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# EECS 16A    Designing Information Devices and Systems I

## Fall 2022    Touch 3B Pre-Lab Reading

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### 1 Touch 3A Review

In the last lab, you completed the first half of building a capacitive touchscreen! You used your function generators to model touch and no touch. If you recollect, we modelled this as a current source with constant current  $I$  as a square wave that gave us the voltage across the capacitive touchscreen as:  $V(t) = \frac{I}{C}t + V_0$ . Since we used a square wave current source, we got a triangle wave voltage output due to the periodic charging and discharging caused by the flipping of the polarity of the current source. You used a comparator to actuate an LED and saw that when there was a touch, the voltage across the capacitors was below  $V_{REF}$  and thus the LED did not turn on. When there was a touch, the voltage across the capacitors was above  $V_{REF}$  and we output a square wave (which caused the LED to continuously flash on and off). Next week, we will look at a more realistic and practical way of implementing the capacitive touchscreen.

### 2 Touch 3B Preview

One problem: from our setup from Touch 3A is that we don't have ideal square current sources in the real-world. To understand why, let's look at current sources. An **ideal** current source is a device which supplies constant current to any load resistor that is connected across it. An ideal current source has infinite parallel resistance connected across its terminals. Thus, the output current is independent of voltage of the source terminals as well as the value of the resistor it is providing current to. A realistic current source is a device that has some internal resistance connected across its terminals. Unlike the ideal version, the current of a real-world current source depends on the voltage of the source. The more this voltage, the smaller the current will be. We will thus explore an alternative to ideal current sources that will still provide us with a way to implement the waveforms from Touch 3A.

#### 2.1 Op Amp Review

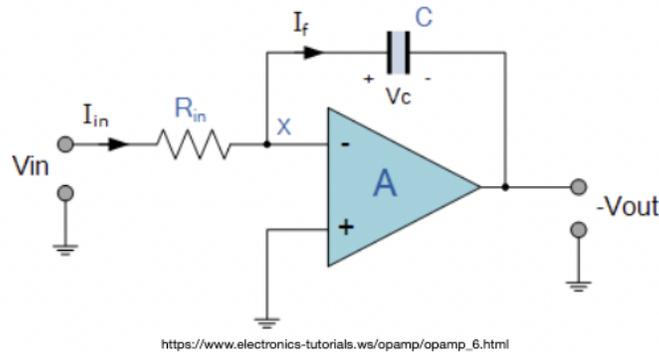
To build our almost ideal current source, we will make use of op amps! Using a periodic voltage source, resistor, and an op-amp is identical to integrating the voltage source instead of a current source. We will dive deeper into the specifics of why we need to use op-amps during lab, so for now, let's go over some properties of op-amps that will help us build a current source. Recall the golden rules of op-amps (note these are only true in **negative feedback**):

- (a) The two input terminals do not draw any current.
- (b) The input voltages  $V^+$  and  $V^-$  are equal.

The first rule holds since we assume that the input resistance for an op-amp is infinite. The second rule holds because in feedback, the input and output voltage have to be the same.

## 2.2 The Integrator Circuit

The op-amp voltage integrator is an operational amplifier circuit that performs the mathematical operation of integration. Here is the circuit diagram for an integrator circuit:



Let's go over the circuit equations for this circuit to see why we can use it for our touchscreen. Using golden rule #1, we see that both  $V^+ = 0V$  and  $V^- = 0V$ . Applying KCL on the  $V^-$  node:

$$I_{in}(t) = \frac{V_{in}(t) - 0}{R_{in}} = \frac{V_{in}(t)}{R_{in}} \quad (1)$$

$$I_f(t) = I_{in}(t) = \frac{V_{in}(t)}{R_{in}} \quad (2)$$

We now have a system that gives us total control of the current passing through the capacitor. If  $V_{in}$  is a square wave voltage source, then  $I_f$  will be a square wave current source!

Let's now look at the integration properties of this configuration. Recall the current-voltage relationship for capacitors from Touch 3A:

$$I_f(t) = C_{pixel} \frac{dV_c(t)}{dt} \quad (3)$$

$$V_c(t) = V_c(t_0) + \int_{t_0}^t \frac{I_f}{C_{pixel}} dt \quad (4)$$

$$V_c(t) = V_c(t_0) + \int_{t_0}^t \frac{V_{in}(t)}{R_{in}C_{pixel}} dt \quad (5)$$

where we have plugged in the value for  $I_f(t)$  from (2).

We can now write the output voltage of the integrator as,  $V_{out}(t) = 0 - V_c(t) = -V_c(t_0) - \int_{t_0}^t \frac{V_{in}(t)}{R_{in}C_{pixel}} dt$ . If we

set the initial condition  $V_c(t_0) = 0V$ , we get  $V_{out}(t) = -\frac{1}{R_{in}C_{pixel}} \int_{t_0}^t V_{in}(t) dt$

We can now see that the output of the op-amp responds to changes in the input voltage over time as the op-amp integrator produces an output voltage which is proportional to the integral of the input voltage. Thus, we have modeled a change in capacitance into a change in voltage, just like in Touch 3A. We will have two different voltages for touch and no-touch. If we set our value for  $V_{REF}$ , we can model a binary system of touch and no-touch and use a comparator and an LED to complete actuation.