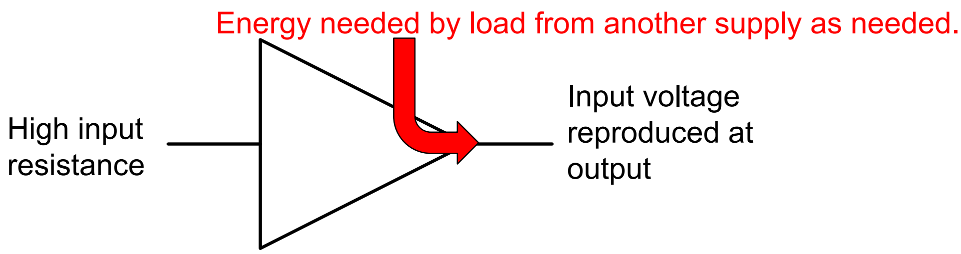
Buffering

- 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.



- 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

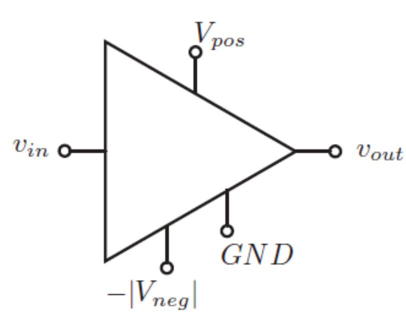
- In an ideal world, an amplifier IC takes an input signal (for example, V_{in}), and multiplies it by a fixed amount to produce an output signal.

  Example:

  $V_{out} = A_V \cdot V_{in}$

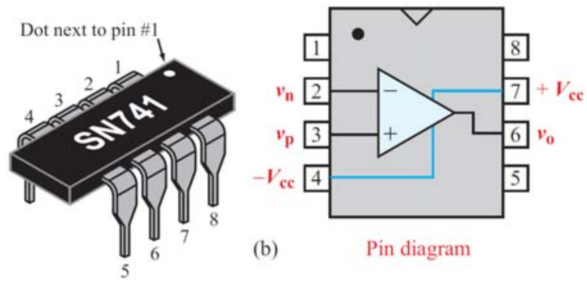
  where A_V is the multiplier, called a voltage gain

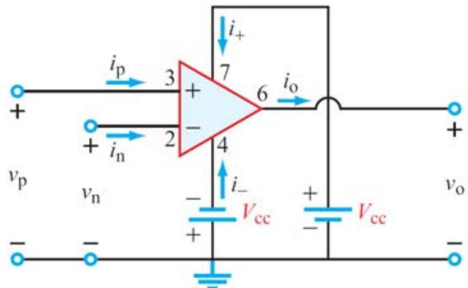
- Of course, the energy for this multiplication has to come from somewhere. Therefore, an amplifier IC has power supply connections as well.



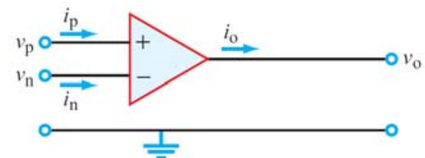
Operational Amplifier "Op Amp"

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

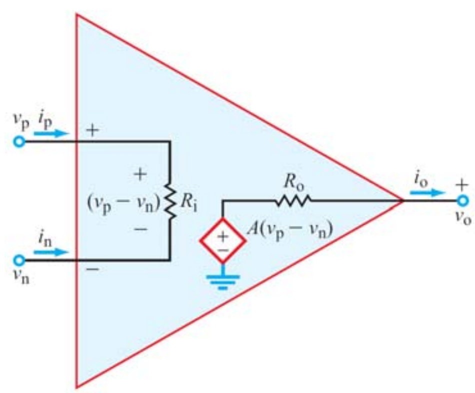




Op Amp with power supply not shown (which is how we usually display op amp circuits)



Equivalent Circuit and Specifications



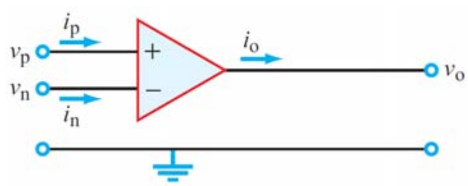
Parameter	Typical Range	Ideal Op Amp
Open-loop gain A	10^4 to 10^8 (V/V)	∞
Input resistance R_i	10^6 to 10^{13} Ω	∞ Ω
Output resistance R_o	1 to 100 Ω	0 Ω
Supply voltage V_{cc}	5 to 24 V	As specified by manufacturer

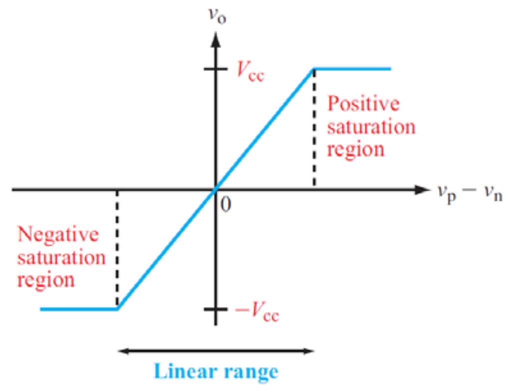
- In other words, a really good buffer, since $R_i \to \infty$. All the needed power for the output is drawn from the supply

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

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



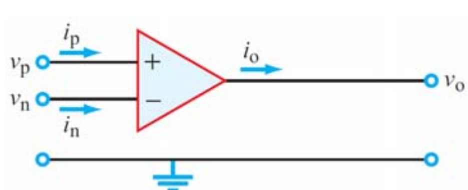


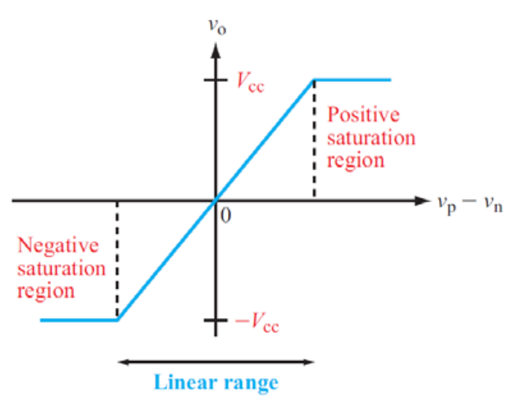
- In typical Op Amps, the gain is *really* high (e.g., ~10^8)

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 $v_n > V_p$?

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



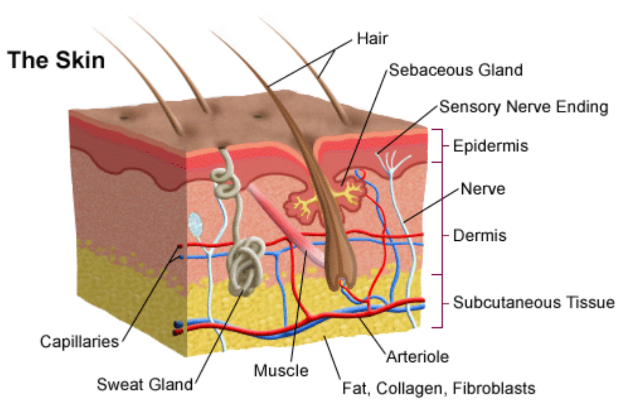


Useful Videos

- Intro to Amplifiers: http://youtu.be/IsZSzyCK5mw
- Op Amps: http://youtu.be/Xy0ePsLv5Bs
- Types of Amplifiers: http://youtu.be/U8Fz0LEWVlo
- Ideal Op Amps: http://youtu.be/4jL578YD3Ak

Capacitive Touch Screens

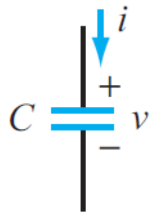
- Resistive touch screens suffer from:
  - Need for hard pressure
  - Complicated multi-touch implementation
- Capacitive touch screens address these problems.
- To begin, let's consider the electrical equivalent of human skin



How should we model this?

Capacitors

Passive element that stores energy in electric field

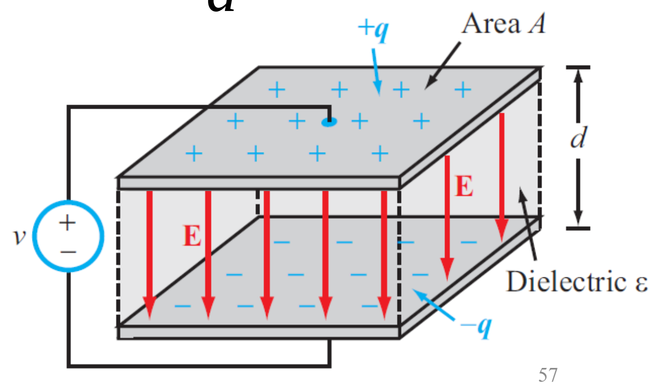


$$i = C\frac{dv}{dt} \qquad q = Cv$$

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

Parallel plate capacitor

$$C = \frac{\varepsilon A}{d} \qquad F\ (Farads)$$

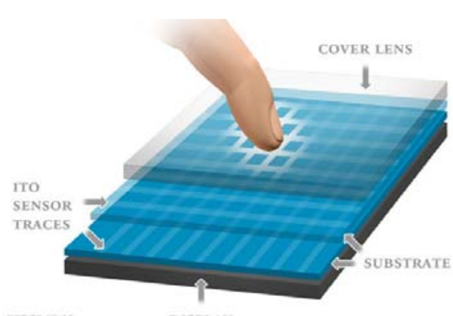


To DC signals, capacitor looks like open circuit

Voltage on capacitor must be continuous (no abrupt change)

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



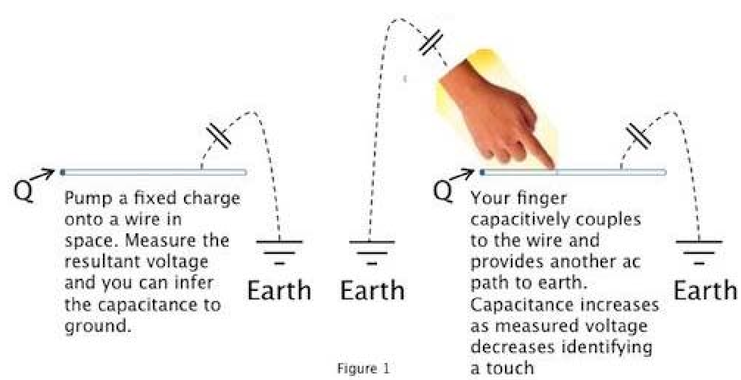
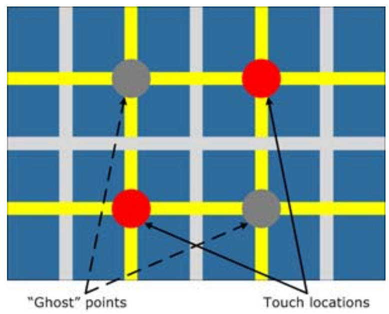


Figure 1

Self-capacitance: Multi-touch problems

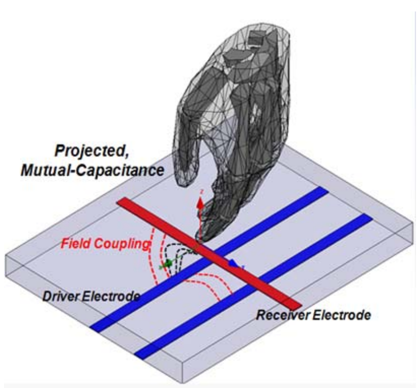
- Since self-capacitive systems only measure capacitance from the electrode to the earth, they have a problem with ghosting

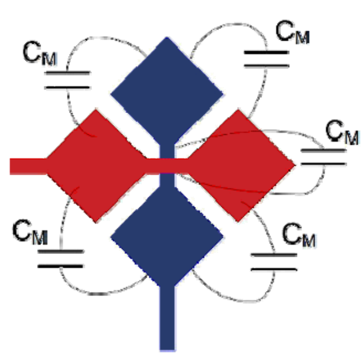


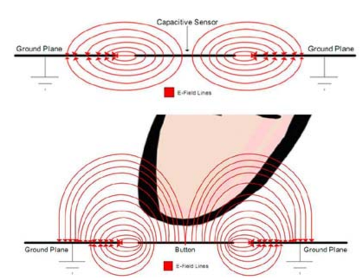
"Ghosting" effect with self-capacitive touchscreens

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.



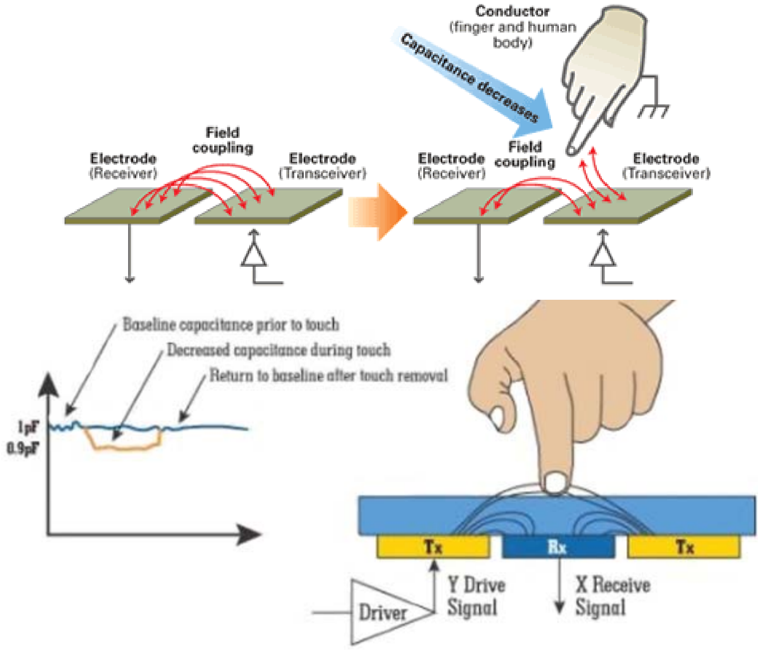




- The strong fringing fields between the planar electrodes interact with their local environment, including nearby fingers

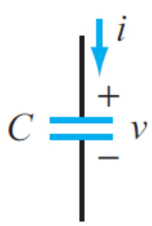
Response to touch

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



Detecting capacitance changes

- So how can we detect capacitance changes? To answer this, we need to review current/voltage/charge relationships in capacitors.



$$i = C\frac{dv}{dt} \qquad q = Cv \qquad v = \frac{1}{C}\int_{t_0}^{t} i\,dt + v(t_0)$$

- Remember that we know how to apply a voltage and measure current, or apply a current and measure voltage.

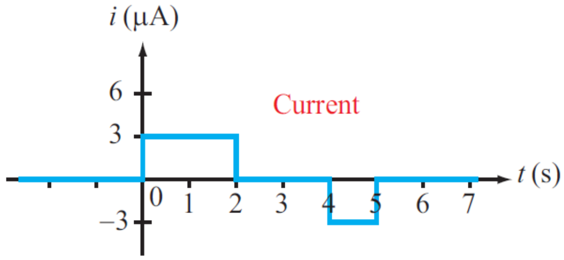
- How would you implement a capacitance measurement circuit?

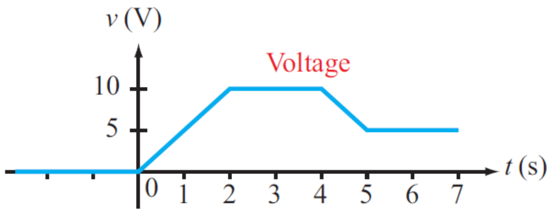
Capacitor Response: Given v(t), determine i(t)

- One way to detect capacitance:
  - Use a constant current
  - If you start from a known charge level, the voltage in a given time is proportional to capacitance

$$i(t) = C\frac{dv}{dt}$$

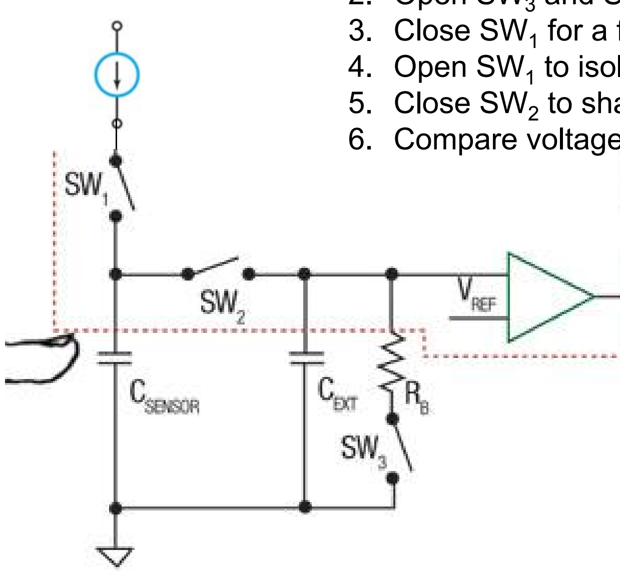
$C = 0.6\text{-}\mu\text{F}$





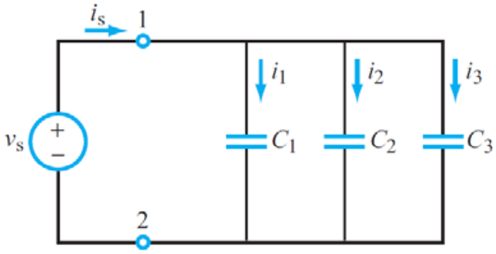
Example Capacitive Touch Screen Reader

1. Close SW_3 and SW_2 to discharge the capacitors
2. Open SW_3 and SW_2
3. Close SW_1 for a fixed time to charge C_{sensor}
4. Open SW_1 to isolate C_{sensor}
5. Close SW_2 to share charge between C_{sensor} and C_{ext}
6. Compare voltage of capacitors to V_{ref}



Capacitors in Parallel

-use KCL
-voltage is the same across each capacitor



$$i_s = i_1 + i_2 + i_3$$

$$= C_1 \frac{dv_s}{dt} + C_2 \frac{dv_s}{dt} + C_3 \frac{dv_s}{dt}$$

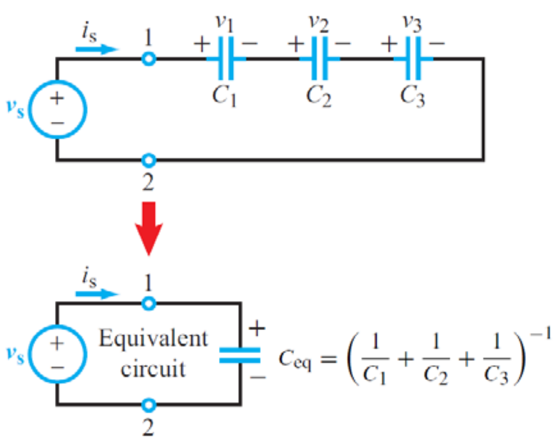
$$i_s = C_{eq} \frac{dv_s}{dt}$$

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

Capacitors in Series

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

Combining In-Series Capacitors



$$i_s = C_1 \frac{dv_1}{dt} = C_2 \frac{dv_2}{dt} = C_3 \frac{dv_3}{dt}.$$

$$v_s = v_1 + v_2 + v_3.$$

$$i_s = C_{eq} \frac{dv_s}{dt}$$

$$= C_{eq} \left(\frac{dv_1}{dt} + \frac{dv_2}{dt} + \frac{dv_3}{dt} \right)$$

$$= C_{eq} \left(\frac{i_s}{C_1} + \frac{i_s}{C_2} + \frac{i_s}{C_3} \right),$$

$$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}.$$

Useful Videos

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