Op-Amp Golden Rules Revisited
ENGN/PHYS 207—Fall 2018

The Golden Rules–Fact or Fiction?

We've extensively used the 2 op-amp golden rules:

1. No current flows into the op-amp, $i_+ = i_- = 0$.
2. The voltage at inverting and non-inverting terminals is equal, provided there is negative feedback: $v_+ = v_-$.

Just how good are these rules in approximating the real behavior of op-amps? Where do these golden rules come from anyway? Let's take a look and find out.
The golden rules are great, but real op-amps aren't ideal, so let's explore what happens if we account for the non-ideal nature of our op-amp.
Figure 1 A shows a standard inverting amplifier configuration.

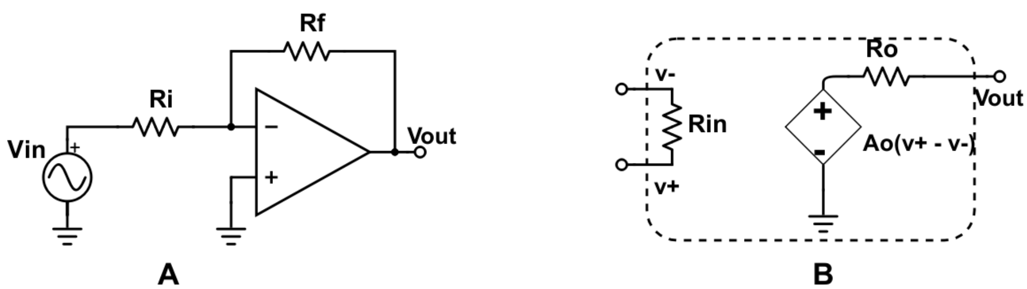

Figure 1: A: Op-amp inverting amplifier. B: Linear model of op-amp. The diamond element symbol is a dependent voltage source. It outputs a voltage depending on the difference proportional to the op-amp inputs $v_+ - v_-$, multiplied by the open loop gain A_o.

1. First consider the ideal op-amp case. How much current flows into the op-amp (+) and (-) terminals? What is the voltage gain of the inverting amplifier shown in circuit A. Given the input V_{in} is a 2V amplitude sine wave, what will the output signal V_{out} be? Assume the op-amp is powered by ± 12 V.
2. Now it is time to tackle the non-ideal op-amp case. Figure 1 B shows the linear dependent source model of an op-amp—in other words, a simplified circuit model for the op-amp internals. Complete the wiring job such that the linear model is configured as a non-inverting op-amp (per Figure 1 A).
3. There are 5 nodes in the circuit you just wired, including ground. We know the ground node = 0 V, so that's solved. We know another node connected straight to the function generator's voltage, so we can write, for instance, $V_a = V_{in}$. Now we need to write 3 more equations, all in terms of nodal voltages and/or resistance values, that will allow us to solve for all voltages in the circuit. In all, we'll have a system of 4 equations.

4. Package these 4 equations in matrix form, which allows for easy solution methods:

$$[G][V] = [I]$$

where $[V] = [V_a, V_b, V_c, V_d]$; where $[G]$ is a 4×4 matrix, and $[I]$ is known as the forcing vector (a 4×1 in this case). Later in this problem, we'll solve for the nodal voltages using:

$$[V] = [G]^{-1}[I]$$

5. The ***input resistance*** R_{in} is listed in the TL082 (look through the table labeled "DC Electrical Characteristics") . Report the "typical value."

6. The ***open-loop voltage gain*** is listed as the parameter A_{VOL}. Report the typical value. Be careful with units. For example, 10 V/mV means you get 10 V out for a 1 mV input for an open loop voltage gain of 10V/0.001, for a gain of 10,000.

7. The op-amp ***output impedance*** (simplified to be a resistance in our model) is hiding in Figure 21 of the TL082 datasheet. This figure shows a strong frequency dependency, but let's just choose a mid range value of about $R_o = 50\ \Omega$.

8. We are now in a position to plug in values and solve for the nodal voltages. Do so now. Matlab can be your friend.

9. Next, compute the gain of the real amplifier model V_{out}/V_{in}. How does this compare to the ideal model in which the Golden Rules were employed?

10. With the nodal voltages solved, we can also compute how much current flows into the op-amp. Given V_{in} is a 2V sine wave, what is the maximum amount of current flows through the op-amp input resistance R_{in}? How much current flows through the feedback resistor R_F? Thus, is the current flow into the op-amp negligible or not?

11. Compare/contrast your results for the ***ideal*** vs. ***real*** cases. Based on this analysis, what do you conclude about our assumptions of ideal op-amps? Should we trust in the Golden Rules?