Practical Integrators and Operational Amplifier Offset

Lab 2: The Field Effect Transistor

ECE 327: *Electronic Devices and Circuits Laboratory I*

Abstract

For the field effect transistor lab, we need to implement an integrator. In this document, a simple operational amplifier integrator is shown along with methods of compensating for input imbalance.

Contents

1 Integrator

Figure 1.1 shows a simple operational amplifier (OA) integrator.

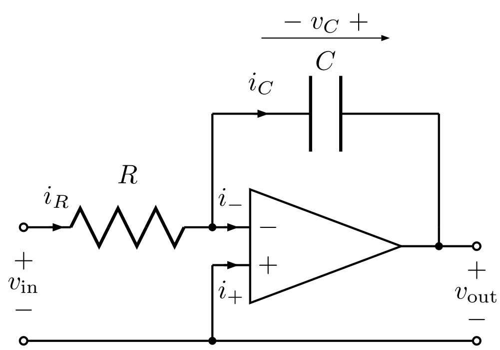


Figure 1.1: Integrator.

Theory

Ideally, $i_- = i_+ = 0\,\text{A}$ and the potential difference between the two OA inputs is $0\,\text{V}$. Therefore,

$$i_R = \frac{v_{\text{in}}}{R} \quad \text{and} \quad i_R = i_C \quad \text{and} \quad i_C = C v_C',$$

where v_C' is the time derivative of the potential difference across the capacitor. Assuming the capacitor is initially not charged, the output v_{out} is described by

$$v_{\text{out}}(t) = -\frac{1}{RC}\int_0^t v_{\text{in}}(\tau)\,\mathrm{d}\tau.$$

So a zero-mean square wave input with positive peak potential A (i.e., the peak-to-peak potential is $2A$) will produce an output zero-mean triangle wave with slope magnitude $\frac{A}{RC}$ where the rising edges of the output correspond to the $-A$ edges of the input. If A is too large, the output will be clipped at the OA rails.

2 Practical Problems and Solutions

In a *real* OA,

$$i_- \neq 0 \quad \text{and} \quad i_+ \neq 0 \quad \text{and} \quad i_- \neq i_+.$$

This is especially the case with old BJT OAs like the LM741. The imbalance in input currents manifests itself like a nonzero DC signal sitting on one of the inputs. This apparent DC offset to the input signal will cause a zero-mean input to make the OA rail.

There is no easy solution to this problem. Here, we list a few approaches to ameliorating the offset problem. These solutions aren't perfect, nor are they even applicable in some cases.

Good Solution: Finite DC Feedback

The problem may be viewed as the capacitor configuring the operational amplifier for infinite DC gain. By placing a resistor in parallel with the feedback capacitor, we can provide finite DC gain, as shown in Figure 2.1. Now, instead of the input offset potential resulting in a ramp, it results in a constant output

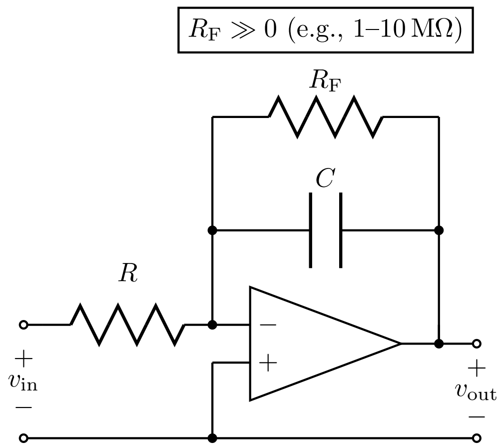


Figure 2.1: Integrator with Finite DC Gain (i.e., "Miller integrator").

offset that is an amplified version of the input offset. To reduce the magnitude of the output offset, we can reduce the size of R_F. However, as R_F gets smaller, the circuit performs less like an integrator and more like a lowpass filter (i.e., we move the knee of the filter farther to the right as we lower R_F).

Note that some OAs add a large feedback resistor internally, and some capacitors have leakage that manifests itself like a large feedback resistor. Therefore, **you may observe this effect even when you do not add your own external feedback resistor**.

Better Solution: Capacitive Coupling

Alternatively, because our input signal has no DC offset, we can capacitively (i.e., AC) couple the input to the integrator, as shown in Figure 2.2. To prevent filtering out signals of interest, C_{in} must be large. Large

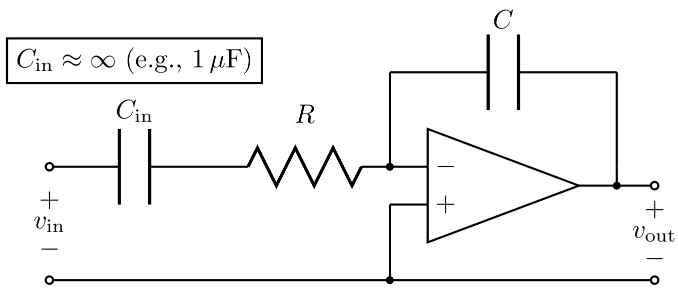


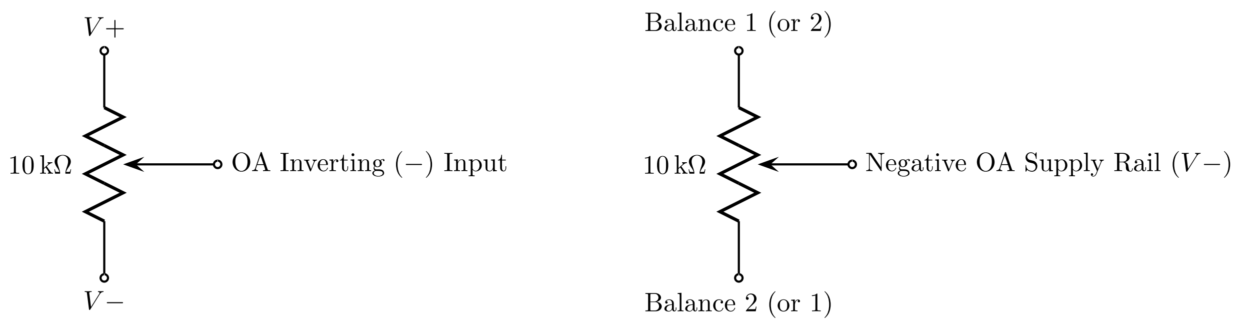
Figure 2.2: Integrator with Capacitively-Coupled Input.

capacitors are typically polarized, so care should be taken in their placement. It may be a good idea to give the input some DC offset and connect the capacitor's negative end (i.e., the cathode, where positive DC current exits) toward the operational amplifier (because it will have a virtual ground there).

Capacitively coupling the input lets the left end of the resistor "float" with respect to DC. The capacitor will charge in such a way that it will make up for the DC offset so that the current through the resistor is only due to the AC component of the signal. The resulting output will have an offset exactly the magnitude of the imbalance offset, which hopefully should be small.

Best Solution: Trimming for Balance

A different approach is to try to *null the offset*. Here, we briefly discuss two such methods. In both cases, the nulling effect is temporary. Because offsets drift with temperature and time[1], products with long lifetimes may need to periodically re-correct for this drift.



(a) Input offset method.

(b) Input balancing method.

Figure 2.3: Offset nulling potentiometer configurations.

Method 1: Adding Input Offset

This approach works well for all operational amplifiers.

1. Use the "Miller integrator" approach for finite DC feedback, shown in Figure 2.1, to produce an integrator with constant output offset.
2. Then, attach a potentiometer to the inverting input node (i.e., the − input of the OA) as in Figure 2.3(a).

The inverting input serves as a summing junction, and so the potentiometer allows you to add your own offset to balance the offset of the OA. Tune the potentiometer until the offset on the output disappears.

Method 2: Internal Balance Trim

Use the "OFFSET NULL" or "BALANCE" pins provided by most OAs (e.g., OAs shown in Figure A.1).

1. **Before you wire your integrator**, *temporarily* short the input pins of the OA together (it may be a good idea to short them both to 0 V).
2. Connect a potentiometer to the "balance" pins as shown in Figure 2.3(b).
3. Connect the OA supply rails so that it is operating.
4. Measure the output of the OA. Adjust the potentiometer until the output reaches the correct 0 V state.

Leave the potentiometer connected, but remove the input short and build your integrator.

Additional offsets: Even balanced OAs produce integrator offsets. For a trimmed OA, the impedance (to ground) looking *out* of the inputs must be *equivalent*. Rather than connecting the non-inverting input (i.e., the + input) directly to ground, use a resistor equal to the impedance seen by the inverting input (i.e., the − input). For example, use R for Figure 1.1, $R \| R_F$ for Figure 2.1, and a large resistor for Figure 2.2. In all cases, use a variable resistor (e.g., two adjacent pins of a potentiometer) so that it can be tuned.

Being careful: While this method should allow you to use the ideal integrator of Figure 1.1, for safety, you should probably ***also*** use one of the other constant-offset methods (i.e., the finite DC feedback method or the capacitive coupling method) described above. Together, your integrator will be near ideal and have very little offset. Of course, you may need to retune your potentiometer(s) periodically.

[1] One reason for "burning in" electronic components before use is to reduce the rate of this drift.

A Parts

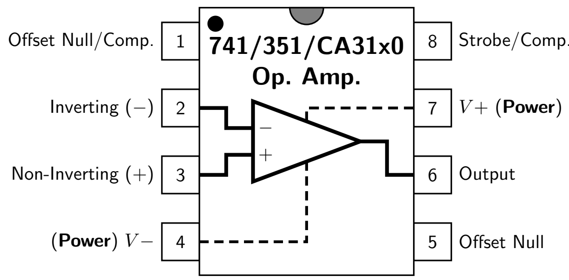


Figure A.1: LM741/LF351/CA3160 op. amp.