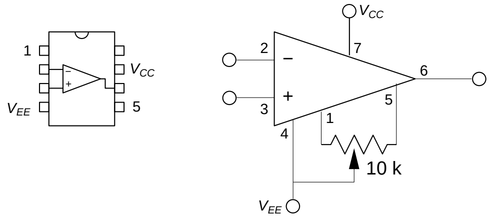
Physics 338 LAB 3 Spring 2016

Operational Amplifiers

0. (See H&H p.225) The Golden Rules

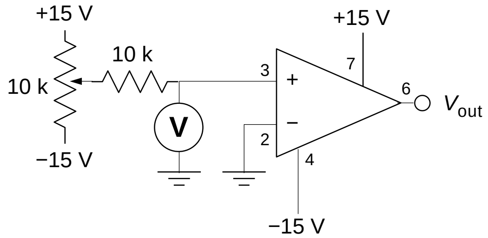


   I. The output attempts to do whatever it can to make the voltage difference between the inputs zero.

   II. The inputs draw no current.

1. Open-loop Test Circuit: 411 Op-Amp

   Construct the open-loop circuit shown and observe its output V_{out} on a scope set to 5 volts/div. Try (& fail!) to measure the open-circuit voltage gain: what happens to V_{out} as you slowly turn the pot? Provide evidence for a statement of the form: "the gain must be bigger than X". (Hint: if the gain were 10^6 and $V_{\text{out}} = 1$ V is desired, calculate the required V_{in} and "simply" adjust the pot to achieve that voltage.)



2. Inverting Amplifier

   Construct an inverting amplifier with a gain of −10, using reasonable values for input and feedback resistors and ±15 V for the power supplies. Drive your amplifier with a 1 kHz sine wave and measure its *small-signal gain* by observing input and output waveforms on the scope. Does the gain depend on the input amplitude? What is the maximum output swing? Sketch a scope trace showing output clipping. Measure the gain at different frequencies: what is an approximate upper frequency limit ($f_{-3\text{dB}}$, where V_{out} has been reduced by a factor of $\frac{1}{\sqrt{2}}$)?

   Measure your circuit's *input resistance* at 1 kHz. To do this, interpose a a resistor substitution box between the function generator and the *circuit's* input, and adjust its resistance until the output amplitude is halved. The input resistance is then equal to the interposed resistor since the two act as a voltage divider. (N.B.: the bare 411's input resistance is huge, but here you are measuring the circuit's input resistance.)

   Now run the frequency to 100 kHz and try to measure the *output resistance* by loading the amplifier output with progressively smaller resistors until the output amplitude is halved. (The 'load resistor' connects the output to ground. You will have to keep the input signal *very* small to avoid current-limiting or "flat-topping" the output, since the amplifier can't supply more than about 10–20 mA.) Recall: $R_{\text{out}} = R/(V/\Delta V - 1)$. Compare your measured output resistance with what the manufacturer's data sheet specifies (there is a copy in the class web site). Can you explain why we didn't try to measure output resistance at 1 kHz?

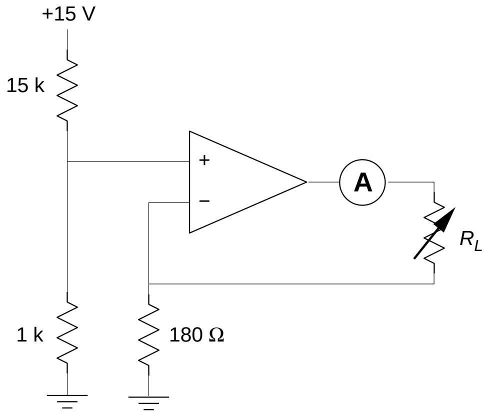
   Finally, measure the *slew rate* (maximum time rate of change of the output voltage) in V/μs. Use a high frequency, large amplitude square wave as input and observe the rising (or falling) edge of the output on the scope. Compare with the manufacturer's specs.

3. Non-inverting Amplifier

   Construct a non-inverting amplifier using the same components as in part 2. Measure its voltage gain and compare with theory. Try to measure its input resistance and record your observations: are they in agreement with the device specs?

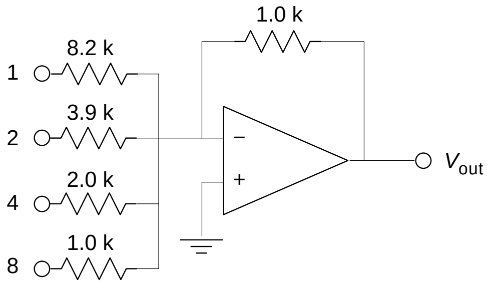
4. Current Source

   Construct the op-amp current source shown. Use M-3800 as ammeter. Vary the load resistance R_L and monitor the current: over what resistance range does the current remain constant? (If the current isn't constant at small R_L, check the op amp output for oscillations.) Compute what the current should be and compare with your measurements. Why does the current not remain constant at large R_L?



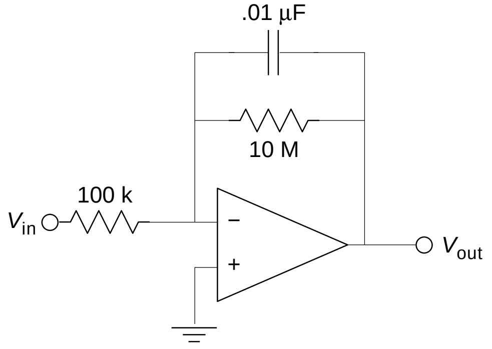
5. Summing Amplifier

   The inverting op-amp configuration, used with summing inputs, can be use to make a digital-to-analog voltage converter. The four "input bits" of a binary (base 2) number (e.g., $1011_2 = 11_{10}$) have voltage values 0 V for "0" and 5 V for "1." Thus, the circuit transforms a 4-bit binary number (0–15) to a proportional analog voltage, with the different input resistors providing appropriate weighting for each bit. Construct this circuit and, using a DMM, measure the output voltage for all possible binary inputs. Plot and fit output voltage vs. digital input. According to your fit, what is the constant of proportionality? Is it as expected from a theoretical analysis of the circuit?



6. Integrator

   Construct the integrator shown. Draw scope traces showing input and output for all the available input waveforms. (To observe the output waveform, you may need to switch Coupling▶AC —which will remove any dc offset— allowing you to switch to an appropriate VOLTS/DIV scale.) Is $V_\text{in} \propto \frac{d}{dt}V_\text{out}$? What is the sign of the proportionality constant?



While observing the output on the scope (dc-coupled), let V_in be a 10 kHz sine wave with a dc offset and vary the offset (i.e., $V_\text{in} = A\sin(\omega t) + B$). Describe what happens. (Note: even if the function generator's dc offset is "off", there will be a small dc offset in the signal produced!) Given V_in, contrast $\int V_\text{in}\, dt$ with what actually appears on the scope.

What is the function of the 10 MΩ resistor? (Remove it and see/report what happens.) Hint: at very low frequencies, which has a smaller impedance: the .01 μF capacitor or the 10 M resistor?

Ground the input. Report the resulting output and use it to calculate the input offset voltage. Is it within specs?

Extra Credit: use the balance circuit shown in part 0 to zero out the offset voltage. Note the effect of this offset on the integrator output.