PiezoDrive

PDL200
200 Volt Linear Amplifier

Manual and Specifications

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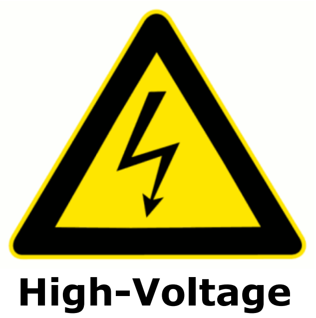
Warnings / Notes

1) 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.



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Contents

1. Quickstart Guide

The PiezoDrive PDL200 has a voltage gain of 20 and an optional offset voltage of between 0V and 200V. To connect the amplifier to an actuator, the following steps should be performed.

1) **Select the voltage limit.** To protect the actuator from overvoltage, switch the voltage limit switch to either 60V (bottom), 200V (middle) or 150V (top).

2) **Set the offset voltage.** Connect the output to a Multimeter using a BNC to 4mm-Plug cable, or suitable adaptor. Leave the input grounded or unconnected. Turn the device on. Switch the offset voltage on and tune the offset adjustment to the correct level with a small insulated flathead screwdriver. The offset voltage is usually set to half the maximum actuator voltage. Disconnect the Multimeter when finished.

3) **Connect the input signal and load.** The PDL200 is now ready for use.

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.

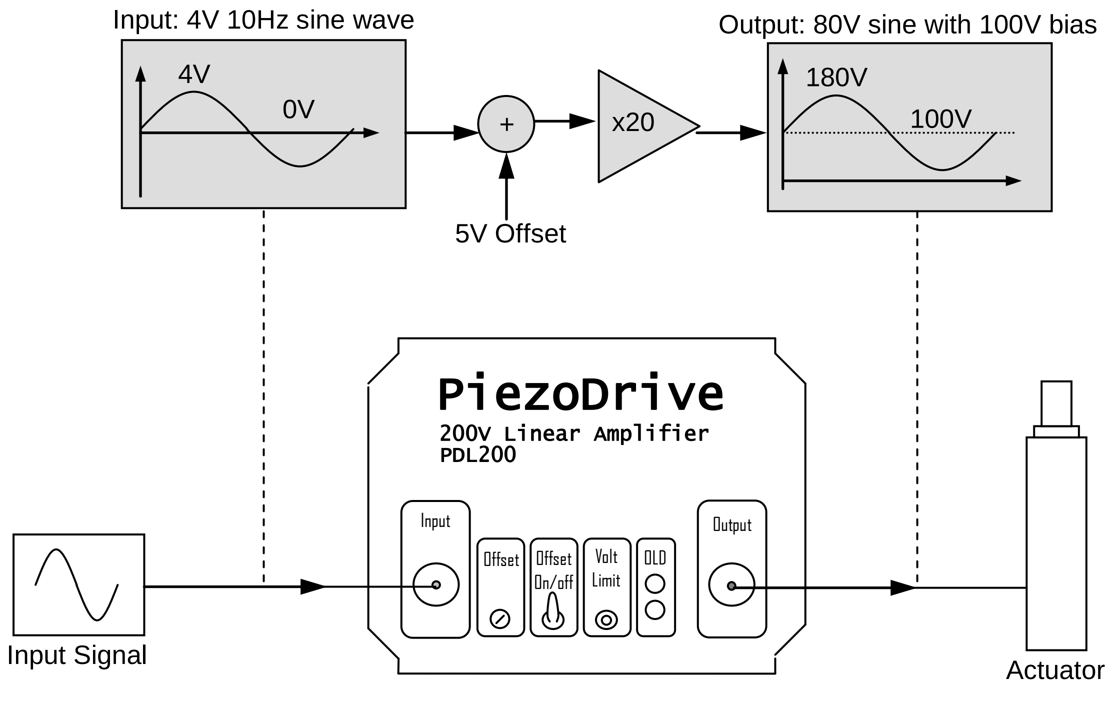


Figure 1. An example application where an actuator is driven by a +/- 80V sine wave with an offset voltage of 100V

2. Brief Specifications

The PiezoDrive PDL200 is a 200 Volt amplifier designed to optimize the performance of multilayer piezoelectric stack actuators. The PDL200 is compact in size but provides a level of performance not currently available from commercial amplifiers. Brief specifications of the PDL200 are listed below. Detailed specifications are contained in the following sections.

Inputs	Differential (to eliminate ground loops and noise). Z_{in} = 27 kΩ
Voltage	-10V to +60 V, +150 V or +200 V (Selectable Limit)
Current	+/-600mA Peak, 220mA RMS. Dynamic Current Limiting™
Gain	20 V/V
Offset	From 0V to 200V with front panel adjustment
Connectors	BNC input and output connectors.
Load	Stable with unlimited capacitive loads
Bandwidth	Greater than 400 kHz (unloaded)
Overload	Thermal, current and voltage overload protection
Noise	Ultralow noise, <150 μV RMS with a 1 μF load
Environment	0 - 40°C (32-104°F) Non-condensing humidity
Enclosure	Rugged desktop enclosure with no fans or vents. Also mounts into a standard eurocard subrack and onto an industrial DIN rail.

3. Input Signal Conditioning

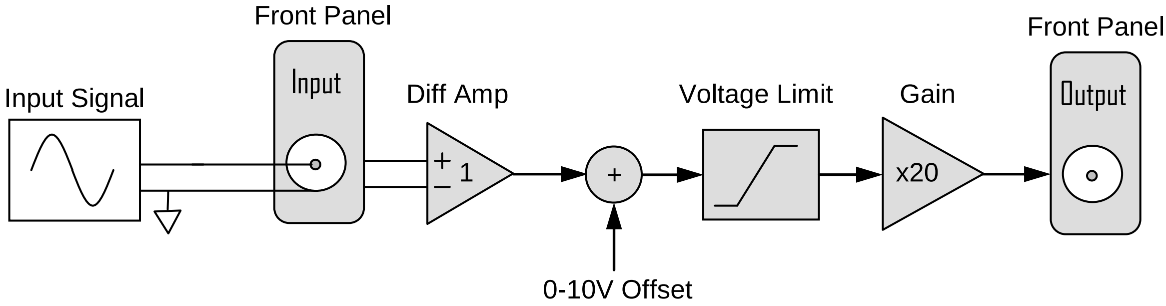


Figure 2. Simplified signal path of the PDL200.

Input Circuit

The input circuit of the PDL200 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 the amplifier ground. The input impedance is 27 kOhm.

Offset Voltage

After the input stage, an optional offset voltage is added to produce an electrical bias of between 0V and 200V. Typical stack actuators are biased at half of their full scale voltage. To set the offset voltage, connect the 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. Switch the offset voltage on and tune the offset adjustment to the correct level with a small insulated flathead screwdriver.

Voltage Limit

The voltage limit is a switch on the front panel that restricts the maximum output voltage to either: 60V, 150V or 200V. The minimum output voltage is approximately -10V.

Gain Stage

The gain of the PDL200 is fixed at 20. Other gains are available on request.

4. Bandwidth / Rise Time

Frequency Response

The unloaded bandwidth of the PDL200 is extremely high and typically greater than 400 kHz.

Although the amplifier is stable with any capacitive load, an increase in load capacitance will result in a proportional decrease in bandwidth. With a capacitive load, the PDL200 exhibits an approximately first-order response with a bandwidth f_c determined by

$$f_c = \frac{1}{190C} \text{ Hz}$$

where *C* is the load capacitance.

The bandwidth and frequency response for a range of capacitive loads is shown below.

Load Capacitance	Bandwidth
100 nF	53 kHz
300 nF	18 kHz
1.0 µF	5.3 kHz
3.0 µF	1.8 kHz
10 µF	530 Hz
30 µF	180 Hz
100 µF	53 Hz

Table 1. Bandwidth versus load capacitance.

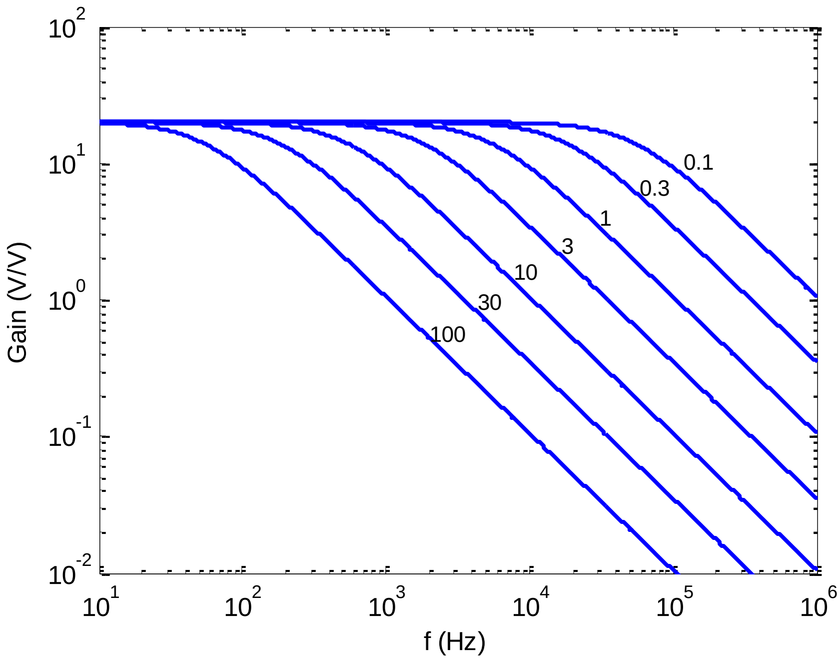


Figure 3. Frequency response for different load capacitances (in µF)

Rise Time

For step inputs that do not violate the current limits (see following section) the slew-rate will be dominated by the first-order response of the amplifier.

The time-constant is

$$T = \frac{1}{2\pi f_c} = 30C$$

where *C* is the load capacitance.

A list of time constants for a range of load capacitances, and an example step response is shown below.

Load Capacitance	**Time Constant** (T)	**Settling Time** (3T, 95%)
100 nF	3 µs	9 µs
300 nF	9 µs	27 µs
1.0 µF	30 µs	90 µs
3.0 µF	90 µs	270 µs
10 µF	300 µs	900 µs
30 µF	900 µs	2.7 ms
100 µF	3 ms	9 ms

Table 2. Time-constant versus load capacitance

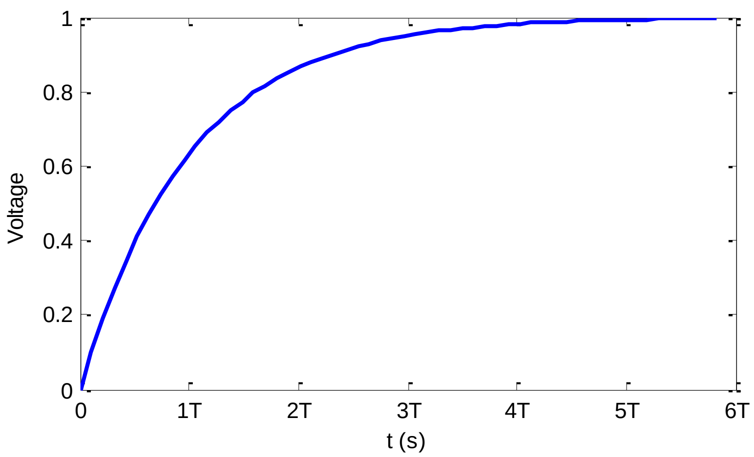


Figure 4. Small signal step response

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.

5. Output Current Limitations

Peak Output Current	**600mA**
RMS Current	**220mA**
Average DC Current	**100mA**

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.

PiezoDrive amplifiers are the first amplifiers that contain **Dynamic Current Control**™. Dynamic Current Control allows a small amplifier to deliver an exceptionally large output current of 600 mA for a small period of time. To protect the output transistors from dissipation overload, larger maximum currents are permitted for lesser periods of time.

A plot of permissible maximum current and time is shown below. This is exact for single pulses only, if repetitive pulses are applied within approximately 50 milliseconds, the average current limit must also be considered.

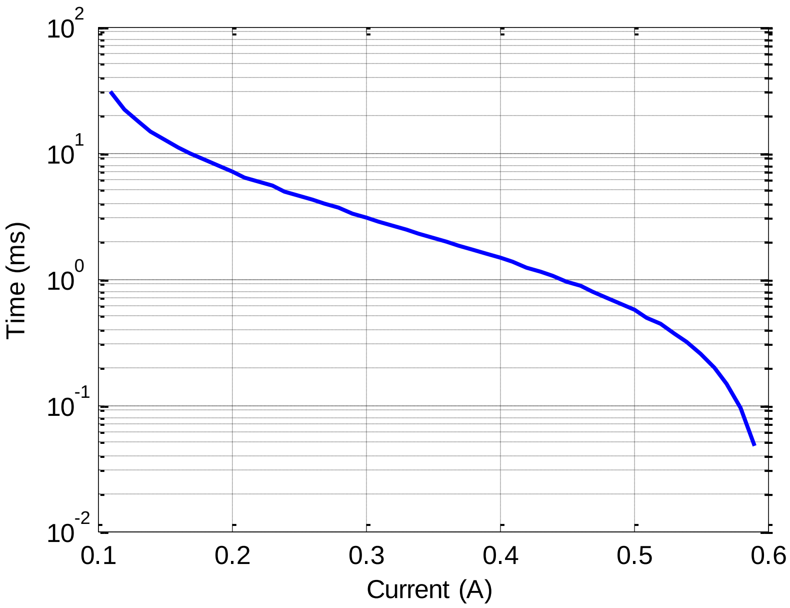
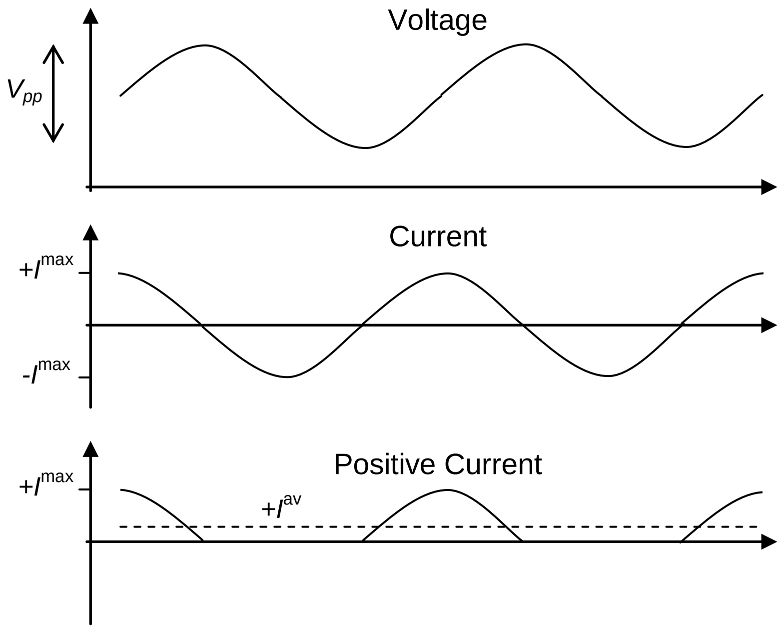


Figure 5. Maximum permissible current and time

With Capacitive Loads

The PDL200 is specifically designed for use with capacitive loads. Compared to other amplifiers with standard current limits, Dynamic Current Control allows the reproduction of larger amplitude waveforms with higher frequency. Rather than a standard conservative current limit, Dynamic Current Control limits the *average* current in the positive and negative directions. This behaviour and its advantages are explained in the following examples

The voltage and current waveforms for a **sinusoidal output** 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.

The positive and average current waveforms are illustrated in the bottom plot. Dynamic Current Control limits the average current this can be calculated from

$$I^{av} = \frac{1}{T} \int_{ta}^{tb} I(t)\, dt$$

where *T* is the period and *[ta tb]* is the interval where the current is positive.

The average current for a sinusoid is

$$I^{av} = \frac{1}{T}\int_0^{\frac{T}{2}} I^{max} \sin\left(2\pi \frac{t}{T}\right)\, dt$$

$$I^{av} = \frac{I^{max}}{T}\left[-\frac{T}{2\pi}\cos\left(2\pi \frac{t}{T}\right)\right]_0^{T/2}$$

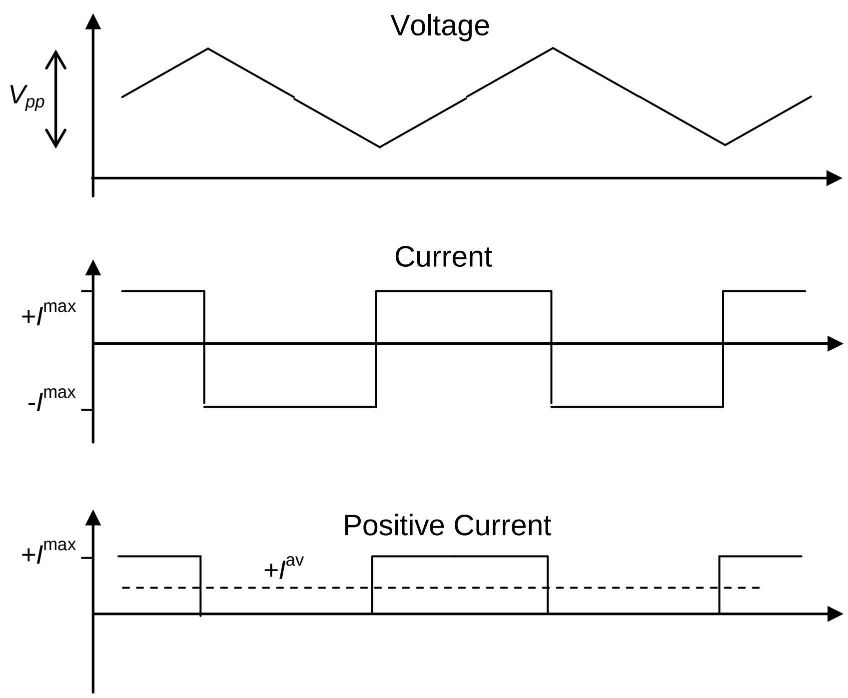
$$I^{av} = \frac{I^{max}}{\pi}$$

Since the PDL200 has an average positive current limit of 100mA, the maximum voltage, frequency and capacitance can be determined from

$$V_{pp} C f < 0.1$$

Compared to a standard amplifier with a current limit of I^{max}, the PDL200 will produce three times more current for a sinusoidal signal. This implies a threefold increase in the maximum frequency, capacitance or amplitude that can be driven.

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



The maximum required current is

$$I^{max} = \pm V_{pp} 2Cf$$

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.

The positive and average current waveforms are illustrated in the bottom plot. Dynamic Current Control limits the average current and not the peak current.

The average current for a triangle is

$$I^{av} = \frac{1}{T}\int_0^{\frac{T}{2}} I^{max}\, dt$$

$$I^{av} = \frac{I^{max}}{T}[t]_0^{T/2}$$

$$I^{av} = \frac{I^{max}}{2}$$

Since the PDL200 has an average positive current limit of 100mA, the maximum voltage, frequency and capacitance can be determined from

$$V_{pp}Cf < 0.1$$

Compared to a standard amplifier with a current limit of I^{max}, the PDL200 will produce double the current for a triangular signal. This implies a twofold increase in the maximum frequency, capacitance or amplitude that can be driven.

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. In this technique, the current limit 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 smaller voltage drop and dissipation of the output transistors when the output voltage is high. Although this provides a larger maximum peak current, it is only available when the output voltage is near its maximum. Thus, fold-back current limiting is only suitable for resistive loads and is undesirable for capacitive loads like piezoelectric actuators. The maximum current for a piezoelectric actuator occurs at the mean of the waveform, not at the peak.

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.

6. Power Bandwidth

Power bandwidth is the maximum frequency sine-wave that can be reproduced at full voltage. For capacitive loads, the power bandwidth is dictated by the load capacitance and current limit.

An expression for the maximum operating conditions for a sine-wave and capacitive load was derived in Section 5,

$$V_{pp}Cf < 0.1$$

This implies a power bandwidth of

$$f_{max} = \frac{0.1}{200C}$$

The above equation is valid when Dynamic Current Limiting is active, that is, when the waveform period is shorter than approximately 10 ms, or when the frequency is greater than 100 Hz. At frequencies below 100 Hz, the power-bandwidth will begin to reduce to the standard value, given by

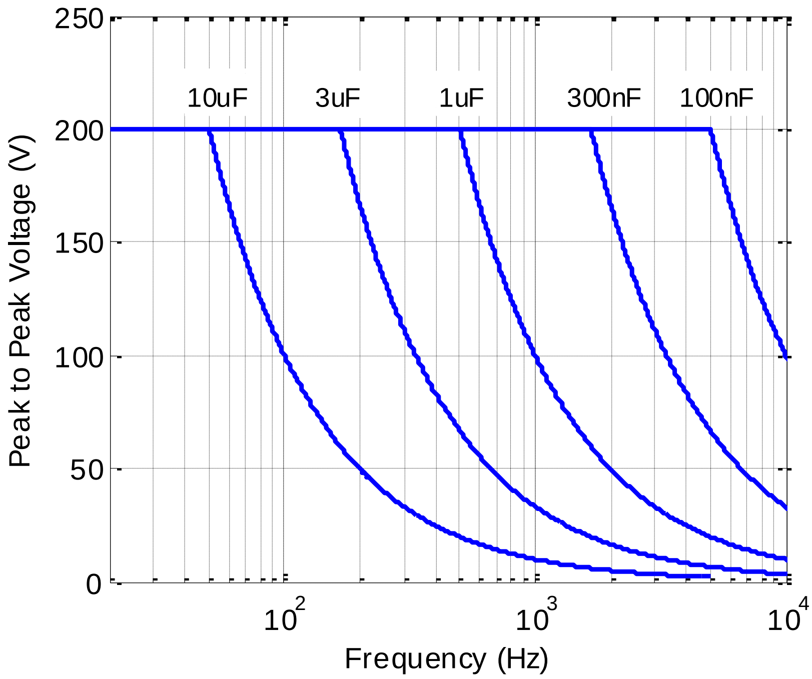
$$f_{max} = \frac{0.1}{628C}$$

A table of the approximate power bandwidth for a range of capacitive loads is shown below.

Load Capacitance	Power Bandwidth
100 nF	5.0 kHz
300 nF	1.66 kHz
1.0 µF	500 Hz
3.0 µF	167 Hz
10 µF	50 Hz
30 µF	6 Hz
100 µF	2 Hz

Table 3. Power Bandwidth Versus Capacitive Load

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.

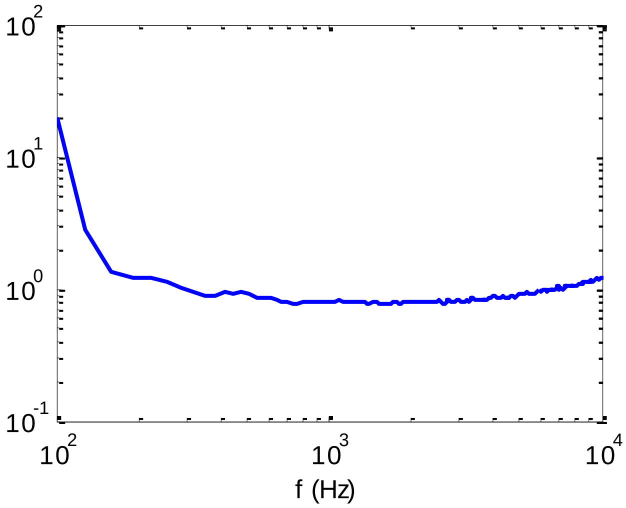


Maximum Sine-Wave Amplitude versus Frequency

7. Noise Performance

The PDL200 is a low noise amplifier designed to exceed the requirements of positioning and imaging systems with sub-atomic resolution.

The output voltage noise density, measured in $\mu V/\sqrt{\mathrm{Hz}}$ **,** is plotted below. The spectral density was measured with zero input voltage, no offset, and no load.



Noise Density Function ($\mu V/\sqrt{\mathrm{Hz}}$ **)**

The noise density in the mid-band region is approximately 1.5 $\mu V/\sqrt{\mathrm{Hz}}$. An estimate of the RMS noise voltage can be found from the noise density and the effective bandwidth,

$$V_{RMS} = N_V\sqrt{1.57 f_c}$$

where N_V is the noise density and f_c is the loaded bandwidth derived in Section 4. As the noise is approximately Gaussian distributed, the peak to peak noise voltage can also be found.

$$V_{pp} = 6N_V\sqrt{1.57 f_c}$$

The following table lists some experimentally measured noise voltages. The RMS value was measured with zero input voltage, no offset, and a 250V Polypropylene film load capacitor. The output voltage noise was amplified by a factor of 100 using a low-noise amplifier with 0.1 Hz AC coupling. The RMS value was measured using a Fluke 189 multimeter with a measurement bandwidth of approximately 100 kHz.

Load Capacitance	Bandwidth	Measured Noise (RMS)
100 nF	53 kHz	770 μV
300 nF	18 kHz	290 μV
1.0 μF	5.3 kHz	125 μV
3.0 μF	1.8 kHz	95 μV
10 μF	530 Hz	57 μV
30 μF	180 Hz	42 μV
100 μF	53 Hz	27 μV

Measured noise versus load capacitance.

If extremely low-noise is required, the bandwidth of the PDL200 can be reduced with the aid of an external resistor. The resistor should be placed as close to the piezoelectric actuator as possible.

The closed-loop bandwidth of the amplifier after the addition of an external resistor *R* becomes approximately

$$f_c = \frac{1}{2\pi(30 + R)C} \text{ Hz}$$

The noise voltage reduction is approximately equal to the square root of bandwidth reduction. That is, if the bandwidth is reduced by a factor of 100, the noise voltage is reduced by 10.

8. Enclosure and Thermal Considerations

Thermal Shutdown	50°C (122°F)

The PDL200 is housed in a compact and rugged enclosure. All surfaces are anodized aluminium including the front and back panel which are engraved and ink filled for high visibility and wear resistance. Dimensions are shown below.

The PDL200 does not contain any fans or vents; heat is dissipated by fins on the sides of the body. Airflow and convection around these fins should not be restricted. If sufficient airflow is not available, the case temperature may rise above 50°C (122°F). At this temperature, a thermal overload condition is triggered which reduces output current to a few mA until the enclosure cools.

9. Power Supply

Line Voltage	Variation	Fuses
115 Vac (50-60 Hz)	105-135 Vac	600 mA Time Delay e.g. Littlefuse 0313.600MXP
230 Vac (50-60 Hz)	210-270 Vac	300 mA Time Delay e.g. Littlefuse 0313.300MXP

Mains power is supplied to the PDL200 through an IEC connector on the back panel. The IEC socket also contains the fuses and operating voltage selector switch.

The PDL200 requires two 3AG (6.35 x 32 mm) fuses, 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.

Maximum power consumption is 40 W.

10. Options

- 19 inch subrack front panel.
- Alternate connectors e.g. Lemo 00 or SHV output connector
- Adaptor for output connector, BNC to 4mm plug adaptor

11. Warranty / Support

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

For technical support, contact info@piezodrive.com