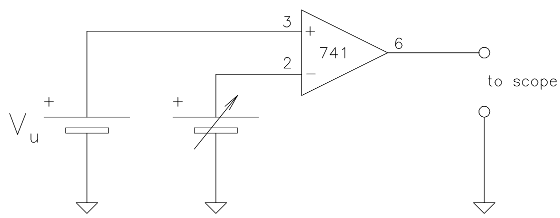
Experiment 2

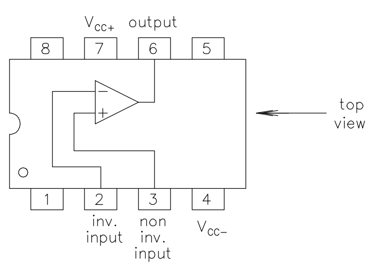
Operational Amplifiers: Basic Concepts

The purpose of this experiment is to introduce op-amp, a key element of analog electronics circuits. Several configurations of a voltage follower will be built, introducing the key characteristics of op-amps.

2.1 Null voltage measurement

(!) Wire up the following circuit using a 741 op-amp.





! **Care should be taken to ensure that all integrated circuits (IC's) are powered with both V_{CC+} and V_{CC-} whenever an input signal is supplied! Failure to do this will destroy IC's**.

Use ±10V output from the job board as V_u (unknown); set it to any value between +0.95 V and −0.95 V. Connect ±1 V output of the job board to the inverting input of the op-amp. Use $V_{CC+} = +15\,V$ and $V_{CC-} = -15\,V$.

(!) Use the scope to monitor the output and adjust the ±1 V supply until a transition from one output voltage limit to the other occurs. Measure and record the positive and the negative voltage limits of the op-amp output.

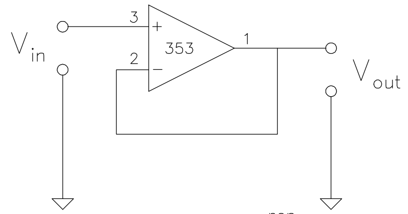
(!) In the same circuit, connect the DMM to the ±1 V supply. Adjust the potentiometer (carefully) to the value where the op-amp output just begins to decrease from its positive limit (as observed on the scope), where it is as close to zero output as you can set it, and where it is not quite at the negative limit. Record these three values. They may be very close to each other; in this case estimate the upper limit on the change of the input voltage(s) that causes the output to jump from one limit to another. Repeat these observations several times.

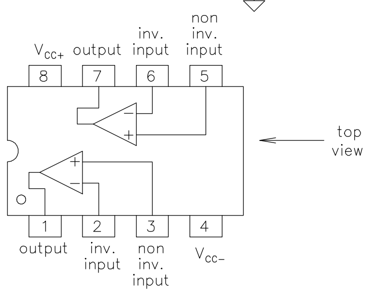
(!) Without changing any settings, use DMM to measure V_u.

[?] Estimate the **open loop gain**, A, of the op-amp and its input offset voltage from the above measurements. Compare with the nominal value, 103 dB for 741.

Note: $V_{\text{output}} = A \times (V_+ - V_-)$, see Simpson, pp. 367–369 or Faissler p. 247–248.

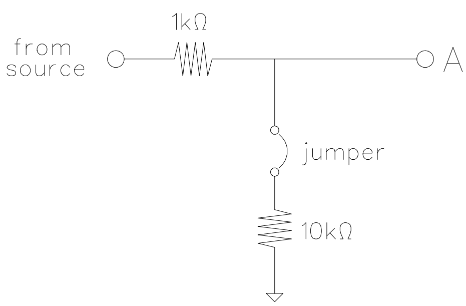
2.2 Voltage follower



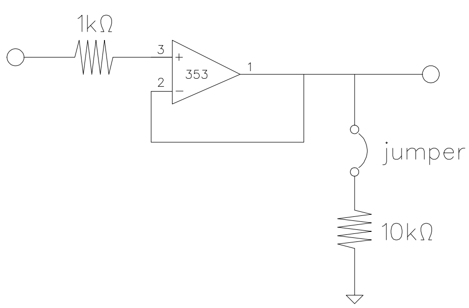


Connect one of the 353 op-amps as a voltage follower.
Use the ±10 V as V_{in} and the DMM to measure V_{out} and V_{in} for five or more settings in the range +10 to −10 V. Calculate the gain.

V_{in}	V_{out}	Gain

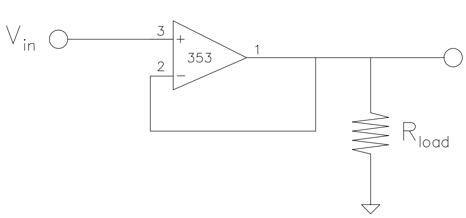


A 1 kΩ resistor will be used in series with the ±10V output to simulate a voltage source with a 1 kΩ internal resistance. A 10 kΩ resistor will be used to simulate the input resistance of the readout device used to measure the source voltage. Wire the circuit on the left, set the source voltage to a value between 1 V and 2 V, and measure the voltage at point A with and without the 10 kΩ load connected.



Now connect an op-amp voltage follower (353) to buffer the voltage source from the load resistance. Measure the follower output voltage with and without the 10 kΩ load resistor connected.

A transducer has an output resistance of 80 kΩ. Describe how a follower could be used to decrease the loading error if the transducer output voltage is to be measured with a 1 MΩ input resistance oscilloscope and indicate the percent error avoided.



Fix the input voltage at +10 V. Connect a 1 kΩ load resistor (R_{load}) to the follower output as shown and measure the output voltage with the DMM. Remove R_{load} and measure the no-load voltage.

Repeat using the 100 Ω and 47 Ω load resistors. Calculate the output current for each case.

R_{load}	V_{out}, with load	V_{out}, without load	I_{out}, with load

The small output voltage change observed with the 1 kΩ load indicates the very low output resistance of the voltage follower. At lower load resistance, it is possible to exceed the maximum output current capability of the op-amp. A significant loading of the output voltage occurs in such a case.

? On the basis of the change in output voltage with a 1 kΩ load, estimate the output resistance of the voltage follower, or if no change was observed, place an upper limit on the output resistance, *i.e.* calculate the value the output resistance would have if the smallest observable change had been measured. It may help to draw an equivalent circuit for the op-amp (see Simpson, Fig.9.21 or Faissler, Chapters 29 and 31).

Calculate the maximum output current the op-amp can supply, based on your observations with the 100 Ω and 47 Ω loads.

2.3 Follower with gain

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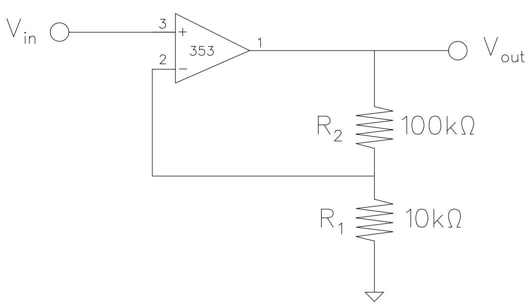

Use a 353 op-amp to wire the follower with gain amplifier circuit as shown. You may find it convenient to use the precision resistor arrays for R_1 and R_2.
Use the ±10 V supply as V_{in} and vary the input voltage in the range of ±5 V. For each value, accurately measure both V_{in} and V_{out}, and calculate the observed gain.

Plot V_{out} *vs.* V_{in}, determine the region of linearity, and fit that part of the data to a straight line to determine gain. Note that you must allow for a non–zero intercept, thus use a two–parameter fit. Compare the gain you obtain with the values calculated at each data point, and with the value you would expect for this circuit from the nominal resistor values.

? Explain what limits the gain for large values of V_{in}.

! Use the ±1 V supply as input, set at slightly below 10 mV. Vary the gain of the circuit by using different values of R_2: 100 kΩ, 1 MΩ, and 10 MΩ.

Compare the measured gains to those expected and explain any deviations.

? Can a gain of less than 1 be obtained with this circuit? Explain why or why not.

! In the above plot, the x–intercept of the straight line corresponds to the input offset voltage, V_{offset}. It may be more clearly observed at low input voltages and high gains. Examine this effect by connecting the follower input to common and measuring V_{out}, for the same R_2 values as above. **Be sure to disconnect the voltage source from the follower input before grounding the latter!**

R_2	Gain	V_{out}	V_{offset}
100 kΩ			
1 MΩ			
10 MΩ			

? Compare your V_{offset} value to the x–intercept above and comment on differences, if any.

? What causes a greater % deviation from nominal gain, V_{offset} or the resistor inaccuracy?

? *Optional*: Repeat the straight–line fit to the data, but this time force the intercept to be zero (*i.e.*, a one–parameter fit). This assumes $V_{offset} = 0$. Calculate and comment on % error caused by this assumption.