Considerations for Selecting a Power Amplifier

Introduction

Application Note 302 is intended to assist people who are not power amplifier experts to understand the basic parameters necessary to properly select one for use in testing and experimentation. A wide range of scientific disciplines, from mechanical engineering to biology and chemistry, use amplifiers in research and test. Amplifiers simply increase the size of a signal by some factor greater than 1 and are necessary when a signal source does not produce an output level sufficient for the task at hand. To select the right amplifier, it is important to understand some of the different parameters and how they affect the performance. The most important parameters to understand are:

- Gain
- Bandwidth (BW)
- Slew Rate (SR)
- Total Harmonic Distortion (THD)
- Input Impedance
- Current Limit

Reviewing these parameters and developing a general understanding of their importance will aid in the amplifier selection process.

Gain

Gain is a measure of the ratio of the output to the input of an amplifier. Most commonly, the signal voltage level is amplified. If the signal is 1V and the gain of an amplifier is 50 then the output will be 50 V.

However, the current or power of the signal could also be amplified if necessary. Usually, a voltage amplifier will also provide current gain and it is important to know what the maximum output voltage is as well as the maximum current. See the section on Current Limit for more information

What about dB?

In some cases, a voltage gain of 50 may be referred to as a power gain of 17dB. When considering gains reported in dB, it is important to understand whether the gain is being reported in voltage gain or power gain. Even when gain is reported as "power gain", the amplifier is multiplying voltage by a constant, and the reported gain assumes that power increases with the square of voltage.

Gain does not always inform the user of what an amplifier can add. For example, a "power amplifier" may have a voltage gain near 1.0, yet will have the advantage of being able to source much more current than the input circuit consumes. Always check the impedance of the load and the output current specification to confirm that an amplifier is matched to your load.

Bandwidth (BW)

Bandwidth refers to what frequencies are able to pass through the amplifier. As signals increase in frequency the amplifier has to respond faster and is limited by its design. Normally low frequencies are not a problem with many amplifiers being able to operate at 0 Hz or DC. It is important to know what the low frequency limit is because many applications require steady state operation. As the frequency increases, the output voltage falls off gradually above a certain transition frequency. It is often identified as the point where amplitude has fallen to 70% of the maximum amplitude and is also referred as the -3 dB point. Unfortunately this is not always the way it is specified, so one has to be careful when reading and comparing specifications. A graph showing the maximum output voltage versus frequency conveys much more information.

The figure below shows a typical output voltage versus frequency curve for an amplifier plotted on a logarithmic graph. The 70% output point (-3 db) is indicated.

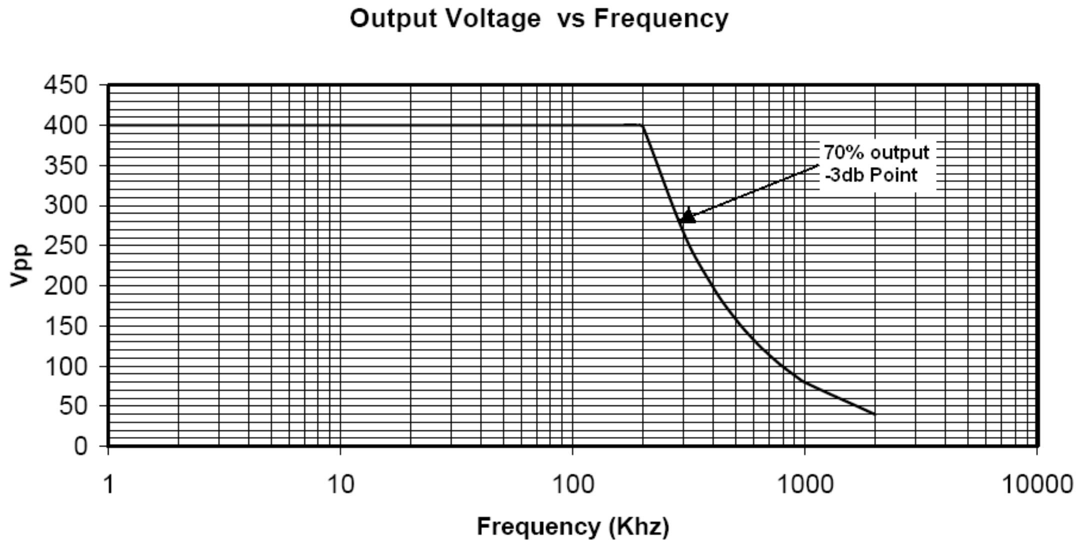


Figure 1 - Output Voltage vs. Frequency for a typical amplifier.

Slew Rate

The slew rate (SR) is defined as the maximum rate of change of the output. Slew rate is used to describe how quickly the output of an amplifier can track its input. Ideally, the output should be instantaneous and accurate. However, if the output signal is very large and there are very fast and large changes in the input, the amplifier may not be able to respond. Slew Rate can be measured by checking the steepest rise response on the output in response to a square wave input. Slew rate is specified in units of volts per second (V/S). You will also see volts per microsecond (V/μS), since typical values of slew rate result in many hundreds of thousands or millions of volts per second. Higher slew rate indicates a faster amplifier.

The following example illustrates how to calculate the slew rate of a sine wave: $V = A\sin(\omega t)$ where A is the peak amplitude.

The maximum slew rate of a sine wave occurs during zero crossings (zero radians, π radians). To find the maximum slew rate, we need to find the derivative of $V = A\sin(\omega t)$ at zero radians.

Slew rate is often the key specification in reproducing pulses and steps. The frequency components of the edge of a steep ramp forming the edge of a pulse may not be easy to determine, making suitability of an amplifier difficult to discern from its Bandwidth, while the slew rate is easy to compare with the slope of the required function.

Note that Slew rate is reported at certain conditions, including the size of the change and the loading conditions. Slew rate is very heavily affected by loading, and is normally reported in conditions in which the amplifier's current limit does not come into play. Under real capacitive loading, including even short cables, it is important to compute the current being drawn as the voltage rate is applied to the capacitance, and verify whether current limit will reduce the voltage slew rate.

$$SlewRate\ (\max) = \frac{d}{dt} A\sin(\omega t) = A\omega\cos(\omega t)$$

$$\text{At } \omega\text{t} = 0,$$

$$\text{General Slew Rate Equation}$$

$$SlewRate\ (\max) = \text{A} \cdot 2\pi F$$

$$\text{Where A} = \text{peak signal amplitude}$$

$$\pi = 3.1415$$

$$\text{F} = \text{signal frequency} = 1000\text{Hz}$$

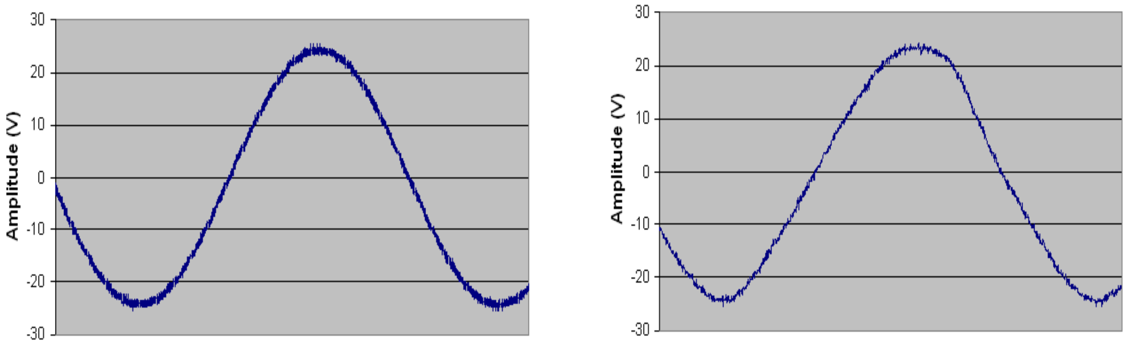
$$\text{A} = 200\ \text{V (this is the peak amplitude)}$$

$$\cos(0) = 1$$

$$\omega = 2\pi\text{F} = 2 \cdot (3.1415) \cdot 1000 = 6283$$

$$SlewRate(\max) = 200 \cdot 6283 = 1256600\, V/s \text{ or } 1.2566\, V/\mu s$$

Slew rate and bandwidth are interrelated. Higher slew rate translates into higher bandwidth. Figure 2 illustrates how the slew rate can affect the reproduction of a sine wave. The left hand figure represents a waveform without any slew rate distortion whereas the right hand figure is the output of an amplifier with insufficient slew rate. It is important to know the maximum slew rate of your test signal and verify that the amplifier has sufficient slew rate to reproduce it.



A sine wave without slew rate distortion.

A sine wave distorted by a lower slew rate.

Figure 2 – Slew Rate Examples.

Total Harmonic Distortion (THD)

All circuits are imperfect and fail to reproduce the input signal faithfully. THD is a measure of the error introduced by the amplifier. THD may be expressed in dB or % but in either case, a lower number is preferred because it indicates more accurate signal reproduction. Sometimes this is specified as THD+N; meaning Total Harmonic Distortion plus Noise. Noise is an undesirable interference with the amplified signal originating within the amplifier. The THD+N specification combines both sources of error into one convenient value that can be compared between devices.

Input Impedance

Input impedance indicates the amount of current required to drive the amplifiers input. Ideally the amplifier would have a high input impedance and therefore require very little current. Unfortunately, a high input impedance may limit the bandwidth of an amplifier and introduces additional noise into the signal. Most signal generators and amplifiers are designed to be compatible with 50 Ω impedance as 50 Ω coax is easy to make, common and is a reasonable compromise between optimal signal transfer and optimal power transfer.

It is important that the output impedance of a signal source and the input impedance of an amplifier match for accurate signal reproduction. In some cases, the signal source consists of a DAQ card or plug in computer board that is not compatible with 50 Ω impedance. Higher amplifier input impedance around 2 KΩ is normally sufficient to solve this problem and is an available option in TEGAM amplifiers.

Current Limit – Resistive and Capacitive Loading

The device that the amplifier drives is referred to as the load. The load governs how much current is drawn from the amplifier at a given voltage. The maximum output current is limited by the amplifier to protect it from damage. If the load is basically resistive, such as a heater element, it is fairly easy to verify that the amplifier is properly sized by using Ohm's law.

$$V = I \cdot R$$

Suppose $V = 200V$ and the load resistance is $1K\Omega$,

We have,

$$I = V/R = 200/1000 = 0.2 \text{ A or } 200 \text{ mA}$$

Figure 3 shows an actual amplifier with a resistive load.

Figure 3 - A resistive load at the output of the voltage amplifier.

But loads like Piezo Transducers (PZT) and MEMS electrostatic actuators are predominantly capacitive and require more care in sizing the amplifier. The loading effect of a capacitor changes with the applied frequency and therefore must be taken into account. The impedance actually decreases as the frequency increases and is expressed by the following equation:

We know that impedance in rectangular form is given as $Z=R \pm jX$; where, R and X are resistance and reactance, respectively.

$$X_C = 1/(2\pi FC)$$

Where X_C is the reactance of the capacitor at a given frequency

$\pi = 3.1415$

$F = \text{signal frequency} = 1000\text{ Hz}$

$C = \text{capacitance of the load}$

$$X_C = 1/(2(3.1415)\,1000 \cdot (1 \cdot 10^{-6})) = 159.16\Omega$$

As the capacitance of a component increases, its capacitive reactance (X_C) becomes smaller, assuming the frequency is held constant. As the frequency increases for a given value of capacitance, the capacitive reactance becomes smaller, closer to zero.
The magnitude of Z_C is found out by,

$$Z_C = \sqrt{R^2 + X_C{}^2}$$

If the component is mainly capacitive, the resistive part is negligible as compared to Xc. The impedance decreases with increase in the frequency or capacitance value. The amplifier tries to amplify but it fails as its demand for more current exceeds the amplifier rating.

$$V = I \cdot Z_C$$
$$I = V/Z_C = 200/159.16 = 1.256\text{ A}$$

From the equations above, we can notice that increase in the capacitance value lowers the reactance and increases the current requirement for a constant voltage and frequency value.

Figure 4 - A capacitive load at the output of the voltage amplifier can change its slew rate.

The final case is an inductive load such as a solenoid, motor, relay coil and other electromechanical actuators. As with the capacitor, the inductive load also changes with frequency. However the inductors impedance increases with frequency and is expressed by the following equation.

$$X_L = 2\pi FL$$

Where X_L is the reactance of the inductor at a given frequency

$\pi = 3.1415$

$F = \text{signal frequency} = 1000\text{ Hz}$

$L = \text{inductance of the load}$

$$X_L = (2(3.1415)\ 1000 \cdot (1 \cdot 10^{-3})) = 6.283\,\Omega$$

As the inductance of a component increases, its inductive reactance X_L becomes larger, assuming the frequency is held constant. As the frequency increases for a given value of inductance, the reactance also increases.
The magnitude of Z_L is found out by,

$$Z_L = \sqrt{R^2 + X_L^{\,2}}$$

If the component is mainly inductive, the resistive part is negligible as compared to X_L. X_L is small at low frequencies and large at high frequencies blocking high frequencies while acting as a short.

$$V = I \cdot Z_L$$
$$I = V/Z_L = 200/6.283 = 31.83\ \mathrm{A}$$

These examples above show different current requirements in an amplifier with different types of loads.

For the non-electrical engineer, these parameters may not be commonly understood. However, after reading this application note you have the basic information to select an amplifier for your application.

If you have any comments or would like to discuss your amplifier related problem or need, please email me at asabnis@tegam.com or call at 440-466-6100.