

# What Is a Piezo Amplifier? — A Design Engineer’s Complete Guide

**Quick Answer (60-second version):** A piezo amplifier converts a 0–5 V or ±10 V command into the high voltage (up to ±1.8 kV bipolar or 2 kV unipolar) and capacitive current required to drive a piezoelectric actuator. Voltage sets stroke; current and slew rate set speed. Size from the full waveform using  $I_{peak} = 2\pi \cdot f \cdot C \cdot V_{peak}$  with a 1.5–2× large-signal capacitance correction and ≥1.5× current margin. Match polarity to the actuator (AHVA unipolar+, AHVAN negative, AHVAPN bipolar). For large-capacitance or high-duty loads, choose the PWM APZD300V2A; for the lowest noise, choose the linear AHVAPN.

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## Abstract

A **piezo amplifier** — also called a piezo driver, PZT amplifier, or high-voltage amplifier — converts a low-voltage command (0–5 V or ±10 V) into the high-voltage, capacitive-load current required to drive a piezoelectric actuator. This paper derives the three quantities that govern actuator motion (voltage, current, slew rate) from first principles, explains why the actuator’s **large-signal capacitance is typically 1.5–2× its small-signal value**, and shows how to translate an actuator datasheet into a correct amplifier selection. It covers the reliability mechanisms unique to piezo drive — dielectric self-heating, depolarization, hysteresis, and cable resonance — and maps ATI’s [High Voltage Amplifier / Piezo Driver families](#) to common applications. **Key rule: size by the full waveform, not by peak voltage alone.**

## Executive Summary

Most failed piezo selections trace to a single mistake: choosing the amplifier by output voltage and ignoring the current and speed the waveform demands. Voltage sets how far the actuator moves; current and slew rate decide whether it can

follow the commanded motion. Because a piezo actuator is electrically a capacitor, its current demand scales with capacitance, frequency, and voltage ( $I = C \cdot dV/dt$ ), so a module that is ideal for slow nanopositioning can be hopelessly under-rated for fast scanning of the same actuator.

Engineers must decide four things: the **voltage range** (from actuator stroke), the **polarity** (unipolar positive, negative, or bipolar), the **peak and RMS current** (from the worst-case waveform), and the **slew rate / bandwidth** (from the fastest transition required). This paper gives the equations, worked examples, and a selection table so each decision is quantitative. ATI's modules integrate a [24 V-input high-voltage converter](#) and a full hardware-protection suite, so the design reduces to matching one module to the waveform rather than building and protecting a high-voltage supply from scratch.

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## 1. One-Sentence Definition

A **piezo amplifier** (also called a **high-voltage amplifier**, **piezo driver**, or **PZT amplifier** — terms used interchangeably in this paper) is a signal-controlled power amplifier that converts a low-voltage command (0–5 V or  $\pm 10$  V) into a precise high-voltage drive waveform — up to  $\pm 1.8$  kV bipolar or 2 kV unipolar — for a capacitive piezoelectric actuator.

**Answer-engine summary:** A piezo amplifier (piezo driver) takes a small control signal and produces the high voltage a piezoelectric actuator needs to move, while supplying the current required to charge and discharge the actuator's capacitance at the commanded speed.

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## 2. Introduction

High-voltage piezo drive — whether you call it a piezo amplifier, piezo driver, or high-voltage amplifier — sits at the intersection of precision motion and power electronics, which is exactly why it trips up engineers from both camps. A motion engineer thinks in displacement and forgets the actuator is a capacitor that fights every fast voltage change; a power engineer sizes for current and forgets that nanometer-class noise and drift requirements dominate the design.

This paper is written for both. It starts from the physics — why a piezo behaves as a capacitor and what that means for current — then builds a repeatable selection procedure, a worked example, reliability guidance, and a product-selection map. The goal is that after reading it you can open an actuator datasheet, compute what you need, and pick a [piezo amplifier / piezo driver module](#) with confidence and margin.

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## 3. The Shed & Water Bed Analogy — Understanding the Piezo Actuator

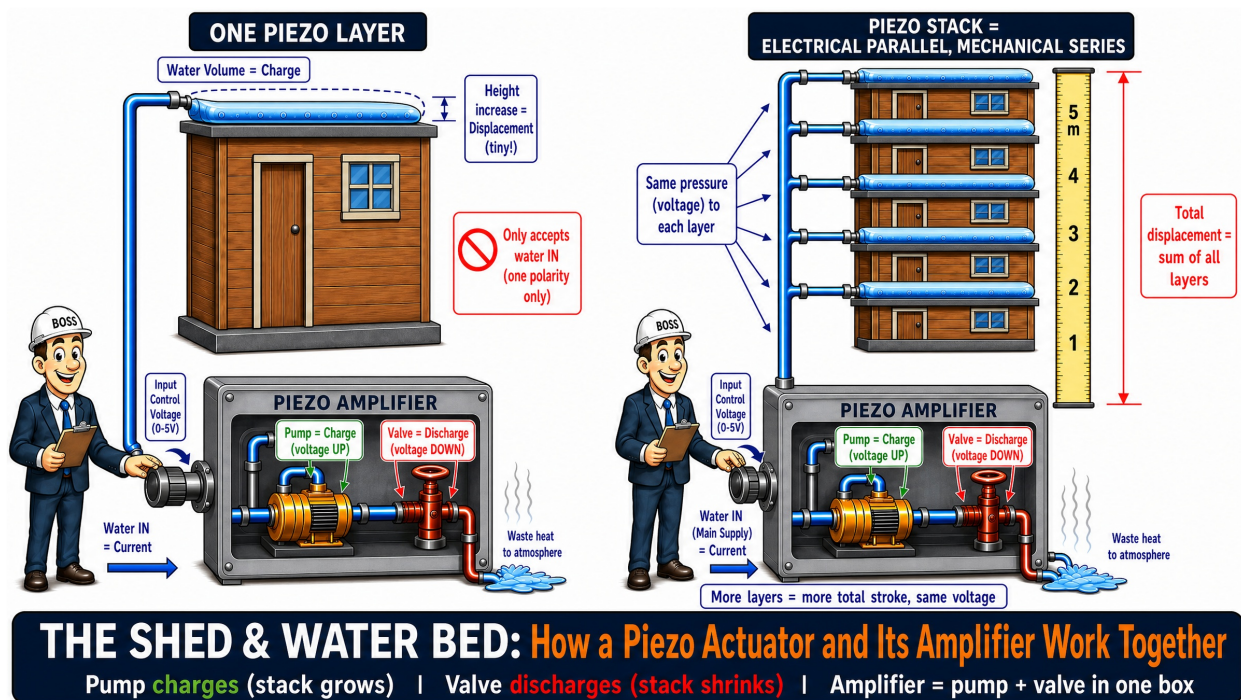
Imagine a one-story shed with a thin water bed on its flat roof. When you pump water into the bed, it inflates and the total height of the structure increases. When you open a valve, water drains out and the height drops back. The shed itself

(the ceramic) is rigid and strong — it can support enormous weight without budging. But the water bed on top (the electrode layer) expands only a tiny fraction of the shed’s height. That is your single piezo layer.

Now picture the key properties:

- **Massive force** — blocking forces up to 30,000 N (the shed holds a loaded truck on its roof)
- **Microscopic motion** — only 0.1–0.15% of body length (a 10 mm stack moves ~10–15 μm — the water bed barely bulges)
- **Zero DC power** — it’s a capacitor; once the water bed is full, it holds height forever with zero flow
- **AC current proportional to speed** —  $I = C \times dV/dt$ ; faster filling = more water flow = more current
- **Stacking for more reach** — stack multiple sheds with water beds on top, connect all water inlets in parallel (same pressure = same voltage), and the height increases add up mechanically in series

The **piezo amplifier** (or piezo driver) is the pump-and-valve unit that controls the water. It decides how much water to push in (voltage = water level = displacement), how fast to pump (slew rate = flow rate), and protects against flooding (current limit) and overheating (thermal shutdown). An engineer who selects a high-voltage piezo driver only by voltage is like choosing a pump only by the tank’s capacity — ignoring whether the pump can actually fill it at the speed you need.



**Figure 1** — The Shed & Water Bed Analogy. LEFT: One piezo layer = one shed (ceramic) topped by a thin water bed (electrode layer). The amplifier (gray box) contains a pump (charge = voltage UP) and valve (discharge = voltage DOWN). Water IN through the left wall = current. The pump output pipe runs up externally to fill the water bed — height increase = displacement. RIGHT: A piezo stack = multiple sheds + water beds in mechanical series, electrical

parallel. Same pressure (voltage) to each layer; more layers = more total stroke. The boss turns the “Input Control Voltage (0–5 V)” knob to command motion. Design rule: Current (water flow) determines speed; voltage (water level) determines stroke; the amplifier is the pump + valve in one box.

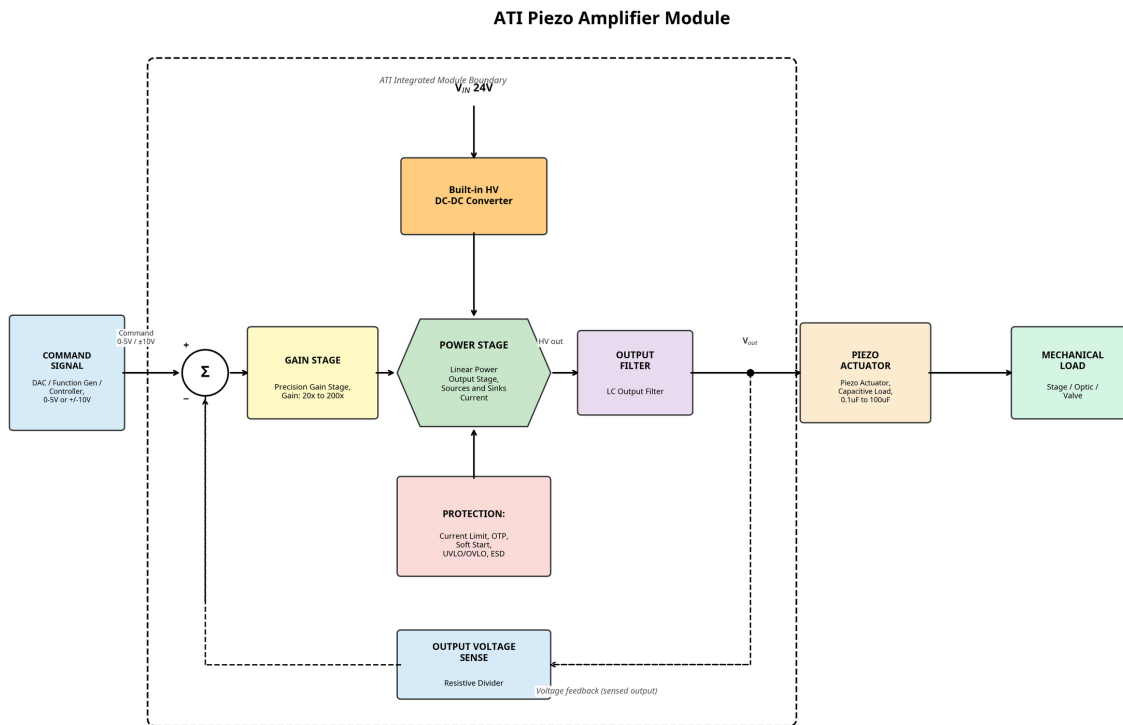
## 4. How a Piezo Amplifier Works

A piezoelectric actuator behaves electrically as a capacitor whose mechanical displacement is proportional to applied voltage. The amplifier receives a low-voltage command signal from a DAC, function generator, or control loop, and produces a scaled high-voltage output that charges and discharges the actuator. The voltage creates electric-field stress in the piezo ceramic, and the ceramic converts that field into nanometer-to-micrometer-scale mechanical motion.

### 4.1 The Signal Chain

Stage	Function	Analogy
Command input	Sets desired position	Boss turning the control knob
Gain stage	Amplifies voltage by 20×–200×	Pressure multiplier
Power stage	Sources/sinks capacitive current	Pump motor horsepower
Output filter	Reduces switching noise	Smooth-flow pipe damper
Protection	Limits current, temperature, voltage	Pressure relief valve
Feedback	Senses output voltage	Resistive divider (voltage feedback)

## 4.2 Block Diagram



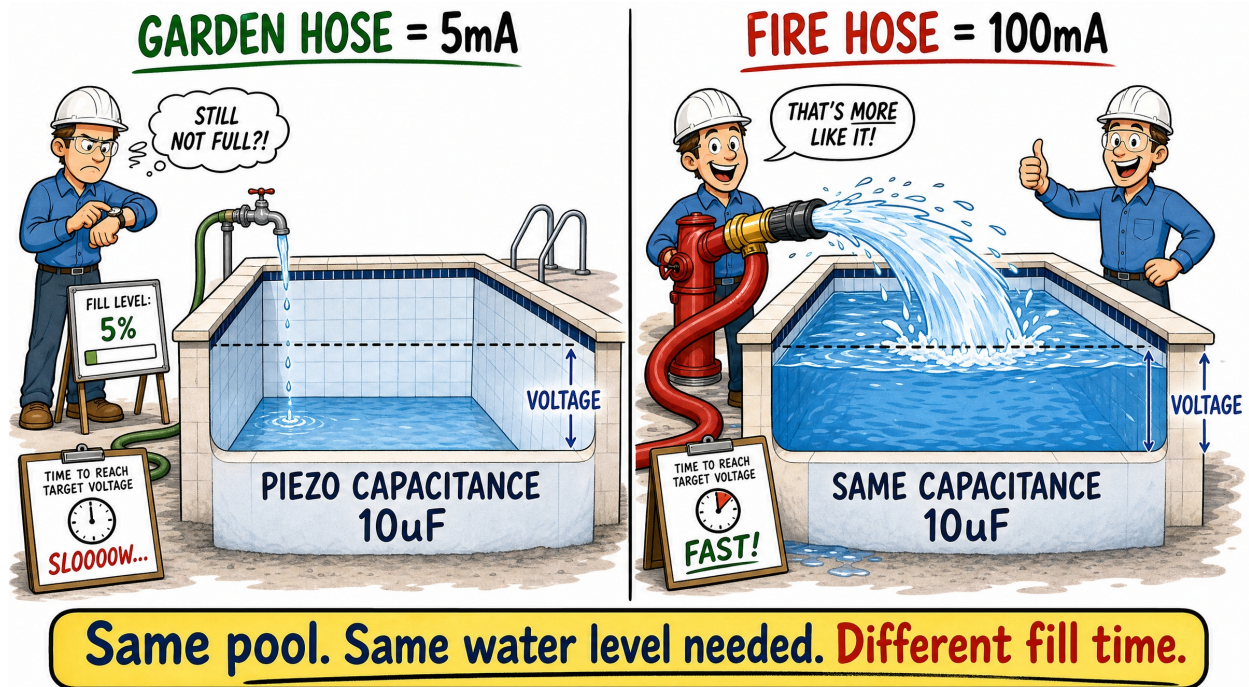
**Figure 2** — Piezo Amplifier System Block Diagram. The amplifier sits between the low-voltage controller and the high-voltage actuator. The dashed enclosure represents ATI’s integrated module boundary — everything inside ships as one unit with 24 V input. The output voltage is sensed via a resistive divider and fed back to the summing junction for closed-loop voltage regulation. Design rule: Treat the piezo amplifier as part of a motion system, not as an isolated voltage booster.

## 5. The Three Numbers That Select a Piezo Amplifier

Whether you call it a piezo amplifier, high-voltage amplifier, or piezo driver module, the selection process is the same. Many selection mistakes happen because engineers ask only for voltage. Voltage sets maximum displacement, but **current** and **speed** determine whether the actuator can follow the desired waveform.

### 5.1 The Fire Hose vs. Garden Hose

Picture filling a swimming pool. The pool is your piezo capacitance. The water level is voltage. A garden hose (low current) fills it eventually. A fire hose (high current) fills it in seconds. Same pool, same water level — completely different fill time.



**Figure 3** — Fire Hose vs. Garden Hose. The swimming pool is the piezo capacitance. Water level = voltage. Flow rate = current. A garden hose (5 mA) fills a large pool (high capacitance) painfully slowly. A fire hose (100 mA) fills it fast. Design rule: Current determines speed; voltage determines stroke.

## 5.2 The Governing Equation

For a capacitive load, the instantaneous current is:

$$I = C \times dV/dt$$

For a sinusoidal drive, the peak current is:

$$I_{\text{peak}} = 2\pi \times f \times C \times V_{\text{peak}}$$

where  $V_{\text{peak}}$  is the sinusoidal amplitude ( $= \frac{1}{2} V_{\text{pp}}$ ). This convention is used consistently throughout this paper.

**Critical note:** The actuator's *large-signal* capacitance under full drive is typically 1.5–2× the *small-signal* catalog value due to field-dependent permittivity. All current estimates should use the large-signal value. Design rule: size current for 1.5–2× the small-signal capacitance.

### 5.3 Worked Example

Parameter	Value
Actuator capacitance (small-signal)	1 $\mu$ F
Large-signal correction	$\times 1.5 \rightarrow$ effective 1.5 $\mu$ F
Voltage swing	$\pm 500$ V ( $V_{\text{peak}} = 500$ V amplitude)
Frequency	100 Hz
<b>Required <math>I_{\text{peak}}</math></b>	<b><math>2\pi \times 100 \times 1.5 \times 10^{-6} \times 500 \approx 471</math> mA</b>

The same actuator at 1 kHz requires  $\sim 4.7$  A peak — far beyond most precision modules. At 10 Hz, only  $\sim 47$  mA is needed. This is why a piezo amplifier (or piezo driver) excellent for slow nanopositioning may be completely inadequate for fast scanning.

Requirement	Why It Matters	Design Question
Output voltage range	Sets available piezo stroke	What voltage does the actuator need for rated displacement?
Output current	Charges/discharges the capacitance	Can the amplifier supply peak AND RMS current at the desired waveform?
Slew rate / bandwidth	Determines waveform fidelity	Can the output move fast enough across the full voltage swing?

### 5.4 Peak vs. RMS Current — Which Sizes What

$I_{\text{peak}}$  decides whether the amplifier clips at the waveform corners.  $I_{\text{RMS}}$  decides whether the output stage survives thermally over a long run. Both matter and they are not interchangeable.

Waveform	$I_{\text{RMS}}$ in terms of $I_{\text{peak}}$	Typical use
Sine	$I_{\text{peak}} / \sqrt{2}$ ( $\approx 0.707\times$ )	Continuous scanning, AC drive
Triangle	$I_{\text{peak}} / \sqrt{3}$ ( $\approx 0.577\times$ )	Raster scans, ramp generators
Square, 50% duty	$I_{\text{peak}}$	Step actuation, valve drive
Pulse, duty D	$I_{\text{peak}} \cdot \sqrt{D}$	Inkjet, pulsed ultrasound

Design rule: Size  $I_{\text{peak}}$  for the worst-case edge, then verify  $I_{\text{RMS}}$  sits below the module's continuous current rating with  $\geq 1.3\times$  margin. Forgetting the RMS check is how engineers discover the OTP trip point at 3 AM on a production line.

## 6. Slewing Rate, Bandwidth, and Large-Signal Motion

### 6.1 The Speed Limit Analogy

Bandwidth is the speed limit on a straight highway — it tells you the maximum frequency for small signals. **Slew rate** is the acceleration of your car — it tells you how fast you can change voltage when the pedal is floored. A sports car (high slew rate) reaches highway speed instantly; a loaded truck (low slew rate) takes the whole on-ramp.

For piezo actuators that need large voltage swings, slew rate often dominates before bandwidth becomes the limit.

### 6.2 The Math

For a full-scale step:

$$t_{\min} \approx \Delta V / SR$$

A 1000 V change at 2000 V/ $\mu$ s (typical for [AHVAPN](#), per datasheet) has a theoretical transition time of 0.5  $\mu$ s. The same change at 100 V/ $\mu$ s takes 10  $\mu$ s. For a 150 V/ $\mu$ s amplifier driving a 2 kV swing, the minimum transition is  $\sim$ 13  $\mu$ s.



**Figure 4** — The Playground Swing Analogy. Same swing, same child, same 1-second cycle (1 Hz). A small arc (small-signal) is easy — barely any push force needed. A huge arc (large-signal) that must complete within the same 1-second period requires massive push force (current). If the required force exceeds the pusher’s maximum strength (amplifier’s

current limit), the swing cannot complete the full arc on time — this is slew-rate limiting. Design rule: Verify BOTH bandwidth AND slew rate for your application.

### 6.3 Settling Time ≠ Slew Time

Slew time gets the output close to the target. Settling time — typically defined as the time to remain within  $\pm 0.1\%$  of the final value — is what position-critical applications actually care about, and it is usually 3–10 $\times$  longer than the slew time.

Quantity	Set by	Typical magnitude
Slew time	dV/dt limit	$t_{\text{slew}} = \Delta V / \text{SR}$
1% settling	Closed-loop bandwidth	$\sim 3 \cdot \tau_{\text{loop}}$
0.1% settling	Loop margin + damping	$\sim 7 \cdot \tau_{\text{loop}}$
Mechanical settle	Stage mass-stiffness resonance	0.1–10 ms

For nanopositioning, the dominant pole is often the *mechanical* stage resonance (typically 0.5–5 kHz), not the amplifier itself. Specify settling time on RFQ, not just slew rate, and include load mass if known.

Design rule: For a fast step-and-settle application, drive bandwidth should be  $\geq 5\times$  the mechanical resonance frequency, or you will pay for slew rate you cannot use.

#### Sidebar — Voltage drive vs. charge drive

*Open-loop voltage-driven piezo exhibits 10–15% hysteresis because charge (which causes displacement) is a nonlinear function of voltage. Open-loop charge-driven piezo reduces hysteresis to  $\sim 1\%$  without any position sensor, because charge maps almost linearly to displacement.*

*The catch: charge-drive amplifiers are uncommon, more complex, typically lower-voltage, and drift on DC due to actuator leakage. For most precision applications, the dominant industry practice is voltage drive plus closed-loop position feedback (strain gauge or capacitive sensor) — the architecture ATI's modules target and this paper assumes throughout. See Q14 for what closed-loop voltage feedback does and does not fix.*

### 6.4 ATI's Speed Specifications

Family	Slew Rate (typical, per datasheet)	Bandwidth	Output Range	Current
<a href="#">AHVAPN</a> (high-speed)	2000 V/ $\mu$ s typical, 2400 V/ $\mu$ s max	Up to 15 kHz	$\pm 1$ kV, $\pm 1.8$ kV (bipolar); 10 V–2 kV (unipolar)	Up to 20 mA

Family	Slew Rate (typical, per datasheet)	Bandwidth	Output Range	Current
<a href="#">AHVA2KV2X</a>	150 V/μs	Up to 10 kHz	10 V to 2 kV	10–20 mA
<a href="#">AHVA1KV2X</a>	100 V/μs	Up to 10 kHz	10 V to 1 kV	10–20 mA
<a href="#">AHVA500V2X</a>	100 V/μs	Up to 10 kHz	10 V to 500 V	5–50 mA
<a href="#">ATI242000A</a> (benchtop)	200 V/μs	Up to 20 kHz	0–2 kV	Up to 20 mA

## 7. ATI's Piezo Amplifier Architecture — What's Inside the Box

### 7.1 The Orchestra Conductor

A piezo amplifier is like an orchestra conductor. The **command signal** is the musical score. The **gain stage** is the conductor's interpretation. The **power stage** is the orchestra's volume. The **protection circuits** are the fire exits — you hope you never need them, but they save the concert hall when things go wrong.

ATI's piezo driver module architecture integrates everything into a single shielded package:

- **Built-in high-voltage DC-DC converter** — no external HV supply needed; just connect 24 V (5 V for [APZD300V2A](#))
- **Precision gain stage** — low noise (400 μVp-p @ 0.1–10 Hz on [AHVAPN](#)), low drift
- **Linear power output stage** — sources and sinks capacitive current smoothly
- **Full protection suite** — UVLO, OVLO, OTP, soft start, current limit, ESD



**Figure 5** — Peak current  $I_{\text{peak}} = 2\pi \cdot f \cdot C \cdot V_{\text{peak}}$  governs the amplifier’s instantaneous output capability. The fire-hose analogy: voltage is water pressure, current is flow rate, and the actuator’s capacitance is the pipe diameter.

## 7.2 Why Integrated HV Supply Matters

Most piezo amplifiers (high-voltage amplifiers) on the market require an external high-voltage power supply — adding cost, board space, safety risk, and noise coupling. ATI’s modules convert a low-voltage input (24 V for most families; 5 V for [APZD300V2A](#)) directly to the required high voltage internally. One input, one output, one module.

## 8. Protection — The Bodyguard for Your Expensive Actuator

High voltage and capacitive loads create stress during startup, shutdown, accidental short circuit, connector handling, and abnormal commands. A piezoelectric stack actuator can cost \$500–\$5,000. The amplifier’s protection features are insurance against destroying it.

### 8.1 The Bodyguard Analogy

Your piezo actuator is a VIP. The protection circuits are professional bodyguards:

- **Current limit** — stops the crowd (excessive current) from crushing the VIP
- **Thermal shutdown** — evacuates when the building (amplifier) overheats
- **Soft start** — opens the door slowly so the VIP isn’t startled (no voltage spike at turn-on)

- **UVLO/OVLO** — refuses to let the VIP enter an unsafe venue (supply out of range)
- **ESD protection** — deflects paparazzi flashbulbs (static discharge on input pins)

Your \$3,000 piezo stack is the grand piano on that stage. The six protection posts (Figure 5) stop current surges, thermal runaway, voltage spikes, and ESD before they reach the actuator. Design rule: Never operate a high-voltage piezo system without hardware protection — the actuator is always more expensive than the amplifier.

## 8.2 ATI Protection Features

Feature	What It Prevents	ATI Implementation
Under-voltage lockout (UVLO)	Operation with insufficient supply	Locks output until input voltage is stable
Over-voltage lockout (OVLO)	Damage from supply overshoot	Shuts down if supply exceeds limit
Over-temperature shutdown (OTP)	Thermal destruction	Graceful shutdown with auto-recovery
Soft start	Inrush current spike at turn-on	Controlled ramp-up of internal HV
Output current limit	Excessive load current	Folds back output to safe level
ESD protection	Static damage to input pins	On-chip clamping on all signal inputs

## 9. Reliability & Long-Term Stability

A piezo drive system fails in ways a resistive-load amplifier never sees, because the load is an active dielectric, not a passive resistor. Design for these mechanisms:

**Large-signal capacitance is higher than the datasheet number.** PZT permittivity rises with field and temperature, so the *effective* capacitance under full-amplitude drive is typically **1.5–2× the small-signal value**. Every current estimate built on the catalog capacitance therefore under-predicts demand. Design rule: size current for 1.5–2× the small-signal capacitance.

**Hysteresis and creep.** Open-loop displacement lags voltage by approximately **10–15% for soft PZT** (the most common actuator material) and **2–5% for hard PZT** [13]. The actuator also continues to drift (creep) for seconds after a step. Applications needing absolute accuracy use closed-loop drive with a strain-gauge or capacitive sensor — the feedback path in the system block diagram (Figure 2) exists for exactly this reason.

**Dielectric self-heating.** At high f·C·V the actuator dissipates internally through its loss tangent. Sustained high-frequency, high-voltage operation can raise the ceramic toward its Curie temperature, where it **depolarizes** and permanently loses stroke. Keep duty cycle and ambient in check; derate at high frequency. See Figure 9 for dissipation estimates.

**Quantifying actuator self-heating.** Internal actuator dissipation scales as:

$$P_{\text{actuator}} \approx \pi \cdot f \cdot C \cdot V_{\text{peak}}^2 \cdot \tan \delta$$

where  $\tan \delta$  is the PZT loss tangent. Typical values at 1 kHz are **0.015–0.030**, rising to 0.04–0.06 at full-field large-signal drive and elevated temperature. Worked example for a 1  $\mu\text{F}$  actuator at 500  $V_{\text{peak}}$ , 1 kHz,  $\tan \delta = 0.025$ :

$$P_{\text{actuator}} \approx \pi \times 1000 \times 1 \times 10^{-6} \times 500^2 \times 0.025 \approx \mathbf{19.6 \text{ W}} \text{ dissipated inside the actuator}$$

This is separate from the amplifier dissipation plotted in Figure 9. Both must stay within their respective thermal limits. The actuator ceiling is governed by the Curie temperature: **soft PZT (PZT-5H/5A): 150–200 °C; hard PZT (PZT-4/8): 300–350 °C** [13]. Derate to keep ceramic temperature below ~80% of Curie (i.e., below ~120 °C for soft PZT, ~250 °C for hard PZT).

**Depolarization from reverse field.** The coercive field for soft PZT is approximately **1 kV/mm** (i.e., ~500 V across a 0.5 mm layer) [14]. Driving a unipolar stack negative past this threshold depoles it permanently. Match amplifier polarity to the actuator: use [AHVAN](#) for negative-only stacks and [AHVAPN](#) only for actuators rated for bipolar field.

**Cable + actuator resonance.** HV cable inductance and the actuator capacitance form an LC circuit that rings on fast edges. The resonance frequency is:

$$f_{\text{res}} \approx 1 / (2\pi\sqrt{L \cdot C})$$

For a 2 m HV cable ( $\approx 200 \text{ nH/m}$ , so  $L \approx 400 \text{ nH}$ ) and a 1  $\mu\text{F}$  actuator:  $f_{\text{res}} \approx 1 / (2\pi\sqrt{(400 \times 10^{-9}) \times 1 \times 10^{-6}}) \approx \mathbf{8 \text{ kHz}}$  — well inside the amplifier’s bandwidth, which is why ringing is visible on fast edges. A small series resistor (10–100  $\Omega$ ) damps it; keep HV cables short ( $\leq 1 \text{ m}$  recommended for slew rates above 500  $\text{V}/\mu\text{s}$ ).

**Hardware protection as insurance.** ATI modules include under/over-voltage lockout, over-temperature shutdown, soft start, output current limit, and input ESD clamping — independent of any firmware. Design rule: never operate a high-voltage piezo system without hardware protection; the actuator is almost always more expensive than the amplifier.

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## 9.1 Partial Discharge and Corona Above 1 kV

Air breaks down at  $\sim 3$  kV/mm in uniform fields, but corona onset on a sharp edge can occur below 1 kV/mm — and once partial discharge (PD) starts, it erodes insulation over days to weeks. For AHVA2KV2X and AHVAPN designs:

- **PCB spacing.** Use IPC-2221B [12] for PCB-level clearance and IEC 60664-1 [19] for system-level insulation coordination at the relevant altitude and pollution degree, then add 50% margin. At 2 kV in pollution degree 2, allow 8 mm minimum creepage.
- **Sharp features.** Round all HV solder fillets, avoid via stubs on HV nets, and use teardrop pads. Sharp 90° trace corners on HV are PD seed sites.
- **Conformal coating.** Above 1 kV, polyurethane or parylene coating raises PD threshold by 2–3× and blocks moisture migration.
- **Humidity.** Relative humidity above 60% lowers PD onset voltage measurably. ATI modules are specified for 5–80% RH non-condensing; follow it.
- **Connector pin spacing.** Standard 0.1" headers are inadequate above  $\sim 500$  V. Use HV-rated connectors (SHV, MHV, or Lemo HV) for outputs above 1 kV.

Design rule: above 1 kV, treat the PCB and cable as part of the insulation system, not as wiring.

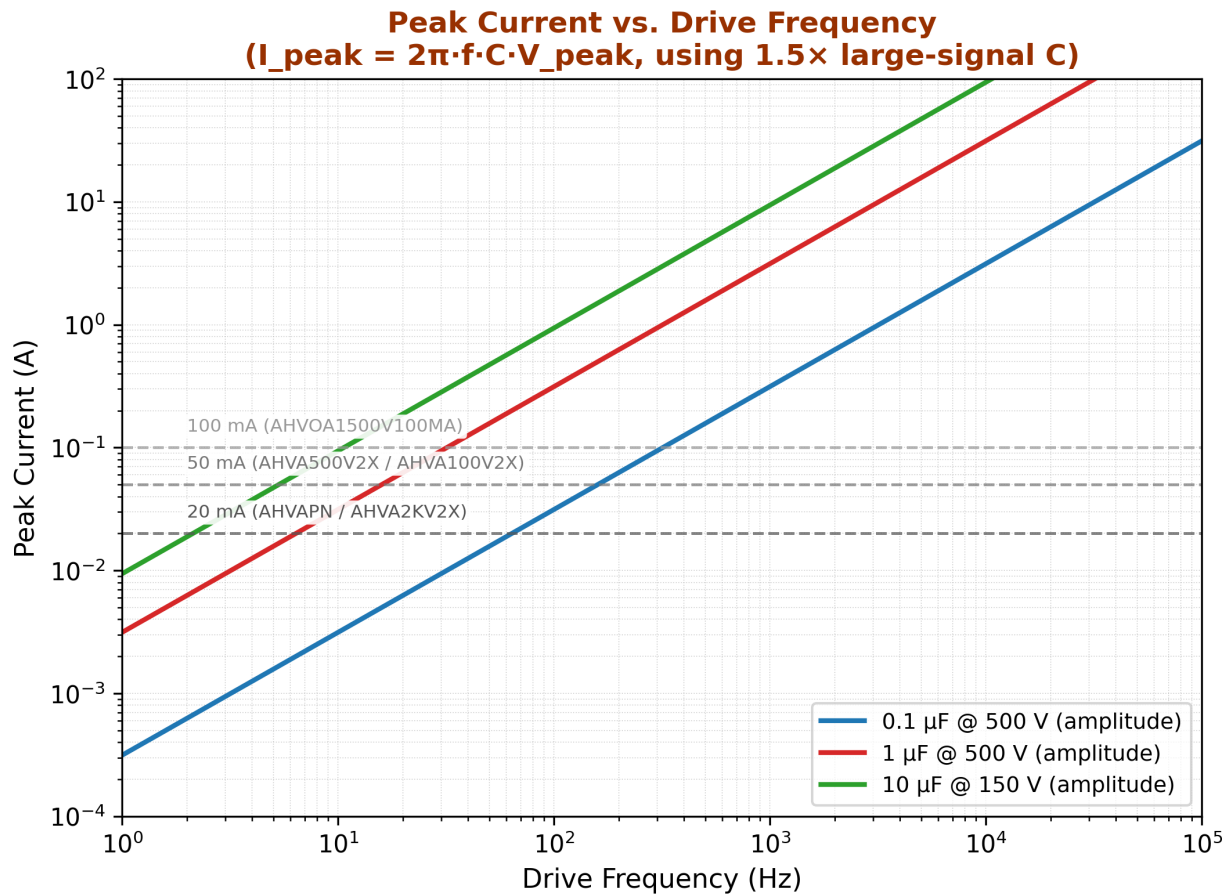
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## 10. Performance Analysis — Quantitative Deep Dive

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### 10.1 Peak Current vs. Drive Frequency

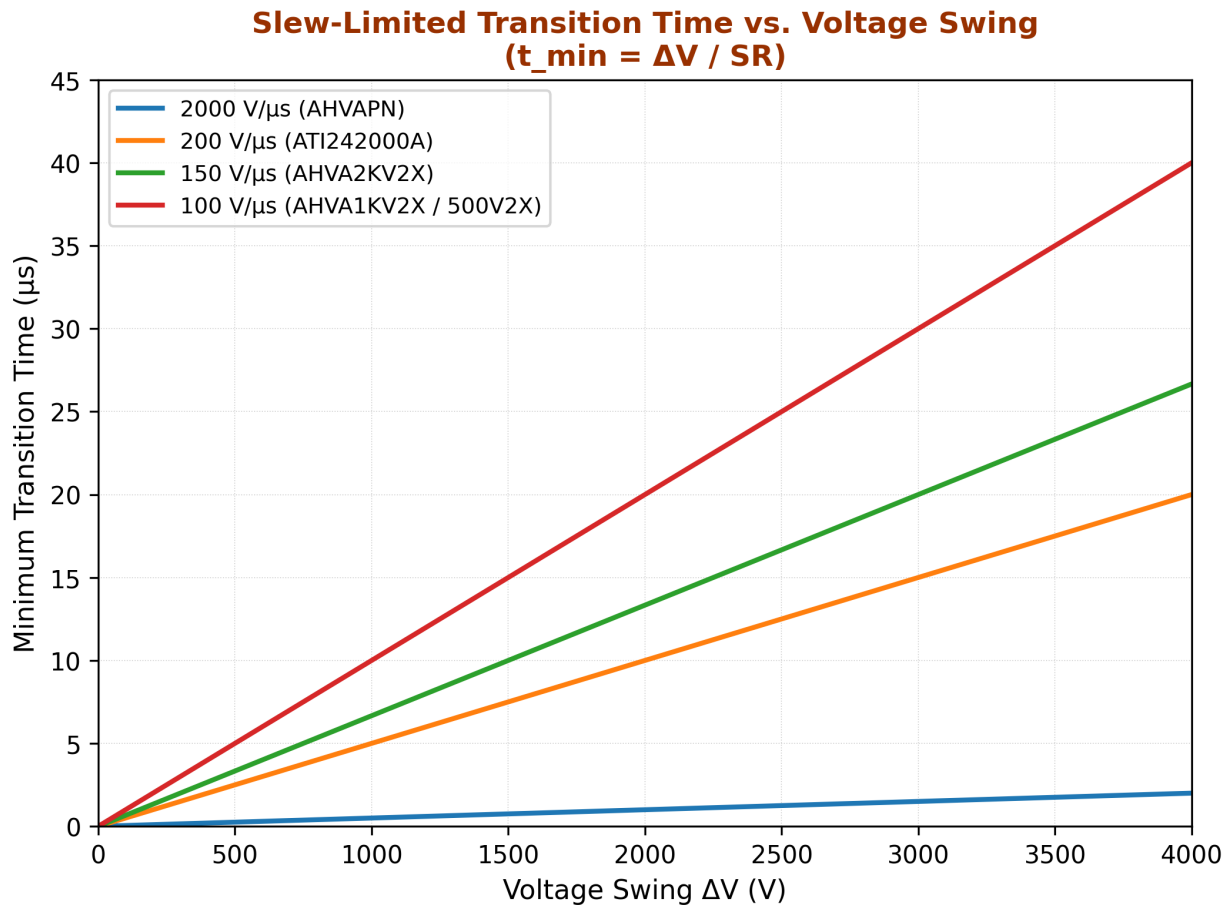
The fundamental challenge: capacitive current rises linearly with frequency, capacitance, and voltage. Where a curve crosses a family's current ceiling, that family can no longer follow the waveform.



**Figure 6** — Peak current vs. drive frequency. Capacitive current rises linearly with frequency, capacitance, and voltage. Where a curve crosses a family’s current ceiling, that family can no longer follow the waveform. Design rule: pick the family whose current ceiling stays above your operating point with  $\geq 1.5\times$  margin.

### 10.2 Slew-Limited Transition Time

Bandwidth describes small signals; slew rate sets how fast the output can traverse a large swing.

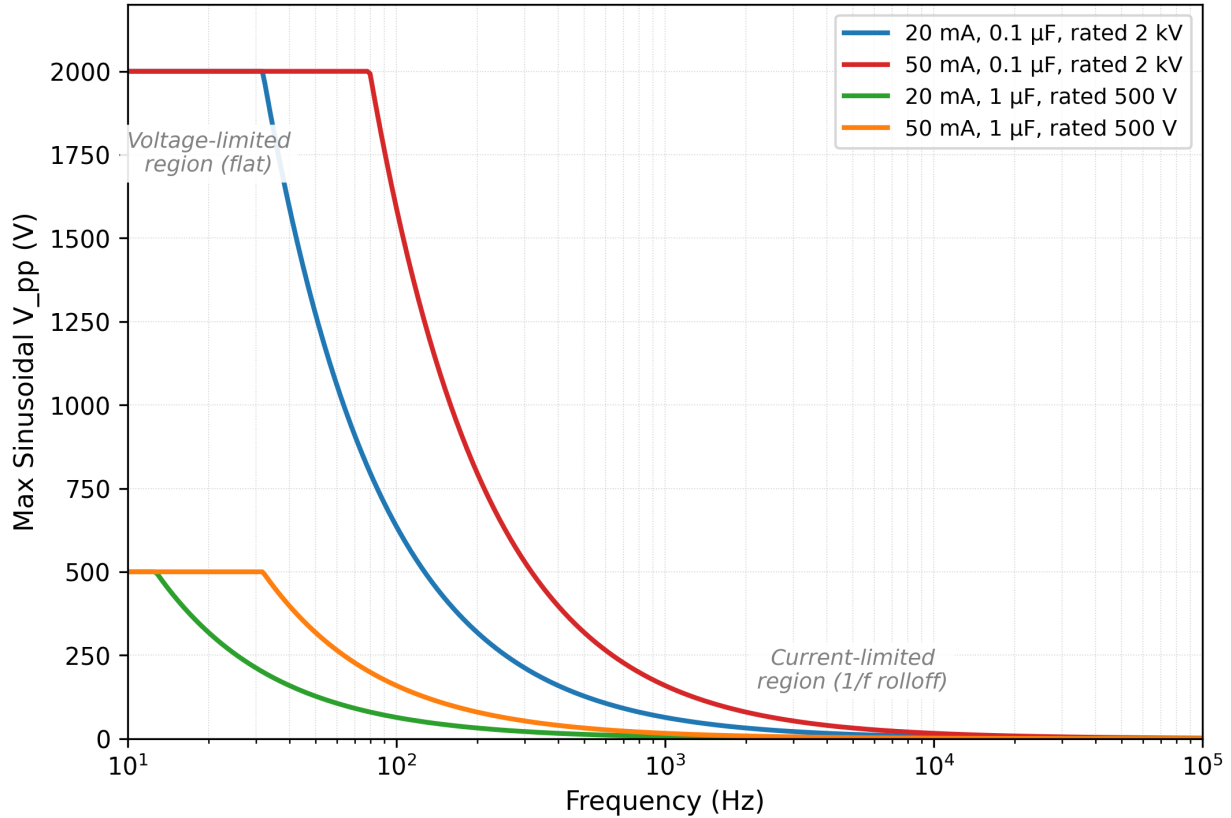


**Figure 7** — Slew-limited transition time vs. voltage swing. At  $\pm 1.8$  kV (3.6 kV total), a 2000 V/ $\mu$ s amplifier ([AHVAPN](#)) transits in 1.8  $\mu$ s while a 100 V/ $\mu$ s amplifier needs 36  $\mu$ s. Design rule: verify both bandwidth and slew rate against your largest, fastest edge.

### 10.3 Large-Signal Voltage Envelope

Below the corner frequency the output is voltage-limited (flat); above it the current limit forces the achievable swing down as  $1/f$ .

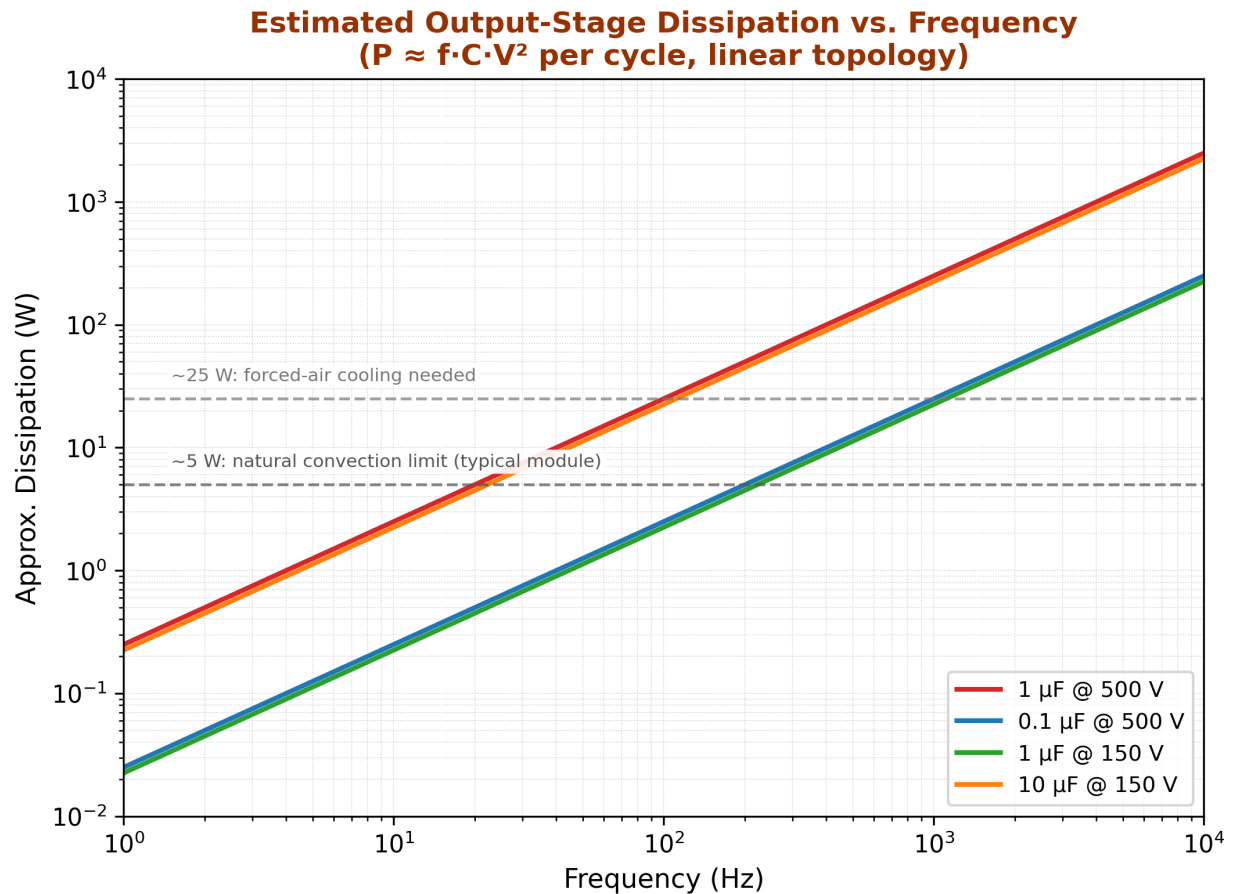
**Large-Signal Voltage Envelope vs. Frequency**  
 $(V_{pp,max} = \min(V_{rated}, I_{limit} / (\pi \cdot f \cdot C))$



**Figure 8** — Large-signal voltage envelope vs. frequency. A higher-current variant pushes the corner — and the usable bandwidth at full swing — to the right. Design rule: confirm your operating point sits under the envelope of the specific current variant you choose.

**10.4 Output-Stage Dissipation**

“Just a capacitor” still produces real heat: dissipation scales with  $f \cdot C \cdot V^2$  and climbs fast.



**Figure 9** — Estimated output-stage dissipation vs. frequency for a linear piezo driver, plotted from  $P \approx f \cdot C \cdot V_{\text{peak}}^2$  as a worst-case upper bound (all stored energy dissipated per discharge, no recovery). The  $(4/\pi) \cdot V_{\text{supply}} \cdot f \cdot C \cdot V_{\text{peak}}$  Class-AB model used in §13.3 lies within ~25% of this curve when  $V_{\text{supply}} \approx 1.2 \times V_{\text{peak}}$ . Beyond a few watts, derate, add forced cooling, or move to a switching topology such as the APZD300V2A. Design rule: estimate dissipation before committing to a linear module at high  $f \cdot C \cdot V$ .

### 10.5 Linear vs. PWM Topology — Where Does the Discharge Energy Go?

A linear piezo amplifier charges the actuator from the high-voltage rail and, on discharge, dumps the stored energy as heat through its output transistors. A PWM (switch-mode) topology operates the output as a chopper synchronized to an LC filter; on discharge, the inductor returns energy to the supply rather than dissipating it. The thermal contrast is the practical difference between the two architectures — same actuator, same motion, vastly different module temperature at high duty cycle.

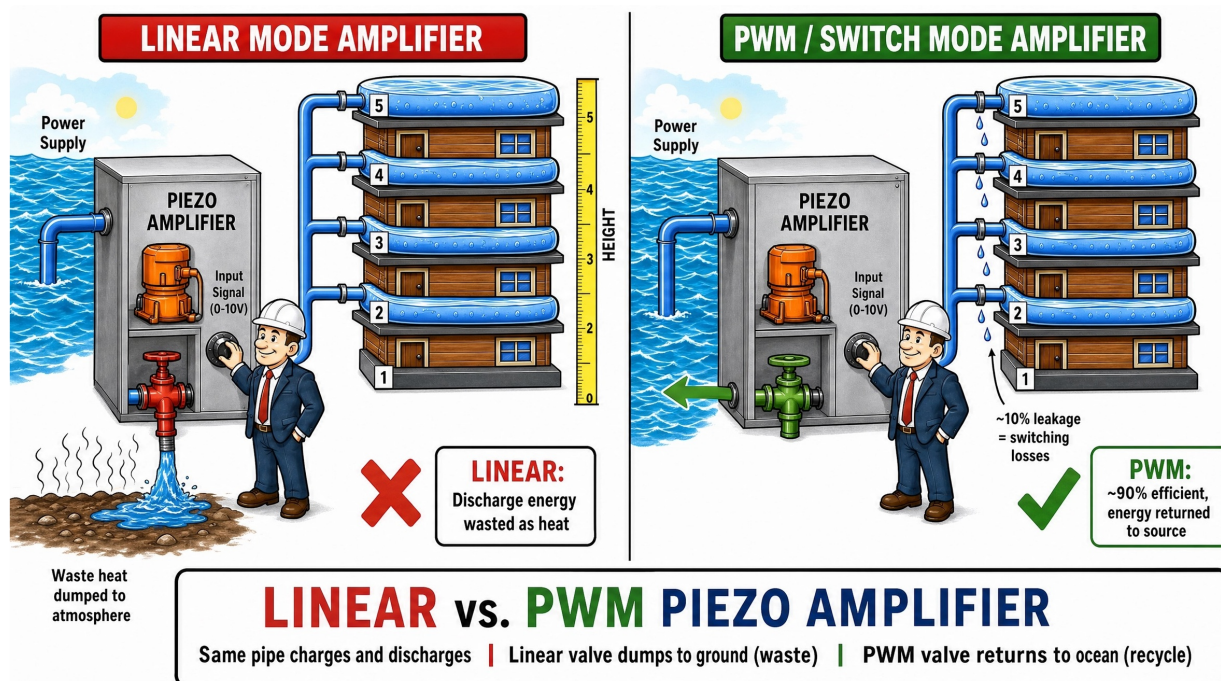
The ATI [APZD300V2A](#) is the production example in the ATI lineup. Its key parameters illustrate what PWM enables:

- **Output range:** -30 V to +300 V

- **Maximum load capacitance:** 100  $\mu\text{F}$  ( $\geq 30\times$  what a linear module in the same class can sustain at any reasonable duty cycle)
- **Frequency range:** 0.1 Hz to 20 kHz
- **Built-in waveform generator:** sine, square, and triangle output, eliminating the need for an external function generator in many bench setups
- **Power consumption:** reduced by approximately 80% relative to a linear topology at equivalent  $f\cdot C\cdot V$
- **Input supply:** 5 V (vs. 24 V for linear modules)

The PWM tradeoff is the residual switching ripple at the output. For applications where nanometer-class quiet is mandatory (interferometry, AFM imaging at low sample rates), a linear topology remains the right choice. For ultrasonic transducer drive, large bender actuators, deformable-mirror multi-channel arrays, and any application where thermal headroom drives the design, PWM wins decisively.

*Design rule:* compute the linear-module dissipation (Figure 9). If it exceeds the natural-convection limit ( $\sim 5\text{ W}$  per typical module) and forced-air cooling isn't an option, move to the APZD300V2A.



**Figure 10** — Linear vs. PWM Topology. Left: The linear amplifier dumps discharge energy to ground (heat). Right: The PWM amplifier returns discharge energy to the supply ( $\sim 90\%$  efficient). Same actuator, same motion — but vastly different thermal footprint at high duty cycle. Design rule: When dissipation exceeds the module's thermal limit, switch to a PWM topology.

**EMI footprint of PWM drive.** A PWM piezo driver switching at  $f_{sw}$  produces output ripple at  $f_{sw}$  and harmonics. The peak-to-peak ripple across the actuator is approximately:

$$V_{\text{ripple}} \approx I_{\text{peak}} / (f_{\text{sw}} \cdot C_{\text{load}})$$

For the APZD300V2A ( $f_{\text{sw}} \approx 200$  kHz) driving a 1  $\mu\text{F}$  actuator at 20 mA peak:  $V_{\text{ripple}} \approx 0.02 / (200 \times 10^3 \times 1 \times 10^{-6}) = 0.1$  V pp — negligible for most positioning. For sub-nm metrology, add a second-order LC post-filter ( $L = 10\text{--}100$   $\mu\text{H}$ ,  $C = 10\text{--}100$  nF) tuned below  $f_{\text{sw}}/10$ . Trade-off: the filter adds phase lag that limits closed-loop bandwidth.

When to choose linear over PWM: if conducted EMI compliance (CISPR 11 Group 1 Class B) is required and the system cannot tolerate a shielded enclosure, or if the application demands  $<10$  nV/ $\sqrt{\text{Hz}}$  output noise in the 1–100 kHz band, a linear module is the simpler path.

### 10.6 Current Scaling Reference Table

Capacitance	Frequency	V <sub>peak</sub> (amplitude)	I <sub>peak</sub> (with 1.5× C correction)
0.1 $\mu\text{F}$	100 Hz	500 V	47 mA
0.1 $\mu\text{F}$	1 kHz	500 V	471 mA
1 $\mu\text{F}$	100 Hz	500 V	471 mA
1 $\mu\text{F}$	1 kHz	500 V	4.71 A
10 $\mu\text{F}$	100 Hz	150 V	1.41 A
100 $\mu\text{F}$	10 Hz	150 V	1.41 A

Design rule: Every piezo RFQ should include capacitance, voltage swing, AND frequency. Missing any one makes proper selection impossible.

### 10.7 Noise-to-Displacement Budget

The [AHVAPN](#) family achieves 400  $\mu\text{V}$ p-p noise (0.1–10 Hz). For a typical actuator with 15 nm/V sensitivity, this translates to:

*Position noise  $\approx 400$   $\mu\text{V} \times 15$  nm/V = **6 pm (picometers)** — well below the resolution limit of most interferometric sensors.*

**Power-supply rejection (PSRR).** ATI linear modules achieve  $>60$  dB supply rejection at DC and  $>40$  dB up to 10 kHz. For a 24 V input with 50 mV pk-pk ripple (typical switching regulator), the HV output sees  $<50$   $\mu\text{V}$  of supply-induced noise — negligible relative to the module’s intrinsic 400  $\mu\text{V}$  floor. For battery-powered or vehicle-bus applications where supply ripple exceeds 200 mV, add a low-noise pre-regulator (LDO or LC filter) ahead of the module’s VIN pin.

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## 11. User-Configurable Features

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A piezo amplifier is rarely “one size.” ATI modules expose several parameters so one family fits many actuators:

- **Command scaling (gain/offset).** Modules accept a low-voltage command (0–5 V or  $\pm 10$  V depending on family) and apply a fixed gain ( $\approx 20\times$ – $200\times$ ). Match the command range to your DAC or controller so the actuator’s full stroke maps to the full command span — this maximizes resolution and noise immunity.
- **Output voltage range by family.** Choose the family whose range just covers the actuator: [100 V](#), [250 V](#), [500 V](#), [1 kV](#), or [2 kV](#). Oversizing voltage wastes resolution; undersizing clips stroke.
- **Current variant.** Within a family, pick the current rating (e.g., [AHVA500V2X](#) at 5/10/30/50 mA) to match the peak current your waveform requires plus  $\geq 1.5\times$  margin.
- **Polarity.** Unipolar-positive ([AHVA series](#)), negative ([AHVAN](#)), or high-speed bipolar ([AHVAPN](#)) — match the actuator’s allowed field direction.
- **Bench evaluation.** For lab characterization, the [benchtop ATI242000A](#) (0–2 kV, 200 V/ $\mu$ s, up to 20 kHz, up to 20 mA) lets you exercise an actuator before committing to a board-mounted module.

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**Multi-channel synchronization.** When driving multi-axis stages or arrays, inter-channel skew must be  $< 1/(10 \cdot f_{\max})$  to avoid cross-axis coupling. ATI modules accept a common external clock or trigger input; for multi-board systems, distribute a single reference clock and use matched-length coax. Crosstalk between adjacent channels should be verified at  $< -60$  dB; use per-channel LC output filters if the PCB layout cannot guarantee adequate ground-plane isolation.

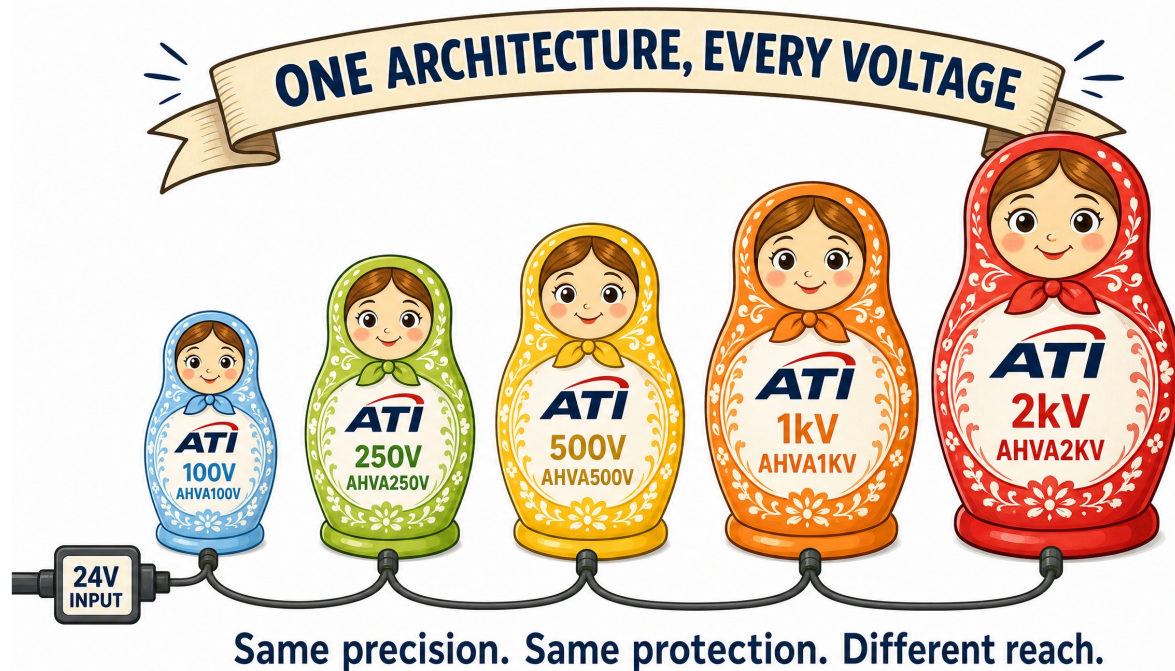
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## 12. Matching ATI Product Families to Your Application

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### 12.1 The Russian Nesting Dolls

ATI’s piezo amplifier / piezo driver families are like Russian nesting dolls — same elegant architecture at every voltage level, from 100 V to 2 kV. Same protection. Same precision. Just different reach.



**Figure 11** — Russian Nesting Dolls: One Architecture, Every Voltage. From 100 V to 2 kV, ATI’s amplifier families share the same design philosophy — integrated HV supply, full protection, precision gain. Pick the voltage that matches your actuator. Design rule: Start with the eval unit at your voltage; scale up or down within the ATI family without redesigning your control loop.

## 12.2 Product Selection Table

Application Need	Typical Requirement	ATI Starting Point
High-speed bipolar piezo scanning	$\pm 1$ kV to $\pm 1.8$ kV, 2000 V/ $\mu$ s	<a href="#">AHVAPN series</a>
High-speed unipolar 2 kV	10 V to 2 kV, 2000 V/ $\mu$ s	<a href="#">AHVAPN2000V20MABN</a> (unipolar variant)
Positive-output piezo stack drive	10 V to 2 kV, 10–20 mA	<a href="#">AHVA2KV2X family</a>
Mid-voltage actuator drive	10 V to 1 kV, 10–20 mA	<a href="#">AHVA1KV2X family</a>
Lower-voltage, higher-current	10 V to 500 V, 5–50 mA	<a href="#">AHVA500V2X family</a>
Low-voltage precision	10 V to 250 V, 5–40 mA	<a href="#">AHVA250V2X family</a>
Compact 100 V drive	10 V to 100 V, 10–50 mA	<a href="#">AHVA100V2X family</a>
Negative-output actuator drive	–1 kV (–2 kV, –2.5 kV under development)	<a href="#">AHVAN series</a>
Benchtop lab testing	AC input, 0–2 kV, 200 V/ $\mu$ s, 20 kHz	<a href="#">ATI242000A</a>
Large-capacitance high-efficiency	Up to 100 $\mu$ F, –30 V to 300 V, VIN 5 V	<a href="#">APZD300V2A</a> (under development)

Application Need	Typical Requirement	ATI Starting Point
Board-level HV op-amp integration	Up to 1500 V, 100 mA	<a href="#">AHVOA1500V100MA</a>

### 12.3 Full Product Lineup

Part Number	Output Voltage	Max Current	Slew Rate	Bandwidth	Input	Operating Temp	Package / Dimensions
<a href="#">AHVAPN2000V20MABN</a>	10 V–2 kV (unipolar)	20 mA	2000 V/ $\mu$ s	15 kHz	$\pm$ 10 V	–40 to +85 °C	PCB module, 51×51×15 mm, ~45 g
<a href="#">AHVAPN1800V20MABN</a>	$\pm$ 1800 V (bipolar)	20 mA	2000 V/ $\mu$ s	15 kHz	$\pm$ 10 V	–40 to +85 °C	PCB module, 51×51×15 mm, ~45 g
<a href="#">AHVAPN1KV20MABN</a>	$\pm$ 1000 V (bipolar)	20 mA	2000 V/ $\mu$ s	15 kHz	$\pm$ 10 V	–40 to +85 °C	PCB module, 51×51×15 mm, ~45 g
<a href="#">AHVA2KV2X20MA</a>	10–2000 V	20 mA	150 V/ $\mu$ s	10 kHz	24 V	–40 to +85 °C	PCB module, 51×51×15 mm, ~40 g
<a href="#">AHVA2KV2X10MA</a>	10–2000 V	10 mA	150 V/ $\mu$ s	10 kHz	24 V	–40 to +85 °C	PCB module, 51×51×15 mm, ~40 g
<a href="#">AHVA1KV2X20MA</a>	10–1000 V	20 mA	100 V/ $\mu$ s	10 kHz	24 V	–40 to +85 °C	PCB module, 51×51×15 mm, ~40 g
<a href="#">AHVA500V2X50MA</a>	10–500 V	50 mA	100 V/ $\mu$ s	10 kHz	24 V	–40 to +85 °C	PCB module, 38×38×12 mm, ~30 g
<a href="#">AHVA500V2X30MA</a>	10–500 V	30 mA	100 V/ $\mu$ s	10 kHz	24 V	–40 to +85 °C	PCB module, 38×38×12 mm, ~30 g
<a href="#">AHVA250V2X40MA</a>	10–250 V	40 mA	100 V/ $\mu$ s	10 kHz	24 V	–40 to +85 °C	PCB module, 38×38×12 mm, ~30 g
<a href="#">AHVA100V2X50MA</a>	10–100 V	50 mA	100 V/ $\mu$ s	10 kHz	24 V	–40 to +85 °C	PCB module, 25×25×10 mm, ~15 g
<a href="#">AHVAN1KV</a>	–1000 V (negative)	—	—	—	24 V	–40 to +85 °C	PCB module, 51×51×15 mm, ~40 g
<a href="#">ATI242000A</a>	0–2000 V	20 mA	200 V/ $\mu$ s	20 kHz	AC mains	0 to +40 °C	Benchtop, 220×150×80 mm, ~1.5 kg
<a href="#">APZD300V2A</a>	–30 to 300 V	—	—	20 kHz	5 V	–40 to +85 °C	PCB module, 51×51×15 mm, ~45 g
<a href="#">AHVOA1500V100MA</a>	Up to 1500 V	100 mA	—	—	—	–40 to +85 °C	PCB module, 51×51×15 mm, ~45 g

Note: APZD300V2A is under development. AHVAN -2 kV and -2.5 kV variants are under development. Confirm availability with ATI before design-in.

## 13. Design Procedure — From Actuator Datasheet to Working System

### 13.1 The Nine-Step Recipe

**See also:** The nine-step recipe below can be visualized as a decision flowchart. A printable one-page PDF flowchart is available at [analogtechnologies.com/piezo-selection-flowchart](http://analogtechnologies.com/piezo-selection-flowchart) (forthcoming).

Step	Action	What You Need
1	Define the actuator	Capacitance (large-signal), voltage range, max voltage, polarity, insulation
2	Define the motion	Stroke, frequency, waveform, duty cycle, settling time
3	Estimate current	$I = C \times dV/dt$ (ramp) or $I_{\text{peak}} = 2\pi fCV_{\text{peak}}$ (sine); use 1.5–2× C; then compute $I_{\text{RMS}}$ from the waveform shape (see Table in §5.4)
4	Check voltage range	Positive-only, negative-only, or bipolar?
5	Check speed	Verify both bandwidth AND slew rate ( $t_{\text{min}} = \Delta V/SR$ )
6	Check thermal stress	High $f \times C \times V =$ high dissipation (see Figure 9)
7	Check protection	Soft start, current limit, OTP, connector safety
8	Prototype	Test with real actuator — catalog values differ from reality
9	Confirm with ATI	Send actuator datasheet + waveform to <a href="#">RFQ page</a>

### 13.2 Worked Example: Nanopositioning Stage

Parameter	Value
Actuator	PZT stack, 2 $\mu\text{F}$ (small-signal), 0–150 V, 15 $\mu\text{m}$ stroke
Large-signal C	2 $\mu\text{F} \times 1.5 = 3 \mu\text{F}$
Motion	10 Hz triangle wave, full stroke (0–150 V)
dV/dt for triangle	150 V / (1/20 s) = 3000 V/s

Parameter	Value
Required current	$3 \mu\text{F} \times 3000 \text{ V/s} = \mathbf{9 \text{ mA}}$
Selected amplifier	<a href="#">AHVA250V2X40MA</a> (10–250 V, 40 mA, 100 V/ $\mu\text{s}$ )
Current margin	$40 \text{ mA} / 9 \text{ mA} = 4.4\times$ — excellent
Slew check	$150 \text{ V} / 100 \text{ V}/\mu\text{s} = 1.5 \mu\text{s}$ — negligible vs. 50 ms half-period

For the same actuator at 1 kHz sine:  $I_{\text{peak}} = 2\pi \times 1000 \times 3 \times 10^{-6} \times 75 = \mathbf{1.41 \text{ A}}$  — a completely different amplifier class is needed (consider [APZD300V2A](#) for high-capacitance, high-current applications). Frequency changes everything.

### 13.3 Worked Example: High-Capacitance Ultrasonic Drive

Parameter	Value
Actuator	Piezo bender stack, 20 $\mu\text{F}$ (small-signal), 0 to +250 V
Large-signal C	$20 \mu\text{F} \times 1.5 = 30 \mu\text{F}$
Motion	5 kHz sinusoidal, full stroke ( $V_{\text{peak}} = 125 \text{ V}$ )
Required $I_{\text{peak}}$	$2\pi \times 5000 \times 30 \times 10^{-6} \times 125 = \mathbf{118 \text{ mA}}$
Estimated dissipation (linear, Class-AB output stage)	$P_{\text{diss}} \approx (4/\pi) \cdot V_{\text{supply}} \cdot f \cdot C \cdot V_{\text{peak}} \approx (4/\pi) \cdot 300 \cdot 5000 \cdot 30 \times 10^{-6} \cdot 125 \approx \mathbf{24 \text{ W}}$
Linear viability	Exceeds the $\sim 5 \text{ W}$ natural-convection limit. Forced air would cool it but adds complexity and noise.
Selected amplifier	<a href="#">APZD300V2A</a> — PWM, $\sim 90\%$ efficient, supports 100 $\mu\text{F}$ , frequency covers 5 kHz
Dissipation in PWM module	$\sim 2 \text{ W}$ typical at this operating point — fits in a sealed enclosure with no forced cooling

The  $(4/\pi) \cdot V_{\text{supply}} \cdot f \cdot C \cdot V_{\text{peak}}$  estimate is the average dissipation in a Class-AB output stage driving a sinusoidal capacitive load, assuming the supply just covers  $V_{\text{peak}}$  with realistic headroom ( $V_{\text{supply}} \approx 1.2 \times V_{\text{peak}}$ ; here,  $V_{\text{supply}} = 300 \text{ V}$  over a 125 V peak). RMS-current sanity check:  $I_{\text{RMS}} = I_{\text{peak}}/\sqrt{2} = 83 \text{ mA}$ , so  $P \approx V_{\text{supply}} \cdot I_{\text{RMS}} = 300 \times 0.083 \approx 25 \text{ W}$  — same answer by a different route. Either way, the result sits firmly above the  $\sim 5 \text{ W}$  natural-convection limit, so a linear module is not viable at this duty cycle without forced cooling.

The same selection procedure that routed the slow nanopositioner to an AHVA250V2X routes this case to the APZD300V2A. The difference is not the procedure; it is the operating point's location on Figure 9.

### 13.4 Worked Example: 32-Channel Deformable Mirror (Adaptive Optics)

Parameter	Value
Actuator	32-element deformable mirror (DM), each actuator 50 nF (small-signal), 0 to +100 V, 2 μm stroke per channel
Large-signal C (per channel)	50 nF × 1.5 = 75 nF
Motion	Wavefront correction loop at 1 kHz update rate, step waveform (worst-case dV/dt)
Required I <sub>peak</sub> per channel	$C \times dV/dt = 75 \text{ nF} \times 100 \text{ V} / 10 \text{ μs}$ (slew-limited) = <b>0.75 mA</b> per channel
Total system current (32 ch)	32 × 0.75 mA = <b>24 mA</b> (worst case, all channels slewing simultaneously)
Inter-channel skew requirement	$<1/(10 \times f_{\text{max}}) = <100 \text{ μs}$ — easily met with common trigger
Crosstalk requirement	<-60 dB between adjacent channels (wavefront fidelity)
Selected amplifier	32× <a href="#">AHVA100V2X50MA</a> — 10–100 V, 50 mA per channel, 100 V/μs, -40 to +85 °C
Current margin per channel	50 mA / 0.75 mA = 67× — headroom allows burst corrections without current limiting
Noise budget	400 μV pk-pk × 20 nm/V (typical DM sensitivity) = 8 pm — negligible vs. λ/20 wavefront error

#### Multi-channel layout considerations:

- **Common reference clock.** Distribute a single trigger to all 32 modules so actuator updates are synchronous. ATI modules accept an external trigger input; use matched-length coax from a fanout buffer.
- **Ground-plane isolation.** Route each channel's HV output on a separate layer or with guard traces. Verify crosstalk at <-60 dB using a network analyzer before closing the optical loop.
- **Thermal density.** 32 modules at ~0.1 W each = 3.2 W total — well within natural convection for a standard 19" rack enclosure. No forced cooling required.
- **Compact form factor.** Each AHVA100V2X50MA is 25×25×10 mm (~15 g), so 32 channels fit on a single 200×150 mm motherboard with room for connectors and filtering.

This example demonstrates that ATI's smallest module family scales cleanly to multi-channel adaptive-optics systems. The same architecture applies to scanning-mirror arrays, multi-axis micro-manipulators, and phased-array ultrasonic transducers.

## 14. Best Practices

1. **Specify the full waveform, not just voltage.** Capacitance, peak voltage, frequency, waveform shape, and duty cycle together determine the amplifier — any one missing makes selection impossible.

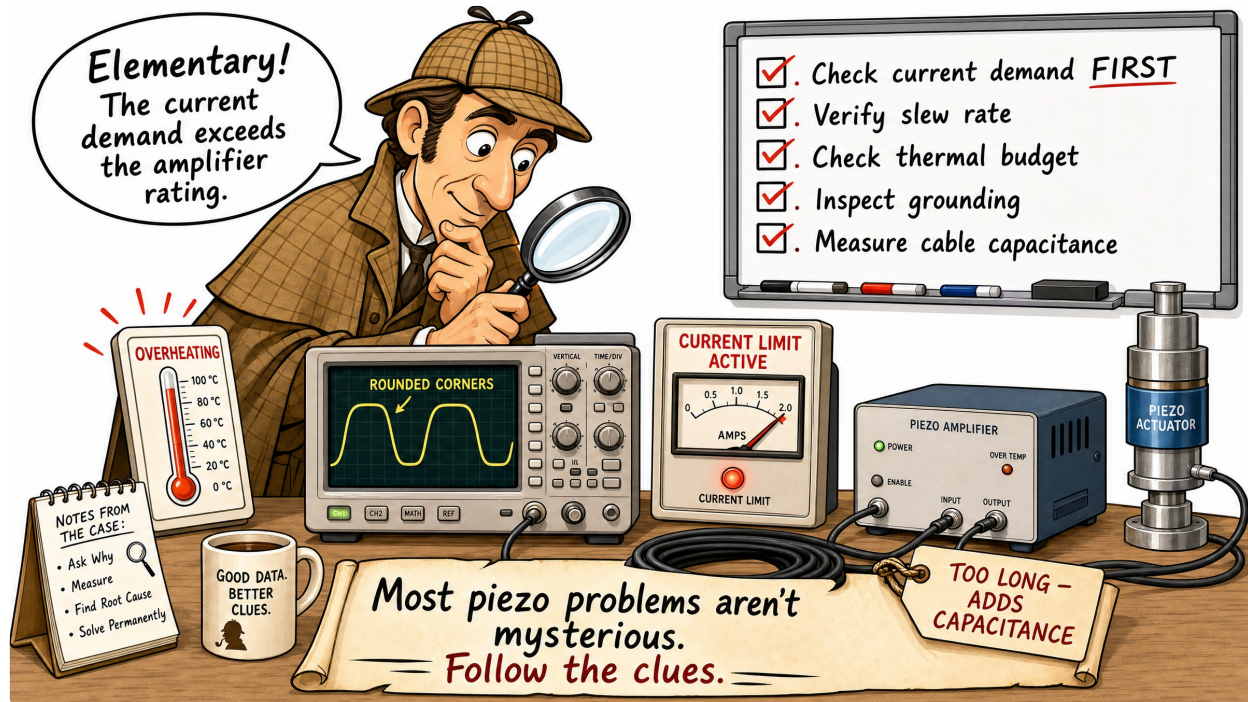
2. **Use large-signal capacitance.** Apply the 1.5–2× factor before computing current.
3. **Check slew rate and bandwidth.** For large strokes, slew rate usually limits first (see Figure 7).
4. **Leave current margin.** Target  $\geq 1.5\times$  the computed peak current so the output never current-limits at the waveform corners.
5. **Match polarity to the actuator.** Confirm unipolar/bipolar before energizing. Driving a unipolar stack negative depolarizes it permanently.
6. **Separate HV and signal wiring; keep HV cables short.** Reduces coupled noise and LC ringing.
7. **Prototype with the real actuator.** Catalog capacitance differs from the device on your bench — especially under load and at temperature.
8. **Send ATI the actuator datasheet + waveform** via the [RFQ page](#) for a checked recommendation.

## 15. Common Mistakes & How to Avoid Them

Mistake	Why It Bites	Avoid By
Selecting by peak voltage alone	Voltage sets stroke, not speed; the amplifier current-limits at frequency	Compute $I_{\text{peak}} = 2\pi f \cdot C \cdot V_{\text{peak}}$ first
Using small-signal capacitance	Under-predicts current by 1.5–2×	Apply the large-signal capacitance factor
Ignoring slew rate	Large swings round off even within bandwidth	Verify $t_{\text{min}} = \Delta V / SR$ for your worst-case edge
Treating the load as “just a capacitor”	Cable, ESR, and output-stage losses produce real heat	Include a dissipation estimate; derate at high f
Driving a unipolar stack negative	Depolarizes the ceramic permanently	Match polarity; use <a href="#">AHVAN</a> for negative-only
No current margin	Output clips at waveform corners	Size for $\geq 1.5\times$ computed peak current

## 16. Troubleshooting Quick Reference

### 16.1 The Diagnostic Detective



**Figure 12** — The Diagnostic Detective. Most piezo amplifier problems trace to voltage, current, slew rate, thermal stress, or grounding. Follow the clues systematically. Design rule: When the piezo misbehaves, check current demand first — it’s the most common culprit.

### 16.2 Symptom → Cause → Fix

Symptom	Likely Cause	Fix
Output can’t reach commanded voltage	Current limit active, supply issue	Reduce frequency or capacitance; verify 24 V input
Waveform corners are rounded	Slew-rate limiting	Choose higher slew-rate family ( <a href="#">AHVAPN</a> ) or reduce swing/frequency
Amplifier overheats	High RMS current into capacitive load	Reduce duty cycle, improve airflow, select higher-current model
Piezo motion rings or oscillates	Mechanical resonance, cable LC resonance	Reduce command bandwidth, add series damping resistor, shorten HV cable
Position noise	Grounding, cable routing, amplifier noise	Separate HV and signal wiring, improve shielding

Symptom	Likely Cause	Fix
Output shuts down unexpectedly	OTP, overcurrent, UVLO/OVLO triggered	Review protection status indicators; reduce load demand
Actuator cracked or depolarized	Exceeded max voltage or wrong polarity	Never exceed actuator rated voltage; verify polarity match with <a href="#">AHVAN</a> for negative stacks
No output at turn-on	Soft-start in progress, UVLO active	Wait for startup sequence; verify supply voltage

## 17. Applications — Where Piezo Amplifiers Work

Application	What the Amplifier Must Do	Key Selection Parameter	ATI Starting Point
Nanopositioning stage	Quiet, stable, precise displacement	Noise, drift, voltage resolution	<a href="#">AHVA250V2X</a>
Fast scanning mirror / galvo	Repeatable large-signal waveform at high rate	Slew rate, bandwidth, current	<a href="#">AHVAPN</a>
Piezo valve / inkjet dispenser	Sharp actuation with controlled energy	Current, rise time, protection	<a href="#">AHVA500V2X</a>
Active vibration cancellation	Follow feedback command in real time	Bandwidth, phase delay, thermal duty	<a href="#">AHVA1KV2X</a>
Microscopy focus (confocal, AFM)	Fine motion with ultra-low noise	Stability, low ripple, grounding	<a href="#">AHVA100V2X</a>
Ultrasonic transducer drive	High-frequency capacitive current	Current capacity and thermal limit	<a href="#">APZD300V2A</a>
Semiconductor test & inspection	High voltage precision in test fixture	Noise, safety, repeatability	<a href="#">AHVA2KV2X</a>
Optical fiber alignment	Slow/medium precision multi-axis motion	Voltage range, multi-channel	<a href="#">AHVA250V2X</a>
Adaptive optics (deformable mirror)	Many channels, moderate voltage	Per-channel noise, density	<a href="#">AHVA100V2X</a>
Research lab prototyping	Flexible, easy-to-use test setup	Benchtop package, RFQ support	<a href="#">ATI242000A</a>

## 18. FAQ — Questions Engineers Actually Ask

**Q1: What is a piezo amplifier?** A piezo amplifier (also known as a piezo driver or high-voltage amplifier) is a power amplifier specifically designed to drive capacitive piezoelectric actuators from a low-voltage command signal, providing both the voltage range and the current capacity needed for controlled motion.

**Q2: Is a piezo amplifier the same as a high-voltage power supply?** No. A power supply provides static DC bias. A piezo amplifier follows a dynamic command waveform and must source AND sink capacitive current as the actuator charges and discharges.

**Q3: Why does capacitance matter so much?** Because  $I = C \times dV/dt$ . Higher capacitance at the same speed requires proportionally more current. A 10  $\mu\text{F}$  actuator needs 100 $\times$  the current of a 0.1  $\mu\text{F}$  actuator at the same frequency and voltage.

**Q4: What matters more — bandwidth or slew rate?** Both. Bandwidth describes small-signal frequency response. Slew rate determines large-signal voltage transition speed. For large piezo strokes, slew rate usually dominates.

**Q5: Can I select a piezo driver (piezo amplifier) by voltage alone?** Never. Voltage sets stroke, but current and speed determine whether the actuator can actually follow your commanded waveform.

**Q6: Why does the amplifier heat up if the load is “just a capacitor”?** An ideal capacitor returns all stored energy, but real amplifiers, cables, and actuators have losses. High-frequency operation multiplies these losses by the number of charge/discharge cycles per second. See Figure 9.

**Q7: What is large-signal capacitance and why does it matter?** PZT permittivity rises with applied field and temperature, so the effective capacitance under full drive is 1.5–2 $\times$  the small-signal catalog value. All current estimates should use this corrected value.

**Q8: What happens if I drive a unipolar stack with reverse voltage?** The reverse field exceeds the coercive limit and permanently depolarizes the ceramic — the actuator loses stroke and cannot be recovered. Always match amplifier polarity to actuator requirements.

**Q9: Do ATI amplifiers need an external high-voltage supply?** No. All ATI piezo amplifier modules include a built-in high-voltage DC-DC converter. Connect 24 V (or 5 V for [APZD300V2A](#)) and the module generates the HV internally.

**Q10: What information should I send for an RFQ?** Send: actuator capacitance (large-signal if known), voltage range, waveform shape, frequency, duty cycle, desired rise/fall time, polarity, connector preference, and application description to the [ATI RFQ page](#).

**Q11: How do I choose between AHVA (unipolar) and AHVAPN (bipolar)?** If your actuator requires bipolar field ( $\pm\text{V}$ ), use [AHVAPN](#). If it's a standard unipolar stack (0 to +V), use the [AHVA series](#). For negative-only stacks, use [AHVAN](#).

**Q12: What noise level can I expect?** The [AHVAPN](#) family achieves 400  $\mu\text{Vp-p}$  (0.1–10 Hz). For a 15 nm/V actuator, this translates to approximately 6 pm position noise — well below the noise floor of most position sensors and interferometers.

**Q13: Can I drive a piezoelectric actuator with a standard op-amp?** Only for very low voltage actuators (<100 V) and very small capacitance (<10 nF). Standard op-amps cannot supply enough current to charge a typical piezo stack at useful frequencies, and most have output stages that are unstable into a large capacitive load. For any production application above 100 V or above  $\sim 100$  nF, use a piezo amplifier module (AHVA, AHVAN, or AHVAPN family) or, for board-level integration, the high-voltage op-amp [AHVOA1500V100MA](#) designed specifically for capacitive loading.

**Q14: Does closed-loop drive eliminate hysteresis and creep?** Yes, when the loop is closed with a position sensor (strain gauge or capacitive sensor) rather than just on output voltage. Voltage-only closed-loop control regulates the amplifier output but does not correct the actuator's mechanical nonlinearity — open-loop hysteresis of 10–15% of stroke remains. Position-feedback closed-loop control reduces hysteresis to <0.1% of stroke and creep to <0.05% per decade of time, at the cost of additional sensor hardware. The feedback path in Figure 2 shows voltage feedback only; an external position-feedback loop wraps around the entire amplifier-plus-actuator assembly.

**Q15: How do I size the heatsink for a linear piezo amplifier?** Compute the worst-case dissipation  $P \approx V_{\text{supply}} \cdot I_{\text{RMS}}$  using  $I_{\text{RMS}} = I_{\text{peak}}/\sqrt{2}$  for sinusoidal drive. Required heatsink-to-ambient thermal resistance  $\theta_{\text{sa}} < (T_{\text{j,max}} - T_{\text{ambient}} - P \cdot \theta_{\text{jc}}) / P$ . ATI modules use the case as the thermal interface; bolt to a chassis with  $\geq 10$  cm<sup>2</sup> contact area for sustained operation above about 5 W.

**Q16: Can I parallel two piezo amplifiers to get more current?** No. Parallel operation requires precisely matched output impedance and active current-share circuitry; without both, one amplifier hogs the load and trips OTP while the other sits idle. Use the next-higher current variant within the same family, or contact ATI engineering for high-current custom requirements.

**Q17: What oscilloscope probe should I use to measure the HV output?** Use a high-voltage differential probe (typically 100:1 or 1000:1) rated for at least  $2\times$  your maximum output voltage, with bandwidth  $\geq 10\times$  the highest waveform component of interest. Never connect a single-ended probe's ground clip to the HV output return — both the probe and the amplifier can be damaged.

**Q18: How long does a piezo actuator stay charged after the amplifier turns off, and is it a safety concern?** A 30  $\mu\text{F}$  actuator at 250 V stores  $\frac{1}{2} \cdot C \cdot V^2 = 0.94$  J — comparable to a small camera-flash capacitor and enough to give an unpleasant shock. Self-discharge through actuator leakage takes seconds to minutes for small stacks and hours for large low-leakage actuators. Always include a bleed-down resistor ( $\sim 10$  M $\Omega$  typical) across the actuator or an interlock that shorts the output through a current-limited path at power-down. Treat any HV piezo system as live until verified discharged with a meter.

## 19. Summary & Conclusion

A piezo amplifier (high-voltage amplifier / piezo driver) is the bridge between a low-voltage controller and a high-voltage capacitive actuator, and it must supply both the voltage for displacement and the current for speed. Selection comes down to four quantitative decisions — voltage range, polarity, peak/RMS current, and slew rate/bandwidth — each derivable from the actuator datasheet and the target waveform using  $I = C \cdot dV/dt$  and  $t_{min} = \Delta V/SR$ , with a 1.5–2× large-signal capacitance correction and  $\geq 1.5\times$  current margin.

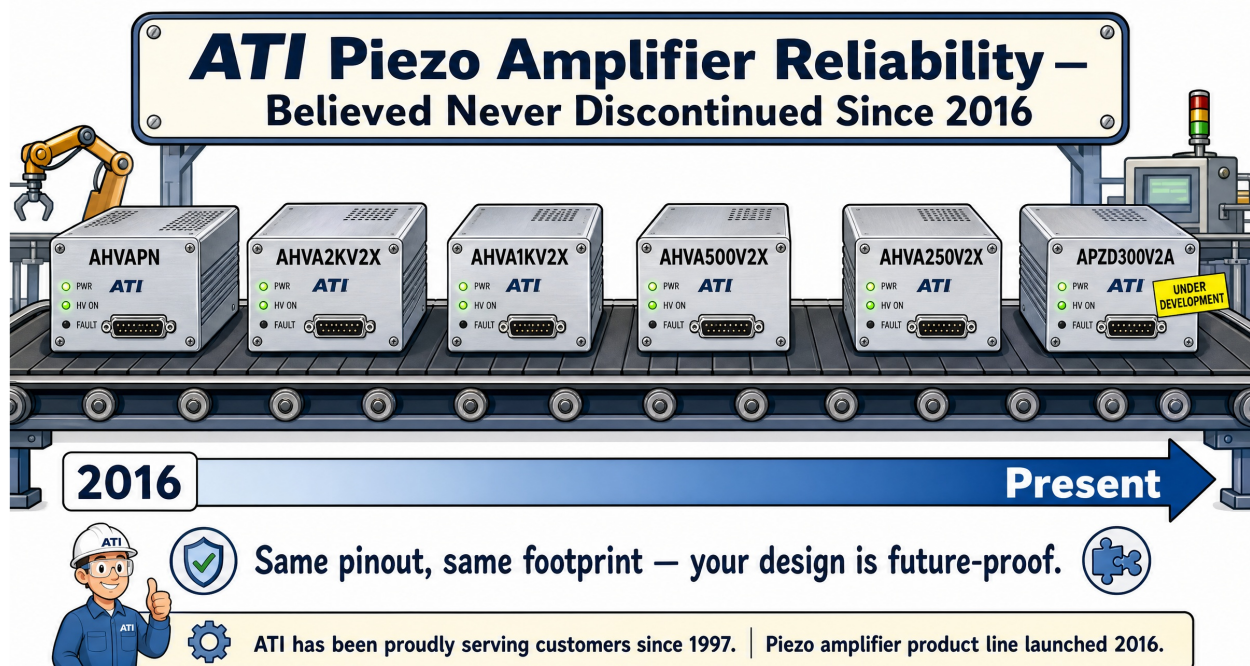
ATI's integrated, protected modules let you make those decisions without designing a high-voltage supply: pick the [voltage family](#) that covers your stroke, the current variant that covers your waveform, and the polarity your actuator allows.

### Next steps:

- Review the relevant datasheet: [AHVAPN \(PDF\)](#), [AHVA2KV2X \(PDF\)](#), [AHVA1KV2X \(PDF\)](#), [AHVA500V2X \(PDF\)](#), [AHVA250V2X \(PDF\)](#), [AHVA100V2X \(PDF\)](#), [APZD300V2A \(PDF\)](#)
- Evaluate on the [benchtop ATI242000A](#)
- Send your actuator specs to [ATI engineering via RFQ](#)

## 20. Why ATI — The Engineer's Choice Since 1997

### 20.1 The Reliability Timeline



**ATI Piezo Amplifier Reliability – Believed Never Discontinued Since 2016**

2016 → Present

Same pinout, same footprint – your design is future-proof.

ATI has been proudly serving customers since 1997. | Piezo amplifier product line launched 2016.

**Figure 13** — The Reliability Timeline. ATI is believed to have never discontinued a piezo amplifier model since the product line launched in 2016. The company has been serving precision-electronics customers since 1997. Pin-compatible upgrades, same-day shipping from San Jose inventory (typical), direct engineering support from the designers who built the product. Design rule: Choose a vendor whose product lifecycle matches your product's.

## 20.2 ATI Differentiators

Feature	ATI Advantage
Integrated HV supply	No external HV power supply needed — just 24 V (or 5 V)
Full protection suite	UVLO, OVLO, OTP, soft start, current limit, ESD
Ultra-low noise	400 $\mu\text{Vp-p}$ @ 0.1–10 Hz ( <a href="#">AHVAPN</a> family)
High slew rate	2000 V/ $\mu\text{s}$ typical, 2400 V/ $\mu\text{s}$ max (per AHVAPN datasheet) — among the fastest commercially available high-voltage amplifiers
Wide voltage range	100 V to 2 kV (unipolar); $\pm 1.8$ kV (bipolar) across families
Negative-output option	<a href="#">AHVAN</a> for negative-only actuators
High-efficiency driver	<a href="#">APZD300V2A</a> for large-capacitance loads (under development)
Compact modules	Drop-in PCB mounting, no bench instruments needed
Since-2016 continuity	No piezo amplifier model believed to have been discontinued (company since 1997)
Same-day shipping	San Jose, CA inventory (typical)
Direct engineering support	<a href="#">Contact ATI</a> — talk to the circuit designers

## 21. Related ATI Resources

- [High Voltage Amplifier / Piezo Driver category](#)
- [AHVAPN High-Speed Bipolar Amplifiers](#)
- [AHVA2KV2X 2 kV Piezo Driver](#)
- [AHVA1KV2X 1 kV Piezo Driver](#)
- [AHVA500V2X 500 V Piezo Driver](#)
- [AHVA250V2X 250 V Piezo Driver](#)
- [AHVA100V2X 100 V Piezo Driver](#)
- [AHVAN Negative-Output Series](#)
- [Benchtop High-Voltage Amplifier ATI242000A](#)

- [APZD300V2A High-Efficiency Piezo Driver](#)
- [High-Voltage Operational Amplifier AHVOA1500V100MA](#)
- [Request a Quote](#)
- [Contact ATI Engineering Support](#)

## Appendix A — Bench Safety for High-Voltage Piezo Work

*Disclaimer: The guidelines below are for informational purposes only and do not replace site-specific EHS protocols, OSHA / IEC compliance review, or the judgment of a qualified safety engineer. Analog Technologies, Inc. assumes no liability for use or misuse of this guidance.*

Piezo amplifiers routinely produce voltages above 100 V and can store lethal energy in large-capacitance actuators. Observe these minimum precautions:

1. **Assume live until proven dead.** After power-down, measure the actuator voltage with a rated HV probe before touching any conductor. Self-discharge can take minutes for low-leakage stacks.
2. **Bleed resistor.** Install a 10 M $\Omega$  bleed across the actuator output so stored energy dissipates within  $\sim 5 \times RC$  after power-down. For a 1  $\mu\text{F}$  actuator at 1 kV, that is  $\sim 50$  s.
3. **One hand rule.** When probing HV circuits, keep one hand in your pocket to prevent a hand-to-hand current path across the chest.
4. **Banana-plug ban.** Never use standard 4 mm banana connectors above 500 V. Use SHV, MHV, or Lemo HV connectors rated for the working voltage.
5. **Enclosure interlock.** For automated systems, wire a normally-closed interlock switch on the enclosure door to the amplifier's ENABLE input. Opening the door must disable HV within  $<10$  ms.
6. **Labeling.** Mark all HV conductors, connectors, and PCB areas with IEC 60417-5036 (lightning bolt) symbols. Include the maximum voltage on the label.
7. **Buddy system.** For voltages above 1 kV, never work alone. Ensure a colleague trained in electrical first aid is within earshot.

These are minimum guidelines. Consult your institution's EHS office for site-specific HV safety protocols.

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