

Laboratory 8

Oscillators and Operational Amplifiers

Introduction

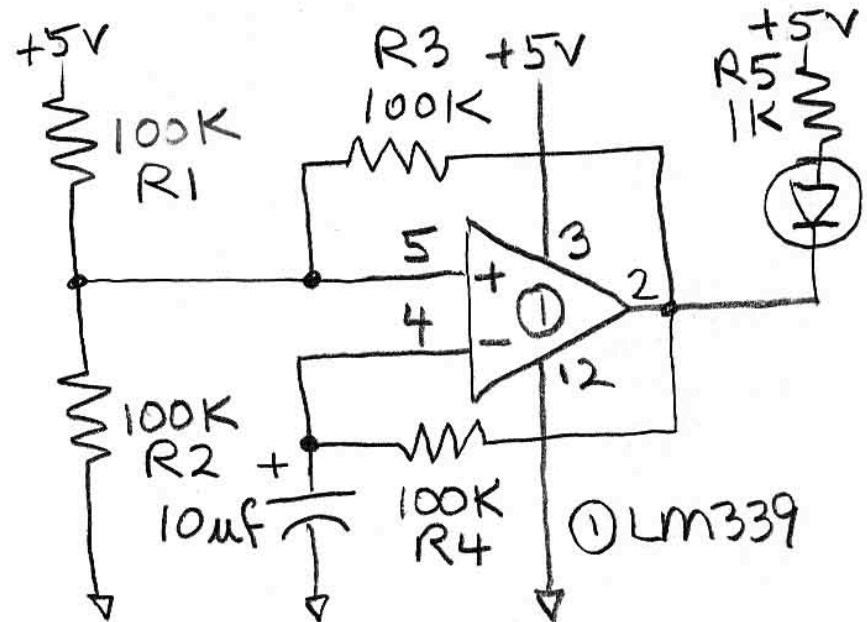
In this lab you will continue to use the LM339 comparator from the previous lab, this time to construct an oscillator using hysteresis. Then you will use the LM1458 operational amplifier (op amp) with the dual power supply provided by the BLIP to build several standard op amp circuits, including a buffer, an inverting amplifier, and a summer.

Comparator Based Oscillator

In the previous lab, you built a thermoregulator circuit, which was unstable as it heated and cooled between two set points established using hysteresis. The circuit below is similarly unstable, again using hysteresis (the feedback resistor R3). But now, instead of changing the temperature of a mini-environment monitored by a thermistor, the output simply changes the voltage on a capacitor, charging and discharging it through a resistor as the comparator switches between 5 V and ground. Build the circuit and measure its frequency by counting the blinking LED against a clock. **(A)** Use the oscilloscope in dual trace mode to examine the voltages on pins 4 and 5 of the comparator. Sketch these voltages, and label when the LED is on and off. **(B)** Explain the voltages in terms of the circuit, including the functions of resistors R1, R2, R3 and R4, and the capacitor. **(C)** Replace R4 with a 1K resistor in series with a 100K pot to permit variable frequency. What range of resistances would this arrangement permit, and what frequencies do you observe from the circuit now? Explain how the frequencies are expected from the RC time constants. **(D)** Draw the schematic of the new circuit **(E)** and keep the circuit on your breadboard for use in subsequent labs.

Parts List

LM339 quad comparator
LM1458 dual op amp



The Operational Amplifier

Thus far, we have been using the comparator (LM339), a stripped-down version of an operational amplifier (op amp) designed simply to compare two input voltages and report which is higher. The comparator basically has two expected output states, either high (near the + power supply) or low (near ground). Now we will move on to a full-fledged operational amplifier (op amp).

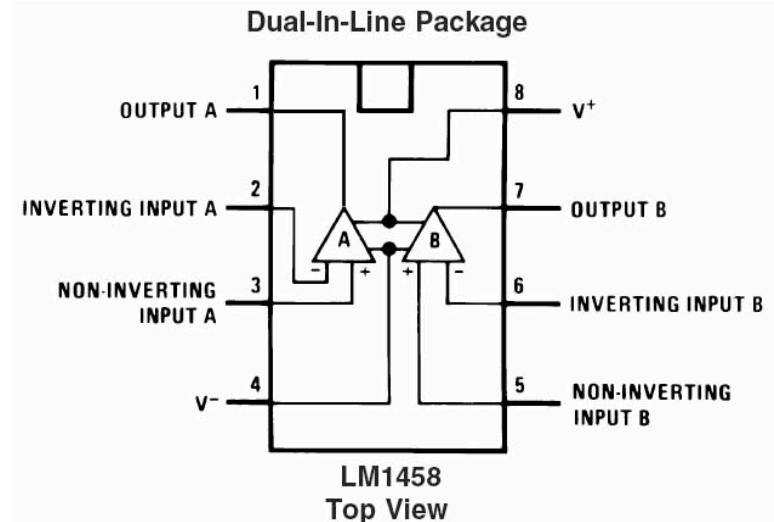
Review the specs below for the LM1458, the op amp that we will use in the lab. Instead of the Open Collector output of the comparator, the full op amp has a Push-Pull output, which can both *source* and *sink* current. As a result, instead of the comparator's *Max Output Saturation Voltage*, (listed as 1 V for the LM339) the LM1458 op amp has a *Minimum Voltage Output Swing* in both the plus and minus directions, listed as ± 3 V (given a ± 5 V power supply) or a full 2V from the "rails" (the limits of the power supply).

Why can the op amp only get within 2 V of the power supply, whereas the comparator could get within 1 V of ground? The comparator's output, a single open-collector transistor, is run either in saturation or cutoff mode, whereas the push-pull output transistors of a true op amp typically operate in the biased region, where collector-emitter voltages are higher, thus further from the rails.

Whereas the comparator output is *digital*, either on or off, the op amp output is *analog*, anywhere in the range of voltages between the rails. Thus, instead of simply a *Response Time*, which for the LM339 is 1 μ s,

LM1458 Dual Operational Amplifier

Positive/Negative supply voltage	± 5 to 15 V
Quiescent Supply Current	8 mA
Voltage Gain	200 V/mV
CMMR	60-90 dB
Max Input Current	25 nA
Max Output Current	20 mA
Min Output Voltage Swing (± 5 V supply)	± 3 V
Slew Rate	0.5 V/ μ s
Max Offset Voltage (input + to -)	6 mV
Output type	Push-Pull

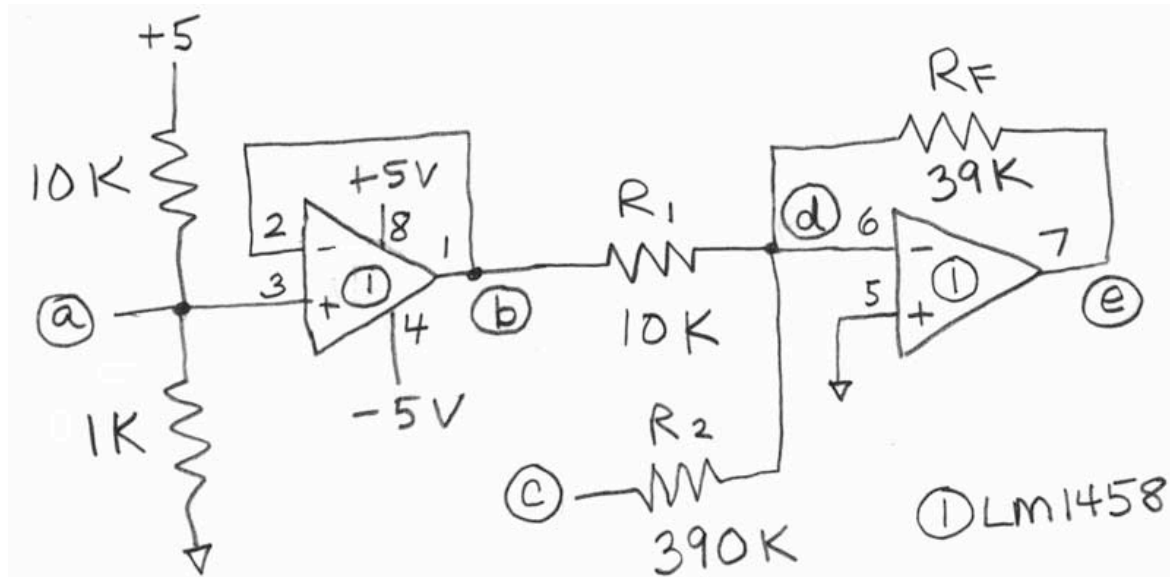


the specs for the LM1458 op amp include a *Slew Rate* of $0.5 \text{ V}/\mu\text{s}$. At that rate, how long would the LM1458 take to change from -3V to $+3\text{V}$? **(F)** Digital circuits are inherently fast because they can slam into the rails. Analog circuits have a more difficult task, stabilizing at some desired voltage in between, and thus may take longer.

Notice that in this subtle new world of the op amp, we also specify a Common Mode Rejection Ratio (CMRR), which for the LM1458 is 70 dB. What ratio of voltages does this represent between the out-of-phase to the in-phase amplification of the op amp? **(G)**

To power the op amp, you will make use of the BLIP's -5V power supply for the first time, so a few notes are in order. Whereas the $+5\text{V}$ power supply from the BLIP can source about 500 ma (direct from USB hub), the -5V power supply generated by the BLIP's on-board DC-to-DC converter (TC7662) can only sink about 40 ma. Thus it must be used sparingly, only where absolutely necessary, and does not deserve an entire bus on the breadboard. Instead, run a green wire from the BLIP's -5 V output (in the power supply header) directly to pin 4 of the LM1458, leaving all the "(-)" blue busses on the breadboard to be used for ground.

Build the circuit shown below, using both op amps from a single LM1458 chip (labeled "1 in the schematic). Note that the power connections to pins 4 and 8, which supply both op amps internally on the chip, are shown only once in the schematic. This is proper etiquette for schematics, permitting the person constructing the circuit to know when all the connections have been made. Certain key points in the circuit are labeled with letters. Thus points (a), (b), (d) and (e) are test points where voltages will be measured, and point (c) is an input where a test voltage can be applied. In the following sections you will make calculations and compare them to your measurements, applying various voltages to point (c).



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Buffer (Unity Gain Amplifier)

The first op amp (left) is configured as a simple buffer, whose output at point (b) (pin 1) should follow the voltage at the op amp's (+) input (pin 3), labeled point (a) What does this circuit accomplish? Rather than simply using a voltage divider to provide a desired voltage output that would change with the load resistance, adding a buffer creates a voltage that is stable over a wide range of currents, through loads of varying resistance. The buffer output acts like an almost perfect voltage source, up to the maximum current of the op amp, which for the LM1458 is as high as 20 mA. Calculate the expected voltage at point (a) using the indicated resistances in the voltage divider and the nominal 5 V power supply. **(H)** With your voltmeter in the 2 V range, measure the voltage at point (a) relative to ground and compare to your calculation. What sources of error can you postulate in your calculation? **(I)** Which property of the ideal op amp permits you to ignore current into pin 3 of the op amp? **(J)** Given the spec for the LM1458, what is the largest error due to the op amp that you are ignoring? **(K)** Measure the voltage at point (b) and compare to the voltage at point (a). Is this consistent with the stated Maximum Offset Voltage in the specs for the LM1458? **(L)**

Inverting Amplifier

Now consider the second op amp (right), which is set up as an inverting amplifier. With point (c) unattached (floating), there will be no current through R_2 , so it can be ignored. The voltage at point (b) serves as the only input to the inverting amplifier, whose virtual ground (d) is maintained by having the output (e) at some fixed ratio with respect to the voltage at (b). Write the formula for the relationship of the voltages at pins (e) and (b) given R_F and R_1 , and predict the voltage at (e). **(M)** Measure the voltage at pin (e) and compare to your calculations. **(N)** Measure the voltage at the virtual ground (pin 6 of the LM1458). Is this within the range of offset voltages in the spec? **(O)**

Summer

A summer can be constructed using the inverting amplifier by introducing a voltage at point (c), providing a second source of current into the virtual ground (through R_2) and beyond into the feedback resistor R_F . First, remove R_1 and measure the output voltage at point (e) given three different input voltages at point (c): +5 V, 0 V, and -5 V. Write the formula for the predicted voltages and compare to your measurements. **(P)** Next, reinsert R_1 and repeat the experiment for the 3 different voltages at point (c), writing the formula for the predicted output voltages at point (e) comparing to the measured voltages. **(Q)**