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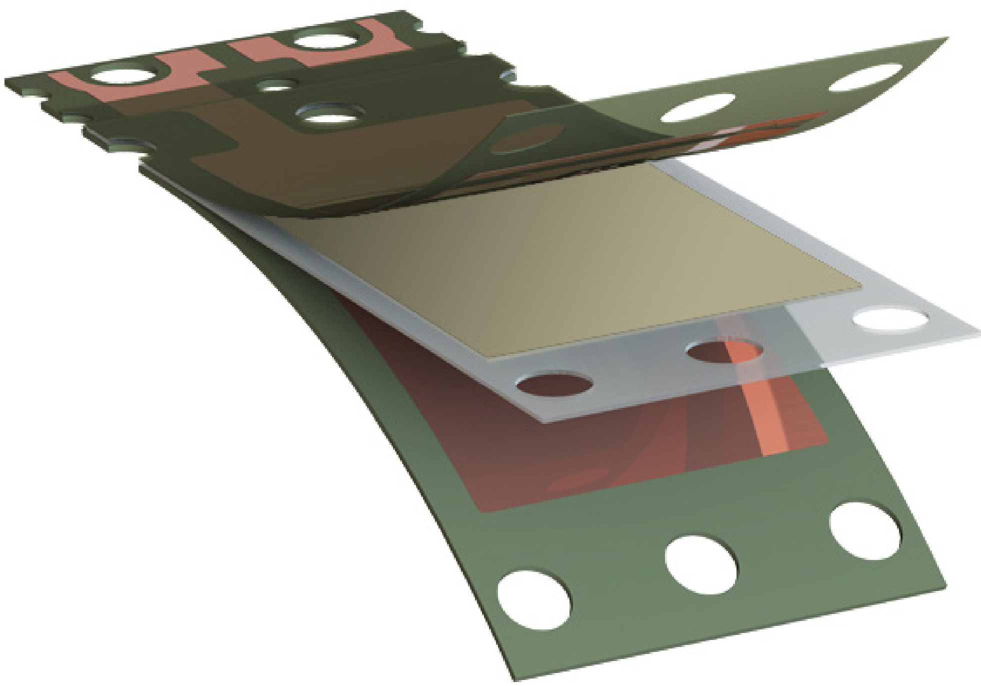
PPA PRODUCTS

Datasheet & User Manual



PPA
PIEZO PROTECTION
ADVANTAGE

PPA PIEZO PROTECTION ADVANTAGE

Midé Technology Corporation warrants that the PPA standard products will be free from defects in workmanship and materials in normal use and operation within 3 months from date of shipment. This warranty only applies when the products are installed, maintained, and repaired in accordance with all of the directions, instructions, diagrams, safety warnings, cautions, and other notices set forth in this document, and if not damaged by persons, actions, or inactions unrelated to Midé. In the event of any such defect of which Midé is informed in writing within such 3 month period, Midé's sole responsibility is, at Midé's option, to provide a replacement at no cost to the Buyer upon the return of the defective product. Requests for compliance with this express, limited warranty shall be honored only when made by the Buyer. Refer to the Terms and Conditions at http://www.mide.com/legal/legal_terms.php#4 for the full legal terms in regard to this warranty.

A number of warnings and cautions appear in the text of this technical manual. They are intended to safeguard personnel and equipment from potential hazards or damage during equipment installation, operation, and maintenance. These warnings and cautions will be presented in the following manner.

WARNING: This represents an operating procedure, practice condition, statement, etc., which if not strictly observed, could result in injury to personnel or long term health hazards.

CAUTION: This represents an operating procedure, practice condition, statement, etc., which if not strictly observed, could result in damage to, or destruction of, equipment or a reduction in performance.

In addition to the specific warnings and cautions included in this manual, Midé recommends that all customers install, operate, and maintain the products in accordance with general safety guidelines included in standards published by OSHA.

Midé's piezo standard products utilize its Piezo Protection Advantage (PPA) to protect the piezo ceramic wafers. Midé's packaging also enables cost effective system integration with mounting features and electrical connection incorporated into the piezoelectric package. Midé has been manufacturing packaged piezos with its patented process for over 15 years; it typically produces between 25,000 and 50,000 units annually. In addition to the manufacturing experience Midé has gained over the years, it has engineered many custom electromechanical solutions that integrate its packaged piezos to solve a wide range of engineering problems.

The PPA standard product line are a range of rectangular piezoelectric packages designed for cantilever, bonded, or fixed beam configurations. Applications for these products include vibration energy harvesting, vibration dampening, precise actuation (especially useful for haptic and valve applications), vibration & strain sensing, as well as many others. Although this product line focuses on rectangular piezos, Midé can design and manufacture a wide range of shapes and sizes. Please refer to Section 7 if a custom design is required.

This datasheet provides comprehensive data for all products. Section 1 provides performance summary information for the main applications of these products and also higher volume pricing for comparison. Section 2 provides more in depth information by product. Section 3 details how electrical connection to the piezos can be achieved. Section 4 explains how these products should be mounted when in the cantilever position and includes detailed information on the PPA-9001 clamp kit. This kit is recommended for all products when they are being evaluated in the cantilever configuration. This kit includes all the necessary hardware to mount and clamp the products, tip masses to tune the beams to resonance, necessary tools for the hardware and electrical tape for insulation. Also included in this section is the recommended epoxy for direct bonding applications. Section 5 provides the material properties for modeling and simulation. Section 6 details the test procedures used to gather all data presented in this datasheet.

Figure 1: Provides an overview of these products as well as to scale drawing for size comparison.

Products	**PPA-1001**	**PPA-1011** **PPA-2011** **PPA-4011**	**PPA-1012**	**PPA-1013**	**PPA-1014** **PPA-2014**	**PPA-1021**	**PPA-1022**
Length (mm) [mils]	(54.4) [2.14]	(71.0) [2.80]	(71.0) [2.80]	(71.0) [2.80]	(53.0) [2.09]	(71.0) [2.80]	(53.0) [2.09]
Width (mm) [mils]	(22.4) [0.88]	(25.4) [1.00]	(41.5) [1.63]	(41.5) [1.63]	(20.8) [0.82]	(10.3) [0.41]	(10.3) [0.41]
Thickness (mm) [mils]	(0.46) [18.0]	(0.71) [28.0] (0.76) [30.0] (1.32) [52.0]	(0.75) [29.5] (0.80) [31.5]	(1.94) [76.5]	(0.74) [29.0] (0.83) [32.5]	(0.74) [29.0] (0.86) [34.0]	(0.70) [27.4] (0.70) [27.4]
Piezo Length (mm) [mils]	(46.0) [1.81]	(46.0) [1.81]	(46.0) [1.81]	(46.0) [1.81]	(27.8) [1.09]	(46.0) [1.81]	(21.6) [0.85]
Piezo Width (mm) [mils]	(20.8) [0.82]	(20.8) [0.82]	(38.4) [1.51]	(33.4) [1.31]	(18.0) [0.71]	(06.4) [0.25]	(03.7) [0.15]
Piezo Thickness (mm) [mils]	(0.18) [06.0]	(0.18) [06.0]	(0.25) [10.0]	(1.47) [58.0]	(0.19) [07.5]	(0.25) [10.0]	(0.18) [07.0]
Number of Piezo Layers	1	1 2 4	1	1	1 2	1	1
Piezo Materials	PZT-5H	PZT-5H	PZT-5H	PZT-5H	PZT-5H	PZT-5H	PZT-5H
Capacitance (nF)	100	97 190 415	120	24	41 94	22	7
Mass (grams)	2.8	3.0 4.0 7.6	6.0	21.5	2.0 2.9	1.4	0.8

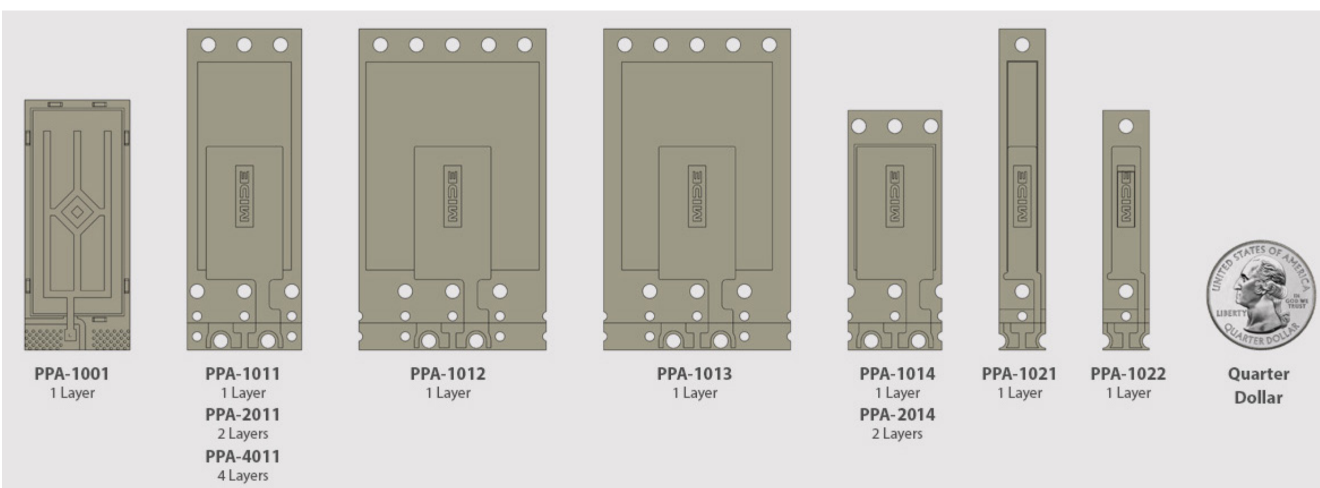


Figure 1: The PPA standard product range is shown to scale, with a United States quarter included as a reference scale.

These products come in 8 product sets, grouped by form factor. Within each set, the first numerical digit in the product part number designates the number of piezo layers. These PPA products come as unimorph (single layer), bimorph (two active piezo layers) and quad-morphs (four active layers). One product set, PPA-103X, is differentiated by piezoelectric material. PMN-PT, PZT-5H, and PZT-5A material choices are available. See Section 5.1 for more information on piezoelectric material properties.

Midé's PPA product line offers cost effective piezoelectric packages to customers, these costs and sale prices drop dramatically with increased volumes as shown in Table 1. These prices are subject to change at any time and are only available when buying directly through Midé. Distributors offer these products at low quantities. Midé typically keeps about 100 units of each product in stock at all times. Orders of over 100 units will have a lead time of 4 to 6 weeks. If an order of 1,000 or more units is desired, please contact Midé for a more accurate lead time estimation. For even larger volume orders, please contact mide for quotation.

Table 1: Volume Pricing of PPA Standard Product Line

Quanity	PPA-1001	PPA-1011	PPA-2011	PPA-4011	PPA-1012	PPA-1013	PPA-1014	PPA-2014	PPA-1021	PPA-1022
1	$36.00	$200.00	$238.00	$300.00	$210.00	$334.00	$194.00	$228.00	$184.00	$176.00
2	$27.00	$150.00	$179.00	$225.00	$158.00	$251.00	$146.00	171.00	$138.00	$132.00
5	$22.00	$120.00	$143.00	$180.00	$126.00	$201.00	$117.00	$137.00	$111.00	$106.00
10	$18.00	$100.00	$119.00	$150.00	$105.00	$167.00	$97.00	$114.00	$92.00	$88.00
100	$12.36	$45.04	$69.75	$107.63	$47.13	$104.59	$43.54	$67.19	$31.09	$28.43
1,000	$8.15	$21.16	$31.93	$51.27	$27.28	$55.86	$20.43	$30.69	$18.15	$16.85
10,000	$5.85	$13.55	$20.03	$30.15	$18.25	$34.18	$13.16	$19.36	$10.86	$10.16

Note: PPA-1001 product is sold in packs of 5

Midé's PPA standard products utilize the piezoelectric effect to convert mechanical energy in the form of vibration or shock into electrical energy. These provide optimal power output when they are properly clamped per the instructions in Section 4 and have a resonant frequency that matches the dominate frequency of the system it is harvesting energy from. All of the PPA products can be tuned to a wide range of frequencies. Adding tip mass greatly reduces the resonant frequency and further adjustment can be made by changing the clamp location. To increase the resonant frequency the piezo beams can be clamped on both ends and/or bonded to a stiffer beam.

The power output of all of the recommended energy harvesting products are compared when tuned to a 60 Hz resonance. Figure 2 shows the comparison between these products for four different acceleration amplitudes: 0.25g, 0.50g, 1.0g, and 2.0g. Figure 3 compares the power output for each product when there is no tip mass added; this represents the upper limit of the products frequency range if the clamping configuration is not changed. Figure 4 compares the power output for each product when there is the maximum tip mass added; this represents the lower limit of the products frequency range if the clamping configuration is not changed. These tests were all with beams clamped in the middle clamp location.

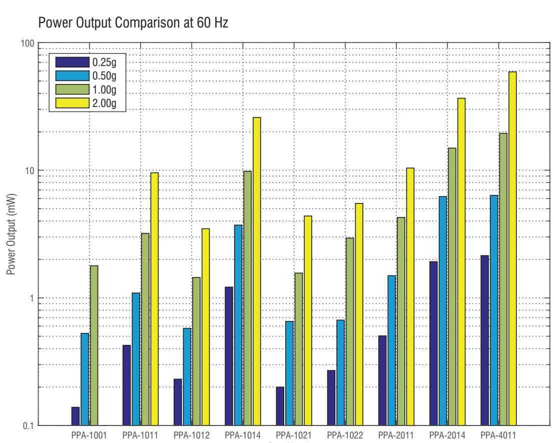


Figure 2: The power output of each product when tuned to 60 Hz is shown for four different acceleration amplitudes: 0.25g, 0.50g, 1.0g, and 2.0g. Please refer to the product's specific section to determine how much tip mass was added to achieve a 60 Hz resonance.

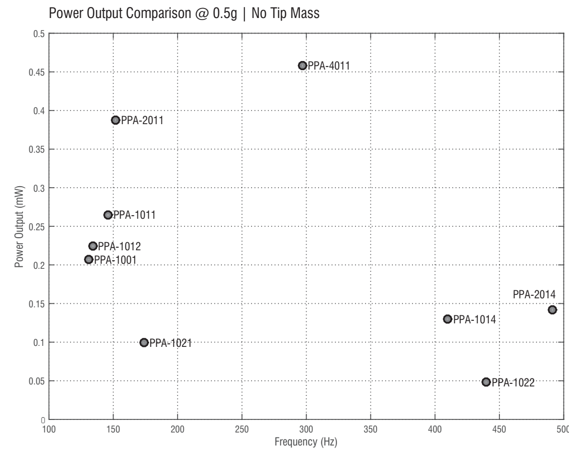


Figure 3: The power output at each product's resonant frequency is compared. These were excited with a 0.5g amplitude sinewave at the respective resonant frequency. No tip mass was added, these frequencies represent the upper end of each products frequency range without adjusting the clamp configuration.

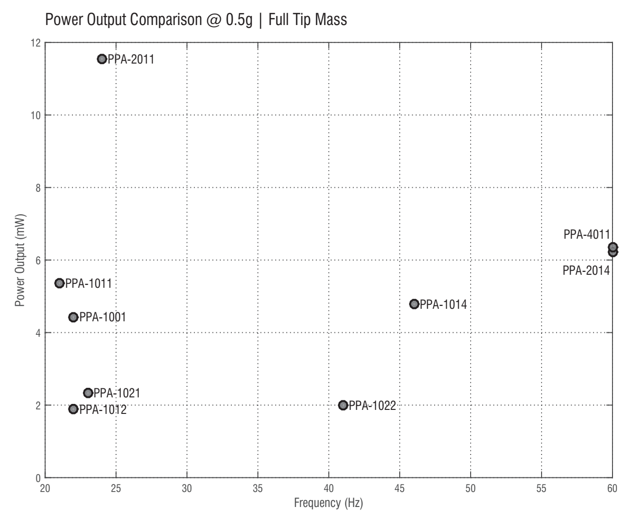


Figure 4: The power output at each product's resonant frequency is compared when the maximum recommended tip mass is added. These were excited with a 0.5g amplitude sinewave at the respective resonant frequency. These frequencies represent the lower end of each products frequency range without adjusting the clamp configuration. Please refer to the product's specific section for the tip mass used.

Please refer to Section 2 for product specific information at a range of frequencies, and acceleration amplitudes.

The PPA products can also be driven as an actuator by applying an electric voltage to them. These are often used in valves where fast and controlled actuation is needed. To compare the relative performance of these range of products a plot of block force and maximum tip displacement is provided Figure 5. Adjusting the clamp location changes this displacement/force relationship; this data is listed for each product in Section 2.

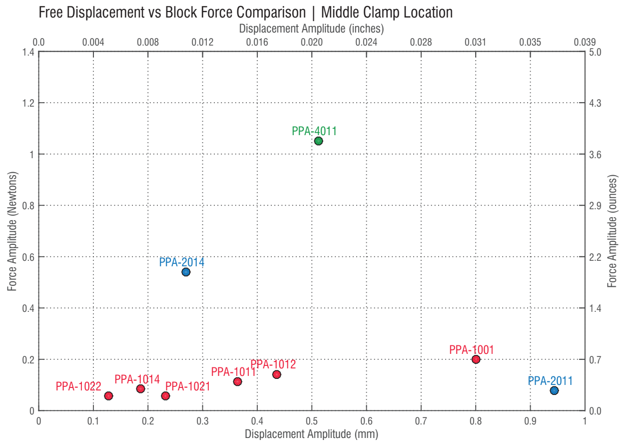


Figure 5: The block force is plotted compared to the maximum, unloaded tip displacement for static, or near static, actuation.

When driven at resonance the peak displacement will be much greater than when driven at static or quasi static speeds. Figure 6 provides a comparison between these products when driven at resonance and a 100 volt amplitude sine wave. The PPA-4011 was only driven with a 50 volt amplitude to prevent damaging the product. Figure 7 provides this frequency and tip displacement comparison when tip mases were added. These tests were all with the products clamped at the middle clamp location.

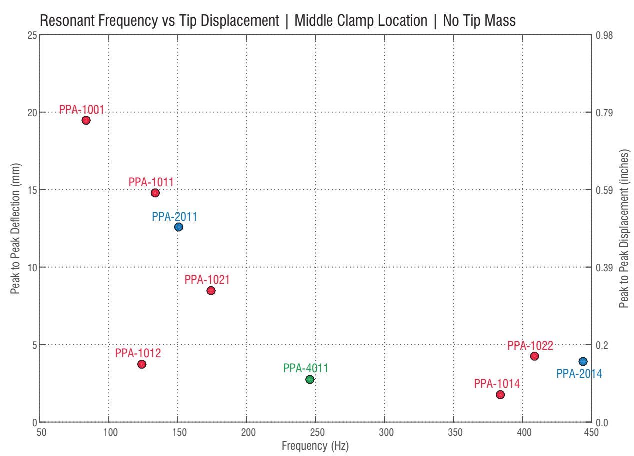


Figure 6: The peak to peak displacement when driven at resonance is shown for all products. They were driven with a 100 volt amplitude sine wave for each product except the PPA-4011 which was only driven with 50 volts.

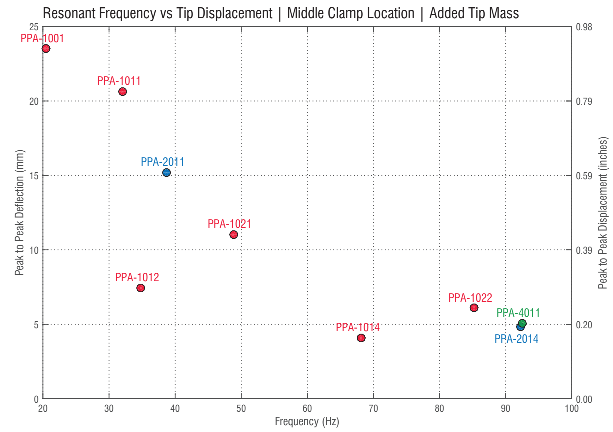


Figure 7: Adding tip mass reduces the resonant frequency and can also increase tip displacement. The PPA-1021 and PPA-1022 had a 3.1 gram tip mass; the rest, excluding PPA-1012 which had a 15.5 gram tip mass, had tip masses of 9.3 grams.

Strain actuation test data is coming soon. Please Contact Us to be placed on a mailing list to receive notification when this information is available.

Piezos provide an electrical output when strained and therefore they are often used as sensors. What's unique about Midé's PPA products is that their size results in a very large output for a given mechanical input. This results in the ability to use piezos as unpowered sensors. This is very useful for applications that require a very long lifetime and/or where batteries may not be an option. Figure 8 provides a plot comparing the sensitivity of each product to the upper limit of the usable frequency range. This frequency range is defined as when the deviation is within ± 3 dB of the sensitivity. Adding tip mass will increase the sensitivity but it will also greatly reduce the bandwidth of the sensor. These tests were with the piezo clamped in the middle clamp location. The -6mm clamp location wouldn't be very useful in this application because it will reduce the bandwidth and the sensitivity because it is not clamped on the piezo. Clamping at the +6mm location will increase the bandwidth but decrease the sensitivity; this may be useful for some applications.

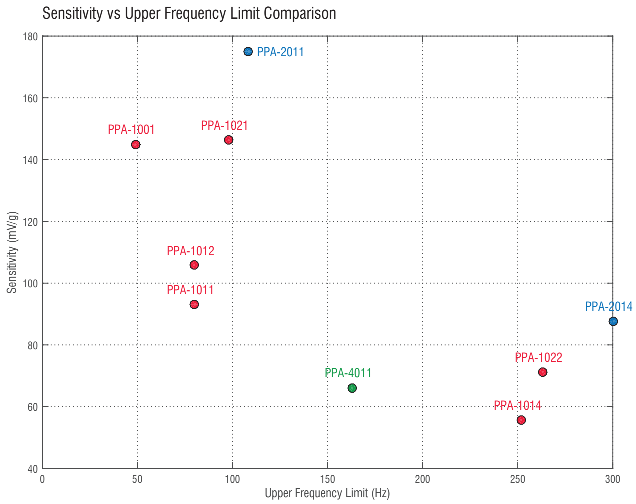


Figure 8: The sensitivity of each product is plotted against the upper limit of the usable frequency range. This frequency range is defined as when the deviation is within ± 3 dB of the sensitivity.

Strain sensing test data is coming soon. Please Contact Us to be placed on a mailing list to receive notification when this information is available.

Midé's vibration energy harvesters convert mechanical energy into electrical energy. Because of this piezoelectric effect, Midé's piezo products are taking mechanical energy out of the system and providing electrical power to a sensing system. Thus Midé's energy harvesters can not only harvest otherwise unused energy, it can also prolong the life of the mechanical system the energy is harvested from by dampening vibrations. If vibration dampening is all that is desired from the piezo, a shunt circuit can be utilized to dissipate the harvested mechanical energy into heat and/or a magnetic field. Thus, through the use of the piezoelectric, the mechanical energy in the system is passively dampened. Vibration dampening test data is coming soon. Please Contact Us to be placed on a mailing list to receive notification when this information is available.

The PPA-1001 is a single layer product recommended for energy harvesting and sensing applications. It also exhibits good performance as a resonant actuator. It is not recommended for applications requiring high force output. This product does not have mounting and alignment holes like the other products; but it is the most cost effective option Midé has.

Performance data for the PPA-1001 is summarized in the following tables and plots. Refer to Section 6 for information on how this data was gathered. Please note that this data is to be used only as reference and that there is some variability from unit to unit. Temperature, clamp conditions, drive quality, all can contribute to additional variability. All test data was gathered at room temperature and with the PPA-9001 clamp kit hardware.

Overview	
Capacitance (nF)	100
Mass (g)	2.8
Full Scale Voltage Range (V)	±120

Layer Material[1]	Thickness (mils)	Thickness (mm)
Polyester	2.0	0.05
Copper	1.4	0.03
PZT 5H	6.0	0.15
Stainless Steel 304	6.0	0.15
Polyimide	1.0	0.03
Total	18.0	0.46

1Information on material properties is provided in Section 5.

[2]The layer thicknesses do not perfectly add up to the actual thickness of the product due to the epoxy layers. These epoxy layers can be ignored for finite element analysis however.

Stiffness			
Parameter	Clamp -6	Clamp 0	Clamp 6
Effective Stiffness (N/m)	N/A	452.15	275.52
Effective Mass (g) Max Peak to Peak	N/A	0.918	0.714
Deflection (mm)	N/A	24.0	20.0

See Section 4.3 for more information on how to use this data to tune your piezo.

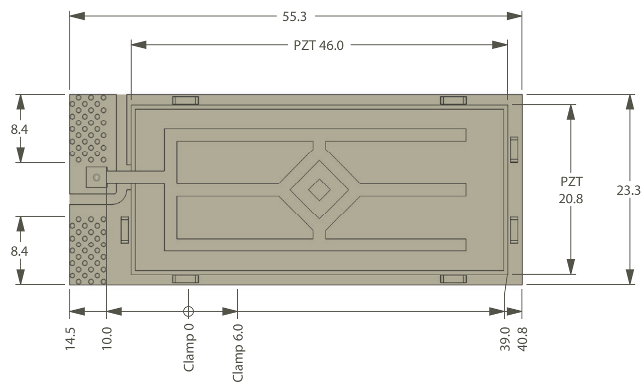


Figure 9: The overall dimensions (mm) for the PPA-1001 are shown. The total thickness is 0.46 mm (18 mils).

Energy Harvesting Data for Middle Clamp Location									
Acceleration Amplitude (g)	Frequency (Hz)	Tip Mass (gram)	RMS Power (mW)	RMS Voltage (V)	RMS Current (mA)	Resistance (kΩ)	RMS Open Circuit	Peak to Peak Displacement (mm)	Peak to Peak Displacement (in)
0.25	132.0	0.0	0.1	1.1	0.1	17.9	2.1	1.1	0.04
0.50	131.0	0.0	0.2	1.9	0.1	18.3	3.6	1.4	0.05
1.00	131.0	0.0	0.7	3.4	0.2	15.7	6.0	1.6	0.06
2.00	129.0	0.0	2.2	5.4	0.4	13.0	9.9	2.2	0.09
0.25	60.0	1.9	0.1	2.9	0.0	61.0	3.8	1.2	0.05
0.50	60.0	1.8	0.5	3.3	0.2	20.8	6.7	2.1	0.08
1.00	60.0	1.7	1.8	7.1	0.3	28.6	12.2	3.9	0.15
0.25	22.0	22.8	1.4	9.0	0.1	60.4	16.4	5.2	0.21
0.50	22.0	22.8	4.4	17.3	0.3	67.6	26.6	9.3	0.37

Block Force and Static Displacement, 100 volt signal			
Parameter	Clamp -6	Clamp 0	Clamp 6
Block Force Amplitude (N)	N/A	0.20	0.23
Displacement Amplitude (mm)	N/A	0.80	0.74

Dynamic displacement, no added tip mass, +/- 100 volt signal			
Parameter	Clamp -6	Clamp 0	Clamp 6
Resonant Frequency (Hz)	N/A	83.3	98.9
Half Power Bandwidth (Hz)	N/A	5.6	7.8
Q Factor	N/A	14.9	12.7
Peak to Peak Deflection at Resonance (mm)	N/A	19.5	15.9
Quasi Static Peak to Peak Deflection (mm)	N/A	1.4	1.1

Dynamic Displacement, 9.3 tip mass, +/- 100 volt signal			
Parameter	Clamp -6	Clamp 0	Clamp 6
Resonant Frequency (Hz)	N/A	20.5	26.4
Half Power Bandwidth (Hz)	N/A	1.4	1.8
Q Factor	N/A	14.6	14.7
Peak to Peak Deflection at Resonance (mm)	N/A	23.5	19.8
Quasi Static Peak to Peak Deflection (mm)	N/A	1.8	1.8

Sensitivity, middle clamp, no added tip mass	
Sensitivity (mV/g)	145
Upper Frequency Limit (Hz)	49.0
Resonance (Hz)	135.0
Sensitivity at Resonance (V/g)	6.6

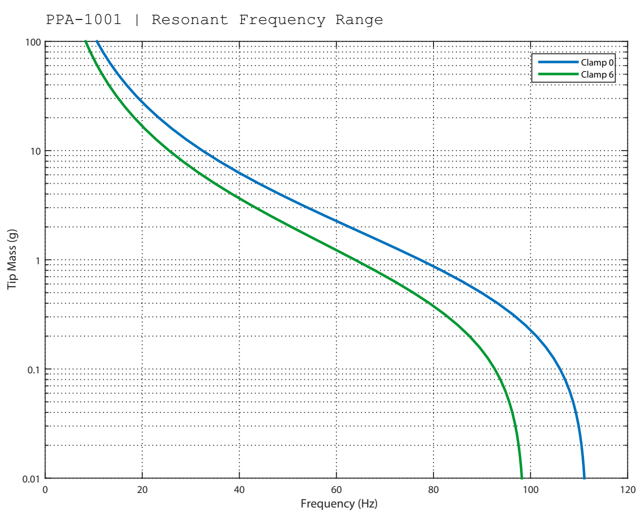


Figure 10: Refer to Section 4.3 for more information on tuning your piezo.

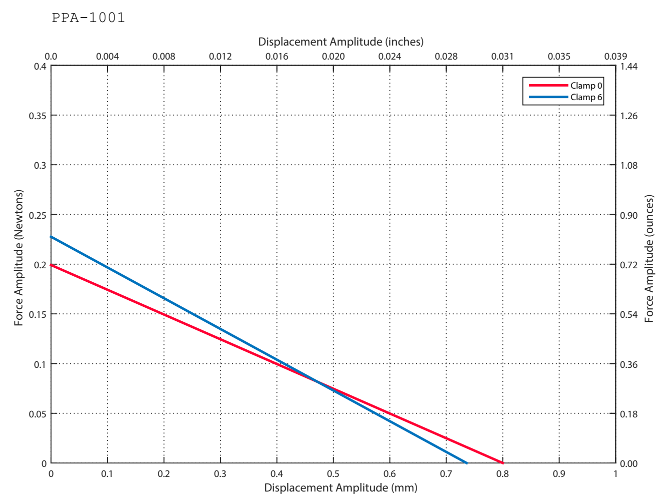


Figure 11: Static displacement and block force are compared for the three different clamp locations. The piezo was driven with 100 volts to generate this data..

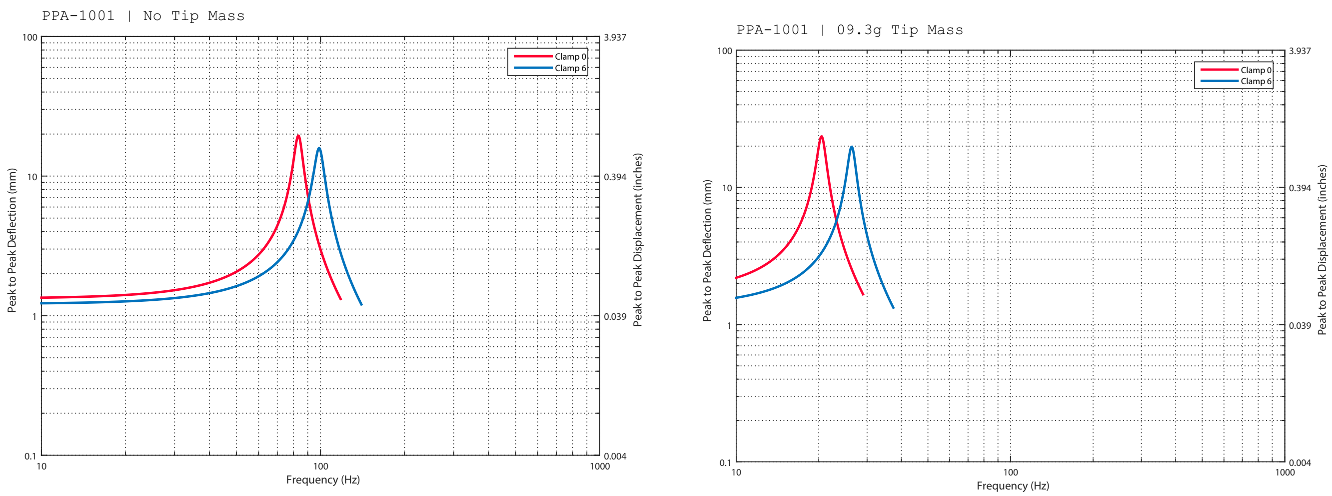


Figure 12: The peak to peak tip displacement is provided for when the piezo is driven with a ± 100 volt signal.

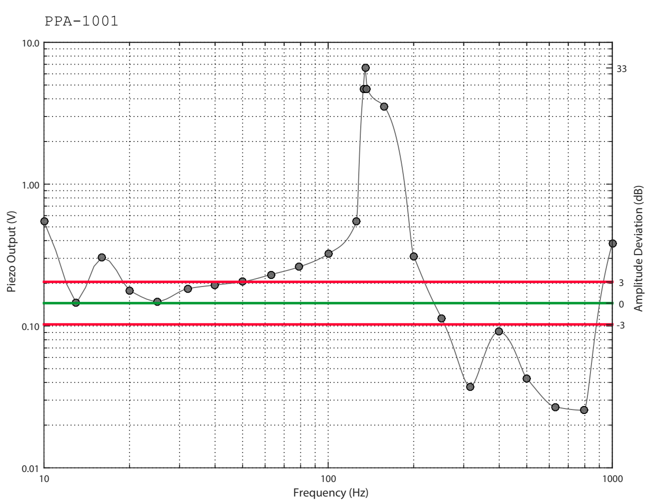


Figure 13: The frequency response of the accelerometer is provided with ±3 dB error bands to highlight the frequency range where accurate measurement can be expected.

The PPA-1011 is recommended for energy harvesting and sensing applications. It also exhibits good performance as a resonant actuator.

Overview	
Capacitance (nF)	100
Mass (g)	3.0
Full Scale Voltage Range (V)	±120

Layer Material[1]	Thickness (mils)	Thickness (mm)
FR4	3.0	0.08
Copper	1.4	0.03
PZT 5H	6.0	0.15
Copper	1.4	0.03
FR4	14.0	0.36
Total[2]	28.0	0.71

[1]Information on material properties is provided in Section 5.

[2]The layer thicknesses do not perfectly add up to the actual thickness of the product due to the epoxy layers. These epoxy layers can be ignored for finite element analysis however.

Stiffness			
Parameter	Clamp -6	Clamp 0	Clamp 6
Effective Stiffness (N/m)	267.45	446.28	591.81
Effective Mass (g) Max Peak to Peak	0.645	0.614	0.506
Deflection (mm)	21.0	20.5	17.0

See Section 4.3 for more information on how to use this data to tune your piezo.

Performance data for the PPA-1011 is summarized in the following tables and plots. Refer to Section 6 for information on how this data was gathered. Please note that this data is to be used only as reference and that there is some variability from unit to unit. Temperature, clamp conditions, drive quality, all can contribute to additional variability. All test data was gathered at room temperature and with the PPA-9001 clamp kit hardware.

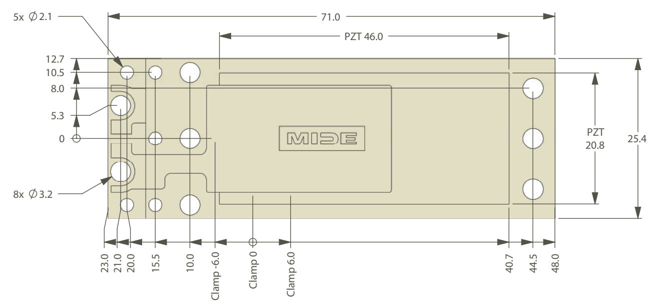


Figure 14: The overall dimensions (mm) for the PPA-1011 are shown. The total thickness is 0.71 mm (28 mils).

Energy Harvesting Data for Middle Clamp Location									
Acceleration Amplitude (g)	Frequency (Hz)	Tip Mass (gram)	RMS Power (mW)	RMS Voltage (V)	RMS Current (mA)	Resistance (kΩ)	RMS Open Circuit	Peak to Peak Displacement (mm)	Peak to Peak Displacement (in)
0.25 0.50 1.00 2.00	147.0 146.0 146.0 145.0	0.0 0.0 0.0 0.0	0.1 0.3 0.7 2.1	1.1 1.8 2.7 4.6	0.1 0.1 0.3 0.5	12.1 12.6 10.2 10.1	1.7 2.8 4.3 7.3	0.9 1.4 2.2 3.7	0.04 0.06 0.09 0.15
0.25 0.50 1.00 2.00	60.0 60.0 60.0 60.0	2.7 2.6 2.6 2.6	0.4 1.1 3.2 9.6	3.3 4.2 7.9 12.8	0.1 0.3 0.4 0.7	25.0 15.8 19.5 17.3	5.7 0.6 13.8 20.7	2.7 3.5 7.0 10.1	0.11 0.14 0.28 0.40
0.25 0.50 1.00	20.8 21.0 21.0	25.3 25.3 25.3	2.5 5.4 16.0	13.8 14.9 23.2	0.2 0.4 0.7	76.6 41.2 33.7	20.2 26.9 39.7	9.7 12.9 34.1	0.38 0.51 1.34

Block Force and Static Displacement, 100 volt signal			
Parameter	Clamp -6	Clamp 0	Clamp 6
Block Force Amplitude (N)	0.09	0.11	0.11
Displacement Amplitude (mm)	0.40	0.36	0.34

Dynamic displacement, no added tip mass, +/- 100 volt signal			
Parameter	Clamp -6	Clamp 0	Clamp 6
Resonant Frequency (Hz)	102.5	133.7	172.2
Half Power Bandwidth (Hz)	5.0	7.6	10.4
Q Factor	20.5	17.6	16.6
Peak to Peak Deflection at Resonance (mm)	15.4	14.8	12.5
Quasi Static Peak to Peak Deflection (mm)	0.8	0.9	0.8

Dynamic Displacement, 9.3 tip mass, +/- 100 volt signal			
Parameter	Clamp -6	Clamp 0	Clamp 6
Resonant Frequency (Hz)	26.1	32.1	39.1
Half Power Bandwidth (Hz)	0.8	1.2	1.8
Q Factor	32.6	26.8	21.7
Peak to Peak Deflection at Resonance (mm)	20.4	20.6	16.7
Quasi Static Peak to Peak Deflection (mm)	0.8	1.0	0.8

Sensitivity, middle clamp, no added tip mass	
Sensitivity (mV/g)	93.11
Upper Frequency Limit (Hz)	80.0
Resonance (Hz)	135.0
Sensitivity at Resonance (V/g)	4.3

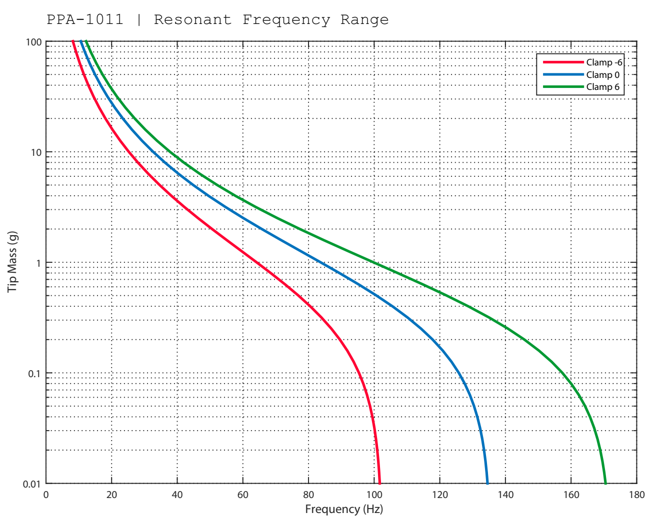


Figure 15: Refer to Section 4.3 for more information on tuning your piezo.

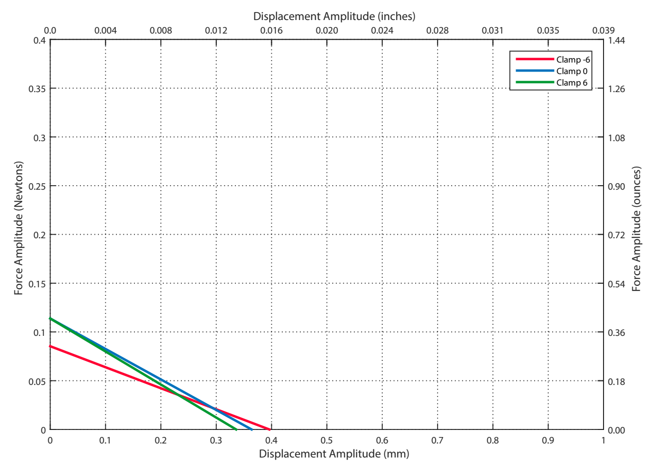


Figure 16: Static displacement and block force are compared for the three different clamp locations. The piezo was driven with 100 volts to generate this data.

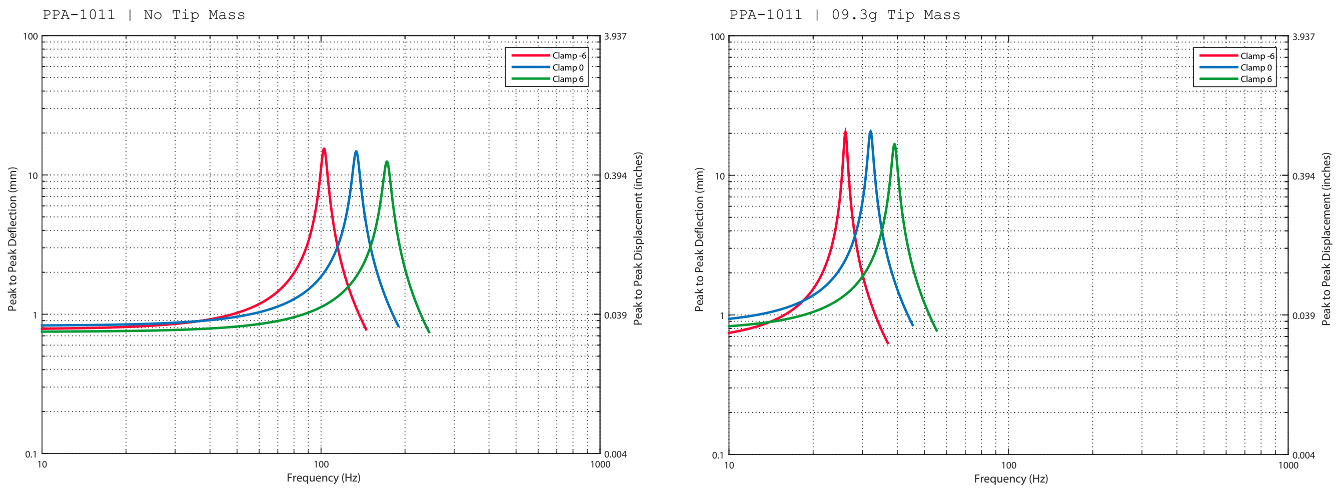


Figure 17: The peak to peak tip displacement is provided for when the piezo is driven with a ± 100 volt signal.

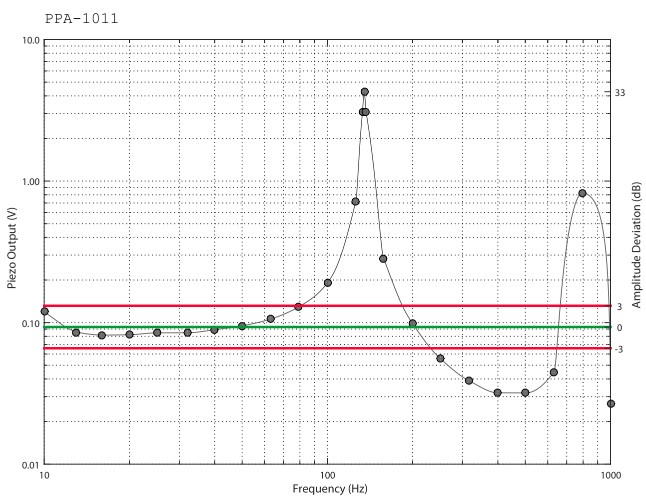


Figure 18: The frequency response of the accelerometer is provided with ±3 dB error bands to highlight the frequency range where accurate measurement can be expected.

The PPA-1012 is single layer piezo product that offers decent performance as a bender. It's much wider than the other products which enable more tip mass to be added easily with is useful in some applications. This product is also recommended for bonded applications.

Performance data for the PPA-1012 is summarized in the following tables and plots. Refer to Section 6 for information on how this data was gathered. Please note that this data is to be used only as reference and that there is some variability from unit to unit. Temperature, clamp conditions, drive quality, all can contribute to additional variability. All test data was gathered at room temperature and with the PPA-9001 clamp kit hardware.

Overview	
Capacitance (nF)	120
Mass (g)	6.0
Full Scale Voltage Range (V)	±200

Layer Material	Thickness (mils)	Thickness (mm)
FR4	3.0	0.08
Copper	1.4	0.03
PZT 5H	10.0	0.25
Copper	1.4	0.03
FR4	14.0	0.36
Total	30.0	0.76

1Information on material properties is provided in Section 5.

2The layer thicknesses do not perfectly add up to the actual thickness of the product due to the epoxy layers. These epoxy layers can be ignored for finite element analysis however.

Stiffness			
Parameter	Clamp -6	Clamp 0	Clamp 6
Effective Stiffness (N/m)	497.59	769.74	1207.05
Effective Mass (g)	1.289	1.077	1.036
Max Tip Deflection (mm)	2.0	8.0	8.0

See Section 4.3 for more information on how to use this data to tune your piezo.

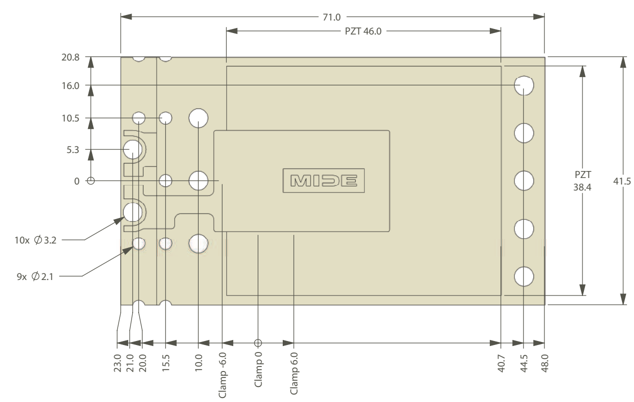


Figure 29: The overall dimensions (mm) for the PPA-1012 are shown. The total thickness is 0.76 mm (30 mils).

Energy Harvesting Data for Middle Clamp Location									
Acceleration Amplitude (g)	Frequency (Hz)	Tip Mass (gram)	RMS Power (mW)	RMS Voltage (V)	RMS Current (mA)	Resistance (kΩ)	RMS Open Circuit	Peak to Peak Displacement (mm)	Peak to Peak Displacement (in)
0.25	135.0	0.0	0.1	0.7	0.1	7.2	1.3	0.7	0.03
0.50	134.0	0.0	0.2	1.3	0.2	7.6	2.1	1.2	0.05
1.00	133.0	0.0	0.6	2.1	0.3	7.2	3.4	1.9	0.08
2.00	132.0	0.0	1.5	3.7	0.4	9.1	5.3	3.2	0.12
0.25	60.0	5.4	0.2	2.0	0.1	16.8	3.3	1.6	0.06
0.50	60.0	5.4	0.6	3.5	0.2	21.5	5.1	2.6	0.10
1.00	60.0	4.9	1.4	6.3	0.2	27.4	7.9	4.1	0.16
2.00	60.0	4.4	3.5	7.7	0.5	16.8	11.6	6.7	0.25
0.25	22.0	38.0	0.4	4.1	0.1	40.3	6.5	3.6	0.13
0.50	22.0	38.0	1.9	8.7	0.2	40.5	12.7	7.8	0.29
1.00	23.0	38.0	7.1	16.2	0.4	36.7	22.7	12.6	0.46

Block Force and Static Displacement, 100 volt signal			
Parameter	Clamp -6	Clamp 0	Clamp 6
Block Force Amplitude (N)	0.11	0.14	0.17
Displacement Amplitude (mm)	0.30	0.44	0.29

Dynamic displacement, no added tip mass, +/- 100 volt signal			
Parameter	Clamp -6	Clamp 0	Clamp 6
Resonant Frequency (Hz)	98.9	124.0	171.8
Half Power Bandwidth (Hz)	6.4	10.2	13.4
Q Factor	15.5	12.2	12.8
Peak to Peak Deflection at Resonance (mm)	4.5	3.8	4.0
Quasi Static Peak to Peak Deflection (mm)	0.4	0.3	0.3

Dynamic Displacement, 9.3 tip mass, +/- 100 volt signal			
Parameter	Clamp -6	Clamp 0	Clamp 6
Resonant Frequency (Hz)	27.4	34.8	43.0
Half Power Bandwidth (Hz)	5.8	1.4	1.8
Q Factor	4.7	24.9	23.9
Peak to Peak Deflection at Resonance (mm)	1.5	7.5	7.6
Quasi Static Peak to Peak Deflection (mm)	0.3	0.4	0.5

Sensitivity, middle clamp, no added tip mass	
Sensitivity (mV/g)	106
Upper Frequency Limit (Hz)	80.0
Resonance (Hz)	133.0
Sensitivity at Resonance (V/g)	3.6

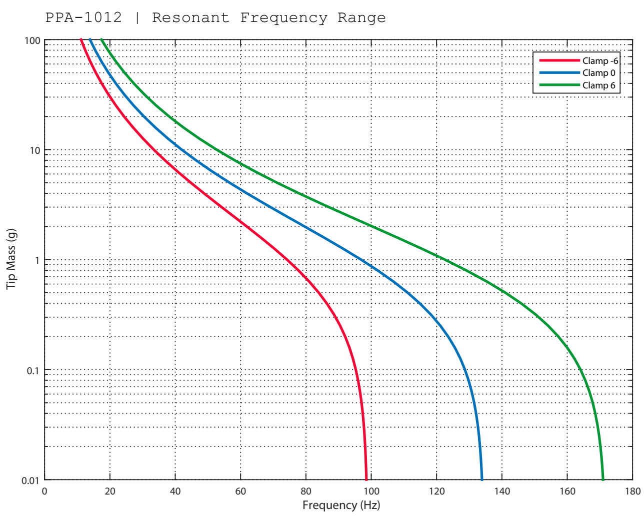


Figure 30: Refer to Section 4.3 for more information on tuning your piezo.

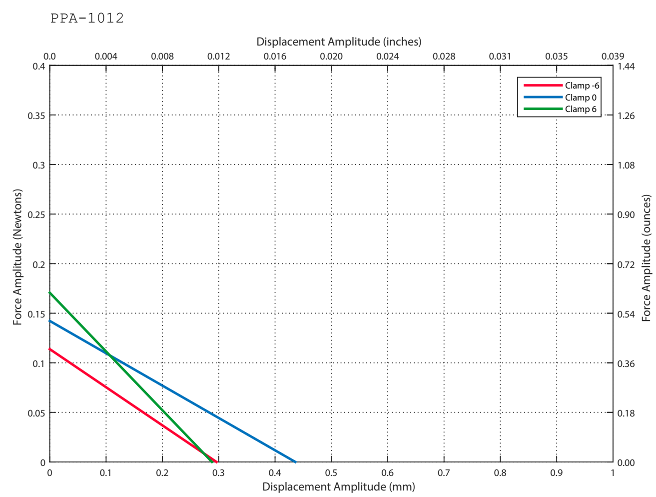


Figure 31: Static displacement and block force are compared for the three different clamp locations. The piezo was driven with 100 volts to generate this data

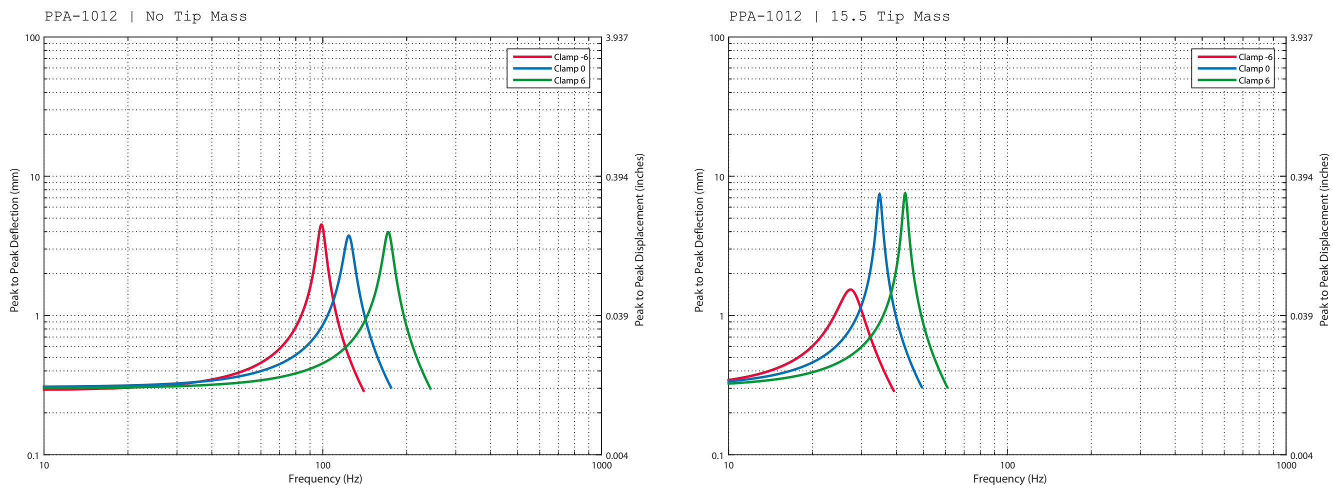


Figure 32: The peak to peak tip displacement is provided for when the piezo is driven with a ± 100 volt signal.

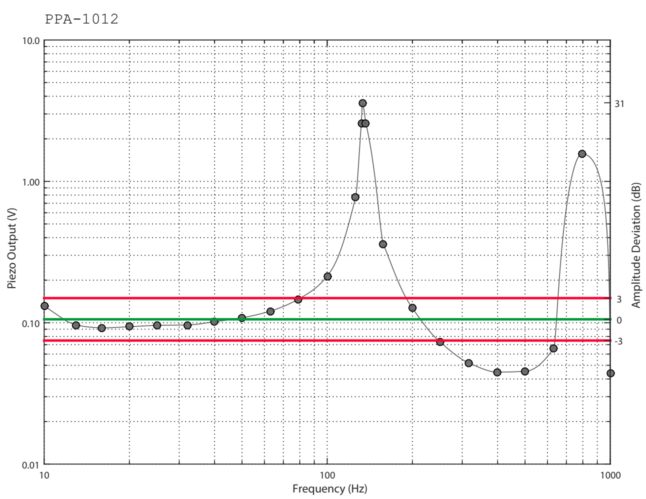


Figure 33: The frequency response of the accelerometer is provided with ±3 dB error bands to highlight the frequency range where accurate measurement can be expected.

The PPA-1013 is single layer piezo product with a very thick piezo making it optimal in bonded configurations. Its thickness makes it ineffective as a bender.

Overview	
Capacitance (nF)	24
Mass (g)	21.5
Full Scale Voltage Range (V)	±500

Layer Material	Thickness (mils)	Thickness (mm)
FR4	3.0	0.08
Copper	1.4	0.03
PZT 5H	58.5	1.49
Copper	1.4	0.03
FR4	14.0	0.36
Total	78.0	1.98

1Information on material properties is provided in Section 5.

2The layer thicknesses do not perfectly add up to the actual thickness of the product due to the epoxy layers. These epoxy layers can be ignored for finite element analysis however.

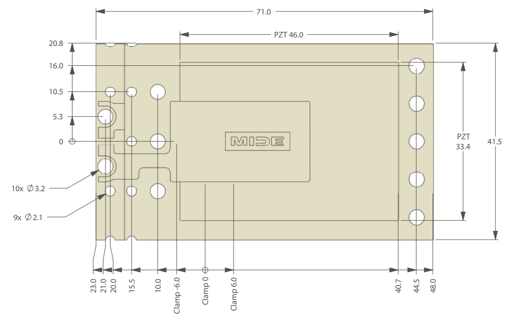


Figure 34: The overall dimensions (mm) for the PPA-1013 are shown. The total thickness is 1.98mm (78 mils).

The PPA-1014 is a single layer product recommended for energy harvesting and sensing applications. It also exhibits good performance as a resonant actuator. It is not recommended for applications requiring high force output. This product has a relatively high natural frequency compared to the other products which is beneficial for some applications. Due to its smaller size and good performance this is a popular product for many applications.

Performance data for the PPA-1014 is summarized in the following tables and plots. Refer to Section 6 for information on how this data was gathered. Please note that this data is to be used only as reference and that there is some variability from unit to unit. Temperature, clamp conditions, drive quality, all can contribute to additional variability. All test data was gathered at room temperature and with the PPA-9001 clamp kit hardware.

Overview	
Capacitance (nF)	40
Mass (g)	2.0
Full Scale Voltage Range (V)	±150

Layer Material	Thickness (mils)	Thickness (mm)
FR4	3.0	0.08
Copper	1.4	0.03
PZT 5H	7.5	0.19
Copper	1.4	0.03
FR4	14.0	0.36
Total	28.0	0.71

1Information on material properties is provided in Section 5.

2The layer thicknesses do not perfectly add up to the actual thickness of the product due to the epoxy layers. These epoxy layers can be ignored for finite element analysis however.

Stiffness			
Parameter	Clamp -6	Clamp 0	Clamp 6
Effective Stiffness (N/m)	898.54	2187.85	4167.91
Effective Mass (g)	0.336	0.339	0.240
Max Peak to Peak Deflection (mm)	6.0	5.0	5.0

See Section 4.3 for more information on how to use this data to tune your piezo.

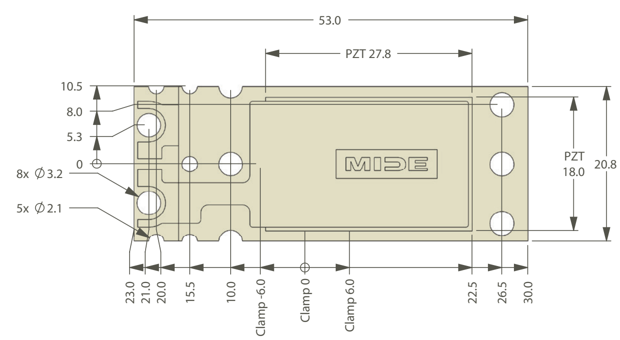


Figure 35: The overall dimensions (mm) for the PPA-1014 are shown. The total thickness is 0.71 mm (28 mils).

Energy Harvesting Data for Middle Clamp Location									
Acceleration Amplitude (g)	Frequency (Hz)	Tip Mass (gram)	RMS Power (mW)	RMS Voltage (V)	RMS Current (mA)	Resistance (kΩ)	RMS Open Circuit	Peak to Peak Displacement (mm)	Peak to Peak Displacement (in)
0.25 0.50 1.00 2.00	413.0 410.0 404.0 400.0	0.0 0.0 0.0 0.0	0.0 0.1 0.4 1.1	0.6 1.3 2.0 3.2	0.1 0.1 0.2 0.4	9.0 13.6 11.1 8.9	1.2 2.2 3.3 5.7	0.3 0.5 0.7 0.8	0.01 0.02 0.03 0.03
0.25 0.50 1.00 2.00	60.0 60.0 60.0 60.0	15.1 15.1 14.9 14.9	1.2 3.7 9.8 25.9	10.8 13.9 19.5 27.3	0.1 0.3 0.5 0.9	95.7 52.1 38.8 28.8	14.4 25.8 30.5 36.1	2.4 3.3 4.0 5.0	0.09 0.13 0.15 0.19
0.25 0.50	47.0 46.0	25.3 25.3	2.0 4.8	14.1 17.2	0.1 0.3	100.0 61.9	17.0 24.8	3.1 4.6	0.12 0.18

Block Force and Static Displacement, 100 volt signal			
Parameter	Clamp -6	Clamp 0	Clamp 6
Block Force Amplitude (N)	0.09	0.09	0.23
Displacement Amplitude (mm)	0.15	0.19	0.09

Dynamic displacement, no added tip mass, +/- 100 volt signal			
Parameter	Clamp -6	Clamp 0	Clamp 6
Resonant Frequency (Hz)	260.2	384.2	663.9
Half Power Bandwidth (Hz)	9.6	72.4	54.4
Q Factor	27.1	5.3	12.2
Peak to Peak Deflection at Resonance (mm)	5.4	1.8	1.6
Quasi Static Peak to Peak Deflection (mm)	0.2	0.3	0.2

Dynamic Displacement, 9.3 tip mass, +/- 100 volt signal			
Parameter	Clamp -6	Clamp 0	Clamp 6
Resonant Frequency (Hz)	48.6	68.2	105.2
Half Power Bandwidth (Hz)	8.6	14.4	7.2
Q Factor	5.7	4.7	14.6
Peak to Peak Deflection at Resonance (mm)	6.1	4.1	9.0
Quasi Static Peak to Peak Deflection (mm)	0.9	0.8	0.5

Sensitivity, middle clamp, no added tip mass	
Sensitivity (mV/g)	56
Upper Frequency Limit (Hz)	252.0
Resonance (Hz)	417.0
Sensitivity at Resonance (V/g)	4.0

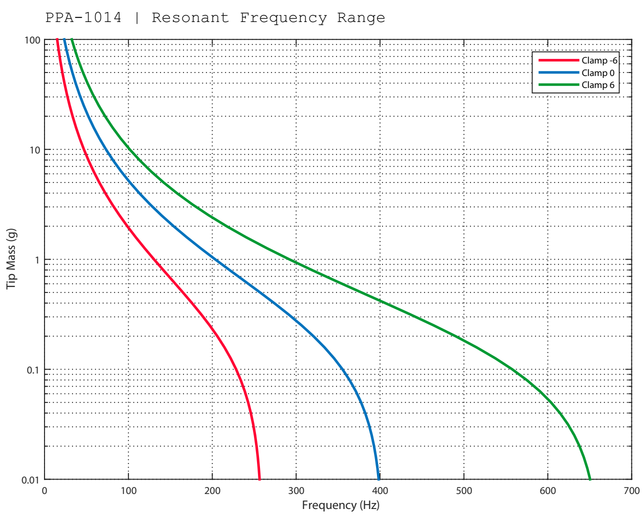


Figure 36: Refer to Section 4.3 for more information on tuning your piezo.

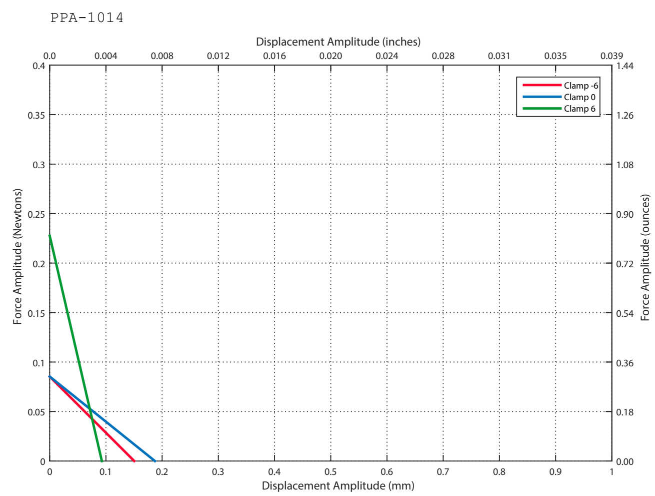


Figure 37: Static displacement and block force are compared for the three different clamp locations. The piezo was driven with 100 volts to generate this data.