PDX Voltage Amplifiers

Manual and Specifications

PiezoDrive
Newcastle Innovation Ltd.
Industry Development Centre
University Drive, Callaghan NSW 2308, Australia

www.piezodrive.com

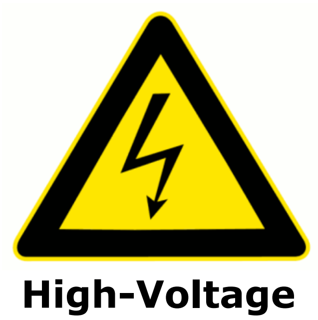
V4 May 2013

Warnings / Notes

1) **The return wire on the output connector should not be grounded.**

   The only connection to the output should be the piezoelectric actuator
   Do not connect the return conductor to Earth or Ground, for example to measure the output voltage with an oscilloscope.

2) This device produces hazardous potentials and should only be used by suitably qualified personnel under the supervision of an observer with appropriate first-aid training. Do not operate the device when there are exposed conductors.



PiezoDrive

PDX Series
High-Speed Voltage Amplifiers

Manual and Specifications

Contents

V4 May 2013

1. Quickstart Guide

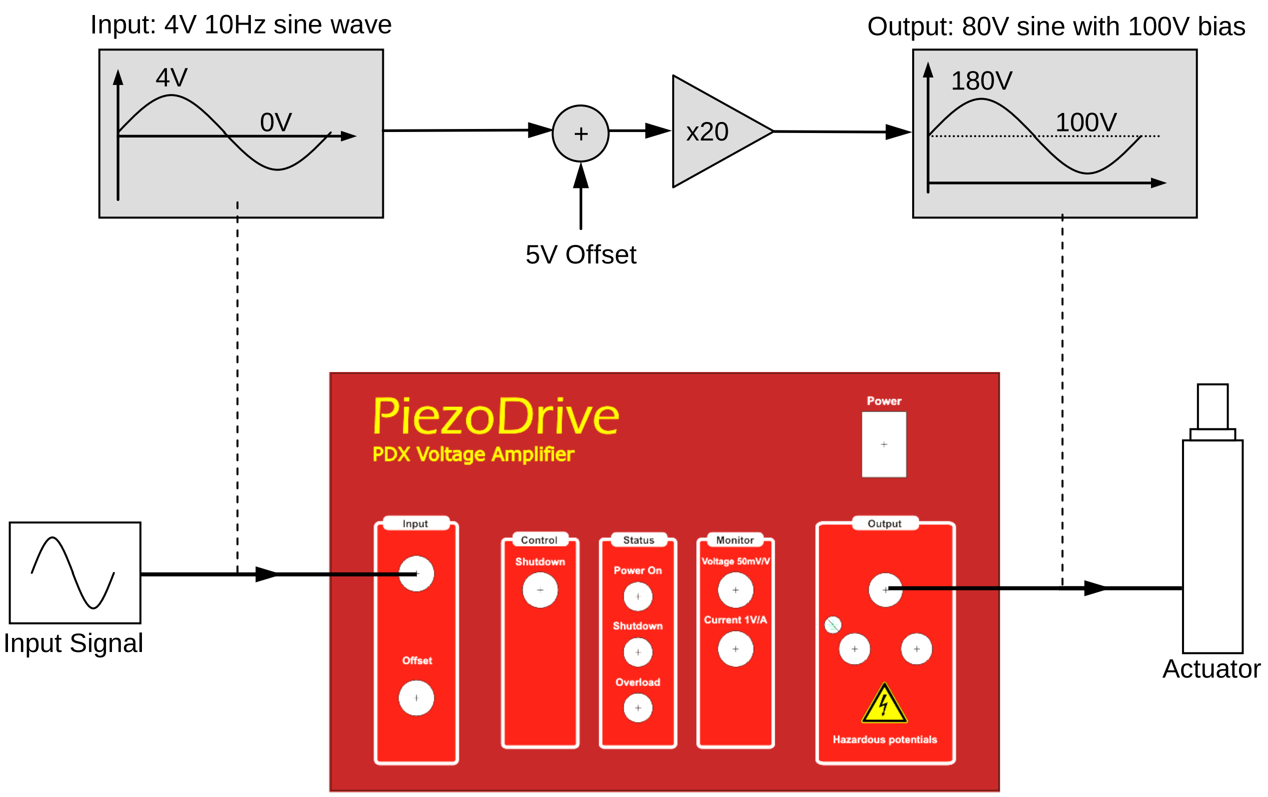
The PDX amplifiers have a fixed voltage gain of 20 and an offset voltage of zero to 200V. To connect the amplifier to an actuator, the following steps should be performed.

1) **Set the offset voltage.** Connect the Voltage Monitor Output to a Multimeter using a BNC to 4mm-Plug cable, or suitable adaptor. Leave the input grounded or unconnected. Turn the device on.

   Keeping in mind that the Voltage Monitor Output has a gain of 1/20 V/V, rotate the offset adjustment until the desired offset voltage is reached. The bias voltage for a piezoelectric actuator is typically half the maximum actuator voltage. When completed, turn the device off.

2) **Connect the input signal and load.** Note that the return connection to the actuator cannot be grounded, for example to earth, a shield wire, or to a grounded oscilloscope probe. The only connection to the high-voltage output should be the actuator.

An example application is shown below. In this case, the input voltage is a +/- 4V sine wave and the offset voltage is set to 100V.



An example application where an actuator is driven by a +/- 80V sine wave with an offset voltage of 100V

2. Brief Specifications

The PDX amplifiers have two output voltage ranges and three peak current ranges.

The **b** variant is designed for general purpose and scanning applications where peak current may last for up to 100ms. The **c** variant is designed for applications where large currents are required for short periods of time. The **d** variant provides the highest peak output current, but for the shortest time.

Model	**PDX150**			**PDX200**		
Variant	**b**	**c**	**d**	**b**	**c**	**d**
Inputs	Differential (to eliminate ground loops and noise). Z_{in} = 22 kΩ					
Voltage	-30V to 150V*			-30V to 200V*		
Peak Current	2A	5A	10A	1.5A	5A	10A
Overload Time	100ms	1ms	100us	100ms	1ms	100us
RMS Current	1.6 A			1.1 A		
Gain	20 V/V					
Offset	From 0V to Full-Range with front panel adjustment					
Connectors	Input: BNC, Monitor Outputs: BNC, Output: LEMO and 4mm Jack					
Load	Stable with unlimited capacitive loads					
Bandwidth	Greater than 80 kHz (1uF Load)					
Power Bandwidth	9.5 kHz			7.2 kHz		
Overload	Thermal, current and voltage overload protection					
Noise	Ultralow noise, < 320 μV RMS					
Environment	0 - 40°C (32-104°F) Non-condensing humidity					
Enclosure	Rugged desktop enclosure. 19 inch rack compatible					

* Minimum voltage range

3. Output Connection Diagram

The actuator can be connected to the amplifier by either two 4mm banana plugs or a 2-way LEMO 0B socket (LEMO EGG.0B.302.CLL). For high-speed applications the LEMO connector and Belden cable is recommended since this provides a considerably lower inductance and higher electrical bandwidth. Additional LEMO cable assemblies in lengths from 1m to 5m are available from www.PiezoDrive.com

The mating plug is a LEMO 0B 2-Way Straight Cable Plug. Ordering details and specifications are listed below. These parts can be obtained directly from www.mouser.com

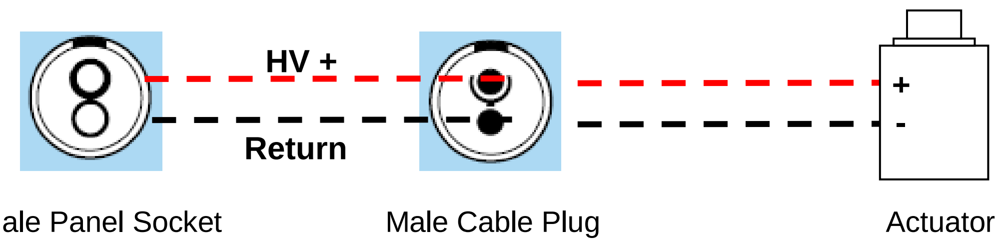
Plug	LEMO 0B 2-Way Straight Cable Plug
Crimp Terminal Version	*LEMO FGG.0B.302.CYCZ
Solder Tag Version	LEMO FGG.0B.302.CLAZ
Max Conductor Size	AWG22
Cable Collet	*FGG.0B.742.DN
Cable Diameter	*3.1mm – 4mm
Strain Relief Boot	*GMA.0B.035.DN (3.5–3.9mm Cable)

* Supplied with amplifier. Note that the crimp terminal plug requires a tool, if this is not available, the solder tag plug should be used.

A shielded two conductor cable is required to connect the amplifier to a piezoelectric actuator. A recommended cable is the Belden 8451 cable. The specifications are listed below.

Cable	*Belden 8451
Conductor Size	AWG22 (0.64mm diameter)
Resistance	53 mOhms/m
Capacitance	115 pF/m core–core, 220 pF/m core-shield
Outside Diameter	3.5mm

The actuator wiring diagram is shown below.



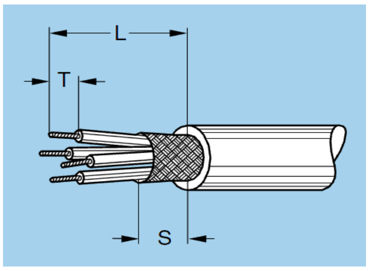
If the cable has a shield, it should be connected to the body of the plug via the collet as described on the following page. Do not connect the shield to the load or use it as a ground return.

The Return connection is not ground.

Do not connect the Return conductor to Earth or Ground, for example to measure the output voltage with an oscilloscope. The only connection to the output should be the piezoelectric actuator

LEMO Plug Cable Preparation

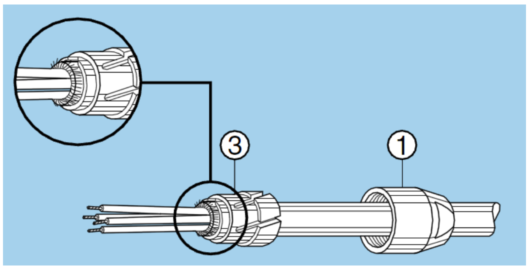
(Taken from LEMO B Series Cable Assembly Instructions)



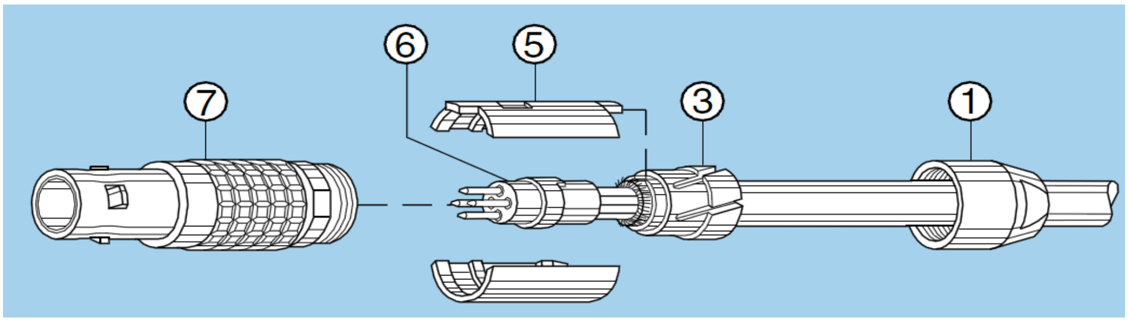
Solder			Crimp		
L	S	T	L	S	T
13.0	7	3.0	17.0	7	4.0

LEMO Plug Assembly

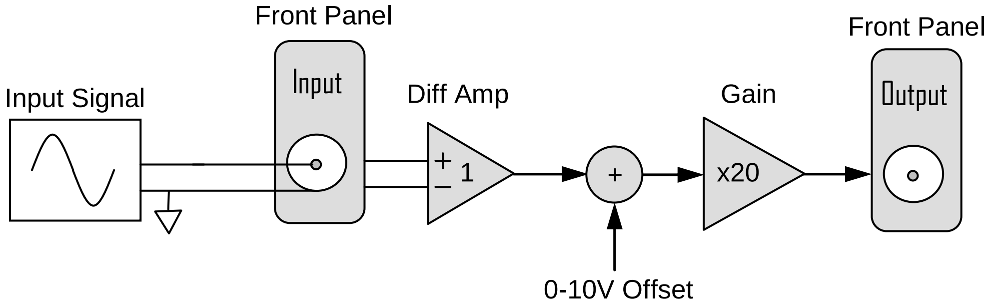
(Taken from LEMO B Series Cable Assembly Instructions)



1. Strip the cable as above
2. If the cable is shielded, fold the shield back over the cable
3. Slide the strain relief, collet nut (1) and collet (3) onto the cable.
4. Solder or crimp the conductors onto the contacts.
5. Assemble the plug,



4. Input Signal Conditioning



Simplified signal path of the PDX Drives

Input Circuit

The input circuit has a function similar to a unity gain differential amplifier. This circuit is designed to eliminate ground-loops and noise resulting from the connection of instruments with different power supplies. The full scale range of the input circuit is +/- 10V. The signal ground is allowed to float by approximately +/- 0.6V before it is electrically connected to ground. The input impedance is 22kOhm.

Offset Voltage

After the input stage, an optional offset voltage is added to produce an electrical bias of between 0V and 200V. A typical stack actuator should be biased at half of the full scale voltage. To set the offset voltage, connect the voltage monitor output to a multimeter using a BNC to 4mm-plug cable, or suitable adaptor. Preferably ground the input, or leave it unconnected. Turn the amplifier on and tune the offset adjustment to the correct level.

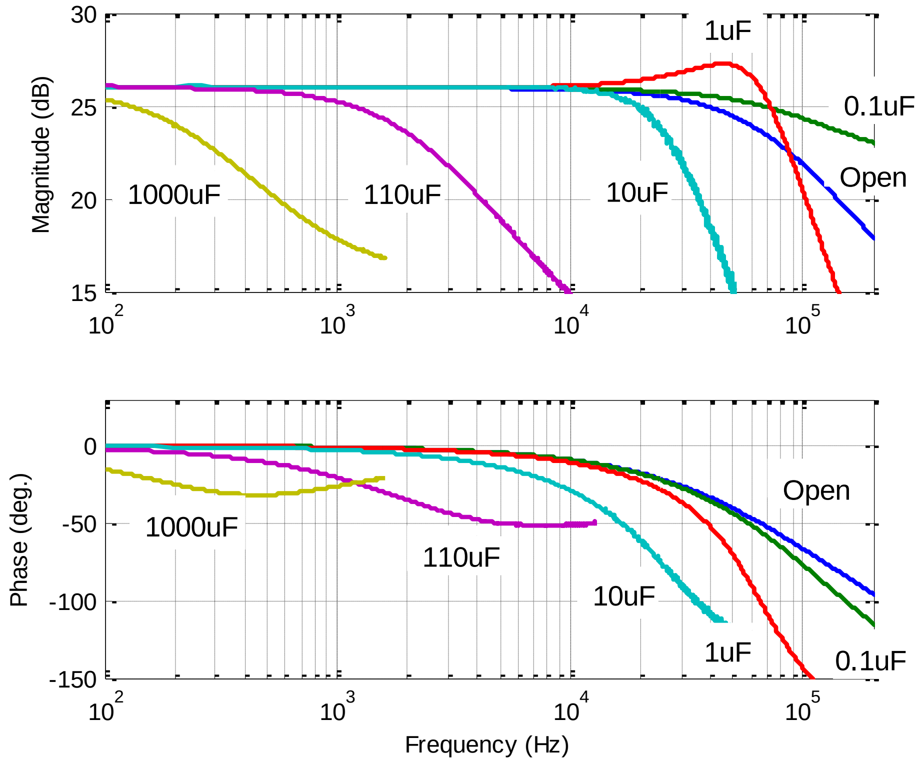
Gain Stage

The gain is fixed at 20. Other gains are available on request.

Monitor Outputs

There are two monitor outputs on the front panel. The voltage monitor has a gain of 1/20 V/V. and the current monitor has a gain of 1 V/A. The maximum output current from the monitor outputs is 10 mA.

5. Small Signal Bandwidth



Frequency response for a range of load capacitances

The PDX amplifiers have an extremely wide bandwidth and can tolerate any capacitive load. The small-signal frequency response is plotted for a range of capacitive loads in the figure above. The -3dB bandwidths are listed below

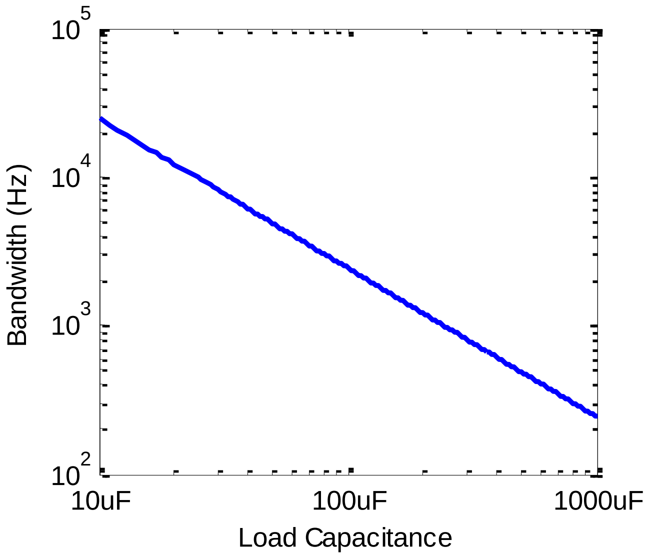
Load Capacitance	Bandwidth
No Load	78 kHz
0.1 uF	200 kHz
1.0 µF	84 kHz
10 µF	27 kHz
100 µF	2.7 kHz
1000 µF	270 Hz
10000 µF	27 Hz

Approximate bandwidth versus load capacitance.

With a load capacitance of greater than 10uF, the bandwidth can be approximated by,

$$f_c = \frac{1}{4.1C} \text{ Hz},$$

where *C* is the load capacitance. This relationship is also plotted below.



Bandwidth versus load capacitance

If the load capacitance is approximately 1uF or less, the bandwidth will exceed the unloaded bandwidth of 78kHz. The maximum bandwidth is approximately 200kHz with a load capacitance of around 0.1uF.

6. Output Current Limitations

Model	PDX150			PDX200		
Variant	b	c	d	b	c	d
RMS Current I_{rms}	1.6 A			+/- 1.1 A		
Average DC Current I_{av}	+/- 0.7 A			+/- 0.5 A		
Peak Current I_{pk}	2A	5A	10A	1.5A	5A	10A
Overload Time	100ms	1ms	100us	100ms	1ms	100us

The PDX amplifiers contain a new technology called *Dynamic Current Control*™. Compared to other amplifiers with fixed current limits, Dynamic Current Control allows a larger peak current and the reproduction of larger amplitude waveforms with higher frequency.

The PDX amplifiers are available in three peak current ranges. The **b** variant is designed for general purpose and scanning applications where peak current may last for up to 100ms. The **c** variant is designed for applications where large currents are required for short periods of time. The **d** variant provides the highest peak output current, but the shortest overload time.

This section contains an introduction to driving capacitive loads, followed by a description of the Peak Current Limit and Average Current Limit.

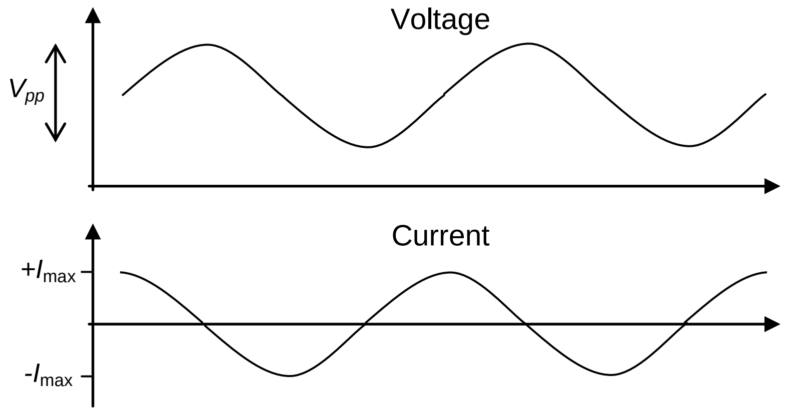
Driving Capacitive Loads

With a capacitive load, the required output current is proportional to the rate of change in voltage, that is

$$I = C\frac{dV}{dt}$$

where I is the current, C is the load capacitance and dV/dt is the rate of change in voltage. Thus, more current is required for fast edges or transitions, larger amplitudes and higher frequencies.

The voltage and current waveforms for a **sinusoidal voltage** and capacitive load are shown below.

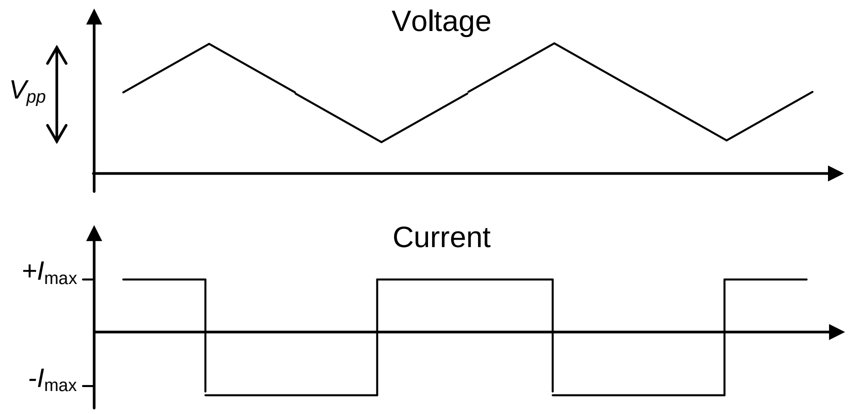


The maximum required current is

$$I_{max} = \pm V_{pp} \pi C f$$

where I_{max} is the maximum positive and negative current, V_{pp} is the peak-to-peak amplitude (i.e. double the amplitude), *f* is the frequency and *C* is the load capacitance.

For a **triangular** signal, the voltage and current waveforms with a capacitive load are shown below.



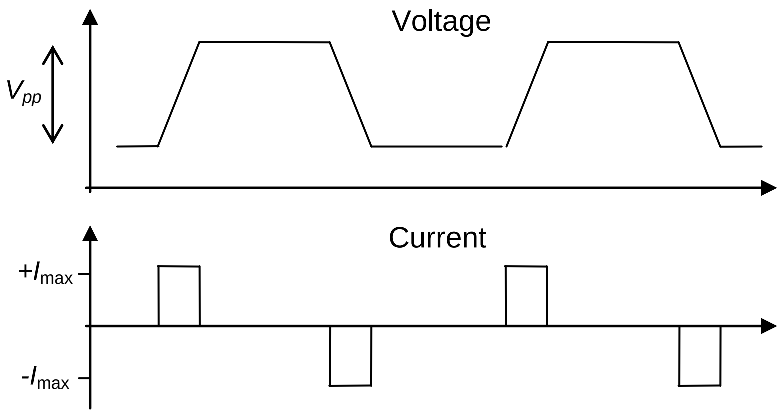
The maximum required current is

$$I_{max} = \pm V_{pp} 2 C f$$

where I_{max} is the maximum positive and negative current, V_{pp} is the peak-to-peak amplitude (i.e. double the amplitude), *f* is the frequency and *C* is the load capacitance.

Peak Current Limit

During normal operating conditions with a capacitive load, the PDX amplifiers are protected by a peak current limit. If the maximum output current is exceeded, the amplifier will behave like a constant current source and the 'Overload' indicator on the front panel will light. As an example, consider a capacitive load driven by a square wave. The output voltage and current wave forms are shown below. At each transition, the amplifier enters current limit.



Average Current Limit

In addition to the peak current limit, there is also an average current limit that protects the amplifier from short circuit. If the average current limit engages, the amplifier will enter an overload condition and the output circuit will be disabled for approximately five seconds.

The positive average current is computed by measuring the current flowing out of the amplifier. The current measurement is rectified then averaged with a leaky integrator. An identical circuit exists for the negative average current. The time-constant of the leaky integrator is listed below:

Current Limit	Max Duration	Time Constant
10A	100us	2.2ms
5A	1ms	10ms
2A	100ms	270ms
1.5A	100ms	270ms

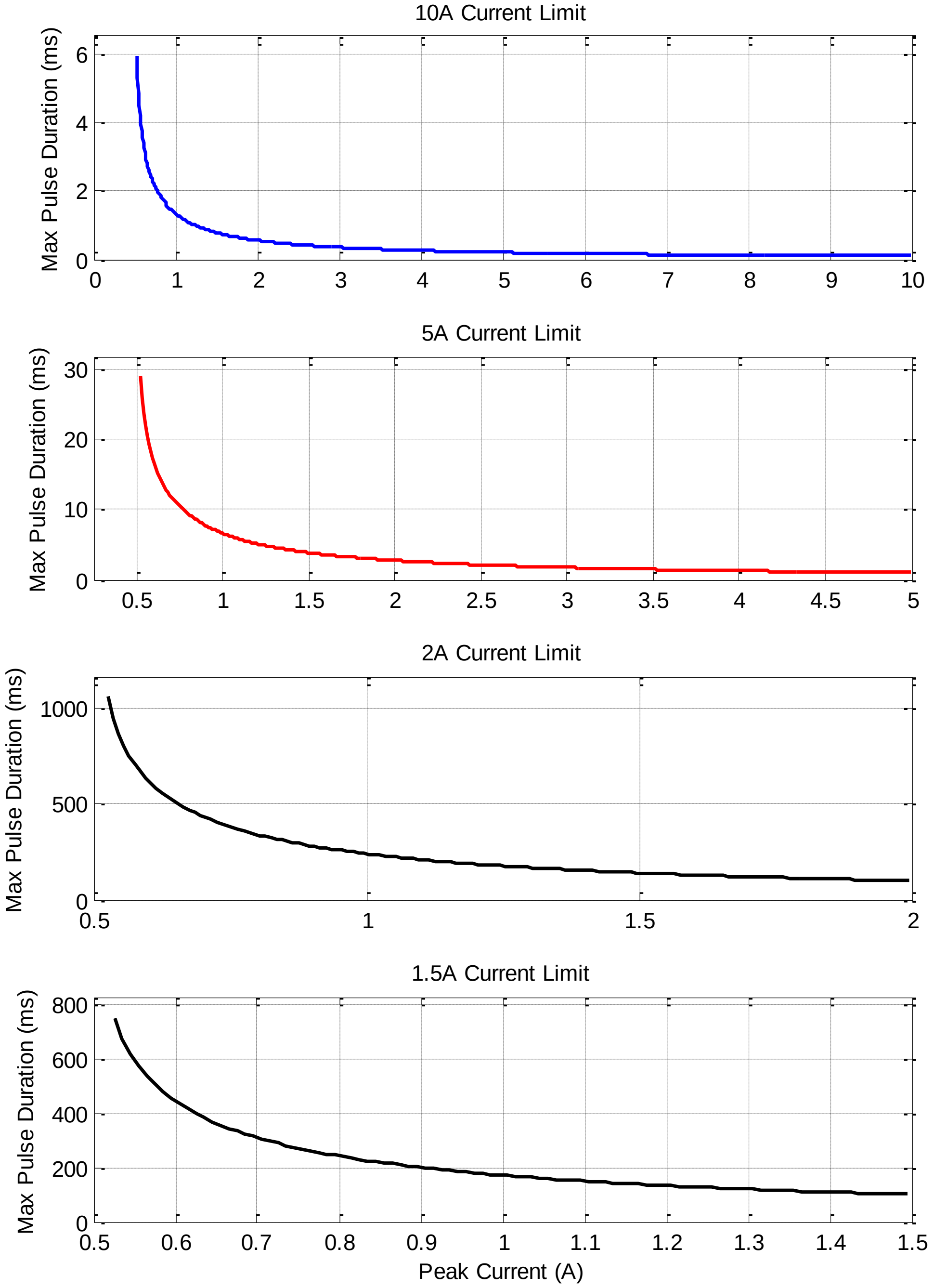
Averaging Time Constant

Note that the time-constants for the 1.5A and 2A variants are significantly longer than the models designed for pulse applications. No significant relaxation occurs for around 27ms, which implies that the average current measurement is essentially exact for waveforms with a period less than 54ms or a frequency greater than 18Hz.

Due to the short time-constant of the 5A and 10A variants, these amplifiers are not suited for low-frequency scanning applications. For low-frequency signals, the short time-constant effectively limits the maximum peak current to the rated average-current.

A benefit of the average current limit is that current pulses less than the peak current are allowed for longer periods of time. The maximum non-repetitive pulse duration versus the output current is shown below.

Maximum Pulse Duration Times



Fold-back current limiting Versus PiezoDrive Dynamic Current Control

Some high-voltage amplifiers use a current-limiting technique referred to as fold-back current limiting. This technique implies a current limit that changes with the output voltage. When the output voltage is high, more current can be delivered compared to when the output voltage is zero or negative. This is due to the lower power dissipation that occurs when the output voltage is high. Since the maximum current is only available at the maximum voltage, fold-back current limiting is suitable for resistive loads but not capacitive loads like piezoelectric actuators. The peak current for a capacitive load can occur at any voltage.

Fold-back current limiting can result in unreliable performance when driving piezoelectric actuators. A waveform that may be successfully reproduced with a certain bias voltage may become distorted when the bias voltage is reduced. In addition, the step-response of the amplifier changes depending on the output voltage of the amplifier.

Actuator Capacitance versus Bias Voltage and Temperature

The power bandwidth, slew-rate and small-signal bandwidth of a piezoelectric amplifier are all primarily limited by the actuator capacitance. Larger actuators and actuators with a greater number of internal layers have a higher capacitance.

Care must be taken when interpreting the capacitance values specified by actuator manufacturers. These values are measured at room temperature and with zero bias voltage. Due to the non-linearity of piezoelectric dielectrics, the small-signal capacitance increases with higher electric field. Hence, when operating at full range or high bias-voltage the capacitance value specified by the manufacturer should be multiplied by approximately a factor of two.

In addition to capacitance non-linearity, piezoelectric dielectrics are also highly temperature dependant. For example, the sensitivity and capacitance of common piezoelectric actuators can double with every 50 degrees Celsius increase in temperature. If the ambient temperature is above 25 degrees Celsius, the capacitance increase must be taken into account. Due to dielectric heating, large temperature increases can also occur when driving piezoelectric actuators at high-speed or full-range. This is particularly true of small actuators with a low thermal-mass; a 50 degree temperature increase can occur in just a few seconds of heavy excitation.

7. Power Bandwidth

The **b** variants of the PDX150 and PDX200 are designed to maximize the power bandwidth in general purpose and scanning applications. The power bandwidth is the maximum frequency sine-wave that can be reproduced at full voltage. For capacitive loads, the power bandwidth is primarily limited by the load capacitance and current limit.

An expression for the maximum current of a capacitive load driven by a sine-wave was derived in the previous section,

$$I_{max} = \pm V_{pp} \pi C f$$

Where V_{pp} is the peak-to-peak output voltage, *C* is the load capacitance, and *f* is the frequency. Given a peak current limit of I_{pk} , the maximum frequency sine-wave is

$$f_{max} = \frac{I_{pk}}{V_{pp} \pi C}$$

Since the PDX amplifiers limit both the peak and average current, it is also important to consider the average current requirements. The average positive or negative current for a sine-wave with a peak current of I_{max} is

$$I_{av+} = \frac{1}{2\pi} \int_0^{\pi} I_{max} \sin(\theta)\, d\theta$$

$$I_{av+} = \frac{I_{max}}{2\pi} [-cos]_0^{\pi} = \frac{I_{max}}{\pi}$$

Hence, the maximum possible sine-wave with a peak current of $I_{max} = I_{pk}$ requires an average current of I_{pk}/π which is guaranteed by the specifications of the PDX150b and PDX200b amplifiers.

The situation is different for triangular waveforms. A triangular waveform requires a peak current of

$$I_{max} = \pm V_{pp} 2 C f \ ,$$

and an average current of

$$I_{av+} = \frac{1}{T} \int_0^{T/2} I_{max}\, d\theta = \frac{I_{max}}{2}$$

Hence, a triangular waveform is limited by average current, not peak current. The peak current should not exceed $2 \times I_{av}$, which implies

$$2 \times I_{av} = \pm V_{pp} 2 C f$$

Thus, the maximum frequency of a triangular wave is similar to that of a sine wave:

$$f_{max} = \frac{I_{av}}{V_{pp} C}$$

The approximate power bandwidth for a range of capacitive loads is shown below.

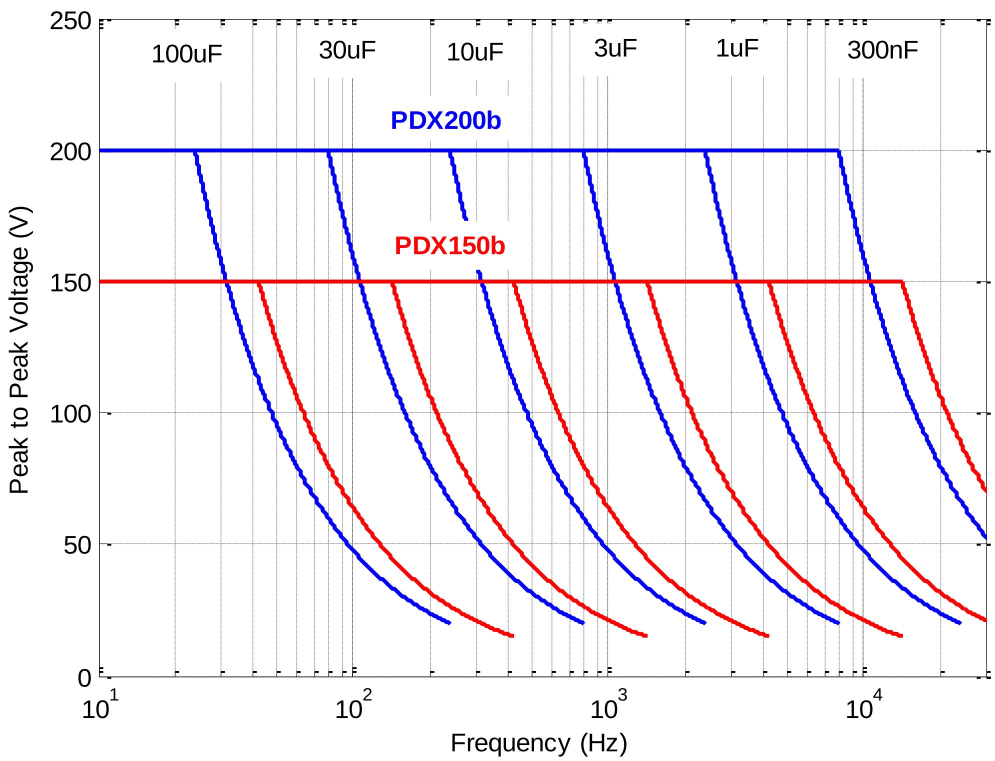
Load Capacitance	PDX200b Power Bandwidth (200Vp-p Sine-wave)	PDX150b Power Bandwidth (150Vp-p Sine-wave)
100 nF	*7.2 kHz	*9.5 kHz
300 nF	*7.2 kHz	9.2 kHz
1.0 µF	2.3 kHz	4.2 kHz
3.0 µF	790 Hz	1.4 kHz
10 µF	230 Hz	424 Hz
30 µF	79 Hz	141 Hz
100 µF	23 Hz	42 Hz

Approximate Power Bandwidth Versus Capacitive Load

* With very small loads, the power bandwidth is limited by the slew-rate, which is approximately 4.5 V/uS. The maximum frequency imposed by the slew-rate is

$$f^{max} = \frac{4.5 \times 10^6}{\pi V_{pp}}$$

Also of interest is the maximum peak-to-peak voltage that can be applied to a capacitive load versus frequency. The maximum peak-to-peak voltage is plotted in the following figure for a range of capacitive loads.



Maximum Amplitude Sine-Wave versus Frequency

8. Noise Performance

The PDX amplifiers are low noise amplifiers designed to exceed the requirements of positioning and imaging systems with sub-atomic resolution.

The table below lists some experimentally measured noise voltages.

Load Capacitance	Bandwidth	Measured Noise (RMS)
No Load	78 kHz	300 uV
0.1 uF	200 kHz	320 uV
1.0 µF	84 kHz	312 uV
10 µF	27 kHz	280 uV
100 µF	2.7 kHz	167 uV
1000 µF	270 Hz	102 uV

Measured noise versus load capacitance.

The noise was measured with a FLUKE189 TrueRMS Multimeter. The bias-voltage was 30V and the input was short-circuited.

9. Overload Protection

There are two overload indicators on the front panel: **Shutdown** and **Overload**.

The **Overload** indicator will illuminate if there is more than 2 Volts difference between the desired output voltage and the actual output voltage. This can occur if the maximum current limit is exceeded or if the bandwidth of the input signal is too high. This overload indicator does not represent a fault condition and is present mainly to alert the user that the input signal is not being faithfully reproduced.

The **Shutdown** indicator will illuminate during a shutdown caused by an average current overload or if the amplifier overheats as a result of excessive ambient temperature, poor air-flow, or fan failure. None of these conditions should occur during normal operation. Hence, if a shutdown occurs, the amplifier and attached actuator should be inspected. The most common cause of a shutdown is intermittent short-circuits produced by a damaged actuator.

When the amplifier is **Turned On** the overload protection circuit is engaged by default and will take approximately five seconds to reset. This behaviour is disabled if the amplifier was turned off while operating normally within a period of two minutes between the turn off and turn on.

The behaviour of the amplifier during an average current overload is discussed in *Output Current Limitations*. The output current is reduced to a few milliamps which may allow a partial signal if the load is small or open circuit.

External Shutdown

In addition to the internal shutdown triggers, the output stage of the amplifier can also be disabled by applying a positive voltage to the external shutdown connector (+2V to +12V).

The impedance of the external shutdown input is approximately 2.5kΩ.

The external shutdown is useful for implementing thermal protection of an actuator or for disabling a feedback system.

10. Enclosure

The PDX amplifiers are housed in a rugged aluminium desktop enclosure. The dimensions are shown below.

The PDX amplifiers have a rear air intake and side exhaust vents for cooling. These should not be obstructed. If sufficient air-flow is not available, the amplifier will enter a thermal overload state as discussed in the previous section.

The PDX amplifiers can be bolted together in a side-by-side two-channel arrangement. With the addition of rack-mount handles, this configuration can be mounted into a standard 19-inch rack. A 19-inch rack-mount kit is also available for a single amplifier.

11. Power Supply

Line Voltage	3AG Fuse (6.35 x 32 mm)
115 Vac (50-60 Hz)	5A 250V Time Delay
230 Vac (50-60 Hz)	2.5A 250V Time Delay

Mains power is supplied through an IEC connector on the back panel. The IEC socket also contains the fuses and operating voltage selector switch.

Two fuses are required, one for each of the active and neutral lines. The fuses are located in the back panel power connector and can be accessed by removing the power connecter and lifting out the fuse holder with a screw driver.

When changing the fuses, ensure that the supply voltage selector remains at the correct voltage.

Maximum power consumption is 200W

The PDX amplifiers require an earthed supply for safe operation.

If the amplifier is turned off during a period of small or zero output current, the output may remain active for approximately thirty seconds. During this period, the output potential should be treated as live. Piezoelectric actuators can also store charge and should be treated with care when disconnected from the amplifier.

12. Options

- 19 inch rack mounting kit for two amplifiers
- 19 inch rack mounting kit for a single amplifier

13. Warranty / Support

PiezoDrive amplifiers are guaranteed against manufacturing defects for a period of 3 months.

Technical support contacts can be found at www.piezodrive.com