# Lab 11: Op-amp II: Summing, Integrating, and Filtering

## 1 Op-amp Integrator

Here we'll make a (nearly perfect) integrator, in stark contrast to the simple $RC$ approximation we built previously.

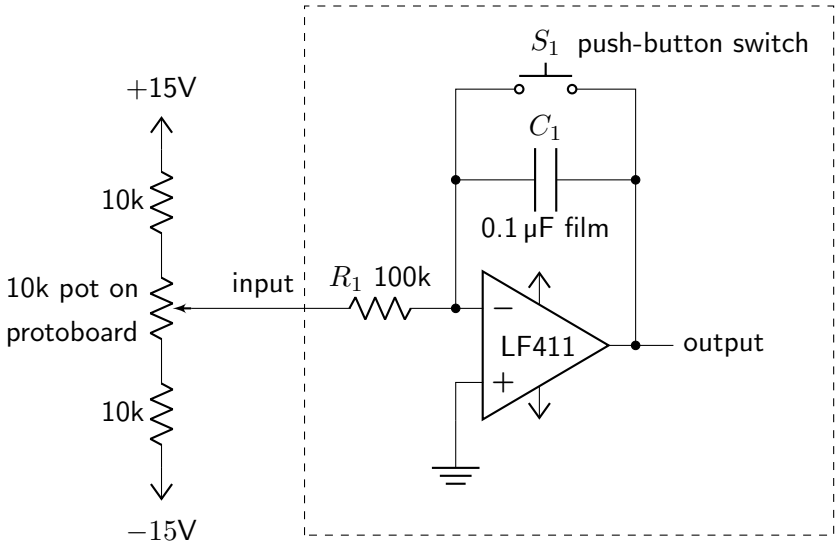



Figure 1: Op-amp integrator. Build the part inside the dashed box first.

(a) Wire up the integrator of Figure **??**, only the part inside the dashed box leaving the "input" terminal floating (i.e., not connected to anything yet). Observe the output on the scope; see what happens over a few seconds, then press the button. Explain below what happens when you press the button. When the circuit is powered on, the output voltage is random. Pushing the button discharges the capacitor and resets the output to 0 V.
If you watch for some time, there is a very slow drift of the output voltage due to the very small input bias current (typ. 50 pA) of the LF411.

(b) Suppose we connect the input of the integrator (left of $R_1$) to +1 V DC. What do you expect the output "slew rate" (slope, in volts per second) to be? What is the path of current flow? Recall that the non-inverting input of the op-amp is at 0 V (Golden Rule I). The current flowing through $R_1$ must be $1\,\text{V}/100\,\text{k}\Omega = 10\,\mu\text{A}$. That current flows into $C_1$ (Golden Rule II), increasing the charge in it as $\frac{Q}{t} = 10\,\mu\text{A} = 10\,\mu\text{C/s}$. This increases the voltage across the capacitor at the rate $\frac{V}{t} = (\frac{*}{Q}t)/C = (10\,\mu\text{C/s})/0.1\,\mu\text{F} = 100\,\text{V/s}$. The output voltage will decrease at this rate.

(c) To get a feel for the integral, drive the integrator input terminal from the 10 kΩ potentiometer at the bottom of the protoboard, as shown in the left half of Figure **??**. Fiddle a bit with the pot to enjoy life in an integrating world (you can use the scope, or maybe the DMM, to look at the wandering output, setting your horizontal scale large enough to see the slow changes you are applying by hand).

(d) Now drive it instead with a 10 Hz, ±0.5 V (1 Vpp) square wave from the function generator. For this measurement you should set the scope's horizontal rate to be 200 ms/div, and the vertical scale to 2 V/div, or maybe 5 V/div. What output waveform do you expect? Draw a sketch.

(e) You may be surprised to see the output waveform walk its way up (or down), eventually saturating at the op-amp's output voltage limit (about ±14 V). Why does this happen? There is a small "input offset voltage" in any op-amp. (It's about 1 mV for the LF411.) This causes the integrator to slowly accumulate DC voltage even though the input is perfectly symmetric above and below 0 V (which, by the way, may not be 100% true for the function generator).

If you want to keep it from walking away, you can get into the "offset" parameter setting of the func gen, and play with it, moving it up or down 10 or 20 millivolts. Try reaching a perfect "null" (where the input waveform's time-averaged integral is zero), thus no integrator output drift.