Lab Amplifier Connection

Lab amplifier is being used in many R&D (research and development) labs. A laboratory amplifier can amplify voltage, or current, or power, or any combination. Some examples of laboratory amps are driving high-frequency magnetic coil (high current), piezo transducer driver, function generator amplifier, and more. Our waveform amp products are designed as a general purpose R&D bench instrument. This application note discusses some common test and measurement application usages of lab amplifiers.

Lab Amplifier Connection

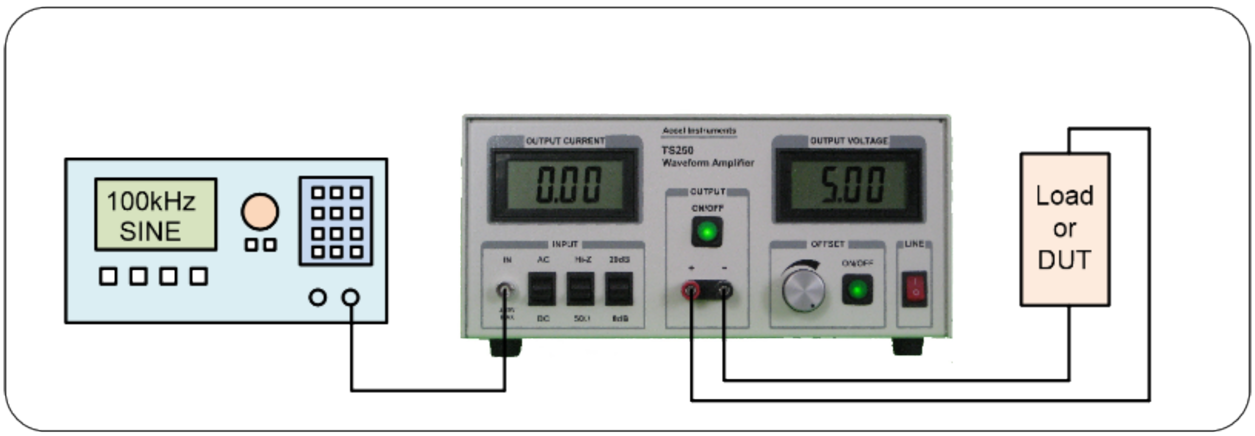

Figure 1. TS250 Waveform Amplifier is used as a lab amp.

Lab Amplifier as Companion to Function Generator

Many lab experiments require waveforms that are high voltage or high current or high power. Although most research labs have function generator for the purpose of generating such waveforms. However, most function and signal generators are unable to fulfill some of these requirements. These generators' output resistance are 50 ohm. They are designed to connect to 50 ohm coaxial cables and terminate into 50 ohm loads. This 50 ohm output resistance severely limits its output current to about 100mA (5V into 50 ohm). For lab bench testing, our function-generator amplifiers are ideal companion to these signal/function generators.

Our waveform amplifier products such as the TS250 have very low output resistance (~50 mOhm). This allows it to drive very low resistance loads. Their output current is up to 6A, depends on the model. See the *Selection Guide* below for output current and voltage range. As shown in Figure 1, a lab amplifier is an ideal companion instrument for producing high power or current or voltage for many scientific and research experiments.

Voltage Gain

Most available voltage sources for laboratory test applications are often low-voltage. Example of such voltage sources are DAQ (data acquisition), sensors, and signal generator. Often time these source voltage need to be amplifier to produce high voltage in excess 10V to 60V or more. Lab amp is ideal for amplify weak and low voltage signals. The T Waveform Amplifier offers a gain of 0dB (1x) or 20dB (10x) to boost the voltage.

Current Gain

Our lab amplifiers feature input unity gain. In this mode, lab amplifier boosts the current, but not the voltage. Many voltage signal and sources does not have the current capability to drive heavy (high current) load. These voltage sources are either have high source impedance which results in high voltage drop when loaded, or low output current capability. Function generator, for example, has 50 ohm output impedance. Some other voltage signal sources have low output impedance, but are not design to output high current. When loaded with low resistance, its output active devices will not able to support high current and causing the output to collapse. Therefore these signals need high current laboratory amplifiers.

The TS200 and TS250 fulfill many testing applications require high current to drive their low-impedance load such as coils, piezo, low resistance load, and other devices. The T current-gain laboratory power amplifier has very low output impedance (50m ohm typical). They can output up to 6A current. See the TS200 and TS250 data sheets for output current capability. Their inputs are selectable either high-impedance or 50 ohm termination. The TS250 features a switch-selectable gain setting. For amplifying current without amplifying voltage, use the 0dB setting. You can also use the 20dB setup that will amplify both current and voltage.

Power Gain

In addition to current and voltage gain, power gain is also important is some applications. Output power is maximize when both the current and voltage are maximum for a given resistive load. Our laboratory power amplifiers specify a maximum output voltage and current. If available, choose a load resistance such that lab power amplifier outputs maximum voltage and current. This will result in maximum power output to the load.

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Piezoelectric Transducer Driver

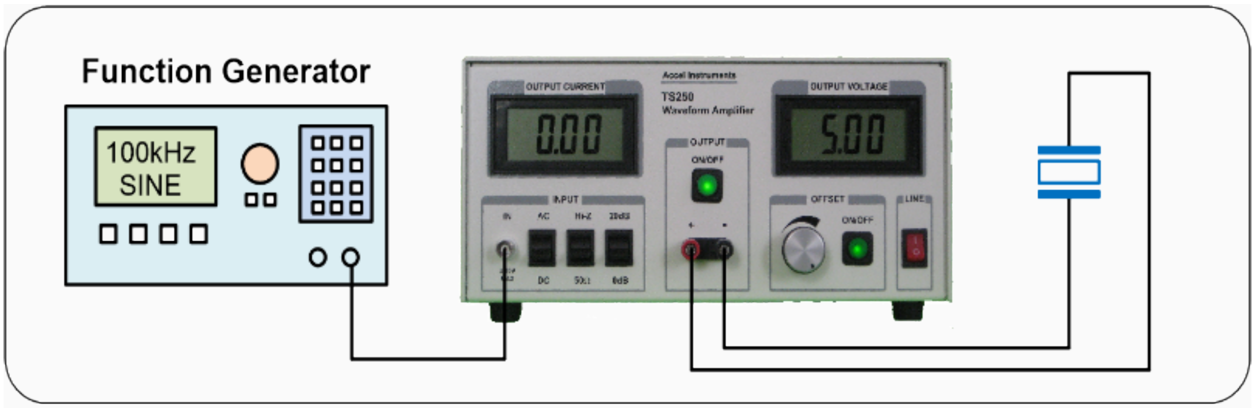

Figure 2. The TS250 lab amp for driving piezoelectric transducer.

Laboratory amplifier is perfect for driving large-capacitance piezo devices especially at high-frequency. Piezoelectric transducers and actuators are capacitive. Because of their large capacitance value, their impedance is very low when operate at high frequencies. At the same time piezo transducers need high driving voltage. A high-current lab amplifier is needed to drive these piezo elements. The required output current is governed by Ohm's law. The lab amp current is directly proportional to capacitance, frequency, and voltage as given in Equation 1. Referred to Equation 1, V is the voltage, I is the current, C is the piezo transducer capacitance, and f is the frequency.

For instance, for a 3.3uF piezoelectric actuator that requires 20V peak voltage and 10kHz test frequency, the required peak current is 4.14A. In this case a very high-current laboratory power amplifier is needed to drive the piezoelectric transducer.

$$I=V/Z=V/|1/j\omega C| =V\omega C \qquad \textit{Equation-1}$$

Driving Magnetic Coils

Many laboratory and scientific experiments required time-varying or AC magnetic field. Such magnetic field is produced by an AC current is passing through a solenoid or coil. Often time high current are needed to generate sufficient field strength. Most bench function generator does not have the high-current drive capability. The coil current is often a sinusoid and the magnetic field is also sine wave. Two common methods for driving electromagnetic coils are discussed below.

The coil drivers such as the T200 and the T250 can output high-current (up to 6A or more) for producing high field intensity up to several hundred kilohertz. Our laboratory power amplifiers can drive magnetic devices such an AC Helmholtz coil pair, solenoid, relay, probes, and more. The easiest driving method is directly connecting the coil to the lab amplifier. This is called the direct-drive method and discussed below. The direct-drive method is best suited for low-frequency or low-inductance, or both. The second method for driving the coils is the resonant method. The resonant method is used for high-frequency and high-inductance coil.

Low Frequency and Direct-Drive

The coil impedance is proportional to the inductance and frequency. When the frequency is low, the coil impedance is usually low, especially if its resistance and inductance are also low (Equation-2). High coil current and high field strength are achieved even with lower driving voltage (Equation-4). For instance, for a Helmholtz coil pair with 0.1 ohm resistance and the reactance at 60Hz is 1 ohm, the absolute impedance is about ~1 ohm. For a desired magnetic field strength that required 5A current, the driver only needs 5V. For low frequency or low inductance, high current is easily obtained using our laboratory amplifier shown in Figure TBD.

$$Z=R+j\omega L \qquad \textit{Equation-2}$$

$$|Z| = \sqrt{R^2 + (\omega L)^2} \qquad \textit{Equation-3}$$

$$I = \frac{V}{|Z|} = \frac{V}{\sqrt{R^2 + (\omega L)^2}} \qquad \textit{Equation-4}$$

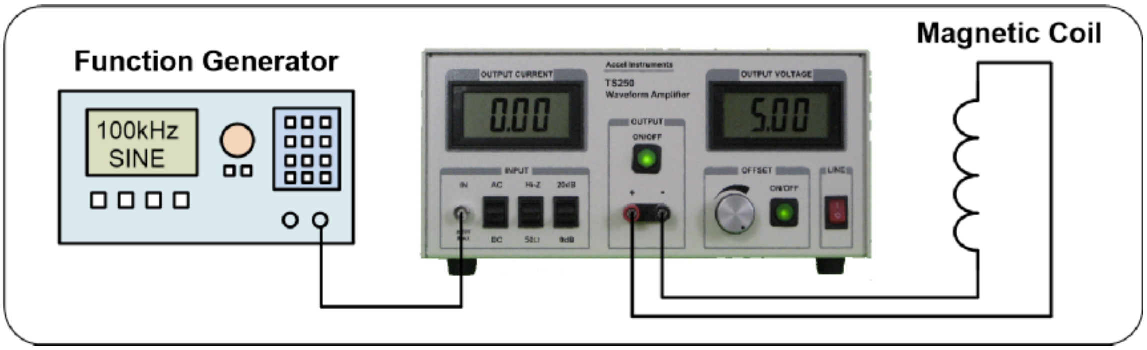

Figure 3. Magnetic coil is driven by a high-current laboratory amp.

High Frequency and Resonant Method

At higher frequency the AC magnetic coil reactance (or impedance) is increased proportional to the angular frequency, ω. The electromagnetic solenoid/coil impedance is usually very high. In generally, at high-frequency the reactance is much larger than the resistance and dominates the overall impedance. As an example, the reactance of an 10mH high-frequency solenoid is 1257 ohm at 20kHz. Its resistance is usually in the range of few ohms. If 2A current is needed, a 2514V amplifier driver is needed. Therefore high frequency requires high voltage to drive high current through the solenoid coil. Advance reactance-cancellation technique using resonant can be adopted to reduce the lab amplifier driver voltage as shown in Figure 4.

In Figure 4 a series capacitor is connected with AC magnetic coil to operate in resonance mode. The capacitor's impedance polarity is opposite to the coil's impedance. As a result the capacitor becomes an impedance cancellation component. It reduces the overall reactance. At resonant frequency the electromagnetic coil reactance completely cancels the series capacitor reactance. The only thing remains is the magnetic coil parasitic resistance which usually small value. This resonant technique enables the laboratory amp to drive very high current through the coil. Because resonant occurred in narrow frequency range, the drawback of this technique is different test frequency requires different capacitance. Calculating of resonant frequency and capacitor value are detailed in the Resonant Technique Article.

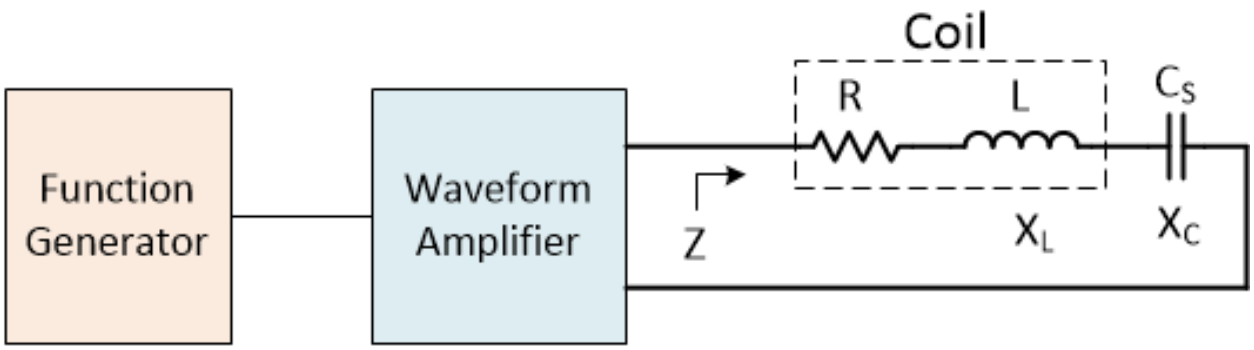

Figure 4. AC magnetic coil is modeled as an inductance and resistor. The series capacitor cancels the coil impedance.

Noise and Transient Simulation

Another common application of the lab amplifier is to simulate power supply noise and transient to stress test subsystems and modules. An example of such test is to simulate automotive cold crank battery voltage waveform. During car engine cranking the battery voltage that supplies all subsystem in the car suffers severe voltage transient and fluctuation. The nominal 12V battery voltage can drop as low as 3 volt in 5ms and spike to as high as tens of volts during a load dump. Our family of waveform amplifiers are ideal for simulating such transient voltage for stress testing devices and subsystems.

Figure 1 above shows the basic setup. Using an external arbitrary signal generator to program the transient (cold crank) voltage profile. Since signal generator outputs maximum 5V into 50 ohm and if transient voltage is higher than 5V, se the lab amp voltage gain feature to boost the voltage. Use the gain of 10 (20dB) setting.

Calculate Transient Current

Most unit-under-test (subsystems and modules) have large capacitance at the input. It requires high current to drive these large capacitors. The below technique describe how to calculate the maximum current.

The first step is to determine the unit-under-test (UUT) input capacitance. The current into the capacitor is given in Equation-5 and Equation-6. Most transient simulations are linear ramp up or ramp down. Therefore the peak current is the voltage slope times the capacitance as shown in Equation-7. The voltage slope is the final voltage minus the initial voltage divided by the ramp time. For example, an auto cold crank voltage ramp from 12V to 3V in 5ms and the subsystem input capacitance is 1000uF. The current during this ramp is (3V-12V)/0.005s = -1.8A. The negative value indicates the current is draw out of the capacitor. This means the lab power amp is sinking current. If the calculated current is too high and exceeded the maximum amplifier spec, you may parallel connect two or more laboratory amps to increase the current as shown in Figure 5.

$$V(t) = \frac{1}{C}\int I(t)dt$$ **Equation-5**

$$\frac{dV(t)}{dt}C = I(t)$$ **Equation-6**

$$I = \frac{VC}{T}$$ **Equation-7**

Advanced Lab Amplifier Techniques

Parallel Laboratory Amplifier Connection

Our series of lab amplifiers already outputs high current. If higher current is needed, multiple lab amps can be connected in parallel. In some scientific experiments such magnetic coil, very high current is needed. Figure 5 below is an example of two TS250 laboratory amplifiers can be connected together to boost the current output. Connecting amps in parallel will also reduce the total output impedance. Three or even four amplifiers can be connected in parallel for very high current test applications. For parallel connecting laboratory power amplifiers, each output needs a resistor to isolate from each other. 0.1 ohm to 1.0 ohm series resistance is typically used. It is recommended the voltage drop across resistors is between 200mV to 1000mV at peak current. For example, the TS250-1 peak current is 4.4A. A 0.2 ohm resistor will result 880mV drop at peak current. You may use larger resistance for higher output voltage models or lower output current. Since the output is high current, the resistors must be rated for high power dissipation.

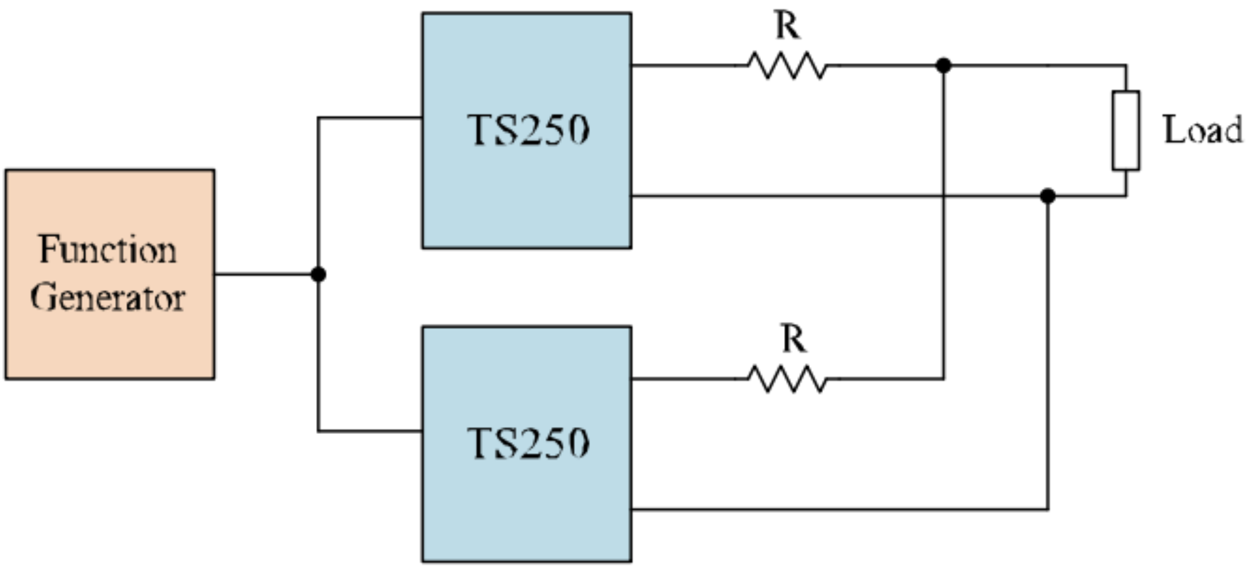

Figure 5. High-current is obtained using two waveform amplifier connected together.

Combine DC Voltage and Lab Amplifier

Some lab bench test applications require large DC voltage and AC waveform. Power supply ripple rejection testing for example, the DC voltage could be as high as 100V, while the ripple noise voltage is only 1Vpp or so. If the device-under-test (DUT) has high input capacitance and the test frequency is high (100kHz), it required up to +/-6A or more. In order to meet this requirement, the signal generator has to be able to output 6A and 100V. This signal generator must output 600 watt power at 100kHz. Such generator is not readily available.

To overcome the above mentioned shortcoming, you can use a laboratory amplifier and an isolated DC power supply to achieve such a high current, high voltage, and high power function generator. As illustrated in Figure 6, our high-current lab amplifier is connected to the isolated power supply series. The negative terminal of the lab amplifier driver is connected to the ground.

The GND node is also connected to the function generator ground in additional to the DUT ground. The laboratory amp positive output is connected the isolated DC voltage supply's negative terminal. Finally the isolated power supply's plus terminal is connected to the device-under-test. The voltage applied to the DUT is the DC voltage (VDC) plus the AC voltage (VAC).

The external capacitor(s) connected across the power supply enables a low-impedance high-frequency AC current path to the DUT. The recommend capacitance is at least ten times the DUT input capacitance. You may use multiple capacitors connected in parallels. Choose low ESL and ESR capacitors such as ceramic caps for high frequency and high current response. Visit the high voltage function generator amplifier page for additional information.

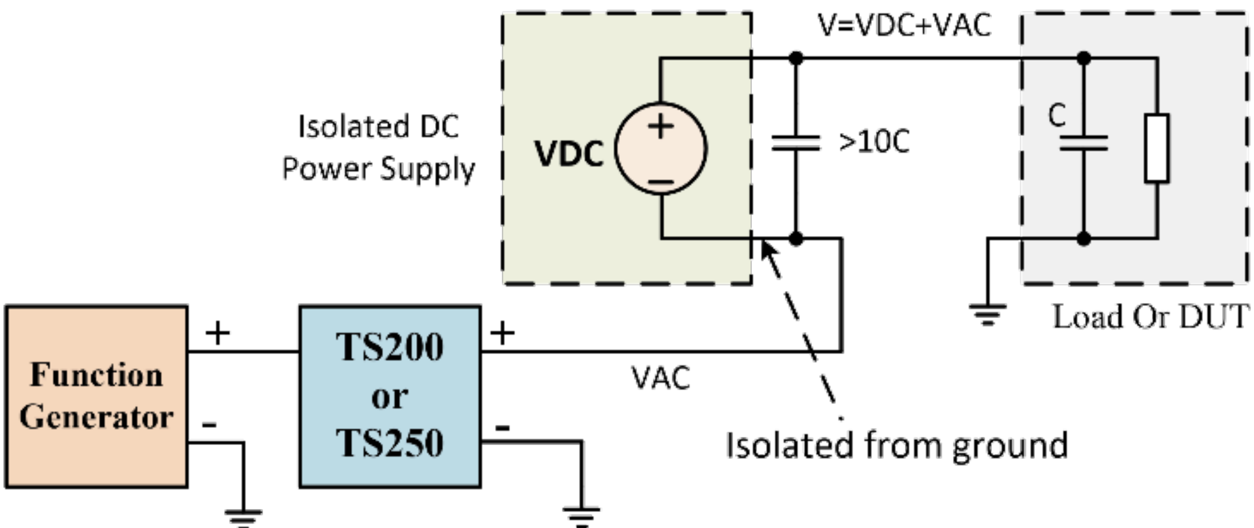

Figure 6. An external isolated DC voltage supply combined with a laboratory amplifier achieve high voltage signal generator.

Table 1. High-Voltage Lab Power Amp Selection Guide

Model	Voltage Range	DC Current	Max Peak Current
TS200-0A/B	-10V to + 10V	0 – 4.0A	0 – 5.0A
TS200-1B	-20V to + 20V	0 – 2.8A	0 – 3.8A
TS200-4A/B	0V to + 15V	0 – 3.5A	0 – 4.5A
TS250-0	-10V to + 10V	0 – 5.0A	0 – 6.0A
TS250-1	-20V to + 20V	0 – 3.1A	0 – 4.4A
TS250-2	-30V to + 30V	0 – 2.1A	0 – 3.0A
TS250-3	-40V to + 40V	0 – 1.7A	0 – 2.5A
TS250-4	-6V to + 15V	0 – 4.0A	0 – 5.0A
TS250-5	-6V to + 30V	0 – 2.1A	0 – 3.0A
TS250-6	-6V to + 45V	0 – 1.7A	0 – 2.5A
TS250-7	-6V to + 65V	0 – 2.1A	0 – 2.5A

Select a Function Generator

Our lab amplifiers are designed to work with commonly available signal generators and function generators. Laboratory amplifiers signal inputs are designed with standard BNC female connectors. Standard 50-ohm coaxial cable is commonly used to connect to waveform generators. Some recommended signal/function generators are shown in Table 2.

Table 2. Function Generator Selection Guide

Manufacture	Model	Features
Rigol	DG1022	Low-cost
BK Precision	4014B	Low-cost
Tektronix	AFG1000	
Keysight	33220A	20MHz
Keysight	33250A	Variable slew-rate control