Ideal Voltage Feedback (VFB) Op Amp

INTRODUCTION

The op amp is one of the basic building blocks of linear design. In its classic form it consists of two input terminals, one of which inverts the phase of the signal, the other preserves the phase, and an output terminal. The standard symbol for the op amp is given in Figure 1. This ignores the power supply terminals, which are obviously required for operation.
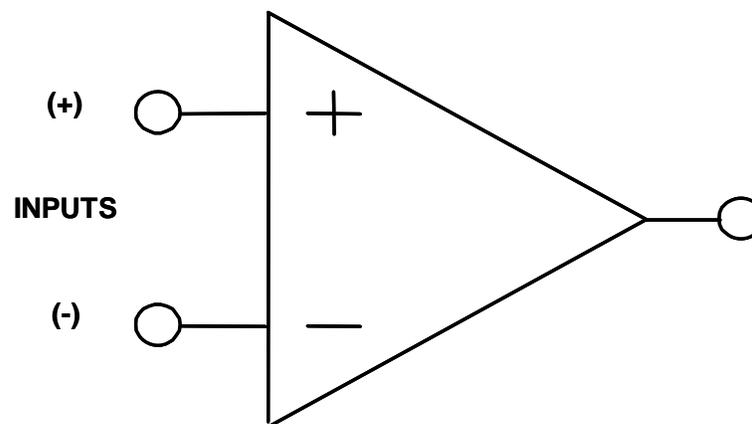

Figure 1: Standard Op Amp Symbol

The name "op amp" is the standard abbreviation for operational amplifier. This name comes from the early days of amplifier design, when the op amp was used in analog computers. (Yes, the first computers were analog in nature, rather than digital). When the basic amplifier was used with a few external components, various mathematical "operations" could be performed, such as addition, integration, etc. One of the primary uses of analog computers was during World War II, when they were used for plotting ballistic trajectories. See Reference 2 for more history of op amps.

IDEAL VOLTAGE FEEDBACK (VFB) MODEL

The classic model of the ideal voltage feedback (VFB) op amp has the following characteristics:

1. Infinite input impedance
2. Infinite bandwidth
3. Infinite voltage gain
4. Zero output impedance
5. Zero power consumption

None of these can be actually realized, of course. How close a real implementation comes to these ideals determines the quality of the op amp.

This is referred to as the voltage feedback (VFB) model. This type of op amp comprises nearly all op amps below 10 MHz bandwidth and on the order of 90% of those with higher bandwidths. Current feedback (CFB) is another op amp architecture and is discussed in a separate tutorial. The attributes of an ideal VFB op amp are summarized in Figure 2.
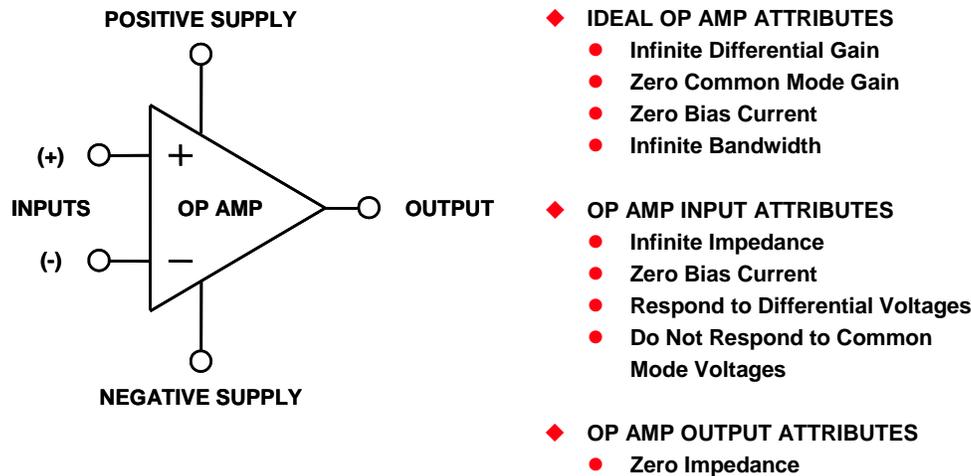

POSITIVE SUPPLY

INPUTS

(+)

(−)

OP AMP

OUTPUT

NEGATIVE SUPPLY

◆ **IDEAL OP AMP ATTRIBUTES**
- **Infinite Differential Gain**
- **Zero Common Mode Gain**
- **Zero Bias Current**
- **Infinite Bandwidth**

◆ **OP AMP INPUT ATTRIBUTES**
- **Infinite Impedance**
- **Zero Bias Current**
- **Respond to Differential Voltages**
- **Do Not Respond to Common Mode Voltages**

◆ **OP AMP OUTPUT ATTRIBUTES**
- **Zero Impedance**

Figure 2: The Attributes of an Ideal Voltage Feedback Op Amp

BASIC OPERATION

The basic operation of the ideal op amp can be easily summarized. First, we assume that there is a portion of the output that is fed back to the inverting terminal to establish the fixed gain for the amplifier. This is negative feedback. Any differential voltage across the input terminals of the op amp is multiplied by the amplifier's *open loop gain* which is infinite for the ideal op amp. If the magnitude of this differential voltage is more positive on the inverting (–) terminal than on the non-inverting (+) terminal, the output will swing negative. If the magnitude of the differential voltage is more positive on the non-inverting (+) terminal than on the inverting (–) terminal, the output voltage will swing positive. The infinite open loop gain of the amplifier will attempt to force the differential input voltage to zero. As long as the inputs and output stays in the operational range of the amplifier, it will keep the differential input voltage at zero, and the output will be the input voltage multiplied by the gain determined by the feedback network. Note that the output responds to differential-mode voltage and not the common-mode input voltage.

INVERTING AND NON-INVERTING CONFIGURATIONS

There are two basic ways configure the ideal voltage feedback op amp as an amplifier. These are shown in Figure 3 and Figure 4.

Figure 3 shows what is known as the inverting configuration. With this circuit, the output is out of phase with the input. The signal gain of this circuit is determined by the ratio of the resistors used and is given by:
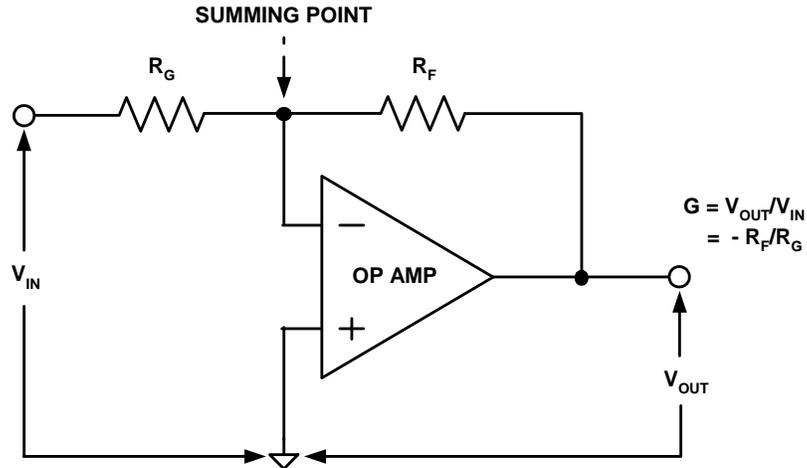
$$G = -\frac{R_F}{R_G}$$

Eq. 1

SUMMING POINT

R_G R_F

V_{IN}

OP AMP

$G = V_{OUT}/V_{IN}$
$= -R_F/R_G$

V_{OUT}

Figure 3: Inverting Mode Op Amp Stage

Figure 4 shows what is know as the non-inverting configuration. With this circuit the output is in phase with the input. The signal gain of the circuit is also determined by the ratio of the resistors used and is given by:

$$G = 1 + \frac{R_F}{R_G}$$

Eq. 2

OP AMP

R_F

R_G

V_{IN}

V_{OUT}
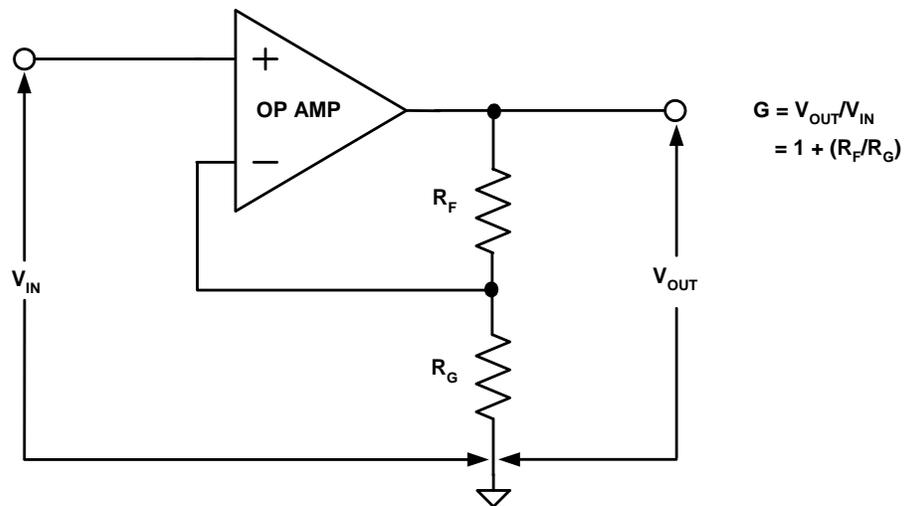
$G = V_{OUT}/V_{IN}$
$= 1 + (R_F/R_G)$

Figure 4:   Non-Inverting Mode Op Amp Stage

Note that since the output drives a voltage divider (the gain-setting network) the maximum voltage available at the inverting terminal is the full output voltage, when the circuit is configured for a minimum gain of 1 ($R_G = \infty$).

Also note that in both inverting and non-inverting configurations the feedback is from the output to the inverting terminal. This is *negative* feedback and has many advantages for the designer. These will be discussed more in detail.

It should also be noted that the gain is based on the *ratio* of the resistors, not their actual values. This means that the designer can choose from a wide range of values, within certain practical limits.

However, if the values of the resistors are too low, a great deal of current is required from the op amp output for proper operation. This causes excessive power dissipation in the op amp itself, which has many disadvantages. The increased dissipation leads to self-heating of the chip, which can cause a change in the dc characteristics of the op amp itself. Also, the heat generated can eventually cause the junction temperature to rise above 150°C, the commonly accepted maximum limit for most semiconductors. The junction temperature is the temperature at the silicon chip itself. On the other end of the spectrum, if the resistor values are too high, there is an increase in noise and the susceptibility to parasitic capacitances, which can also limit bandwidth and possibly cause instability and oscillation.

From a practical sense, resistors below 10 Ω and above 1 MΩ are more difficult to procure, especially if precision resistors are required.

INVERTING OP AMP GAIN DERIVATION

Let us look at the case of an inverting amp in a little more detail. Referring to Figure 5, the non-inverting terminal is connected to ground. We are assuming a bipolar (positive and negative) power supply. Since the op amp will force the differential voltage across the inputs to zero, the inverting input will also appear to be at ground. In fact, this node is often referred to as a "virtual ground".
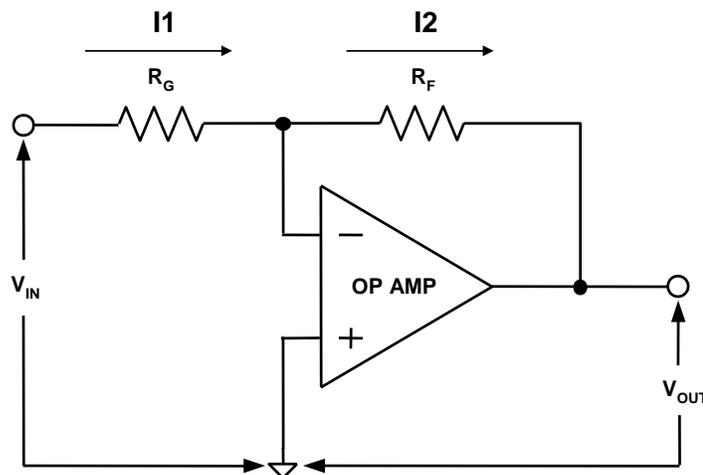

Figure 5:   Inverting Amplifier Gain

If there is a voltage (V_{IN}) applied to the input resistor, It will set up a current (I1) through the resistor (R_G) so that

$$I1 = \frac{V_{IN}}{R_G}$$
Eq. 3

Since the input impedance of the ideal op amp is infinite, no current will flow into the inverting input. Therefore, this same current (I1) must flow through the feedback resistor (R_F). Since the amplifier will force the inverting terminal to ground, the output will assume a voltage (V_{OUT}) such that:

$$V_{OUT} = I1 \times R_F$$
Eq. 4

Doing some simple arithmetic we then can come to the conclusion (Eq. 1) that:

$$\frac{V_{OUT}}{V_{IN}} = G = -\frac{R_F}{R_G}.$$
Eq. 5

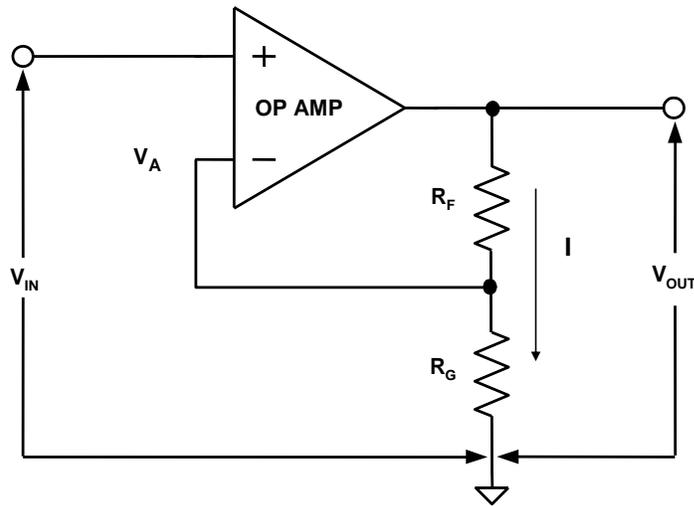**NON-INVERTING OP AMP GAIN DERIVATION**

Figure 6: Non-Inverting Amplifier gain

Now we examine the non-inverting case in more detail. Referring to Figure 6, the input voltage is applied to the non-inverting terminal. The output voltage drives a voltage divider consisting of R_F and R_G. The voltage at the inverting terminal (V_A), which is at the junction of the two resistors, is equal to

$$V_A = \frac{R_G}{R_G + R_F} V_{OUT}.$$
Eq. 6

The negative feedback action of the op amp will force the differential voltage to 0, so

$$V_A = V_{IN}.$$ Eq. 7

Applying a little simple arithmetic we obtain:

$$\frac{V_{OUT}}{V_{IN}} = G = \frac{R_G + R_F}{R_G} = 1 + \frac{R_F}{R_G} \ ,$$ Eq. 8

which is what we specified in Eq. 2.

In all of the discussions above, we referred to the gain setting components as resistors. In fact, they are impedances, not just resistances. This allows us to build frequency dependant amplifiers and will be covered in more detail in later tutorials.

REFERENCES:

1. Hank Zumbahlen, *Basic Linear Design*, Analog Devices, 2006, ISBN: 0-915550-28-1. Also available as *Linear Circuit Design Handbook*, Elsevier-Newnes, 2008, ISBN-10: 0750687037, ISBN-13: 978-0750687034. Chapter 1

2. Walter G. Jung, *Op Amp Applications,* Analog Devices, 2002, ISBN 0-916550-26-5, Also available as *Op Amp Applications Handbook*, Elsevier/Newnes, 2005, ISBN 0-7506-7844-5. Chapter 1.