AN61

# Bandwidth for Power Amplifiers Crash Course

## INTRODUCTION

Getting the highest bandwidth out of a Power Op Amp is one of the most common challenges in high-power analog. Whether you're outputting a 3 MHz sinewave into a semiconductor during testing, or getting the sharpest corners on a 100kHz triangular wave to drive a mirror deflector, more bandwidth is always in high demand. This note gives a quick reference for determining the full bandwidth of an Apex product and for maximizing that speed to its full potential.

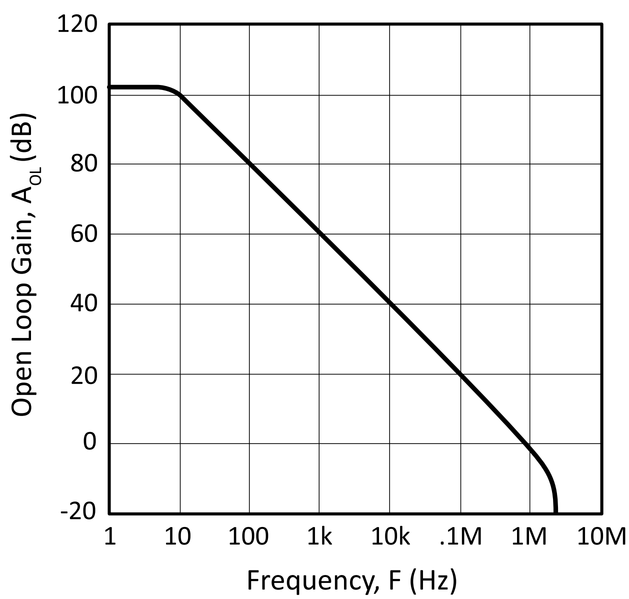
## WHAT IS THE BANDWDITH OF AN APEX PRODUCT?

There are many numbers and graphs in an Apex datasheet that claim a certain maximum frequency. Understanding these numbers requires a basic knowledge of the following factors:

### *GAIN BANDWITH PRODUCT IS NOT THE WHOLE STORY*

The Gain Bandwidth Product (GBWP) is usually a very attractive number, as it would seem to imply that driving an amplifier in unity gain results in a frequency in the tens of megahertz. This is a very incomplete notion. The published GBWP applies only in a certain range of frequencies, typically from 100 Hz to 1 MHz. The frequency response, provided in all Apex linear amp datasheets, paints a broader picture. Figure 1 shows that the gain-frequency relationship rolls off faster at frequencies greater than 1-2 MHz. This roll-off can happen at even lower frequencies when a capacitive load is present.

**Figure 1: Typical Small Signal Response**



### *SLEW RATE*

The next most common frequency limitation is slew rate (SR). This is the fastest rate of voltage change with which the amplifier can move its output, in V/µs. This number, on its own, does not give a maximum bandwidth. The slew rate must be combined with the output amplitude to give a maximum frequency without slew rate limiting:

For sinusoids

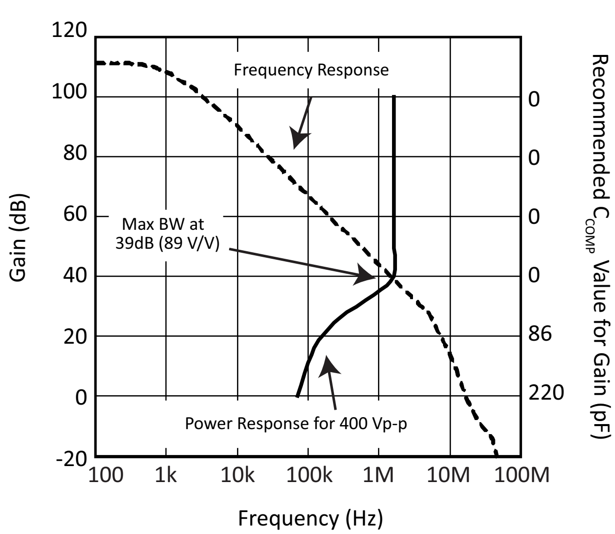
$$f_{MAX} = \frac{(SR)\left[\frac{V}{\mu s}\right]}{\pi V_{OUT,(P-P)}[V]}$$

For waveforms other than sinusoids, the slew rate must be used to calculate the maximum wave frequency specifically. Also keep in mind that slew rate is not set in stone. Slew rate is quite often affected by loading, compensation capacitor, layout, temperature, and several other factors.

### *POWER BANDWDITH*

Power Bandwidth and slew rate are inter-related. The Power Bandwidth is the maximum frequency for a sinusoidal waveform operating at the full voltage swing of the amplifier without slew rate limiting. This means the Power Bandwidth can often be exceeded if the output amplitude is lower than the maximum available voltage swing of the part. Apex datasheets typically plot the Power Response over several values of compensation capacitor (more on this later). In a nutshell, each compensation capacitor is associated with a recommended gain for the amplifier. This new gain-frequency relationship has a positive slope, in contrast with the GBWP, so there is usually an optimum gain value for each application based on these two relationships. See Figure 2 for the intersecting relationships.

**Figure 2: Intersection of Small Signal Response and Power Response**



*TOTAL HARMONIC DISTORTION*

Total Harmonic Distortion (THD) is difficult to fully characterize, as it depends on supply voltage, output power, gain, and more. However, the general trend is that THD increases with frequency. The question then becomes: how much distortion can your high-frequency design tolerate?

*POWER DISSIPATION*

Loads with capacitance or inductance change their impedance with frequency and cause excess power dissipation in the amplifier. Be sure to consider power dissipation over the entire frequency range before deciding on a power op amp.

*STABILITY CONCERNS*

Stability is a complex issue that deserves its own application note, as do all the above factors. The faster an amplifier is designed to be, the more likely it is to slip into oscillation and instability. These oscillations can be cured with a number of compensation techniques, all of which decrease the overall bandwidth.

## HIGH-FREQUENCY STABILITY TECHNIQUES

When working with reactive loads at low gains, stability quickly becomes an issue. Please see AN19 Stability for Power Op Amps for a more in-depth analysis of stability.

*COMPENSATION CAPACITOR*

When an amplifier has pins for a compensation capacitor connection, increasing the capacitance here is the simplest way to stabilize a circuit. However, the value of this capacitor has an inverse relationship with slew rate and GBWP; the higher the compensation value, the lower the slew rate and GBWP.

**Figure 3: Compensation Capacitor**

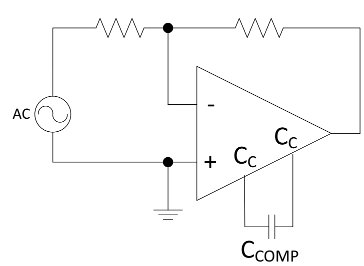
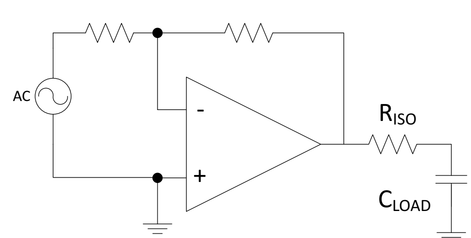



**Figure 4: Isolation Resistor**



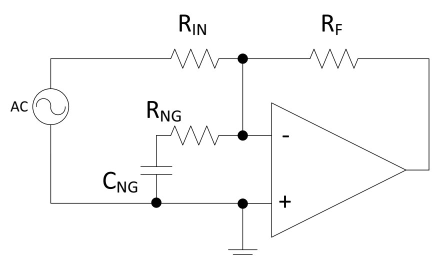
### *ISOLATION RESISTOR*

This technique generally takes the least bandwidth away from the circuit, and it works well for waveforms that require sharp corners into capacitive loads. The isolation resistor makes the load look less capacitive, stabilizing the circuit. Of course, the losses in this resistor become significant at higher frequencies, which is why this technique is not recommended for applications where high-frequency sinewaves are required.

### *NOISE GAIN*

Noise gain is a very versatile technique that can be used in combination with the Compensation Capacitor and Isolation Resistor. It adds another component to the amplifier's summing junction, falsely increasing the apparent gain of the system. In inverting-mode configurations, the loop gain set by RIN and RF remains true to the load, but the amplifier as a whole gets the stability benefits of a higher gain. This technique also pairs well with gain switching, as RIN can be changed without significantly impacting the phase margin.

**Figure 5: Noise Gain**




## DON'T BE AFRAID OF INVERTING MODE!

Sure, non-inverting mode has its advantages. High input impedance and single supply capabilities are attractive for many designs. But here are a number of arguments for the inverting mode in high-frequency systems:

### *INVERTING MODE IS MORE STABLE*

In inverting mode, the input pins of the amplifier remain at a relatively constant common mode voltage - usually 0V. This is inherently more stable than a non-inverting configuration, where the common mode voltage varies as much as the input signal. The near-constant common mode voltage keeps the operating point at a much less stressful level, resulting in improved performance.

### *INVERTING MODE ALLOWS FOR NOISE GAIN*

Noise Gain works because it increases the non-inverting gain and leaves the inverting gain constant. Trying to use Noise Gain on a non-inverting circuit would result in an undesirable “peaking” in the transfer function.

### *INVERTING MODE HAS LOWER HARMONIC DISTORTION*

For the reason described in section 4.1, harmonic distortion is much lower in circuits using inverting gains than ones with non-inverting gains. This is why THD is almost always characterized with inverting gains.

## LAYOUT

If you're working with high-frequency circuits, you're likely already aware of all the stringent requirements in laying out PCBs. The following are some more unique challenges that are encountered by Apex parts specifically.

### *TRACES ON THE COMPENSATION CAPACITOR PIN*

A 1cm trace on the $C_{COMP}$ pin can easily (and unintentionally) add 1-5 pF. When using a $C_{COMP}$ , it is critical to minimize this trace length and account for the parasitic capacitance. If a $C_{COMP}$ is not desired for the application, consider making the pads for the $C_{COMP}$ pins as small as possible. In some cases, Apex parts have shown significant improvements in performance when the entire pad was removed, leaving the $C_{COMP}$ pin floating in an inert hole.

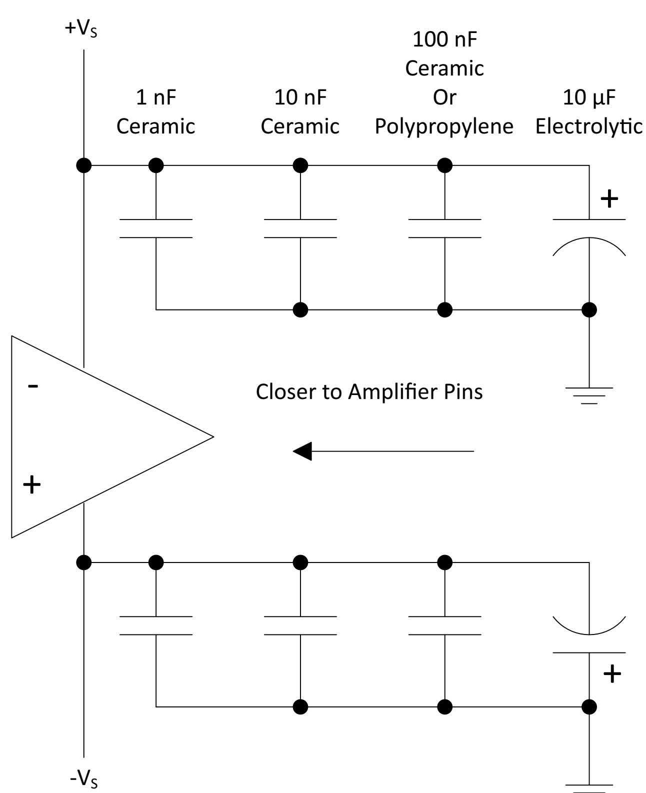
### *GROUND CASE*

All Apex hybrid power op amps isolate the case from the internal circuit for reasons of design flexibility. Leaving the case floating can lead to signals coupling through each other, much like a PCB with no ground plane. This can lead to erroneous phase shifts and distortion. For the best performance, Apex recommends grounding the case/heat tab of all hybrid power op amps. If this is not possible or inconvenient, connecting the case to a stable DC voltage (such as a supply rail) has a similar effect.

### *POWER SUPPLY BYPASS*

You may be satisfied with one 100 nF high-quality ceramic capacitor and one larger, electrolytic bulk bypass capacitor, but consider adding some even smaller values for high-frequency bypass. It is not uncommon to bypass with 100 nF, 10 nF, and 1 nF ceramic capacitors, with the smaller values closer to the pins of the amplifier. Using so many capacitors guarantees good performance over the entire frequency range; smaller value capacitors are generally built with shorter traces of copper between the ceramic layers, and so have better high-frequency characteristics.

**Figure 6: Power Supply Bypass for the Frequency-Conscious**



## NEED TECHNICAL HELP? CONTACT APEX SUPPORT!

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