ABOUT OPERATIONAL AMPLIFIERS

By Eddie Ciletti for AE-231 March 2006

In order to have **voltage gain**, the most basic, single-stage amplifier – vacuum tube or solid state – will invert the polarity as part of the process. It is easier to understand voltage gain (a mic preamp) than it is current gain (a power amp), the latter having the ability to do work, to break a sweat, to get hot. (Do ya get it?)

A transformer can manipulate voltage between primary and secondary but not without an inverse change of current. Step the voltage up, for example, and the current capacity comes down and vice versa. The power formula P= VI (or E*I) shows this relationship quite clearly. With 120 volts on a primary that is capable of carrying 1-amp of current, the power at the primary is 120 watts. Step down to 12-volts on the secondary (a 10:1 ratio) and it's quite possible for the secondary to have a 10-amp capacity. Again, the power, 12-v times 10-A = 120 watts.

Most power transformers are not quite that efficient and most amplifiers are even less efficient. Power amps also require a power supply, but aside from that, a power amp can convert impedance from high-to-low and essentially allow any voltage of any impedance to drive a low impedance load, such as a speaker, without the voltage and current trade-off.

Now what you might think of as a power amplifier is not limited to driving speakers. It is simply a matter of relativity. A condenser mic requires an impedance converter just to convert delicate changes in sound pressure to microphone level. Whatever is inside a microphone constitutes both voltage and current gain. That said, we will initially look at opamps as voltage amplifiers even though they are simultaneously behaving as power amps.

The **operation**al amplifier (Op Amp) was originally developed to perform arithmetic "**operation**s" for an analog computer, hence the name. For example, voltage gain is multiplication. A summing amplifier (like a mix buss) is simple addition. A differential amplifier performs subtraction.

All opamps have at least three signal connections - two inputs and an output - one input flips the incoming signal polarity by 180 degrees (inverting = "-") while the other input does nothing to the signal polarity (non-inverting = "+").

Most opamps operate on bipolar power, typically plus 15-volts and minus 15-volts. This allows nearly a 30-volt peak to peak signal to develop. It is just as easy to run the same opamp on a 9-volt battery, the amplifier must simply be biased at half the supply voltage, 4.5-volts in this case. Can you draw a circuit to accomplish this goal?

The OPAMP graphics page has five configurations that you should be able to draw from memory. All of these amplifiers appear in some form on the LA-3 student kit schematic, with which you should also be familiar enough to be able to draw from memory. There are several more opamp configurations, the side-chain of a compressor-limiter being examples of "application specific" circuits. You should at least be able to recognize those that are in the LA-3 kit. There is one packaging variation between the IC opamps on the graphic page versus those in the LA-3 kit. Can you determine that difference?

SUBTRACTION

The **Input Amplifier** circuit used in the LA-3 kit must accept a balanced line-level signal – two signals of opposite polarity. If these two signals were brought up on a pair of faders, they would cancel out. But a differential amplifier does just that, amplify by subtracting the difference. With all resistors being equal, a 1-volt signal at each input – one being of opposite polarity - the equation for what happens next is $V_2 - V_1 * (R_3 / R_1)$ or 1 – (-1) * (10k-Ω/10k-Ω) = 2 * 1 = 2, a gain of 2, not zero (not cancellation).

Conversely, if the two signals were identical, including polarity (as would be the case with induced noise) the difference amp would subtract one from the other and get ZIP, a.k.a. "squat!" The induced noise is also known as the Common Mode signal and the amplifier's ability to discriminate between desirable signals and noise is known as the Common Mode Rejection Ratio or CMRR.

VOLTAGE FOLLOWER

At the top left of the OPAMP page is a unity gain non-inverting amplifier known as a Voltage Follower. There are two in the LA-3 kit, both isolate or "buffer" the optical attenuators (one for AC and the other for DC) from the circuitry that follows. For example, when the photo resistor is 82k-Ω, the divider cuts the signal in half (that's –6dB). IF the junction of these two resistors had to drive a pair of potentiometers – the LEVEL and Gain Reduction pots for example – the level at the divider would significantly change. (The combined pot values (two 10k-Ω resistors in parallel = 5k-Ω). Surely you can see that this would be a problem – can you draw and explain why – be thankful for the Voltage Follower.

NOTE: Opamps in general, and this circuit in particular, have a very high input impedance - so as to not load the divider - and low output impedance - so as to not be bothered by driving two pots.

INVERTING AMP (Addition)

At top right is an amplifier that serves several functions. In recording consoles it is the summing buss for the main stereo mix, aux sends and groups. When R_1 (the input resistor) and R_f (the feed back resistor) are equal, the signal V_{in} equals the output signal V_{out} – the gain is unity. In the LA-3kit, opamp 2a is **the make-up gain amplifier** that follows the Level pot, where R_1 = 10k-Ω and R_f = 110k-Ω. Can you calculate the gain for this amplifier? This amplifier drive the RING of the TRS output connector.

Following the make-up gain amplifier is another inverting amplifier, this time the relationship between input and feedback resistors is the same, a ratio of 1. The purpose of this amp is simply to invert the polarity of the signal to drive the TIP of the output TRS connector.

NON-INVERTING AMPLIFIER

The formula for the non-inverting amp pretty much says it all – it's one PLUS the relationship between the voltage divider $\mathbf{R}_1$ and $\mathbf{R}_f$. If these two resistors are identical, the signal from $\mathbf{V}_{out}$ is divided in half to the inverting input. So, the formula $1 + \mathbf{R}_f / \mathbf{R}_1 = \mathbf{2}$ and if you haven't figured it out, a gain of 2 means that $\mathbf{V}_{out}$ is DOUBLE $\mathbf{V}_{in}$ and uh, for the umpteenth time, that's a gain of, well, I hope you guessed **6dB**!!!

The EL panel has a fairly wide dynamic range, they can be connected directly to the 120-volt RMS power line. It is a high impedance device. It will show visible light with only 80-volts RMS. An opamp running from a bipolar 15-volt supply can deliver a nearly 30-volt P-to-P voltage swing, not enough to excite the EL panel. However, with a step up transformer, 30-volts AC can easily be transformed to 80-volts.

The current required to drive the step-up transformer is significant, so the non-inverting amp used to drive the EL panel is "buffered" by an external pair of transistors to increase the current drive / power capacity. The devices have about 4-times the surface area of the opamp and so are capable of dissipating more heat.

BALANCED OUT

There are several ways to make balanced input and output amplifiers, the differential output amp on the "graphics" page is similar to the one we used for the LA-3 kit with one exception – this amplifier assumes the incoming signal, $\mathbf{V}_{in}$ is at nominal level. The LA-3 "RING" output amp was also the make-up gain amplifier. The version shown on the graphics page has two cascaded unity-gain inverting amplifiers.