Choosing Components Part 2: Audio Amplifier Basics

AUDIO AMPLIFIERS

Once upon a time, if you were designing an electronic system and you needed an audio amplifier, you had to design it yourself. Today you would most likely choose an "off-the-shelf" integrated circuit "gain block". It's usually easier to select an amplifier than to design it from scratch. But to select an IC amplifier, you need to know which specifications are important to your application. Otherwise, you must pick a part at random and hope it does the job; the "plug-and-chug" approach.

SO, WHAT'S TO KNOW?

As you would expect from reading Part 1 of this series, an audio amplifier has many parameters which characterize its performance. The question is which specifications are critical to your application and which ones are not. To answer that question you need to know three things: 1) how you want the amplifier to perform in your design, 2) which parameters determine that performance, and 3) what the values need to be for those parameters.

There is more to say about audio amplifiers than will fit in one article, so we there will be several Tech Tips on this subject. In the following paragraphs we will discuss some key concepts needed to understand amplifier specifications and relate them to performance.

GAIN

The gain of an amplifier is the ratio of the output signal to the input signal. There are three categories of gain: voltage gain (Av), current gain (Ai) and power gain (Ap). Any amplifier has a value for all three gains, but typically you must specify just one of them. Depending on the application, Av and Ai may be expressed as a simple ratio or as the log (base 10) of the ratio:

$$\text{EQ-1:}\quad Av = \frac{Vout}{Vin} \qquad \text{or} \qquad \text{EQ-2:}\quad Av = 20 \, Log \frac{Vout}{Vin}$$

When using the log of the ratio, the result is referred to as dB. Strictly speaking, dB actually refers to the log of the power gain:

$$\text{EQ-3:}\quad dB = 10 \, Log \frac{Pout}{Pin} = 10 \, Log \frac{(Vout)(Vout)/Rout}{(Vin)(Vin)\,/\,Rin} = 10 \, Log \frac{Rin}{Rout} + 20 \, Log \frac{Vout}{Vin}$$

But having Av expressed as a logarithm is very useful, and referring to it as dB is part of the culture.

BANDWIDTH AND FREQUENCY

The bandwidth (BW) of an amplifier is the range of frequencies, from lowest to highest, over which the amplifier delivers sufficient gain. The meaning of "sufficient" depends on your application, but one common meaning is when the gain (20 Log Av) has dropped by 3dB. IC amplifiers of the "op-amp" variety (operational amplifiers) will work from DC up to some frequency, the "break-point", where gain has dropped by 3dB. Amplifiers which amplify DC as well as AC are said to be "direct-coupled".

How much bandwidth does an audio amplifier need? It depends on what you mean by "audio". In a telephone circuit, 300 Hz to 3300 Hz is adequate bandwidth. In high-fidelity audio, 20 Hz to 20 kHz would be required. In some applications, 100 kHz is considered to be an "audio" frequency. Amplifiers are called audio amplifiers to distinguish them from either DC amplifiers used in instrumentation applications and from high-frequency (1 MHz and up) amplifiers used in radio frequency (RF) applications.

GBW

Amplifiers have a property referred to as the "gain-bandwidth product" or GBW. The GBW of a given amplifier is a constant. If you set the amplifier to a gain of Av (ratio, not dB), then the bandwidth is given by:

EQ-4: $$BW = GBW / Av$$

For example, suppose the GBW is 100,000. At a gain of 10, the amplifier will have a bandwidth of 10,000 Hertz. At a gain of 100, the amplifier will have a bandwidth of only 1000 Hertz.

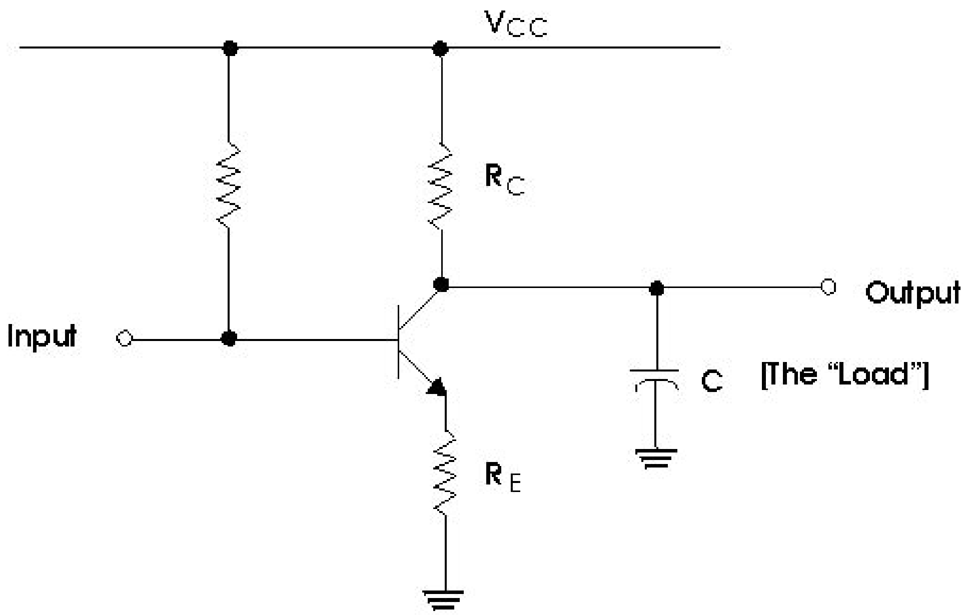

Figure 1

Look at the simple one-transistor amplifier in ***Figure 1***. The gain of the circuit is given by equation EQ-5 while the bandwidth is given by equation EQ-6.

EQ-5: $$Av = \frac{Rc}{Re}$$

EQ-6: $$BW = \frac{1}{2 * PI * Rc * C}$$

EQ-7: $$GBW = \frac{1}{2 * PI * Re * C}$$

The GBW is found by multiplying Av by BW to get equation EQ-7. Note that EQ-7 says that GBW is independent of Rc. So if we raise the gain by increasing Rc, we also lower the bandwidth. Why don't we just lower C? Because C is the capacitance of what ever the amplifier is "driving", we are stuck with it. Then why don't we just lower Re to increase GBW? The answer is in the next section.

TRADE-OFFS: SPEED and POWER

GBW is an example of a "trade-off". A trade-off occurs when making one thing "better" makes another thing "worse". In designing electronic circuits there are always various trade-offs to be made. GBW is a trade-off between gain and bandwidth. Speed and power-dissipation is another trade-off. When designing an amplifier, it may be possible to increase the GBW (the "speed") if you are willing to have it "run hotter" by dissipating more power.

Let's look again at the circuit in ***Figure 1***. Suppose we lower Re to increase the GBW, but we want to keep the same gain. Then we must also lower Rc. In amplifiers such as figure 1, the average (DC) voltage across Rc is approximately half the supply voltage. So the power (P) dissipated in Rc is

$$\text{EQ-8:} \quad P = \frac{V * V}{R} = \frac{(Vcc / 2) * (Vcc / 2)}{Rc} = \frac{Vcc * Vcc}{4 * Rc}$$

Note that the smaller Rc is, the more power is dissipated in it. So if Re and Rc are both lowered proportionately, we will get an increased GBW but at the cost of more power being dissipated by the circuit. The same analysis would apply to a digital circuit as well.

BODE PLOTS
A Bode Plot is a graph showing how gain and bandwidth are related in an amplifier. It is very useful, and is very commonly found in books and magazine articles on electronics. A typical Bode Plot is shown in ***Figure 2***.

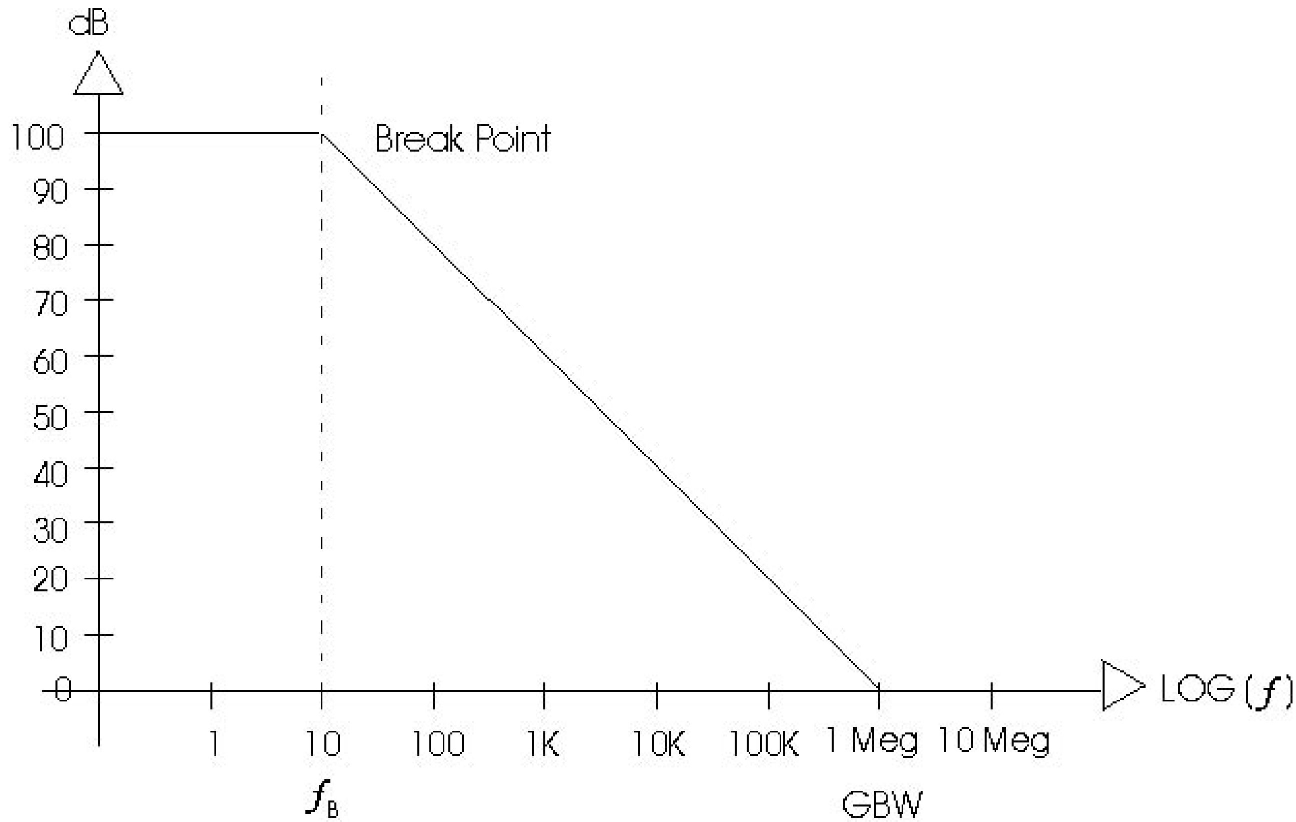

Figure 2

The vertical axis (Y-axis) is in dB. Remember that when dealing with amplifiers, dB is defined by equation EQ-2 given above. The horizontal axis (X-axis) is the Log of the frequency, so each mark on the horizontal axis represents a frequency 10 times higher than the previous mark. The distance from one mark to another, from f to 10f, is called a "decade". The distance from f to 2f is called an "octave".

BREAK-POINT, ROLL-OFF, AND FEEDBACK
Figure 2 shows the maximum voltage gain (Av) of an amplifier as a function of frequency. There are two important things to see on the graph. First is the "break-point" which occurs at the "break-frequency" fB. Av is constant until the break-point. The second thing is that after fB, Av starts to "roll off" at a constant rate of 20 dB per decade. The point where the graph crosses through the horizontal axis is the GBW. A roll-off of 20dB / dec is typical of many amplifiers.

Figure 2 shows that the amplifier starts out with a gain of 100 dB, which is a gain of 100,000. That's more gain than you need for most applications. So high-gain amplifiers in general, and op-amps in particular, use "negative feedback" to reduce the gain to a usable level. A total discussion of negative feedback is beyond the scope of this article. We will just say that negative feedback takes some of the output signal and connects it back to the input in such a way that the signal fed back subtracts from the input. The effect is to cause the amplifier to operate at a lower value of gain while the

GBW stays the same. With no feedback, the amplifier is said to be "open-loop". With negative feedback, it is said to be "closed-loop".

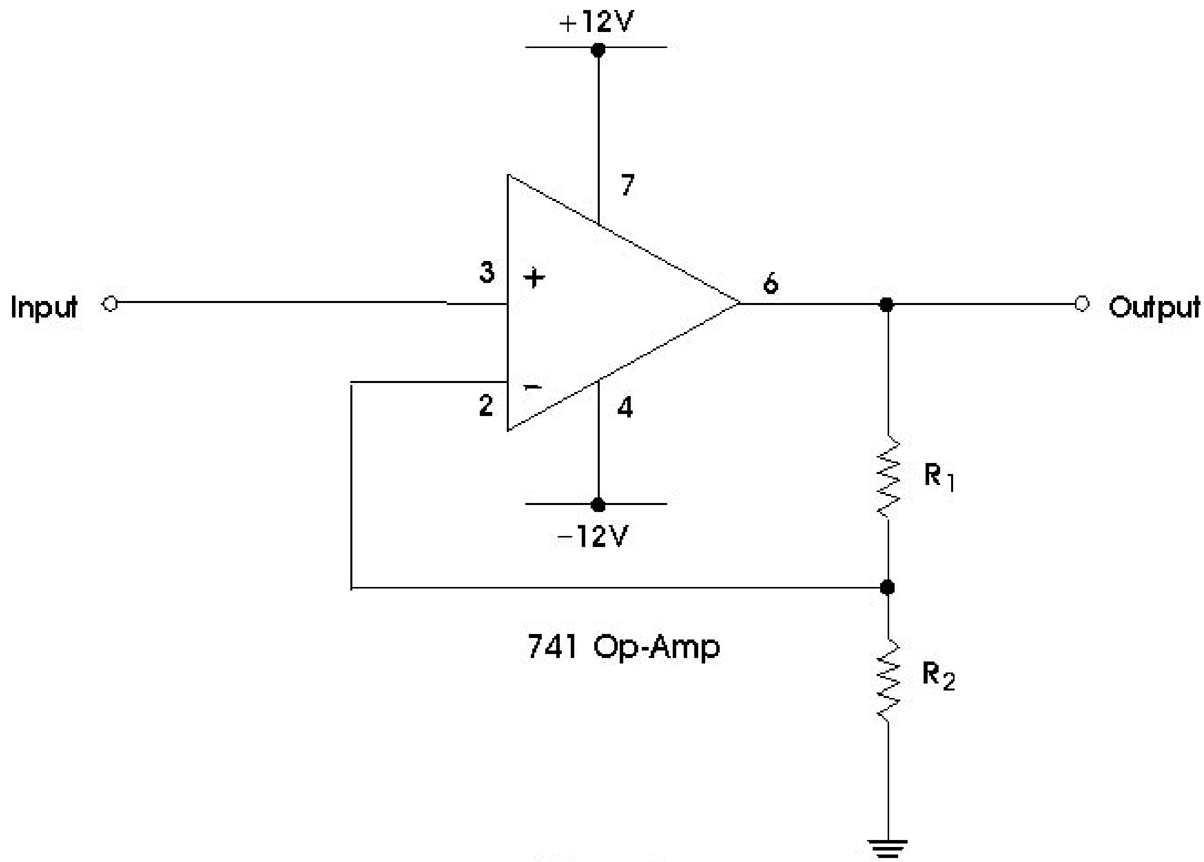

Figure 3

Figure 3 shows a 741 op-amp (an oldie but a goodie) in a closed-loop circuit. The gain is given by the equation:

`EQ-9:     Av  =  1  +  R1 / R2`

Figure 4 shows how the Bode plot for the 741 has been changed by configuring it for a closed-loop gain of 10. Note that the usable bandwidth is much greater than the original fB.

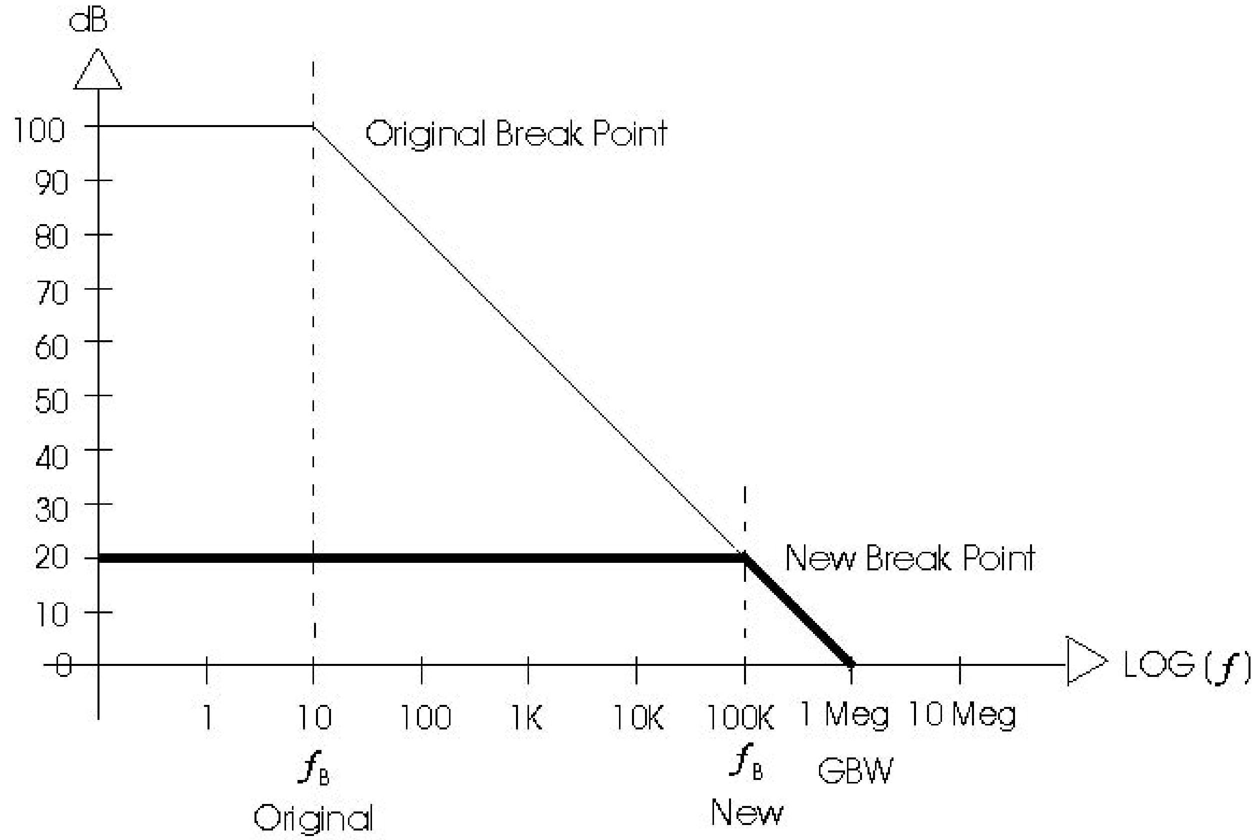

Figure 4

WRAP-UP
Well, that's it for this Tech Tip. In future Tech Tips we will look at other amplifier parameters such as input and output impedance, input offset, and drift. And we will take on op-amps.