This week: Capacitive touchscreen

- Today: capacitive touchscreens
  - Exploits capacitive properties of finger/body
  - Touching the screen changes the capacitance
- A lot better!
  - No moving parts
  - Multi-touch is possible
  - More sensitive
Electronic systems

- Sensing is only a part of a complete system. Most systems perform 3 tasks:
  - Sense (Physical to Electrical)
  - Process (Signal Conditioning)
  - Actuate (Electrical to Physical)
Capacitance and the touchpad

Touching our screen changes capacitance
Touching changes capacitance

- Screen = some capacitance
- Screen + finger = different capacitance

Let’s try to figure out a way to detect this change in capacitance!
How to detect changing capacitance?

- Not so easy to directly measure
- Instead, we try to measure something that a change in capacitance would create
  - Current can be hard to measure directly
  - Changes in voltage are easy to see
What do we know about capacitors?

\[ I = C \frac{dV}{dt} \]

- Note that if current is constant, voltage is just linear with time
  - integrate to get an expression
- Having a linear voltage signal is easy for us to read!
Finding the exact relationship $V(t)$ (for constant current)

\[ I = C \frac{dV}{dt} \]

\[ \frac{dV}{dt} = \frac{I}{C} \]

\[ \int_{0}^{t} dV = \int_{0}^{t} \frac{I}{C} dt \]

\[ V(t) - V(0) = \frac{I}{C} t \]

\[ V(t) = \frac{I}{C} t + V(0) \]

- Voltage increases with time!
- Note: we’re assuming $I$ is constant
- What’s the slope of this line?
Finding the exact $V(t)$

Looks good right?

$$V(t) = \frac{I}{C} t + V(0)$$
Issues with this model

- How high can \( V(t) \) get? Too high.
  - In theory: infinity. In practicality: maybe not quite infinity, but still bad
- We’re going to need to discharge it to make its usage practical
  - Periodically apply a negative current
    \[
    V(t) = \frac{I}{C} t + V(0) \quad \rightarrow \quad V(t) = -\frac{I}{C} t + V(0)
    \]
- Two different slopes!
- What are the shapes of our graphs now?
Applying negative current: The square wave

- A wave that only has two values: high and low
- We will use this to charge and discharge the capacitor
- High: Positive 10mA
- Low: Negative 10mA
- Note: We have 0mA in the beginning to set the initial condition
New waveforms

Voltage and Current vs Time on a Capacitor

Note: $V(0) = 0$ in this plot
Touch-ups

- We know how to measure voltage
- Reminder: we want to detect touch by seeing a change in voltage
- We need to quantify what it means for us to touch the screen
How does our finger affect the system?

- Does a touch increase or decrease the capacitance?

\[ C_{\text{series}} = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \ldots + \frac{1}{C_n}} \]

\[ C_{\text{parallel}} = C_1 + C_2 + \ldots + C_n \]
How does our finger affect the system?

- C increases
- How does the touch affect our voltage waveform?

\[ V(t) = \frac{L}{C} t - V_0 \]

- What happens to the slope?
Detecting touch

- How do we detect this?
  - Want to compare their max value
  - Want to output waveform that is most distinct for each case
Difference In Peak Voltages

- Idea: compare the peaks to some reference voltage
  - Higher peak: no touch
  - Lower peak: touch
Breakpoint

- Watch the Op Amp Lecture before proceeding (scheduled for 4/2)
- Look out for breakpoint in lab
  - Proceed at your own caution if you want to start early
Creating the Triangle Wave

- To get the blue wave, we need to feed an alternating current (red wave) into our capacitor
Building a current source (Note 20)

- Need a circuit that outputs a constant current
- What we have:
  - Voltage sources
  - $V = IR$ relationship for resistors
  - Note 20’s guidance
Note 20: An “almost” current source

- We can use an op amp!
  - GR #1: No current going in to op amp
  - GR #2: $U_+ = U_-$, so let’s make one of them 0V

■ What must be true for this to hold?
Note 20: An “almost” current source

- Since we are in negative feedback, \( u_2 = 0V \)
  \[
  I_s = \frac{V_s - 0}{R_s}
  \]
- All current \( I_s = \frac{Vs}{Rs} \) will go to the element, since \( I_- = 0 \)
Sensing a completion

- Hook up our capacitive touch screen
- We get a constant current $V/R$ through the capacitor
- What’s the output of this circuit?
What’s our new input?

- Function generator
- Can create different waves
- Treat it as a non-constant voltage source
- Use it to output an alternating Vs and -Vs wave
Detecting a Touch: Comparators

- Now that we have a red input square wave from the function generator and a blue triangle wave integrated output, we want to rectify it into “Touch” and “No Touch” states.
Comparing Voltage using Op Amps

- Has 4 inputs
  - V+
  - V-
  - Vs+
  - Vs-
- Has 1 output
  - Vout
Comparators

- Compares input voltage at positive terminal to a reference voltage at negative terminal

If $V_{IN} > V_{REF}$ then $V_{OUT} = +V_{CC}$
If $V_{IN} < V_{REF}$ then $V_{OUT} = -V_{CC}$
Completing actuation

- Use comparator to visualize the different comparator outputs
- An LED will turn on if the voltage across it is high enough!
- So we can observe whether there is a touch or not based on the LED’s lighting behavior
Our real-world circuit

**Processing Integrator**
- $V_{in}$ (from Function Generator)
- $51 \, \Omega$
- $10 \, k\Omega$
- $1 \, M\Omega$
- $C_{pixel}$
- $5 \, V$ (from +25 V of PSU)
- $-5 \, V$ (from -25 V of PSU)

**Processing Comparator**
- $V_{out1}$
- $5 \, V$ (from +25 V of PSU)
- $5 \, V$ (from -25 V of PSU)

**Actuation LED**
- $V_{out2}$
- $330 \, \Omega$
- $V_{ref}$ (from 6 V of PSU)
- LED
Our real-world circuit

Processing Integrator

1 MΩ

C_{pixel}

5 V (from +25 V of PSU)

-5 V (from -25 V of PSU)

Processing Comparator

5 V (from +25 V of PSU)

-5 V (from -25 V of PSU)

Actuation LED

330 Ω

V_{out1}

V_{out2}

V_{ref} (from 6 V of PSU)

V_{in}

(from Function Generator)

51 Ω
Note: Voltage dividers

- The function generator has a 50 Ohm source resistance
- Our function generator also assumes a 50 Ohm load is attached (don’t ask why).
  - What’s the voltage you get across this load?

If you attach a 50 Ohm load, then the load only gets ½ of Vin applied
Note: Voltage dividers

- The function generator will automatically double its output voltage (Vin) so that the voltage across the load (Vload) is what you would expect after it is halved.
What does the 51 ohm do?

- Compute the thevenin resistance of our circuit from the input port
  - It’s about 51 Ohms
- Our circuit (from the input) looks like a 51 Ohm resistor
What does the 51 ohm do?

- Our circuit looks like a 51 ohm load with respect to the input, so the function generator is happy!
- (Note 50 Ohm resistors basically don’t exist so we use 51 because it’s the next closest value)
Our real-world circuit

Processing Integrator

- $V_{in}$
- $1 \text{ M}\Omega$
- $C_{pixel}$
- $5 \text{ V}$ (from +25 V of PSU)
- $-5 \text{ V}$ (from -25 V of PSU)

Processing Comparator

- $V_{out1}$
- $5 \text{ V}$ (from +25 V of PSU)
- $V_{ref}$ (from 6 V of PSU)
- $-5 \text{ V}$ (from -25 V of PSU)

Actuation LED

- $V_{out2}$
- 330 $\Omega$
- LED

(from Function Generator)
Another difference:

● It ensures that the circuit is always in negative feedback
  ○ Since it’s 1 million Ohms it draws almost 0 current, and thus doesn’t really affect our analysis

● If it was not there, the Capacitor acts as an open during constant voltage, so there is no feedback
Taking the limit

- Okay, cool the LED turns on/off.
- But [insert friendly lab TA name here], didn’t you say capacitive touchscreen is way better than resistive? Why do we only have one touch point instead of nine?
Taking the limit

- Note that this isn’t dependent on voltage dividers at all, only on if you are locally touching the capacitor
- **How to add more touch points?**
  - Duplicate the entire circuit and put them next to each other. Each one is a pixel
- They’re independent, so the more you add the more points you can sense
Taking the limit

- Make the caps really small, put them in the size of a screen
- Thousands of these sensing circuits can be made incredibly small
  - (less than 4mm x 4mm)
- Put a thousand of these and you can recognize 1000 different touch points
- No moving parts, much better (and more accurate) than the resistive touchscreen
That’s it!
Extra Stuff: Integrated Circuits (ICs)

TI LMC6482

Breadboard View

Chip Schematic
Extra Stuff: Integrated Circuits (ICs)
Extra Stuff: Integrated Circuits (ICs)

Chip Schematic

- OUTPUT A: Pin 1
- INVERTING INPUT A: Pin 2
- NON-INVERTING INPUT A: Pin 3
- OUTPUT B: Pin 7
- INVERTING INPUT B: Pin 6
- NON-INVERTING INPUT B: Pin 5

Symbol for operational amplifier:

- Input: $V_+$, $V_-$
- Output: $V_{out}$
- Supply voltage: $V_{SS}$

$V_{SS}$ is the ground potential.
Extra Stuff: Integrated Circuits (ICs)
Extra Stuff: Devices

- BJT NPN
- JFET N-channel
- nMOS
- BJT PNP
- JFET P-channel
- pMOS

FinFET

EE143
EE130

Previous Schematic:
Extra Stuff: So why did I go over all of this?

High Rail:
- Vdd
- Vd
- Vcc
- Vc
- V+
- Vs
- Vs+
- +

Low Rail:
- Vss
- Vs
- Vee
- Ve
- V-
- Vs-
- -
Extra Stuff: So why did I go over all of this?