Introduction to Amplifiers

by Kenneth A. Kuhn
Sept. 8, 2001, rev. Sept. 3, 2009

Introduction

This paper introduces the student to electronic amplifiers. The specific type of amplifier to be discussed here is known as the small signal AC amplifier. This type of amplifier takes a small AC signal (perhaps in the nanovolt to millivolt range) from some transducer or signal source and amplifies it to a higher level. Regardless of whether the input or output from the amplifier is a voltage or a current, the purpose of the amplifier is to deliver power gain. That is, the power delivered to the load from the amplifier is higher than the power delivered to the amplifier from the source.

There are several concepts to keep in mind about any amplifier

- Every signal source has a source impedance, Rs
- Every amplifier has an input impedance, Ri
- Every amplifier has an output impedance, Ro
- Every load has a load impedance, Rl
- An amplifier must have a power gain greater than 1 to be useful

There are four possible types of amplifiers:

1. Voltage-in, Voltage-out. This amplifier has voltage gain.

2. Current-in, Voltage-out. This amplifier has trans-impedance gain.

3. Current-in, Current-out. This amplifier has current gain.

4. Voltage-in, Current-out. This amplifier has trans-conductance gain.

We will be primarily concerned with voltage amplifiers. It should be noted that with the appropriate circuit, any of the four types of amplifiers can act as a voltage amplifier. The voltage amplifiers we build in this course will be primarily constructed of Current-in, Current-out, or Voltage-in, Current-out amplifier elements. An amplifier consists of at least one stage and may have two or more stages in order to achieve very high voltage gain.

Introduction to Amplifiers

The basic model of a voltage amplifier consists of three elements: an input which has some shunt resistance called Ri, a voltage controlled voltage source that puts out a voltage A times the input voltage, and a resistance in series with that voltage source called Ro that connects the voltage source to the output. These elements are defined as follows:

Ri	Input resistance of the amplifier
A	Unloaded or open circuit voltage gain of the amplifier
Ro	Output impedance of the amplifier

There are two voltage divisions we have to consider. One occurs at the input of the amplifier due to the voltage divider formed by the resistance of the source and the input resistance of the amplifier. The other occurs at the output of the amplifier due to the voltage divider formed by the output resistance of the amplifier and the resistance of the load being driven. The presence of these voltage dividers reduces the effective voltage gain we realize with the amplifier. There are three different types of voltage gains we consider as described below.

Unloaded stage gain	= A	Eq. 1
Loaded stage gain	= A * output voltage division	Eq. 2
Net gain	= input voltage division * A * output voltage division	Eq. 3

The voltage division factors are as follows:

input voltage division	= Ri / (Rs + Ri) = 1 / (Rs/Ri + 1)	Eq. 4
output voltage division	= Rl / (Ro + Rl) = 1 / (Ro/Rl + 1)	Eq. 5

In the case of a multistage amplifier, the source resistance may be the output resistance of the previous stage and the load resistance may be the input resistance of the next stage.

Introduction to Amplifiers

Power Gain

Power gain is defined as the power delivered to a load divided by the power taken from the source. Considering input and output voltages, this can be expressed mathematically as:

$$Pg = \frac{Pl}{Pi} = \frac{Vl^2 / Rl}{Vi^2 / Ri} = (Vl/Vi)^2 * (Ri/Rl) \qquad \text{Eq. 6}$$

where

Pg Power gain
Vi Input signal voltage to amplifier
Vl Voltage delivered to the load
Ri Input resistance of amplifier
Rl Resistance of load

Vl is the input voltage multiplied by the loaded gain of the amplifier

$$Vl = Vi * A / (Ro/Rl + 1) \qquad \text{Eq. 7}$$

Combining the equations gives

$$Pg = \frac{A^2 * (Ri/Rl)}{(Ro/Rl + 1)^2} \qquad \text{Eq. 8}$$

With a little algebra, Equation 8 can be expressed as

$$Pg = \frac{A^2 * (Ri/Ro)}{(Ro/Rl) + 2 + (Rl/Ro)} \qquad \text{Eq. 9}$$

There are a number of observations we can make about Equation 8. One way we can achieve high power gain is for Ri to be much larger than Rl. It is not obvious from Equation 8 but it is obvious from Equation 9 that power gain is maximized if Ro = Rl since this situation minimizes the denominator. Avoid being tricked into thinking that a high voltage gain is sufficient to achieve high power gain. Consider the following examples.

A = 32, Ri/Rl = 2, Ro/Rl = 1: Pg = 512 A typical amplifier

A = 10, Ri/Rl = .3, Ro/Rl = 5: Pg = 0.83 A useless amplifier since Po < Pi

A = 0.8, Ri/Rl = 1000, Ro/Rl = 1: Pg = 160 Another typical amplifier (voltage gain <1)

Reality check

There is an important reality check that we must consider. What is the ratio of power delivered to a load with an amplifier to the power that would have been delivered to the load had no amplifier been used? Is it possible to achieve less power to a load with an amplifier (that has power gain greater than 1) than by just simply connecting the source to the load without using an amplifier? The answer to these questions determines the real benefit of the amplifier. The source resistance, Rs, now becomes involved.

Using an amplifier, then for a given source voltage, Vs, the power delivered to the load, Pl, is simply the load voltage squared divided by the load. The load voltage is the source voltage, Vs, multiplied by the net voltage gain of the amplifier. Thus, we can write the power delivered to a load from an amplifier, Pla:

$$Pla = \frac{\left[\frac{Vs}{(Rs/Ri + 1)} * A * \frac{1}{(Ro/Rl + 1)} \right]^2}{Rl} \qquad \text{Eq. 10}$$

The power that would be delivered to a load with no amplifier, Pln, can be written as

$$Pln = \frac{\left[\frac{Vs}{(Rs/Rl + 1)} \right]^2}{Rl} \qquad \text{Eq. 11}$$

Dividing Equation 10 by Equation 11 gives

$$\frac{Pla}{Pln} = \left[\frac{A * (Rs/Rl + 1)}{(Rs/Ri + 1) * (Ro/Rl + 1)} \right]^2 \qquad \text{Eq. 12}$$

Equation 12 gives us a test to check an amplifier design to see if it is really helping. This equation is hard to visualize. It is useful to construct a chart that explores a range of possibilities to see what happens. The following chart keeps Rs, A, and Rl constant and varies Ri and Ro.

Rs	Ri	A	Ro	Rl	Computed Pg	Pla/Pln	Comments on Amplifier
600	6	20	6	600	3.92	0.15	Worse than nothing
600	6	20	60	600	3.21	0.13	Worse than nothing
600	6	20	600	600	1.00	0.04	Worse than nothing
600	6	20	6000	600	0.03	0.001	Worse than nothing
600	60	20	6	600	39.21	12.96	Fair
600	60	20	60	600	33.06	10.93	Fair
600	60	20	600	600	10.00	3.31	Poor
600	60	20	6000	600	0.33	0.11	Worse than nothing
600	600	20	6	600	392.12	392.12	Good
600	600	20	60	600	330.58	330.58	Good
600	600	20	600	600	100.00	100.00	Good
600	600	20	6000	600	3.31	3.31	Poor
600	6000	20	6	600	3921.18	1296.26	Very good
600	6000	20	60	600	3305.79	1092.82	Very good
600	6000	20	600	600	1000.00	330.58	Very good
600	6000	20	6000	600	33.06	10.93	Fair

From the results it can be seen that just because an amplifier has a power gain greater than 1 does not mean that the amplifier is useful for a particular application. In these cases, the amplifier would be useful if either the input impedance were more reasonable compared to the source impedance or the output impedance was more reasonable compared to the load impedance.

It will be left as an exercise for the student to prove whether it is possible (or not) for an amplifier to have a power gain less than 1 but have a ratio of Pla/Pln greater than 1. The solution should be in symbolic form.

Equation 12 tells us that in order to obtain the maximum power to the load then it is good for Ri to be much larger than Rs and for Ro to be much smaller than Rl. This is different than from achieving maximum power gain or power transfer. Here we want the maximum actual power.

It is interesting to note that audio power amplifiers operate exactly per Equation 12. A typical audio power amplifier might have an input impedance of tens or hundreds of thousands of Ohms and an output impedance on the order of 0.1 Ohms or less and is intended to drive a speaker with a nominal impedance of 8 Ohms. The purpose of the very low output impedance in relationship to the load impedance is so that the majority of the power developed will be transferred to the load and not be dissipated in the amplifier.

Introduction to Amplifiers

Homework calculations with amplifiers (with answers)

1. An audio power amplifier has an input impedance of 60,000 Ohms and an output impedance of 0.01 Ohms. A 1 Volt rms sine wave applied to the input leads to 10 Watts delivered to an 8 Ohm load. What is the voltage gain of the amplifier? What is the power gain of the amplifier? Express the power gain of the amplifier in dB. (8.9, 600,000, 57.8 dB)

2. If the voltage gain of an amplifier is increased by a factor of ten without affecting the input and output impedances, how much has the power gain been increased? Express the increase in power gain in dB. (100, 20 dB)

3. A certain microphone puts out a 1 mV signal across a 600 Ohm load in response to a sound level of 90 dBa. An amplifier is connected between the microphone and a 600 Ohm load (the amplifier input impedance is the load for the microphone). Determine the voltage gain and power gain required for an amplifier that has a 600 Ohm input and output impedance such that the amplifier will deliver a 0 dBm signal to a 600 Ohm load in response to a 100 dBa signal. Express the power gain in dB. (490, 60,240, 47.8 dB – check: Vin = 3.16 mV, Pin = 16.6 nW)

4. An amplifier has an input impedance of 2500 Ohms and an output impedance of 6200 Ohms and has a voltage gain of 230. A signal source that puts out a 1 mV signal and has a source impedance of 1500 Ohms is connected to the input of the amplifier. The output of the amplifier is connected to a 5100 Ohm load. What is the signal voltage across the load? What is the net voltage gain of the amplifier? What is the power gain of the amplifier in dB? (64.8 mV, 64.8, 37.2 dB)

5. An amplifier has an input impedance of 10,000 Ohms and an output impedance of 150 Ohms and has a voltage gain of 0.8. If a 500 Ohm load is connected, what is the loaded voltage gain of the amplifier and what is the power gain in dB? (8.8 dB)

6. A three stage amplifier is built of the following amplifier stages:
   Stage 1: Rin = 5000 Ohms, Ro = 12000 Ohms, Av = 24
   Stage 2: Rin = 8000 Ohms, Ro = 35000 Ohms, Av = 33
   Stage 3: Rin = 20000 Ohms, Ro = 300 Ohms, Av = 0.9
   The source connected to the input has an impedance of 800 Ohms. The load connected to the output has an impedance of 500 Ohms. What is the net voltage gain of the amplifier? Express the power gain of the amplifier in dB. (55.9, 46.2 dB)

Introduction to Amplifiers

7. An amplifier has in input impedance of 100,000,000 Ohms and an output impedance of 300 Ohms and a voltage gain of 0.4. If the load resistance is 1000 Ohms, what is the loaded voltage gain and power gain of the amplifier? Express the power gain in dB. (0.3077, 9467, 39.8 dB)