Multi-touch in a resistive touch screen

In this system, we drive with a current, and measure the voltage on the terminals of the driving layer.

No touch:
\[ V^+ - V^- = I \cdot (R_u + R_a + R_d) \]

2-finger touch:
The passive layer resistance is in parallel with the active layer resistance \( r_a \)

\[ \text{Passive layer resistance} = R_{\text{touch}} + R_p + R_{\text{touch}} \]

Therefore, we have:
\[ V^+ - V^- = I \left( R_a + R_d + R_a \right) \left( 2R_{\text{touch}} + R_p \right) \]
\[ = I \left( R_a + R_d + \frac{R_a \left( 2R_{\text{touch}} + R_p \right)}{R_a + 2R_{\text{touch}} + R_p} \right) \]

Question: Can this measurement detect a single touch?

Gesture responses: Pinch

The voltage increases as my fingers pinch, since less of the active resistance is shunted, increasing the measured voltage \( (I \cdot R_{\text{eq}}) \)
Exercise: Calculate the finger separation

- Assumptions:
  - Applied current: 1mA
  - Resistivity of both layers is the same
  - R_{contact} is small
  - Y length is 32cm
- Q1: Total Y electrode resistance?
- Q2: Square or rectangular screen?
- Q3: R_{sample21} = ?
- Q4: Finger separation_{sample21} = ?

Gesture Response: Twist

- Just monitoring the active layer doesn’t allow us to detect twist properly, since both clockwise and counter clockwise twists look the same.

- However, by monitoring the passive layers as well, we can distinguish the twist direction.
Example of a real system

Subtraction circuits

Multiplexers: these cycle through the various possibilities

Measuring voltage and current

- You’ve seen that we need to measure voltage to detect finger position.
- We measure voltage using a voltmeter put across the terminals at which we intend to measure voltage.
- We measure current using an ammeter put in series with the path along which we intend to measure current.

- Good voltmeters have really high internal resistance, and good ammeters have really low internal resistance.
- Why?
Buffering

- You saw that the parallel resistor lowers the voltage.
- A voltage measurement device with a non-infinite resistance does the same; we would therefore like a way to connect a voltmeter to the touchscreen without loading the system and lowering the voltage.
- This is easily done using a buffer. A buffer has a high input resistance, but can source the current needed by the load.

![Buffer Diagram](image)

- In effect, a buffer (nearly) reproduces the input voltage, but doesn’t load the input.
- Note that a buffer cannot produce energy, so it draws the energy the load requests from some other power supply.

Amplifier Integrated Circuits

- In an ideal world, an amplifier IC takes an input signal (for example, $V_{\text{in}}$), and multiplies it by a fixed amount to produce an output signal.

  Example:
  
  $V_{\text{out}} = A_{V} \cdot V_{\text{in}}$
  
  where $A_{V}$ is the multiplier, called a voltage gain.

- Of course, the energy for this multiplication has to come from somewhere. Therefore, an amplifier IC has power supply connections as well.
Operational Amplifier “Op Amp”

- Two input terminals, positive (non-inverting) and negative (inverting)
- One output
- Power supply $V_{cc}$ and $-V_{cc}$

![Op Amp Pin Diagram](image)

Op Amp with power supply not shown (which is how we usually display op amp circuits)

Gain of an Op Amp

- Key characteristic of op amp: high voltage gain
- Output, $A$, is the op-amp gain (or open-loop gain) – you’ll see what “open-loop” means later
- Linear response

$$v_o = A(v_p - v_n)$$

![Gain Graph](image)

- In typical Op Amps, the gain is really high (e.g., $\sim 10^8$)
**Op Amp as a comparator**

- Since $A$ is *really* high, we can treat the Op Amp as a comparator.

- What is $v_o$ when $v_p > v_n$?

- What is $v_o$ when $v_n > V_p$?

$$v_o = A(v_p - v_n)$$

**Design Exercise: Clipping Detector**

- Clipping occurs in audio circuits when the input voltage is too large for the amplifier.

- This sounds bad:

  - Example: Unclipped sound (C Major)

  - Example 2: clipped sound (C Major)
Design Exercise: Clipping Detector

- Design an Op-Amp circuit that will light up an LED when an input voltage is above a value, $V_{\text{clip}}$

Useful Videos

- Intro to Amplifiers: [http://youtu.be/lSZSzyCK5mw](http://youtu.be/lSZSzyCK5mw)
- Op Amps: [http://youtu.be/Xy0ePsLv5Bs](http://youtu.be/Xy0ePsLv5Bs)
- Types of Amplifiers: [http://youtu.be/U8Fz0LEWVlo](http://youtu.be/U8Fz0LEWVlo)
Capacitive Touch Screens

- Resistive touch screens suffer from:
  - Need for hard pressure
  - Complicated multi-touch implementation
- Capacitive touch screens address these problems.
- To begin, let’s consider the electrical equivalent of human skin

How should we model this?

Capacitors

Passive element that stores energy in electric field

\[ C \quad \text{Parallel plate capacitor} \]

\[ i = C \frac{dv}{dt} \quad q = Cv \]

\[ v = \frac{1}{C} \int_{t_0}^{t} i \, dt + v(t_0) \]

To DC signals, capacitor looks like open circuit

Voltage on capacitor must be continuous (no abrupt change)
Modeling a touch

Self-capacitive touch screens

- By taking advantage of the fact that fingers provide a capacitive path to ground, touch location can be determined by detecting capacitance changes on X and Y electrode arrays.
Self-capacitance: Multi-touch problems

- Since self-capacitive systems only measure capacitance from the electrode to the earth, they have a problem with ghosting.

Mutual Capacitance Touch Screens

- Mutual capacitance touch screens enable multi-touch operation without the hard touch and complexity of resistive systems.
- Rows and columns of electrodes are used, but (unlike self-capacitive systems), one orientation is always driven, and the other is sensed.
- The strong fringing fields between the planar electrodes interact with their local environment, including nearby fingers.
**Response to touch**

- Nearby fingers bleed away some charge, reducing the effective capacitive coupling between electrodes.

**Capacitors in Series**

- use KVL
- the current is the same through each capacitor

**Combining In-Series Capacitors**

\[
\begin{align*}
i_s &= C_1 \frac{dv_1}{dt} = C_2 \frac{dv_2}{dt} = C_3 \frac{dv_3}{dt}.
\end{align*}
\]

\[
\begin{align*}
v_s &= v_1 + v_2 + v_3.
\end{align*}
\]

\[
\begin{align*}
i_s &= C_{eq} \frac{dv_s}{dt} \\
&= C_{eq} \left( \frac{dv_1}{dt} + \frac{dv_2}{dt} + \frac{dv_3}{dt} \right) \\
&= C_{eq} \left( \frac{i_s}{C_1} + \frac{i_s}{C_2} + \frac{i_s}{C_3} \right),
\end{align*}
\]

\[
\begin{align*}
\frac{1}{C_{eq}} &= \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}.
\end{align*}
\]
Capacitors in Parallel

- use KCL
- voltage is the same across each capacitor

\[ i_s = i_1 + i_2 + i_3 \]
\[ = C_1 \frac{dv_s}{dt} + C_2 \frac{dv_s}{dt} + C_3 \frac{dv_s}{dt} \]
\[ i_s = C_{eq} \frac{dv_s}{dt} \]

\[ C_{eq} = C_1 + C_2 + C_3 + \cdots + C_N \]

Useful Videos

- Capacitors 1: http://youtu.be/sLuNtjglmKY
- Capacitors 2: http://youtu.be/bzoHbcuOsWw