EECS 16A Designing Information Devices and Systems I
Summer 2023 Pre-Lab Reading Touch 3

1 Touch 2 Review

In the last lab, you built your first (resistive) touchscreen! By applying the concept of voltage dividers to your resistive touchscreen, you were able to measure voltages at different touch points. Each of the 9 touch points on our touchscreens has a unique voltage value, so by measuring voltage at the point that you touched your touchscreen, you were able to determine the exact coordinates of your touch. What are some issues with the resistive touchscreen? They are single-touch only and require moving parts (top and bottom) with a complex resistive mesh. To mitigate these issues, we will look at a different kind of touchscreen – the capacitive touchscreen!

2 Touch 3 Preview

A capacitive touchscreen is a touchscreen that is commonly used today. All your phones and tablets have touchscreens that work on the basic principles of capacitive touchscreens. It is composed of a glass-like transparent layer, strips of metal that act as the plate of the capacitor, and another transparent, conductive layer at the top. Real-world touchscreens have many other layers such as flexible surfaces and LCD display layers. The capacitive touchscreen, as the name suggests, exploits the capacitive properties of our fingers/-body. It works on the simple principle that touching the screen induces a change in capacitance due to the addition of our finger(s) since our fingers contain a capacitance. If we can find a way to detect this change in capacitance, we can detect a touch!

2.1 Capacitors

Before we look at the touchscreen, let's look at the component we use to build it - the capacitor! A capacitor is a circuit element that stores charge. It has 2 metallic plates with something called a dielectric material in between the plates. When a voltage is applied, the current going through the capacitor gets obstructed by the dielectric material. This allows positive charge to collect on one plate and negative charge to collect on the other. The capacitance (C) of a capacitor is given by the relation C = $\frac{\varepsilon A}{d}$.

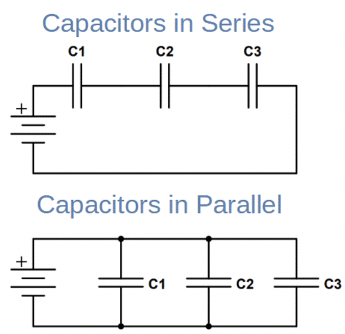
2.2 Current-Voltage Relation for Capacitors

Recall that the relation between voltage and current for a resistor is given by $V = IR$. Is there a similar relationship for capacitors? Yes! It is not as straightforward as $V = IC$. The relationship is derived as follows.

The charge, voltage, and capacitance of a capacitor are related by the equation: $Q = CV$. The derivation for this requires physics concepts beyond the scope of this class so take this as fact for now! The definition of current is the amount of charge per unit time. Mathematically, we can define this as $I = \frac{dQ}{dt}$. If you take the derivative with respect to time of both sides of $Q = CV$, we can plug in $I = \frac{dQ}{dt}$ to get $I = \frac{d}{dt}CV = C\frac{dV}{dt}$ (since C is a constant). We can thus find the voltage with respect to time as $V(t)$ by integrating both sides of the previous equation.

2.3 Capacitors in Series and Parallel

Just like resistors, capacitors can be connected to each other in series and parallel configurations. However, the equivalence relations are not the same.

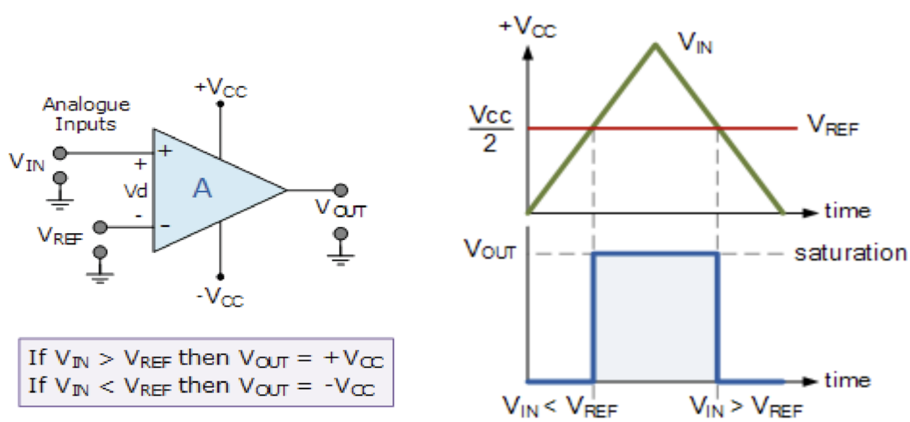


For series, $\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \ldots + \frac{1}{C_n}$

For parallel, $C_{eq} = C_1 + C_2 + \ldots + C_n$

2.4 Op-Amps

An op-amp (operational amplifier) is a device that transforms a small voltage difference into a very large voltage difference [Note 17]. An op-amp can be used as a comparator – something that compares two voltages and indicates which is larger. A comparator is a helpful logical circuit element since it only has two possible outputs. This helps us since we want to model our touchscreen as a 'binary' system with outputs - 'Touch' and 'No Touch'. Here's an op-amp being used as a comparator:



Earlier, we saw a way to relate voltage to capacitance. In lecture, we also saw that touching the touchscreen causes a change in capacitance due to the addition of our finger(s). Thus, there will be a change in voltage. If we can determine a suitable V_{REF}, we can use our comparator to determine if a touch took place on the touchscreen that we're building in lab. To get you thinking about this, if we had certain voltages for touch and no touch as V_{touch} and $V_{no-touch}$, what V_{REF} value do you think would work best? We will look more closely at this in lab!

3 An (Almost) Ideal Current Source

One problem from our setup 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 that supplies a 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 the 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 voltage waveforms we want to detect touch.

3.1 Op Amp Review

To build our almost ideal current source, we will make use of op-amps! Using a periodic voltage source, a 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**):

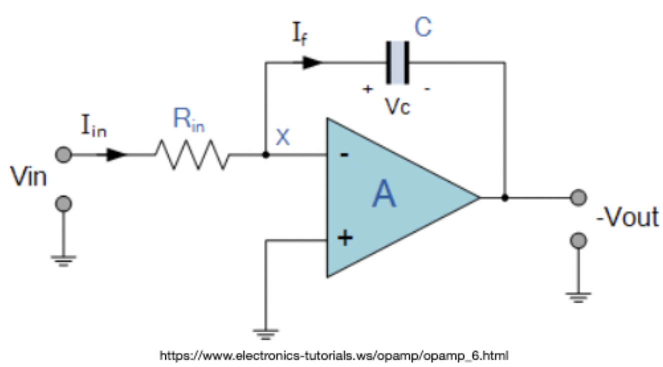
(a) The two input terminals do not draw any current.

(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 has to be the same.

3.2 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:

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

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

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:

$$I_f(t) = C_{pixel}\frac{\mathrm{d}V_c(t)}{\mathrm{d}t} \tag{3}$$

$$V_c(t) = V_c(t_0) + \int_{t_0}^{t} \frac{I_f}{C_{pixel}}\mathrm{d}t \tag{4}$$

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

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

We can now write the output voltage of the integrator as, $V_{out}(t) = 0 - V_c(t) = -V_c(t_0) - \int_{t_0}^{t} \frac{V_{in}(t)}{R_{in}C_{pixel}}\mathrm{d}t$. If we set the initial condition $V_c(t_0) = 0V$, we get $V_{out}(t) = -\frac{1}{R_{in}C_{pixel}}\int_{t_0}^{t} V_{in}(t)\mathrm{d}t$

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 that is proportional to the integral of the input voltage. Thus, we have modeled a change in capacitance into a change in voltage. 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 the actuation.

Contributors:

- Shreyash Iyengar
- Ayush Pancholy
- Anastasia Simonova
- Joyce Zhu