Piezoelectric effect is when certain solid material is compressed under mechanical stress, and it develops a voltage potential by accumulating electrical charges. French physicists Jacques and Pierre Curie discovered the effect in 1880. The inverse piezoelectric effect is when voltage applied to some ceramic materials causes it to expand or contract as shown in Figure 1. Over the next 100 years since the discovery, there have been numerous advancements leading to the discovery of many superior piezo materials (i.e. PZT) and the invention of many practical piezoelectric devices.

**Figure 1** Piezo device expand/contract as applied voltage swing positive to negative

Most piezo (sometimes called PZT) devices today use the inverse piezoelectric effect. Examples of inverse piezoelectric effect devices are: piezo actual, motor, speaker/buzzer, high-power ultrasound transducer for cleaning, imaging, levitation, etc. Some of these PZT devices are operating at DC voltages, while some are driven by AC waveforms such as sine, square, and others. Let’s exam the fundamentals of piezo devices and techniques for driving them.

Piezo devices usually require high voltage to operate. Their required voltage ranges from 10V to as high as 200V. For AC devices, the required frequency is as high as 1 MHz. Additionally, piezoelectric devices are generally capacitive (except at resonant). The combination of high capacitance, high frequency, and high voltage requirements makes it difficult to drive these devices.

Usually piezo manufacturers specify their device capacitance at a given frequency. For the first order of approximation, most non-resonant piezo devices can be approximately modeled as a capacitor shown in **Figure 2**. The impedance is expressed in Equation 1. The current required to drive the PZT device is calculated from Ohm’s law as shown in Equation 2. From Equation 2, the current (I) is proportional to voltage (V), capacitance (C), and frequency (f).
Let’s use an example. For a high-frequency piezoelectric actuator whose capacitance is 1.1uF, the required peak voltage is 30V, and the driving frequency is 15kHz; the peak current required from the driver is about 2.5A (5.0A peak-to-peak). The piezo driver must be able to output such high current, high voltage, and high frequency at the same time. Higher frequency requires even more current.

### High-current piezoelectric amplifier

As discussed above, the piezo transducer device’s operating voltage range can be anywhere from 10V to 200V or more. Furthermore for AC piezo devices that have any combination of high capacitance, high voltage, or high frequency will require a high current driver. Signal and function generators commonly found in labs can output less than 5V into a 50 ohm load. Their output voltage is even lower when the PZT transducer impedance is lower than 50 ohm. Piezoelectric devices often require voltage in the range of 20V or more. Consequently a high output voltage and high output current piezo amplifier driver is required to drive such transducers.

For instance, an actuator/motor specifies 40V peak voltage, but a lab signal generator can only output is 5V or less. To achieve 40V square-wave, a piezo amplifier driver is used to boost the generator signal and outputs high voltage and high current to drive the piezoelectric actuator.

**Figure 3** shows an example of a piezoelectric transducer driver. Note the driver amplifies a combination of voltage, current, and power.
Piezo amplifier voltage requirements

It is important to understand the piezoelectric device voltage requirements before selecting the driver. Some piezo transducers require only the peak-to-peak voltage amplitude, while others specify 0-to-peak voltage. Ultrasound transducers for example, only require a peak-to-peak amplitude to produce the ultrasound level. It accepts voltage swing from negative to positive. For example, a sine wave voltage swing of -30V to +30V, which is 60Vpp. An actuator on the other hand, needs 0-to-peak voltage for proper operation; for instance, 0V to +40V square wave. In conclusion, it is crucial to understand the PZT device specifications on voltage and select a driver that meets the voltage range. Accel Instruments offers a wide range of high voltage driver amplifiers voltages.

Understand capacitive piezo power

As discussed before, the two common piezoelectric devices are mostly capacitive and resistive at resonance frequency. The power requirements are different for these two types of devices. Let’s look at the capacitive devices first.

Many high-frequency piezoelectric transducers/devices are capacitive in nature. Its impedance is given in Equation 1 above. Recall from basic electrical engineering class that a capacitor’s impedance is equal to its reactant. That means the device’s impedance is imaginary (denoted by j) and there’s no real resistance. Reactive devices do not absorb or dissipate power themselves. The power driven into the device is considered reactive power. The reactive power still needs to dissipate somewhere and it is dissipated inside the PZT amplifier driver as opposed to on the device. As a result, the heating is on the piezoelectric driver and not the PZT device itself. The reactive power is expressed in Equation 3, where the impedance (Z) is from Equation 1 and the current (I) is from Equation 2. Use RMS voltage value to calculate the RMS current and power. When selecting a driver, make sure the driver can handle the reactive power.

\[ P_{\text{RMS}} = I_{\text{RMS}}^2 Z \]

Equation 3

Increase real impedance
Increase real impedance

As discussed above, capacitive piezoelectric elements do not dissipate power. All of the reactive power dissipated inside the amplifier which can limit its output current and voltage. Piezoelectric devices are operated on voltage, not necessary current or power, although high current is needed to maintain the voltage especially at high frequency. If the amplifier is limited by heat dissipation, a simple resistive matching technique may be used to better optimize the amplifier power dissipation that will result in increased output voltage and current. By adding a series resistor, the impedance now has a real component and dissipates power outside of the piezo amplifier as shown in Figure 4. Some of the heat is dissipated on the resistor.

![Figure 4](image)

**Figure 4** A series resistor increases the amplifier output voltage by lowering the reactive power.

The recommended resistance range is from 0.25Z (half of the piezo impedance) to Z. The piezoelectric impedance, Z, is calculated in Equation 1 above. Let’s use an example. For a PZT with impedance of 8j-ohm at 20kHz calculated using Equation 1, the series resistor may be 2 ohms to 8 ohms.

The series resistor impedance matching technique is beneficial only if the piezoelectric driver cannot output the maximum voltage due to excess reactive power and internal heating. And this technique only works for sinewave waveform. Additionally some amplifiers may be conditionally stable. The series resistor will improve amplifier stability.

**Figure 5** shows how the series resistor can take the heat out of the piezo amplifier without significantly reduce the voltage. For a capacitive device, the voltage and current are phase shifted by ~90 degree. When the current is maximum, the voltage is near zero. Thus the series resistor does not impact the voltage. When the voltage is maximum, the current is minimum. At this point, the IR drop due to the resistor is small and thus there is minimum reduction in peak voltage. The power absorbed by the matching resistor is significant and reduces the heat in the driver. Equation 4 calculates the series resistor power dissipation. The resistor will be hot. Make sure to choose a resistor rated for high power dissipation. Also choose a low-inductance resistor especially for high frequency PZT devices. The overall load impedance (piezo plus resistor) is calculated in Equation 5.
High-voltage piezo driver example

**Figure 6** is an example of converting a bipolar amplifier into a unipolar high voltage for a piezo device while driving high current and high power at the same time at high frequency. The PZT element has a capacitance of 1 uF. It requires a peak voltage of 80V (0 to 80V sinewave). The desired sine voltage frequency is 11 kHz. The piezo amplifier output voltage is from -40V to +40V. Because the amp driver voltage is not meeting the required 80V, a DC bias power supply is used as shown in Figure 6.

The piezo amplifier is connected in series with a 4-ohm power resistor and (also in series) with an isolated 40V DC power supply. External bypass capacitors are required to minimize AC current flow through the power supply. The bypassed capacitance should be large enough such that its
Impedance is small compared to the PZT impedance. In this example, the piezo actuator impedance is 14.47 Ohm at 11 kHz calculated using Equation 1. The bypass capacitor impedance should be as low as possible, less than 0.5 ohm (>29uF) is recommended.

Using Equation 5 the calculated overall load impedance is about 15.0 ohm. The peak current is about +/-2.67A (5.34App). While the current is positive and negative, the voltage across the piezo is always positive between 0V and ~77V, calculated using peak-to-peak current multiplied by the 14.47 ohm impedance. Using Equation 4, the power dissipated by the series resistor is about 14.3W.

**Figure 6** A DC bias supply combined with a piezoelectric amplifier produce high output voltage.

Driving highly capacitive piezo devices using a high-voltage amplifier was discussed here in detail. The combined high voltage piezo, high frequency, and high capacitance will require a high current piezoelectric amplifier. These devices require reactive power, which further place burden on the amplifier. An application example used a DC supply to boost the voltage and a series resistor to ease the power handling on the piezo amplifier.

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