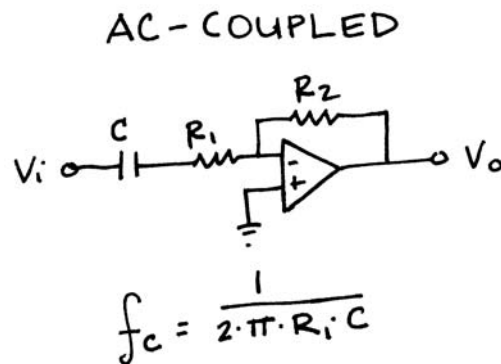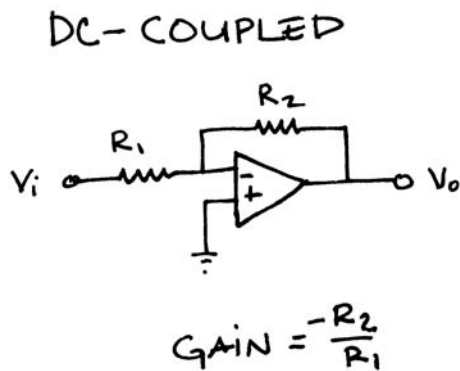# MAS.836
HOW TO BIAS AN OP-AMP

Op-Amp Circuits:

Bias, in an electronic circuit, describes the steady state operating characteristics with no signal being applied. In an op-amp circuit, the operating characteristic we are concerned with is the output voltage of our op-amp. If an op-amp is said to be biased to 2.5V, this means that, for no incoming signal or no sensor excitation, the output voltage will rest at 2.5V. Bias is, therefore, strictly a DC value. Once an AC signal is applied, the output will then begin to move about the bias point. We bias an amplifier to a particular value to keep the op-amp from saturating (amplifying a signal beyond the supply voltage limitations) and to allow the signal to have as large of a range as possible. It is very important to bias an amplifier before sending its signals to the input of an A/D converter. If your signal does not occupy the full input voltage range of your A/D, you will not get the full bit resolution on your data.
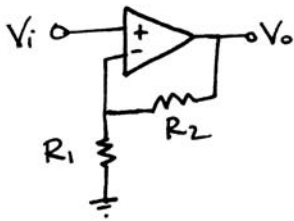
There are, essentially, only three op-amp configurations, and they are shown below. These configurations can be set up to be either AC or DC coupled. An AC coupled amplifier will only amplify signals which change with time, and will not respond to any signals which do not change with time. A DC amplifier will amplify both types of signals, making it more difficult to bias, since our bias voltages are also DC signals. So, unless you need to know the steady state value of an input, you should always AC couple your signals. This not only makes your circuit easier to bias, it also reduces any noise which might exist in the frequencies below those of interest.
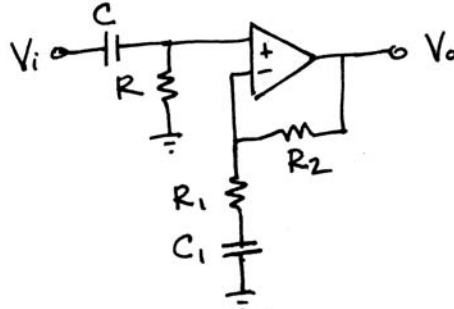
Inverting Amplifier:

$$\text{GAIN} = \frac{-R_2}{R_1}$$

$$f_c = \frac{1}{2 \cdot \pi \cdot R_1 \cdot C}$$

Non-Inverting Amplifier:

DC-COUPLED

$$\text{GAIN} = 1 + \frac{R_2}{R_1}$$

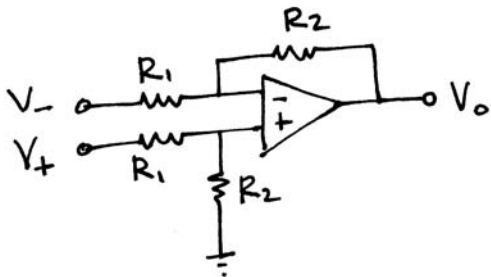AC-COUPLED

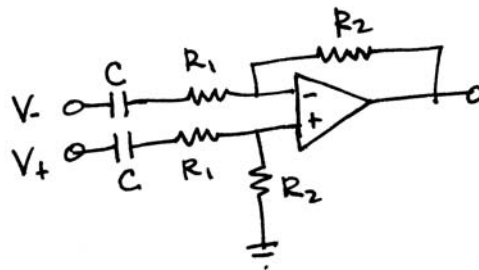$$f_c = \frac{1}{2\cdot\pi\cdot R\cdot C} = \frac{1}{2\cdot\pi\cdot R_1\cdot C_1}$$

Differential Amplifier:

DC-COUPLED

$$\text{GAIN} = \frac{R_2}{R_1}(V_+ - V_-)$$

AC-COUPLED

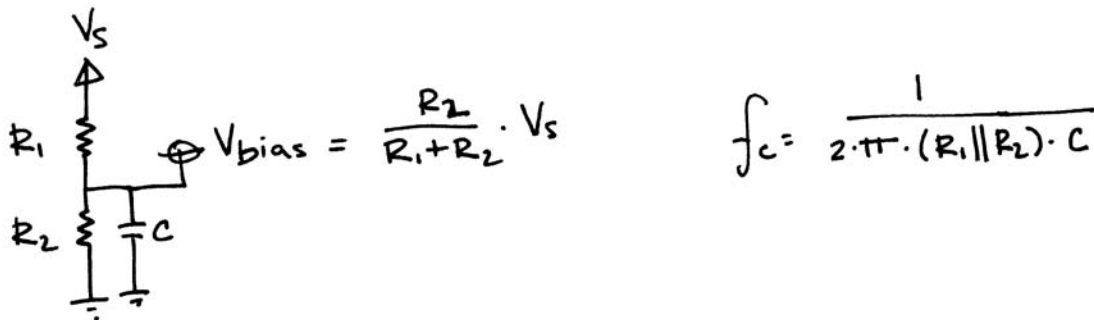$$f_c = \frac{1}{2\cdot\pi\cdot R_1\cdot C}$$

How to Bias an Amplifier:

In order to bias an amplifier, you must put a bias voltage at the INPUT of your op-amp. The output of an op-amp is very strong, and will merely overpower any bias voltage you apply there. But, since the output reflects the voltages present at the input, you can apply a bias voltage at the input, and allow the negative feedback around your amplifier to bring the output to the voltage you desire. A simple rule to follow when biasing your amplifier, is to replace any ground in your circuit with your bias voltage. There are only
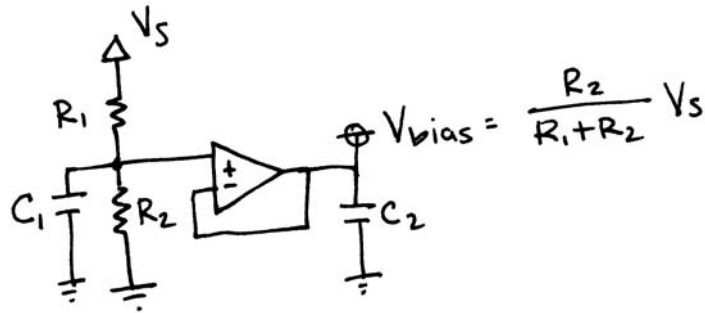
two caveats to this rule. First, you do not need to replace the ground with a bias voltage if that ground is only connected to a capacitor. Since a capacitor can not pass DC signals, it has no effect on the bias of a circuit, so you need not connect it to your bias voltage. Second, you do not need to replace a ground with a bias voltage if that ground is not connected in some way to the input of your op-amp. Since only the input of an op-amp can affect its output, those parts of your circuit which do not affect the input do not need to be biased.

There are three ways to create this bias voltage which will be placed at the input of your amplifier, and they are as follows.
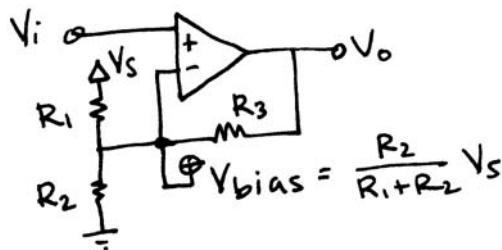
Voltage Divider Biasing: This method is particularly useful when you have a number of op-amps which need to be biased to the same voltage, as you can create a single bias voltage that they will all use. For DC coupled amplifiers, it is important to remember that R1 and R2 must be much, much smaller than any of the other resistors to which they are connected. This will prevent the bias resistors from adding with those resistors and changing the gain or offsets in your circuit. For AC coupled circuits, you need not worry about the size of the resistors, as long as the cut-off frequency of the voltage divider, as shown below, is much, much lower than the lowest cut-off frequency in the associated circuit. This will ensure that the impedance of the bias network will not add significantly at the frequencies of interest. The capacitor also helps eliminate power supply and pick-up noise which could be coupled in to your circuit.

$$V_{bias} = \frac{R_2}{R_1 + R_2} \cdot V_s \qquad f_c = \frac{1}{2 \cdot \pi \cdot (R_1 \| R_2) \cdot C}$$

Voltage Follower Biasing: This method is exactly the same as the voltage divider biasing, except it uses an op-amp (or transistor) to buffer the bias voltage, so choosing small resistor values is no longer necessary. This can help reduce power consumption in a circuit, and give even more accurate gain and offset values, as the impedance the biasing op-amp will present to the rest of your circuit will be infinitesimal compared to any other method. It can also supply a very stable bias voltage to any number of circuits, and will eliminate any cross-coupling of signals between circuits, which might be problematic with a simple voltage divider biasing scheme.

$$V_{bias} = \frac{R_2}{R_1 + R_2} V_s$$

Split Resistor Biasing: This method is the simplest to construct, but has the greatest amount of noise, as capacitors can not be used. Basically, any resistor which used to go to ground, is now split into two resistors; one which goes to ground, and one which goes to the power supply rail. The ratio of R1 and R2 determine the bias voltage, and as long as R1//R2 is equal to the old resistor value, the circuit will operate the same way. This method has the drawback, that if multiple bias voltages are required, it will be very difficult to get the same voltages at each point. So, if there is DC coupling, you can very quickly begin to amplify this error in bias voltages.
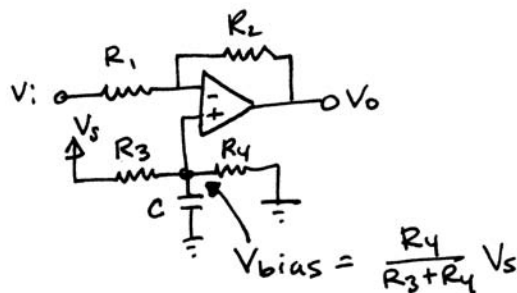

$$V_{bias} = \frac{R_2}{R_1 + R_2} V_s$$

How to Select Component Values:
In order to bias your amplifier, you will need to know two things. First, how much gain does your application require. To find this, merely measure your input signal to find its minimum and maximum values. The difference is your input voltage swing. Now, decide how large your output voltage swing should be, and divide this number by your input voltage swing. The result is your gain. Next, what is the bias voltage you would like to see at the output when you have no signal coming in. For AC amplifiers, this is a simple concept, as it is the center point about which your output will oscillate. But, for DC amplifiers, you will have to select a single operating point to calculate values for. This will include an input voltage and the corresponding output voltage you would like to see. For example, you may want the output to swing from 0V to 5V when the input goes from 2V to 1V. In this case, the gain is (5V - 0V) / (1V - 2V) = -5, and you can use either (2V, 0V), or (1V, 5V) as your operating point. Typically, operating points which have 0V as one of their values will be easier to calculate values for, as the 0 quickly drops out of the equations.

The bias equations for the three main amplifier types are shown below. Both split resistor and bias voltage methods are shown. For the bias voltage methods, either voltage divider or voltage follower circuits can be used.

Inverting Amplifier (DC Coupled):
In this case, the voltage divider biasing method is the best to use, unless you happen to have a voltage follower bias already in your circuit, in which case you can merely connect to that. Since the voltage divider is only connected to the input pin of the op-amp, which draws no current, you can make the resistors arbitrarily large. Also, if you have multiple inverting amplifiers in your circuit, you can connect them all to the same voltage divider, as they all draw no current from the divider.

$$GAIN = -\frac{R_2}{R_1} = -G \rightarrow \boxed{G = \frac{R_2}{R_1}}$$

$$V_{bias} = \frac{R_4}{R_3 + R_4} V_s$$

$$V_o = -G V_i + (1+G) V_b$$

$$\rightarrow \boxed{V_b = \frac{V_o + G V_i}{(1+G)}}$$

$$\frac{V_i - V_b}{R_1} = \frac{V_b - V_o}{R_2} \rightarrow V_o = -\frac{R_2}{R_1}(V_i - V_b) + V_b$$

$$= -\frac{R_2}{R_1} V_i + (1 + \frac{R_2}{R_1}) V_b$$
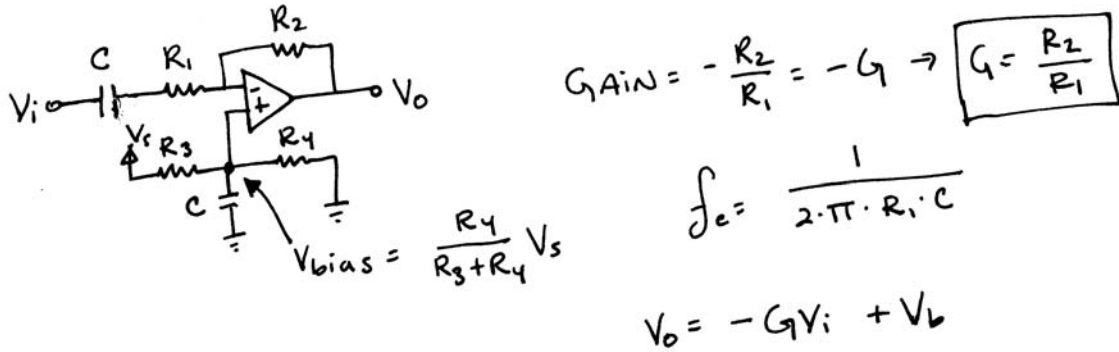
$$= -G V_i + (1 + G) V_b$$

As an example of solving for the bias voltage, we can use our previous numbers of a gain of -5 and an operating point of (2V, 0V). First you select R1 and R2 to give a gain of 5, and then you put G = 5, Vi = 1V, and Vo = 0V into the Vb equation, which gives:

Vb = (0V + 5 x 1V) / (1 + 5) = 5V / 6 = 0.833V.

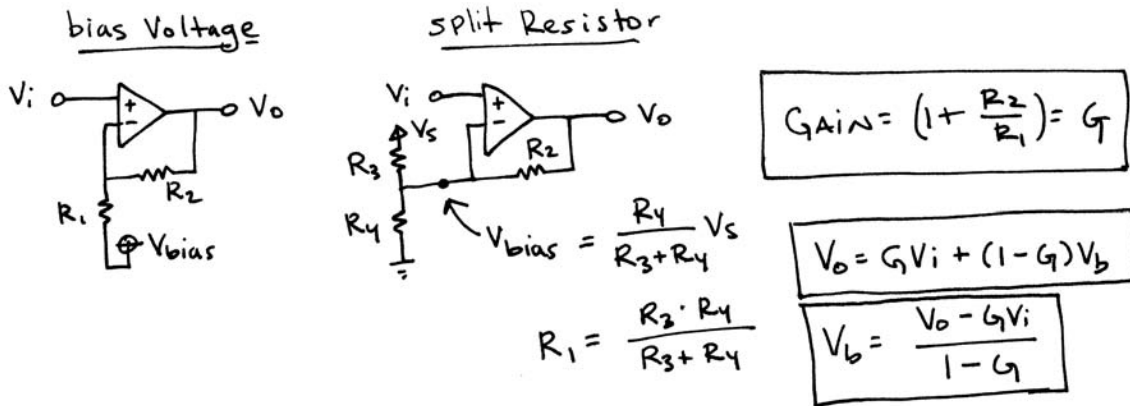Now you can select R3 and R4 to give a Vb of 0.833V, based upon your Vs.

Inverting Amplifier (AC Coupled):

The AC coupled amplifier is biased exactly the same way as the DC amplifier. You select R1 and R2 to give the gain you need, but you no longer need to calculate Vb, as you merely select R3 and R4 to set Vb to the voltage you want the output to be at when there is no input signal.

$$GAIN = -\frac{R_2}{R_1} = -G \rightarrow \boxed{G = \frac{R_2}{R_1}}$$

$$V_{bias} = \frac{R_4}{R_3 + R_4} V_s$$

$$f_c = \frac{1}{2 \cdot \pi \cdot R_1 \cdot C}$$

$$V_o = -G V_i + V_b$$

Non-Inverting Amplifier (DC Coupled):

It is important to note that you may not be able to bias the DC coupled, non-inverting amplifier to any arbitrary voltage. Since the gain (G) will always be greater than one, the denominator in the bias voltage equation will always be negative. And, if you do not have negative voltages in your circuit (which is often the case when biasing), you will be limited to conditions where G x Vi is greater than Vo. For example, if you have an input voltage swing of 0V to 1V, and you would like to bias this up to 1V to 5V, a negative bias voltage would be required (5 x 0V < 1V). For these cases, the DC coupled differential amplifier must be used, usually with the V- terminal connected to ground.

bias Voltage

split Resistor

$$V_{bias} = \frac{R_4}{R_3 + R_4} V_s$$

$$R_1 = \frac{R_3 \cdot R_4}{R_3 + R_4}$$

$$GAIN = \left(1 + \frac{R_2}{R_1}\right) = G$$

$$V_o = G V_i + (1 - G) V_b$$

$$V_b = \frac{V_o - G V_i}{1 - G}$$

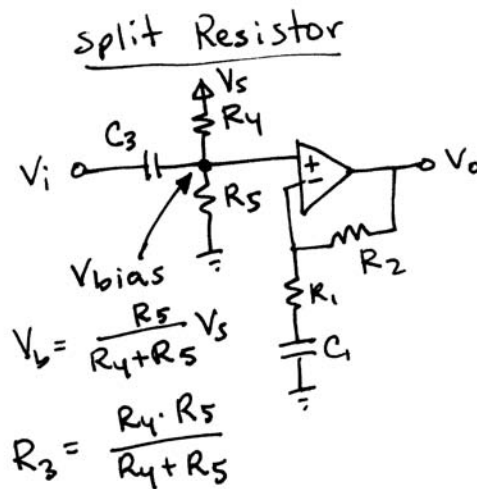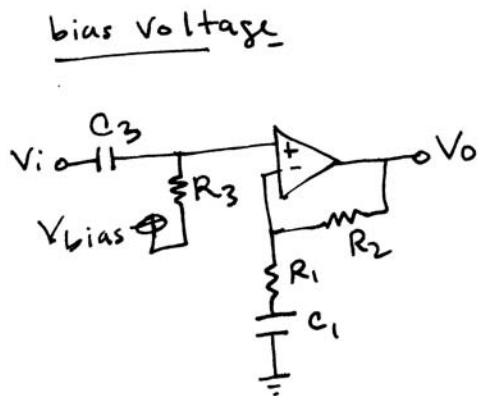$$\frac{V_i - V_b}{R_1} = \frac{V_o - V_i}{R_2} \rightarrow V_o = \frac{R_2}{R_1}(V_i - V_b) + V_i$$

$$= \left(1 + \frac{R_2}{R_1}\right)V_i - \frac{R_2}{R_1}V_b$$

$$V_o = GV_i + (1-G)V_b$$

$$\rightarrow V_b = \frac{V_o - GV_i}{1-G}$$

Non-Inverting Amplifier (AC Coupled):
The AC coupled amplifier is biased a bit differently than the DC coupled amplifier. Rather than place the bias voltage at the inverting input, the inverting input is now decoupled from ground via a capacitor, and the bias voltage is placed at the non-inverting input. The gain is the same, and the bias voltage is merely the voltage you want to see at the output when there is no signal applied. It is important to remember to select R and C values appropriate for the frequencies you are interested in.

bias voltage

split Resistor

$$V_b = \frac{R_5}{R_4 + R_5} V_s$$

$$R_3 = \frac{R_4 \cdot R_5}{R_4 + R_5}$$

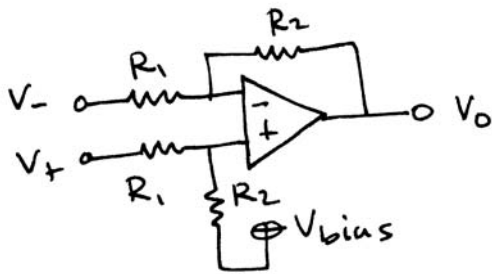$$\boxed{GAIN = \left(1 + \frac{R_2}{R_1}\right) = G}$$

$$f_c = \frac{1}{2 \cdot \pi \cdot R_3 C_3} = \frac{1}{2 \cdot \pi \cdot R_1 \cdot C_1}$$

$$\boxed{V_o = GV_i + V_b}$$

Differential Amplifier (DC Coupled):
The differential amplifier is perhaps the easiest DC coupled amplifier to bias, as the gain of the amplifier does not come into the equation when calculating the bias voltage. But, now you need to know V+, V-, G, and Vo to specify an operating point.
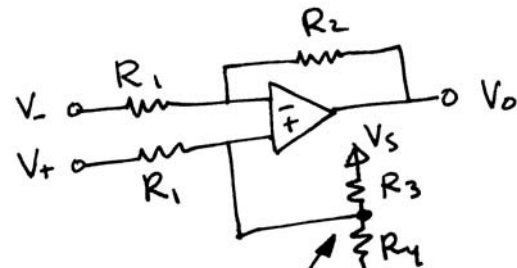
bias Voltage

split Resistor

$$GAIN = \frac{R_2}{R_1} = G$$

$$V_{bias} = \frac{R_4}{R_3 + R_4} V_s$$

$$R_2 = \frac{R_4 \cdot R_3}{R_4 + R_3}$$

$$V_o = G V_i + V_b \rightarrow V_i = (V_+ - V_-)$$

$$V_b = V_o - G(V_+ - V_-)$$

Differential Amplifier (AC Coupled):
The AC coupled amplifier is exactly the same as the DC coupled amplifier, except there are capacitors at the inputs (as can be seen on page 2), so it will not be shown. The equations are identical as well. The only difference is that you must remember to pick your R and C values to pass the frequencies of interest, as is the case with all AC coupled amplifiers.

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