1.0 Input Bias Current Compensation

1.1 Problem

The bias currents of an op-amp introduce DC offset errors when trying to amplify signals precisely. These offset errors are not a significant problem if we're only interested in the AC portion of the signal, but in situation in which the precise DC value of a signal is important, such as in strain gauges, these offset errors are problematic.

1.2 Setup for Determining Offset Error

We are interested in determining the error that bias currents introduce into a normal non-inverting amplifier. To begin, let's do something simple that Stashuk skipped in class and work out how much error this op-amp is going to produce if we don't do anything to compensate for the bias current errors.

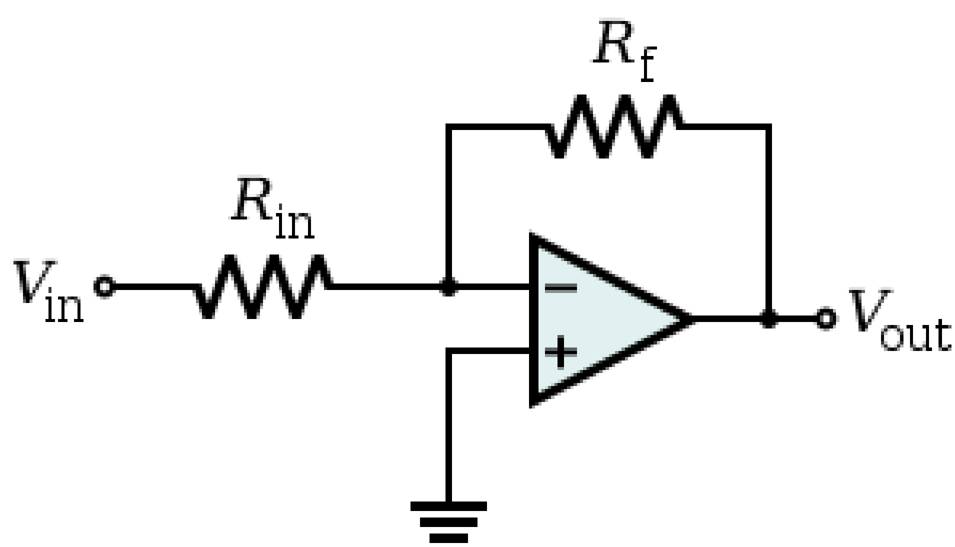

Figure 1: A basic inverting amplifier.

Now we're only interested in the effect of the input bias current, not the effect of the input voltage. Using superposition theorem, we remove the ideal voltage source V_{in} by replacing it with a short circuit to ground.

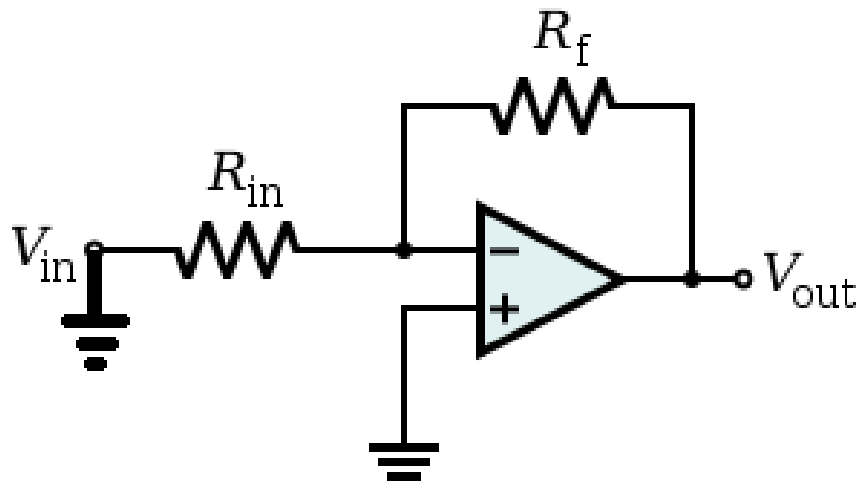

Figure 2: The new circuit after we apply superposition theorem

From our ideal op-amp properties, we know that the op-amp will force the two terminals to have equal voltage

$$V_+ = V_- = 0$$

Therefore, there is zero voltage drop across R_{in}, thus no current will through through this resistor.

$$I_{Rin} = 0$$

This means that all of the input bias current HAS TO FLOW THROUGH THE FEEDBACK RESISTOR. This produces a voltage drop

$$V_{Rf} = R_f I_{B-}$$

This voltage drop directly changes the output voltage

$$V_{out} = R_f I_{B-}$$

This is an important result, because it means that the error induced by the voltage follower is directly proportional to the value of your gain resistor. In other words, circuits that have high value gain resistors will much higher offset errors thanks to input bias currents.

2.0 How to Compensate for Bias Current Offset Error

2.1 Setup

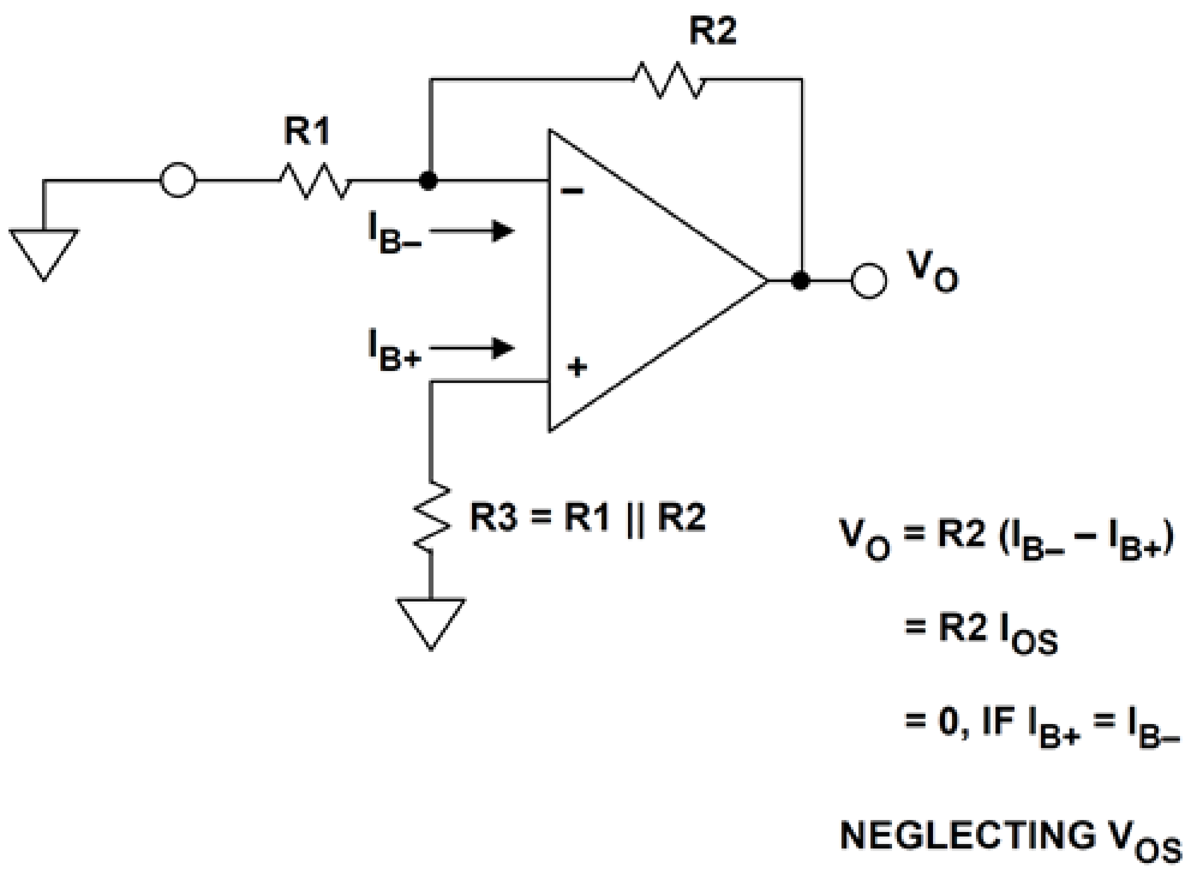

Figure 3: A normal inverting amplifier, with one extra resistor R3.

One way to compensate for the bias currents of the op-amp is to place a resistor between the positive terminal and ground. This input bias current I_{B-} will flow this resistor, and cause the voltage at the positive input terminal to be increased. This means that the so called virtual ground of this op-amp will no longer be at 0V, instead it will be slightly higher. Remembering that op-amps amplify the difference in voltage between V_+ and V_-, we know intuitively that the addition of this resistor will cause the output voltage to fall. Now the challenge is to determine a value for this resistor that lower the output voltage exactly enough to make up for the offset error of the bias currents.

$$V_- = R_3 I_{B+}$$

2.2 First Derivation

Using the same setup as before, we proceed with superposition theorem. First we replace V_{in} with a short circuit, grounding it.

$$V_{in} = 0V$$

Next, we replace I_{B-} with an open circuit. Unlike in Stashuk's class, we're going to do the superposition properly, by only analyszing one source at a time. I_{B+} is now the only current source under consideration. Now we have the following conditions:

$$V_- = V_+ = I_{B+} R_3$$

This is a pretty confusing state of affairs really. I really encourage your to draw this part and take a look at it. This is the only part that I really had to think through carefully while writing this, so I'll try to explain it as best I can. Basically what we've done is raised the voltage level of the virtual ground. Now because the input terminal I_- is at a higher potential than the input V_{in} (which is at 0V). Now, remembering that we made $I_{B-} = 0$, we can compute the new current that will flow through $R1$ and $R2$

$$I_{R1} = \frac{I_{B+}R_3}{R_1}$$

and because no current is flowing into the op-amp at this point (thanks to superposition), we know that

$$I_{R1} = I_{R2}$$

using $V = IR$ we can find the new output voltage. If you don't understand this part, look at the original derivation for the inverting amplifier very carefully.

$$V_{out} = -I_{R1} \cdot R_1 + -I_{R1} \cdot R_2$$

substituting the value of I_{R1}

$$V_{out} = \frac{-I_{B+}R_3}{R_1} \cdot R_1 + \frac{-I_{B+}R_3}{R_1} \cdot R_2$$

which simplifies to:

$$V_{out} = -I_{B+}R_3 + \frac{-I_{B+}R_3}{R_1} \cdot R_2$$

now adding the value for the I_{B-} components, which was derived in the first section, we get:

$$V_{out} = -I_{B+}R_3 + [I_{B1}\frac{-I_{B+}R_3}{R_1}] \cdot R_2$$

Now we've reached the point at which Stashuk started his derivation. We start by setting the input bias currents equal to each other:

$$I_{B+} = I_{B-} = I_B$$

$$V_{out} = I_B[R_2 - R_3[1 + \frac{R_2}{R_1}]]$$

Now we set R_3 =R1 parallel R2

$$R_3 = \frac{R_1 R_2}{R_1 + R_2}$$

which gives:

$$V_{out} = I_B[R_2 - \frac{R_1 R2}{R_1 + R_2}\frac{R_1 + R2}{R_1}]$$

$$V_{out} = I_B[R_2 - R_2] = 0$$

2.3 Second Derivation

This derivation is very similar to the previous one, except that this time we do not assume that $I_{B1} = I_{B2}$. Instead, we assume that $\|I_{B1} - I_{B2}\| = V_{os}$. This complicates things, because it means that we can not know the exact values of the offset currents, only their approximate magnitudes. As we will see, the same resistor method that we used before DOES HELP, but it doesn't completely correct the error.

Assumption:

$$I_{B-} = I_B + \frac{I_{off}}{2}$$

and

$$I_{B+} = I_B - \frac{I_{off}}{2}$$

The average of the bias currents is still the same, it's just distributed unevenly between the two input terminals now. So:

$$I_B = \frac{I_{B+} + I_{B-}}{2}$$

and

$$I_{off} = I_{B-} - I_{B+}$$

using the same setup and R_3 value as before:

$$V_{out} = \frac{-I_{B+}R_3}{R_1} \cdot R_1 + \frac{-I_{B+}R_3}{R_1} \cdot R_2$$

$$R_3 = \frac{R_1 R_2}{R_1 + R_2}$$

we get:

$$V_{out} = [-I_B + \frac{I_{off}}{2}]R_3 + R_2[I_B + \frac{I_{off}}{2} - [I_B - \frac{I_{off}}{2}]\frac{R_3}{R_1}]$$

which simplifies to:

$$V_{out} - I_B[R_3 + \frac{R_2R_3}{R_1} - R_2] + I_{off}[R_3 + R_2 + \frac{R_2R_3}{R_1}$$

which is approximately 10x smaller than if we didn't have R_3 at all. Unfortunately in the real world, this is further complicated by the offset voltage, which we've ignored through this entire thing.