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## PDu150 V5

## Three Channel, Ultra-low Noise <br> Miniature 150V Piezo Driver



The PDu150 is a complete miniaturized power supply and ultra-low noise driver for up to three $100 \mathrm{~V}, 120 \mathrm{~V}$ or 150 V piezoelectric stack actuators. Output currents up to 100 mA per channel are developed at frequencies up to 80 kHz with very low noise. The three channels can be connected in parallel to produce an output current of 300 mA .

The PDu150 is protected against short-circuit, average current overload, and excessive temperature. Passive cooling is available for low power applications or the integrated fan can be used for power dissipations above 5W. The PDu150 can be mounted with four M2.5 screws. The PCB mounting version (PDu150-PCB) is supplied with headers for direct mounting onto a host motherboard.

| Specifications |  |
| :---: | :---: |
| Power Supply | +24V, Ground |
| Output Voltage | -30 V to +150V |
| Peak Current | 100 mA per channel 300 mA single channel |
| RMS Current | 78 mA per channel 235 mA single channel |
| Power Bandwidth | $80 \mathrm{kHz}(150 \mathrm{Vp-p})$ |
| Signal Bandwidth | 180 kHz |
| Slew Rate | $38 \mathrm{~V} / \mathrm{us}$ |
| Gain | 20 V/V |
| Input Impedance | $9.16 \mathrm{k} \Omega$ (Input), <br> $3.3 k \Omega$ (Offset) |
| Input Offset | $\pm 5 \mathrm{mV}$ |
| Load | Unlimited |
| Output Noise | 26 uV RMS, <br> 1 uF Load, 10 Hz to 1 MHz |
| Protection | Short-circuit, average current, and under-voltage protection |
| Quiescent Current | 100 mA ( 10 mA in Shutdown) |
| Dimensions | $76 \times 40 \times 44 \mathrm{~mm}$ ( $\mathrm{L} \times \mathrm{W} \times \mathrm{H}$ ) |
| Environment | 0 to $60^{\circ} \mathrm{C}\left(-32\right.$ to $\left.140^{\circ} \mathrm{F}\right)$ Non-condensing humidity |
| Weight | 80 g |



## Operation

As shown in Figure 2, the amplifiers have differential inputs where the negative input can be connected to an external reference or the internal offset generator. A precision +10 V and -2 V reference voltage ( $\mathrm{R}+$ and $\mathrm{R}-$ ) are provided to allow external potentiometers to generate the amplifier inputs.

The amplifier outputs use a novel low-noise differential architecture and cannot be connected to ground.


Figure 2. PDu150 Block Diagram

## Single Channel Mode

The power bandwidth and output current can be tripled by connecting three amplifiers in parallel as shown below. A third configuration with two parallel channels and one single channel is also possible.


## Offset Voltage Configuration

The offset voltage can be set from either the internal potentiometer or by an external source by configuring the jumper to either "Internal" or "External".

When using the internal offset source, the offset voltage is set by connecting a multimeter across the output and
varying the potentiometer until the desired offset is obtained.

In the external offset mode, the offset voltage is determined by the voltage applied to the OS pin. The offset voltage can be set to zero by grounding the OS pin.

## Using the Reference Voltages

A precision +10 V and -2 V reference voltage ( $\mathrm{R}+$ and R -) is provided to allow an external potentiometer to generate the amplifier input, as shown below. Multiple potentiometers can be used for multiple channels. The 10uF capacitor reduces the noise bandwidth but is not strictly necessary. The capacitor should preferably be a film type but ceramic is acceptable in most applications.


Figure 3. Circuit to create a variable DC input to channel 2

## Output Current

The peak output current is 100 mA per channel or 300 mA for three channels in parallel. In addition, the maximum average current is 35 mA per amplifier. The average current is useful for calculating the power dissipation and average supply current. For a sine wave, the average positive output current is equal to

$$
I_{a v}=\frac{\sqrt{2}}{\pi} I_{r m s}=\frac{1}{\pi} I_{p k} .
$$

## Supply Current

The quiescent power for the amplifier is approximately 2 W or 85 mA . This can be reduced to $<10 \mathrm{~mA}$ by pulling the Enable pin low with an open collector circuit. If the fan is used, the quiescent power is increased by 0.5 W ,

The supply current is related to the total average output current by

$$
I_{s}=\frac{200 \times\left(I_{a v}+0.010\right)}{24} .
$$

where $I_{a v}$ is the total average output current. The maximum supply current is 0.9 A at full power.

## Power Bandwidth

The nominal slew-rate of the PDu150 is $38 \mathrm{~V} / \mathrm{us}$. Therefore, the maximum frequency sine-wave is

$$
f_{\max }=\frac{38 \times 10^{6}}{\pi V_{L(p-p)}}
$$

The power bandwidth for a $150 \mathrm{Vp}-\mathrm{p}$ sine-wave is 80 kHz .

With a capacitive load, the power bandwidth is limited by the output current. The maximum frequency sine wave is

$$
f_{p w r}=\frac{I_{p k}}{\pi V_{L(p-p)} C_{L}}
$$

where $I_{p k}$ is the peak current limit, $V_{L(p-p)}$ is the peak-to-peak output voltage, and $C_{L}$ is the effective load capacitance. The power bandwidth for a range of load capacitance values is listed in Table 1.

| Load | Voltage Range |  |  |
| :---: | :---: | :---: | :---: |
| (uF) | 50 V | 100 V | 150 V |
| 0.01 | 64000 | 32000 | 21000 |
| 0.03 | 21000 | 11000 | 7100 |
| 0.1 | 6400 | 3200 | 2100 |
| 0.3 | 2100 | 1100 | 710 |
| 1 | 640 | 320 | 210 |
| 3 | 210 | 110 | 71 |
| 10 | 64 | 32 | 21 |
| 30 | 21 | 11 | 7 |

Table 1. Power bandwidth (in Hz ) with a capacitive load
The maximum peak-to-peak voltage is plotted below.


Figure 4. Power Bandwidth (150 Vp-p)

## Signal Bandwidth

The small-signal bandwidth for a range of capacitive loads is listed in Table 2. The small-signal frequency responses are plotted in Figure 5.

| Load <br> Capacitance | Signal <br> Bandwidth |
| :---: | :---: |
| No Load | 180 kHz |
| 10 nF | 105 kHz |
| 30 nF | 40 kHz |
| 100 nF | 11 kHz |
| 300 nF | 3.8 kHz |
| 1 uF | 1.0 kHz |
| 3 uF | 320 Hz |
| 10 uF | 62 Hz |
| 30 uF | 24 Hz |

Table 2. Small signal bandwidth (-3 dB)


Figure 5. Small signal frequency response

## Noise

The output noise contains a low frequency component ( 0.03 Hz to 10 Hz ) that is independent of the load capacitance; and a high frequency component ( 10 Hz to 1 MHz ) that is inversely related to the load capacitance.

Optimal noise performance is achieved with passive cooling as magnetic fields from the fan can induce mV level interference in the outputs. In low noise applications, where the fan is removed, some external air-flow is required if the power dissipation is above 5 W , refer to Heat Dissipation for further details.

The noise is measured with an SR560 low-noise amplifier (Gain $=1000$ ), oscilloscope, and an Agilent 34461A Voltmeter. The low-frequency noise is plotted in Figure 6. The RMS value is 15 uV with a peak-to-peak voltage of 100 uV .


Figure 6. Low frequency output noise ( 0.03 Hz to 10 Hz )
The high frequency noise ( 10 Hz to 1 MHz ) is listed in the table below versus load capacitance. The total noise from 0.03 Hz to 1 MHz is found by summing the RMS values, that is $\sigma=\sqrt{\sigma_{L F}^{2}+\sigma_{H F}^{2}}$.

| Load <br> Capacitance | HF <br> Noise | Total <br> Noise |
| :---: | :---: | :---: |
| 10 nF | 450 uV | 450 uV |
| 30 nF | 170 uV | 170 uV |
| 100 nF | 60 uV | 62 uV |
| 300 nF | 34 uV | 37 uV |
| 1 uF | 21 uV | 26 uV |
| 3 uF | 16 uV | 23 uV |
| 10 uF | 16 uV | 22 uV |
| 30 uF | 18 uV | 23 uV |

Table 3. HF Noise ( 10 Hz to 1 MHz ) and total noise

## Overload Protection / Shutdown

The PDu150 is protected against short-circuit and average current overload.

The amplifier can be shutdown manually by pulling the Enable pin low with an open-collector, or open-drain circuit. The Enable pin normally floats at 5V and should not be driven directly.

## Heat Dissipation

The heat dissipation is approximately

$$
P_{d}=200 \times\left(I_{a v}+0.010\right)
$$

For example, with a sinusoidal output, the power is

$$
P_{d}=200 \times\left(V_{L(p-p)} C_{L} f+0.010\right)
$$

For low-current applications that dissipate less than 5 W , the heatsink fan may be removed. If the power dissipation is above 5 W , forced air or the included fan is required.

## Safety

This device produces hazardous potentials and should be used by suitably qualified personnel. Do not operate the device when there are exposed conductors.

Parts of the circuit may store charge so precautions must also be taken when the device is not powered.


## Dimensions

The mounting posts accept M2.5 screws. For the PCB mounting version (PDu150-PCB), a schematic and footprint library are available for Altium Designer at https://www.piezodrive.com/resources/



Figure 7. Dimensions (mm)

## Test Procedure

To test the PDu150, follow these instructions:

1. Move the OFFSET jumper to EXT
2. Connect a 24 V supply between VS and ground.
3. Connect a +1V DC signal to V1, V2, and V3
4. Connect the OS pin to ground
5. Check that the circuit connections match the diagram below.


Figure 8. Test Configuration
Turn the power on and use a battery powered multimeter to measure the voltage between the following positive and negative positions. The measured voltages should be within the minimum and maximum values stated below.

| Positive | Negative | Min | Max |
| :---: | :---: | :---: | :---: |
| VS | $G$ | 23 V | 25 V |
| V1 | G | 0.95 V | 1.05 V |
| V2 | G | 0.95 V | 1.05 V |
| V3 | $G$ | 0.95 V | 1.05 V |
| OS | G | -0.01 V | +0.01 V |
| $1+$ | $1-$ | +19.5 V | +20.5 V |
| $2+$ | $2-$ | +19.5 V | +20.5 V |
| $3+$ | $3-$ | +19.5 V | +20.5 V |

Table 4. First test points and expected voltages
After this test is successful, increase the input voltage to 7.5 V and repeat the test points. The measured voltages should be within the stated minimum and maximum values stated below.

| Positive | Negative | Min | Max |
| :---: | :---: | :---: | :---: |
| VS | $G$ | 23 V | 25 V |
| V1 | $G$ | 7.45 V | 7.55 V |
| V2 | G | 7.45 V | 7.55 V |
| V3 | G | 7.45 V | 7.55 V |
| OS | G | -0.01 V | +0.01 V |
| $1+$ | $1-$ | +148 V | +152 V |
| $2+$ | $2-$ | +148 V | +152 V |
| $3+$ | $3-$ | +148 V | +152 V |

Table 5. Second test points and expected voltages

## Trouble Shooting Notes

The most common perceived issues with the PDu150 are due to incorrect measurement of the output voltages. The PDu150 output is differential, and the negative outputs (1-, 2-, and $3-$ ) cannot be connected to ground. To measure the output voltage use a battery powered multimeter to measure the voltage between 1+ and 1-, for example.

To measure the output voltage with an oscilloscope, connect the oscilloscope ground to the PDu150 ground (any G pin), and connect the probe to either the $1+2+$, or $3+$ output. The actual voltage across the load is double what is being measured, which can be accounted for manually, or by doubling the probe sensitivity in the oscilloscope settings, e.g. change the probe sensitivity from 10x to 20x. Do not connect the oscilloscope ground to the 1-, 2 -, or 3 - terminals.

## Contact / Support

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## Revision History

| Date | Rev | By | Changes |
| :--- | :--- | :--- | :--- |
| 20/01/21 | R5 | KB | Updated test proceedure |
| 20/01/21 | R4 | KB | Test procedure added |
| 16/01/21 | R3 | KB | Temp range updated |

