Basics of Amplification

Transistors, by nature, are current amplifiers -- in response to a small input (for the BJT a current signal at the Base, for the FET a voltage signal at the Gate), transistors control large current signals through the main path (Collector and Emitter for the BJT, Drain and Source for the FET). Notice the careful wording -- they don't "make a small input signal into a large current": they use a small input signal to control a large current, which requires a good DC power source to drive that large current.

The letter ***A*** is used as a variable to represent amplification, or ***Gain***. For the BJT transistor, the current gain was given the symbol β. However, for an amplifier circuit, it would be called the current gain. So, for a current amplifier,

$$A_i = \frac{I_{out}}{I_{in}}$$

Voltage gain compares output voltage to input voltage for a voltage amplifier:

$$A_v = \frac{V_{out}}{V_{in}}$$

Power gain compares output power to input power for a power amplifier:

$$A_p = \frac{P_{out}}{P_{in}}$$

In this course, we will concentrate on voltage gain.

Voltage Amplifier Model

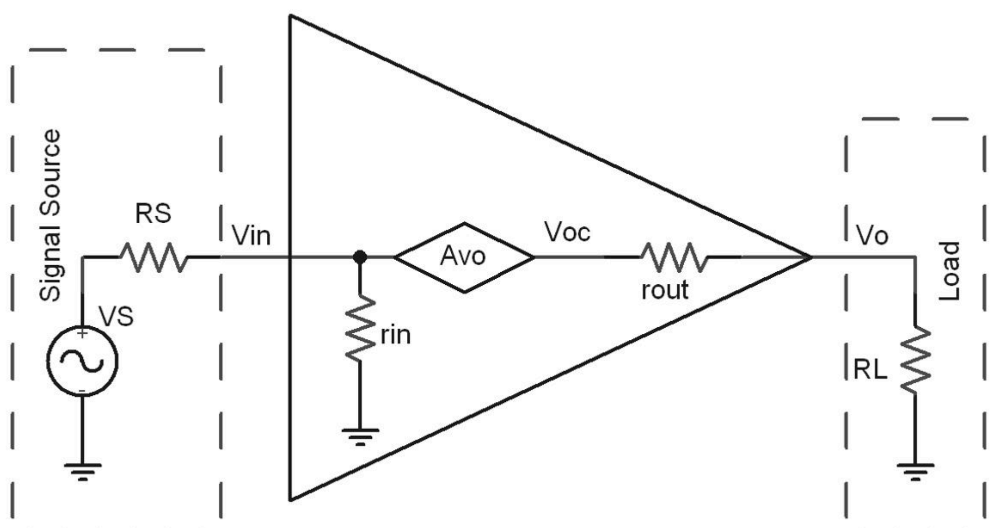
An ideal amplifier would simply take an input signal and multiply it by a gain factor to produce the output signal: $V_{out} = A_v V_{in}$. Unfortunately, not many transistor amplifiers are ideal. Operational amplifiers (op amps) can be very nearly ideal. However, they were designed in response to years of working with the non-ideal characteristics of simple transistor amplifiers.

An ideal amplifier, in order to be ideal, would have:

1. an infinite input impedance so that no current would be drawn from the source, thereby having no effect on the source itself
2. zero output impedance so that being connected to a resistive load would not result in any loss of signal

Unfortunately, most amplifiers have measurable input and output impedances, which need to be taken into account when analyzing the performance of the amplifier.

Here's a model of a non-ideal amplifier, as connected to a non-ideal signal source and a load:



The "A_{vo}" component in the middle would be the ideal amplification component of this model -- the V_{in} signal presented to the A_{vo} diamond is multiplied by the "open circuit gain" to produce the "open circuit output voltage", V_{oc}. More on that terminology in a moment.

$$A_{vo} = \frac{V_{oc}}{V_{in}}$$

The problem is that, when connected to a non-ideal source, V_{in} ends up being less than the driving signal from the inside of the source, V_S, because of a voltage divider created by the signal source's output impedance, R_S, and the input impedance of the amplifier, r_{in}. So,

$$V_{in} = V_S \left(\frac{r_{in}}{R_S + r_{in}} \right)$$

At the output, the full-sized V_{oc} also encounters a voltage divider, so that the real (often called "loaded") output voltage, V_o, is reduced in amplitude as well:

$$V_O = V_{OC} \left(\frac{R_L}{r_{out} + R_L} \right)$$

The overall gain for the amplifier (which doesn't include the loss at the input) is

$$A_v = \frac{V_O}{V_{in}}$$

If you substitute in the formula for V_o, this ends up as

$$A_v = A_{vo} \left(\frac{R_L}{r_{out} + R_L} \right)$$

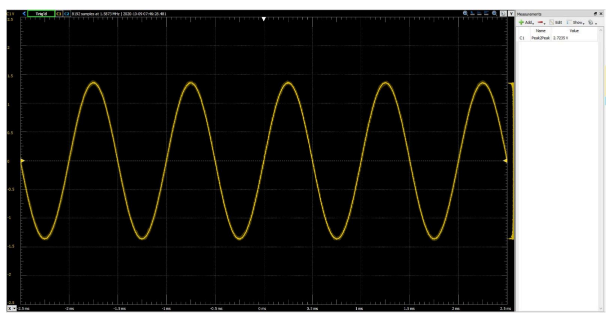
Empirical Amplifier Analysis

An amplifier may be considered as a "black box" -- something that we can get information out of, but we can't see what's inside. However, by taking appropriate measurements, we can determine what's inside the box.

One very useful tool to finding out what's "in the box" of an amplifier, or for that matter any non-ideal voltage source, is to measure the output when there's no load attached. That's where the "vo" in A_{vo} comes from, and the"oc" in v_{oc}. This is the "open circuit" measurement of the source. Since, with no load, there's no current and therefore no voltage drop across the output impedance, we can "see" the internal voltage of the device.

This is true of a signal source such as a function generator as well as for an amplifier -- if we measure the output of a function generator with a high-impedance tool like an oscilloscope or DMM, we get to see the "internal" or open circuit voltage. However, if we attach a load to the function generator, the voltage drops. From this, we can actually determine what the output impedance of the function generator is. Here's a real-life example. The first screenshot is of the output from a function generator directly measured by an oscilloscope. The second one is the same setup, but with a 100 Ω load resistor connected to ground.

3.87 V_{p-p}



2.72 V_{p-p}

Clearly, connecting the load resistor had a big effect, which would not have been the case if the function generator had zero output impedance.

Since the loss is due simply to the voltage divider between the source impedance and the load impedance, we can say

$$V_L = V_S \left(\frac{R_L}{R_S + R_L} \right)$$

...which rearranges to

$$R_S = R_L \left(\frac{V_S - V_L}{V_L} \right)$$

Using this rearranged voltage divider, the internal impedance of the function generator must be 42.3 Ω

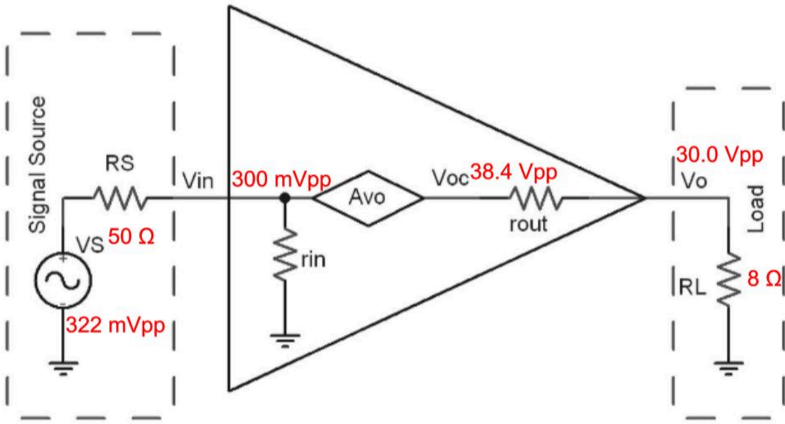
Applying the same logic to our "black box" amplifier model, we can determine the input and output impedances of the amplifier by driving it using a source with a known output impedance, R_S, and by connecting it to a known load. Using the variables from the model,

$$r_{in} = R_S \left(\frac{V_{in}}{V_S - V_{in}} \right)$$

$r_{out} = R_L \left(\frac{Voc - Vo}{Vo} \right)$

Question: Working late in your lab one night, your eyes beheld the strangest sight: an amplifier with no specification label. You grab your 50 Ω function generator and an 8 Ω speaker and set to work. With everything connected together, the voltage at the input is 300 $mV_{p\text{-}p}$ and the voltage at the output is 30.0 $V_{p\text{-}p}$. You disconnect the speaker and measure 38.4 $V_{p\text{-}p}$. With the amplifier disconnected, the function generator's signal measures 322 $mV_{p\text{-}p}$.

1. Start by sketching the black box model of this system, and applying the values supplied to the various nodes and resistances. You should end up with the following:



2. The amplifier's open circuit gain, A_{vo}, must be 128

3. The amplifier's loaded gain, A_v, is 100

4. The amplifier's input impedance appears to be 682 Ω

5. The amplifier's output impedance appears to be 2.24 Ω

There! Without knowing anything about the components inside the box, we've determined ***empirically*** all of the characteristics of this amplifier.

We will be analyzing specific amplifier circuits, and for these we will be able to predict their input and output impedances and their open circuit gains based upon components used in the design. However, we will always come back to this emperical analysis procedure when we want to determine the actual values of these characteristics.