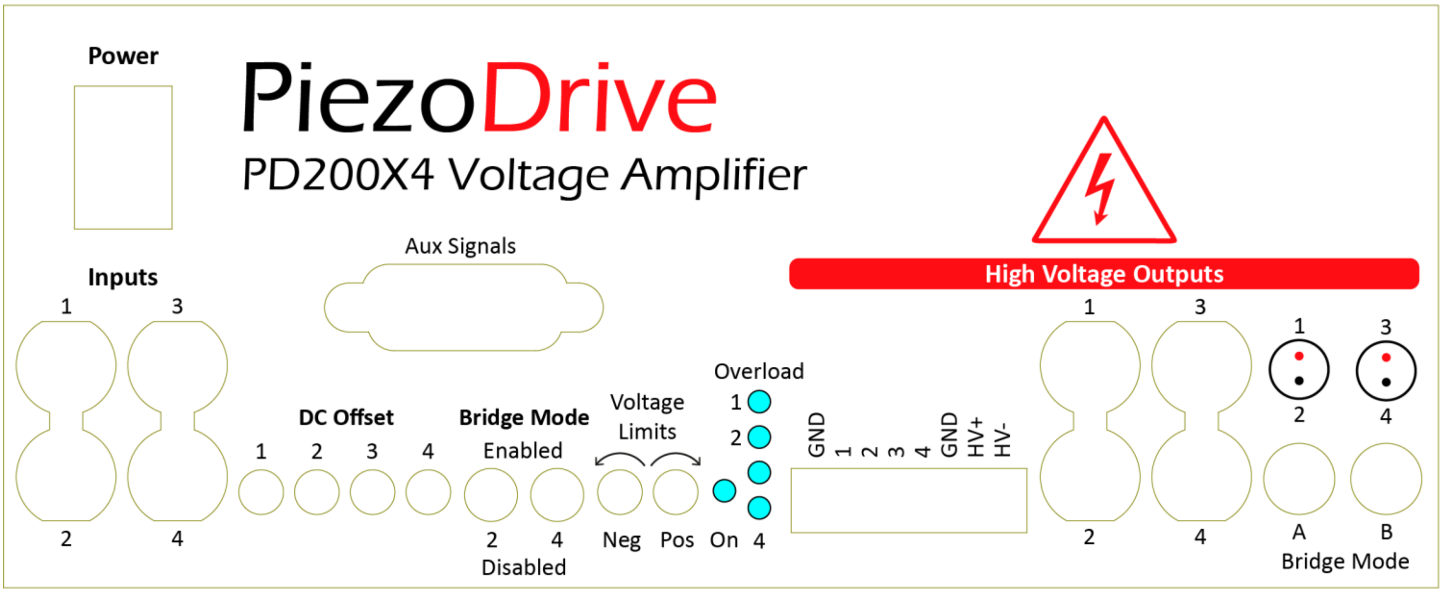

**Figure 7. Low frequency noise from 0.03 Hz to 20 Hz**

The high frequency noise (20 Hz to 1 MHz) is listed in the table below versus load capacitance. The total RMS noise from 0.03 Hz to 1 MHz is found by summing the RMS values, that is $\sigma = \sqrt{\sigma_{LF}^2 + \sigma_{HF}^2}$.

| Load Cap. | Bandwidth | HF Noise RMS | Total Noise |
|---|---|---|---|
| No Load | 684 kHz | 1.60 mV | 1.72 mV |
| 10 nF | 759 kHz | 1.65 mV | 1.77 mV |
| 30 nF | 720 kHz | 1.75 mV | 1.86 mV |
| 100 nF | 388 kHz | 2.08 mV | 2.17 mV |
| 300 nF | 172 kHz | 2.18 mV | 2.27 mV |
| 1 uF | 60 kHz | 998 uV | 1.19 mV |
| 3 uF | 21 kHz | 414 uV | 771 uV |
| 10 uF | 6.4 kHz | 295 uV | 714 uV |
| 30 uF | 2.4 kHz | 280 uV | 708 uV |
| 110 uF | 940 Hz | 264 uV | 702 uV |

**Table 6. RMS noise versus load capacitance (0.03 Hz to 1 MHz)**

# 13 Front Panel




| Control | Type | Function |
|---|---|---|
| Power | | Power On/Off |
| Inputs | Input | Input for channels 1 to 4 (+/-15V max) |
| DC Offset | | Adds a DC offset to the input signal. Can be disabled as an option. |
| Bridge Mode | | See Section 7 |
| Voltage Limits | | Limits the maximum negative and positive voltage of all channels |
| On LED | | Green when the power is on |
| Overload LEDs | | Red when a channel is disabled or in an overload state |
| Screw terminals | Output | Plug-in screw terminals, suits Amphenol TJ0831530000G |
| BNC Outputs | Output | BNC outputs for each channel |
| Bridge Mode | Output | See Section 7. Suits LEMO FGG.0B.302.CLAD52 or PD-0B302-W-120 |
| Aux Signals | Mixed | See description below |

The screw terminals or LEMO connector is recommended for applications requiring more than 1 Amp RMS output current. Preassembled LEMO cable assemblies (e.g. PD-0B302-W-120) are available from [www.PiezoDrive.com](http://www.PiezoDrive.com)

The auxiliary signals connector is a 15-way DSUB receptacle (3M 8315-6000), it suits any 15-way male DSUB plug. The signals and pin layout are shown in Figure 8 and Table 7.

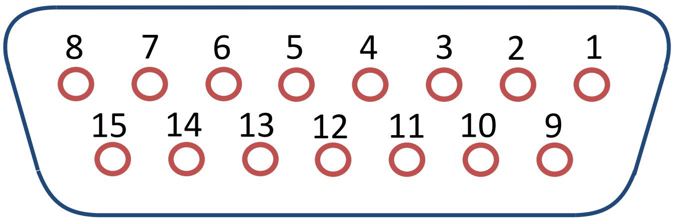



**Figure 8. Front view of auxiliary signals connector**

| Signal | Pin | Function |
|---|---|---|
| Inputs | 1, 2, 3, 4 | Input for channels 1, 2, 3, 4 (+/-15V max) |
| Voltage Monitor | 5, 6, 7, 8 | Voltage monitor for channels 1, 2, 3, 4. Gain = 1/20 V/V |
| Current Monitor | 9, 10, 11, 12 | Current monitor for channels 1, 2, 3, 4. Gain = 1 V/A |
| Disable | 13 | A voltage between +3V and +24V shuts down the amplifier |
| Fault | 14 | +5V when a fault occurs on any channel |
| Temp | 15 | Internal heatsink temperature |
| Ground | Shield | Ground for all signals |

**Table 7. Auxiliary signals pinout**

# 14 Voltage Limits

The output voltage range can be restricted to an arbitrary positive and negative value using two potentiometers on the front panel. To set the voltage limit:

- Remove loads connected to the outputs
- Apply a 100-Hz sine wave to the input of channel 1 with an amplitude that covers the full range of the amplifier. For example, with a 0V to +200V model, apply a 0V to +10V input.
- Measure the output voltage of channel 1 with an oscilloscope and confirm the full voltage range is achieved. If there is any clipping of the sine wave, the voltage limits may have already been set, and may need resetting by winding the potentiometers in the direction of the arrows.
- To limit either the negative or the positive voltage, turn the potentiometer in the opposite direction to the arrow, until the voltage is limited to the desired level.

# 15 Bias Outputs and Piezo Benders

The bias outputs are labelled HV+ and HV- on the front-panel screw terminals. The output voltages are fixed at the maximum output voltages of the amplifier, and are not affected by the voltage limit potentiometers. For example, a PD200X4-V100,100 (with a +/-100V output range) will output +100V and -100V on HV+ and HV- respectively. For amplifier configurations where the HV- output is zero (e.g. PD200X4-V0,200), it is preferable to use ground rather than the HV- output. If specialized bias voltages are required, an amplifier output channel can be used with a DC offset.

The bias outputs provide a small DC output current of approximately 30mA; however, they can source or sink large AC currents, and are ideal for generating bias voltages for piezoelectric actuators, which only require AC current. Bender actuators can be driven with a single or dual bias voltage.

The most common bender actuators are parallel-poled and driven using the 'biased unipolar' or 'three-wire' configuration [1], as shown in Figure 9.

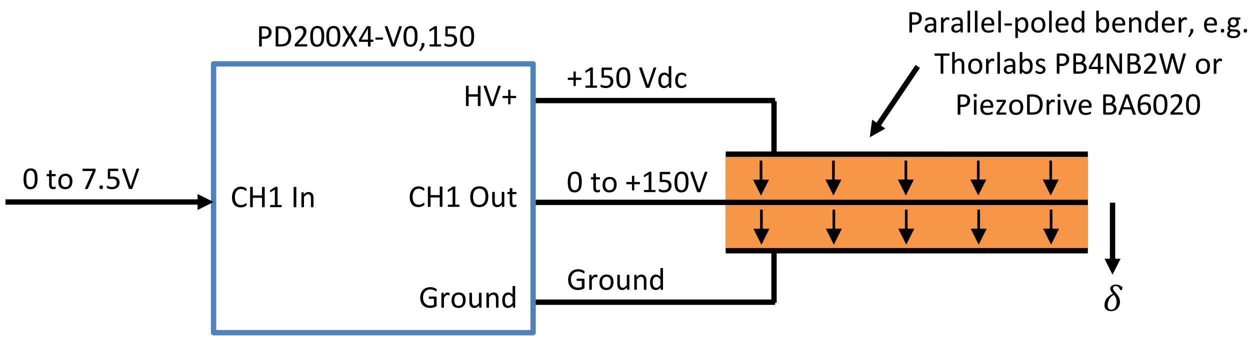



**Figure 9. Parallel-poled bender driven in the biased unipolar configuration [1].**

A zero volt input results in +150V across the top piezo layer and maximum upward deflection. A 7.5V input results in +150V across the bottom piezo layer and maximum downward deflection. The deflection $\delta$ can be represented by

$$\delta = \frac{V_{in} - 7.5/2}{7.5} \delta_{pp}$$

where $\delta_{pp}$ is the peak-to-peak displacement of the bender.

To reduce the maximum DC voltage, a negative bias voltage can be used, as shown in Figure 10.

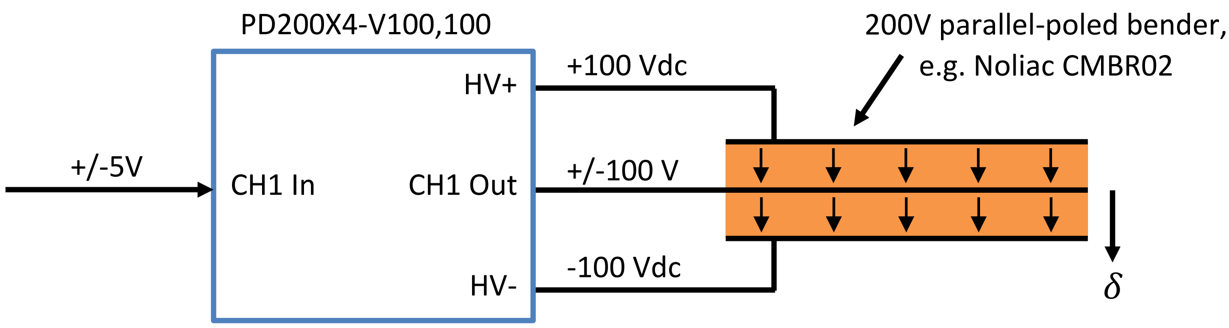



**Figure 10. 200V Parallel-poled bender driven with dual bias sources.**

In Figure 10, the deflection is

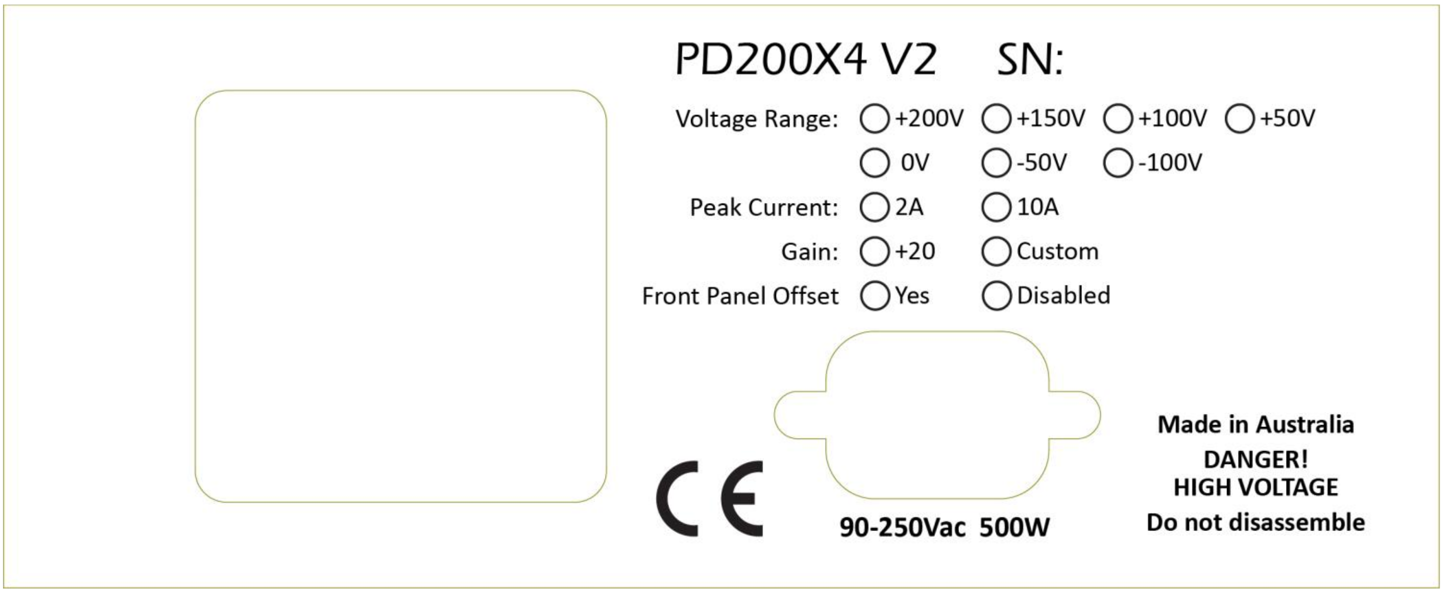
$$\delta = \frac{V_{in}}{10}\,\delta_{pp}$$

where $\delta_{pp}$ is the peak-to-peak displacement of the bender.

**References**


[1] A New Electrical Configuration for Improving the Range of Piezoelectric Bimorph Benders; S. A. Rios, A. J. Fleming; Sensors and Actuators A: Physical, 2015.


# 16 Rear Panel




The power inlet suits an IEC C13 plug.

# 17 Options and Customization

Standard options and customizations are listed in Table 8 and Table 9 respectively. Options do not increase cost and may be user changeable. Customizations are not user changeable and may involve a small price increase.

| Option | Order Code Suffix | Notes |
|---|---|---|
| Offset fixed to zero | -OSD | Recommended for bridge mode |
| Offset fixed to zero on specific channels | -OSD(X) | X is the list of channels, e.g. –OSD(Ch1,Ch2,Ch3,Ch4) |
| 10 Amp peak current | -PULSE | Refer to Section Pulse Current Option9 |
| 10 Amp peak current on specific channels | -PULSE(X) | X is the list of channels, e.g. –PULSE(Ch1,Ch4) |

**Table 8. Standard options**

| Customization | Order Code Suffix | Notes |
|---|---|---|
| Custom gain | -Gain(X) | X is the gain, from 5 to 200, e.g. Gain(50). |
| Custom gain on specific channels | -Gain(X,ChY) | X is the gain, from 5 to 200, and Y is the list of channels, e.g. –Gain(50,Ch1,Ch2). Use multiple suffixes for different gains, e.g. –Gain(50,Ch1)-Gain(100,Ch4). |

**Table 9. Available customizations**

# 18 Rack Mounting

The PD200X4 can be installed in a 19-inch x 2U rack space using the single unit rack kit (order code: SingleRackKit-2U). Two amplifiers can also be installed in a side-by-side configuration using the double unit rack kit (order code: DoubleRackKit-2U).

# 19 Delivery Contents

- PD200X4 amplifier with plug-in screw terminal installed
- IEC C13 power cable, suited to the shipping destination

# 20 Warranty

PiezoDrive amplifiers are guaranteed for 12 months from the date of delivery. The warranty does not cover damage due to misuse.