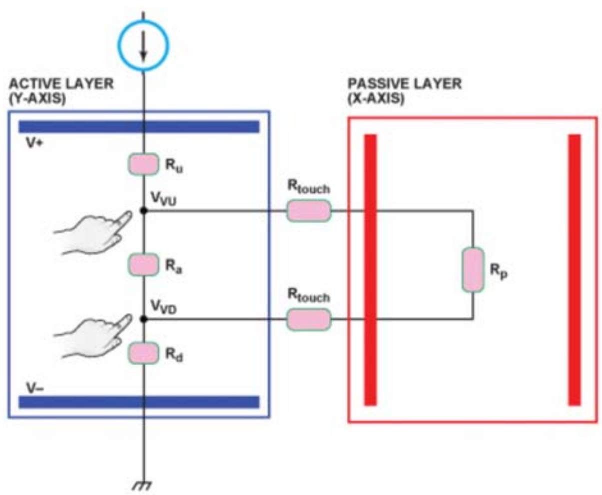
Multi-touch in a resistive touch screen

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



Question: Can this measurement detect a single touch?

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

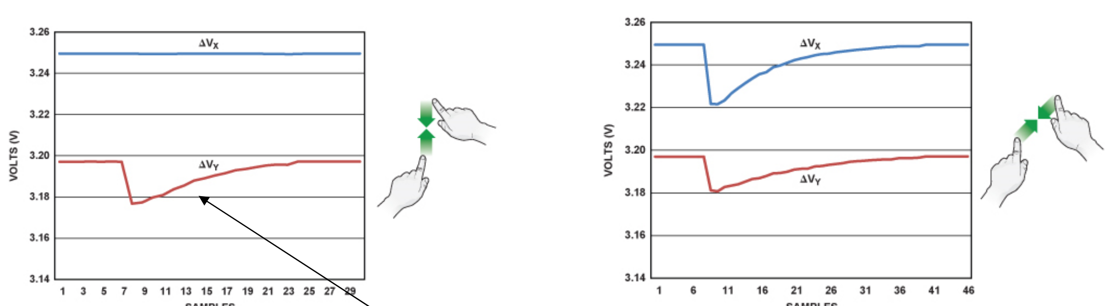
Passive layer resistance = $R_{touch} + R_p + R_{touch}$

Therefore, we have:

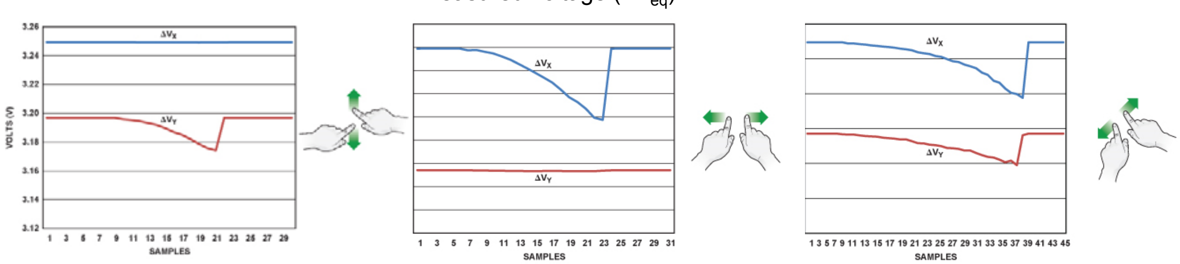
$$V_{+} - V_{-} = I\left(R_u + R_d + R_a \| (2R_{touch} + R_p)\right)$$

$$= I\left(R_u + R_d + \frac{R_a(2R_{touch} + R_p)}{R_a + 2R_{touch} + R_p}\right)$$

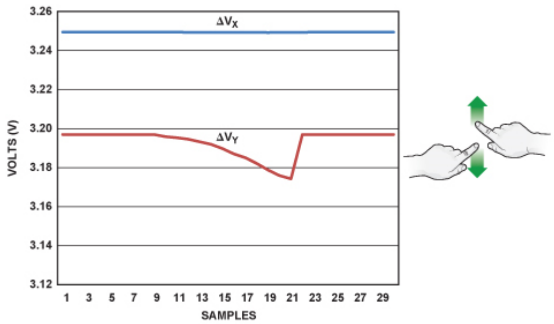
Gesture responses: Pinch



The voltage increases as my fingers pinch, since less of the active resistance is shunted, increasing the measured voltage ($I \cdot R_{eq}$)



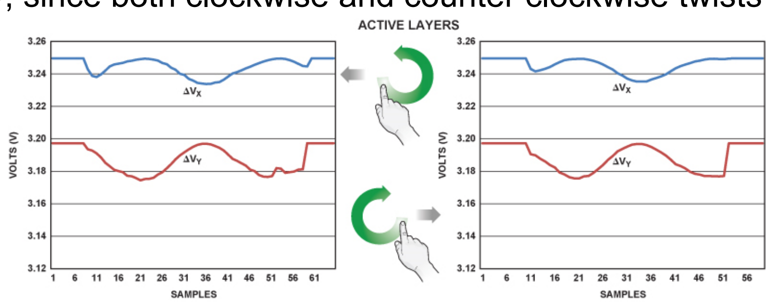
Exercise: Calculate the finger separation



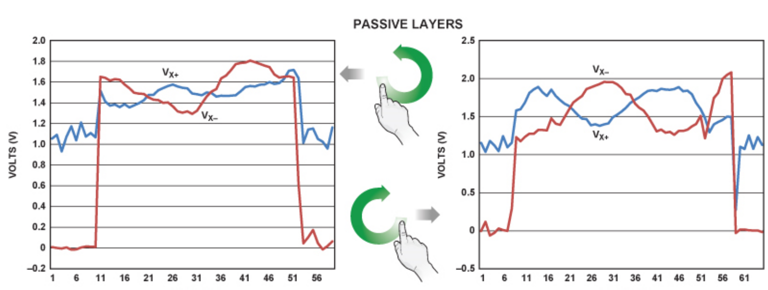
- Assumptions:
  - Applied current: 1mA
  - Resistivity of both layers is the same
  - $R_{contact}$ is small
  - Y length is 32cm
- Q1: Total Y electrode resistance?
- Q2: Square or rectangular screen?
- Q3: $R_{sample21}$ = ?
- Q4: Finger $separation_{sample21}$ = ?

Gesture Response: Twist

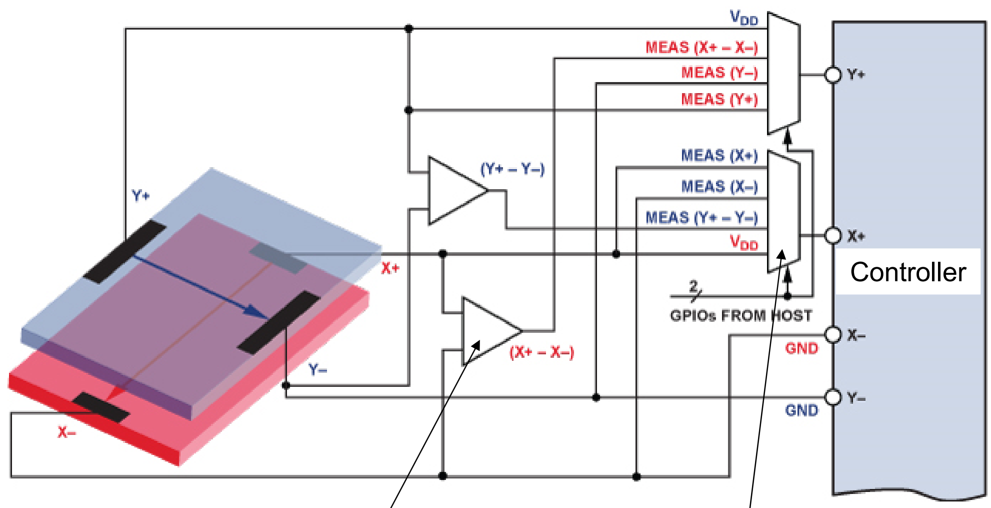
- Just monitoring the active layer doesn't allow us to detect twist properly, since both clockwise and counter clockwise twists look the same.



- However, by monitoring the passive layers as well, we can distinguish the twist direction



Example of a real system

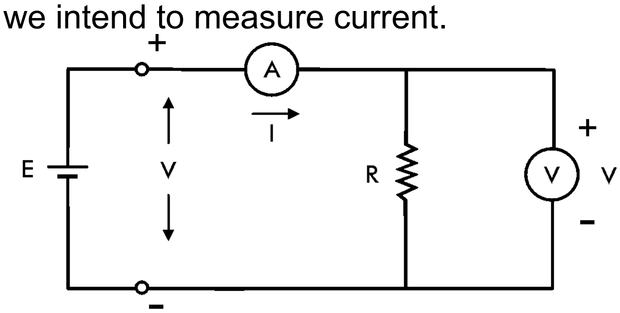


Subtraction circuits

Multiplexers: these cycle through the various possibilities

Measuring voltage and current

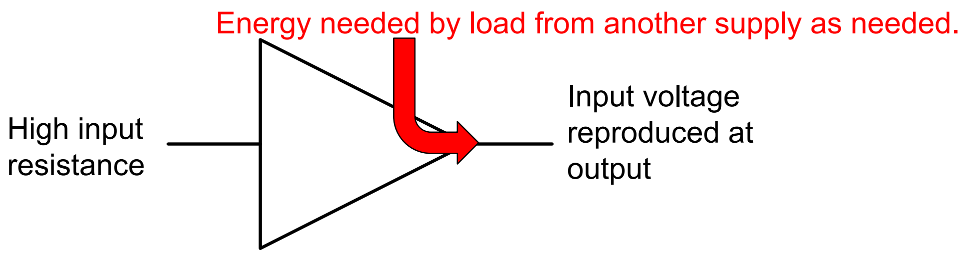
- You've seen that we need to measure voltage to detect finger position.
- We measure voltage using a voltmeter put across the terminals at which we intend to measure voltage
- We measure current using an ammeter put in series with the path along which we intend to measure current.



- 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.



- 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

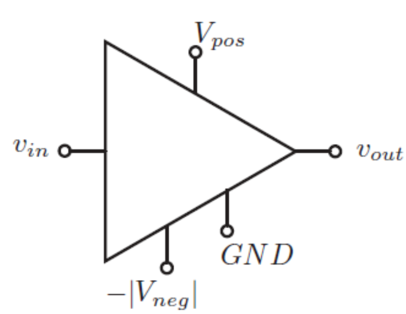
- In an ideal world, an amplifier IC takes an input signal (for example, V_{in}), and multiplies it by a fixed amount to produce an output signal.

  Example:

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

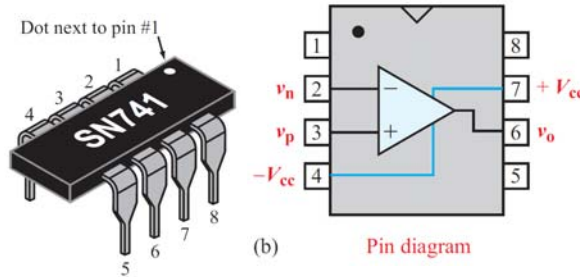
  where A_V is the multiplier, called a voltage gain

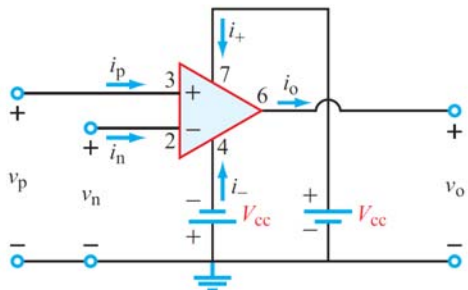
- Of course, the energy for this multiplication has to come from somewhere. Therefore, an amplifier IC has power supply connections as well.



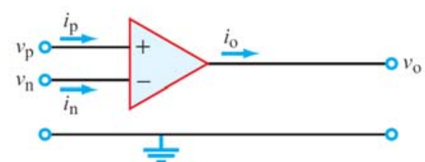
Operational Amplifier "Op Amp"

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





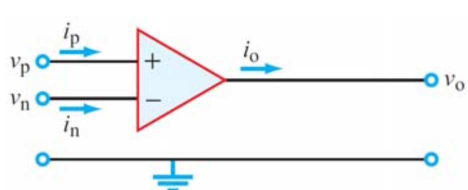
Op Amp with power supply not shown (which is how we usually display op amp circuits)

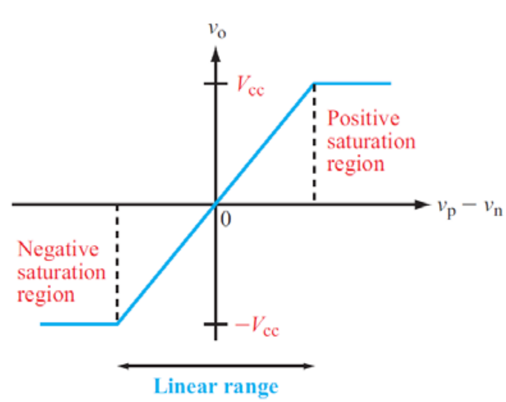


Gain of an Op Amp

- 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

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



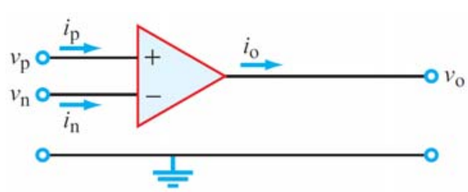


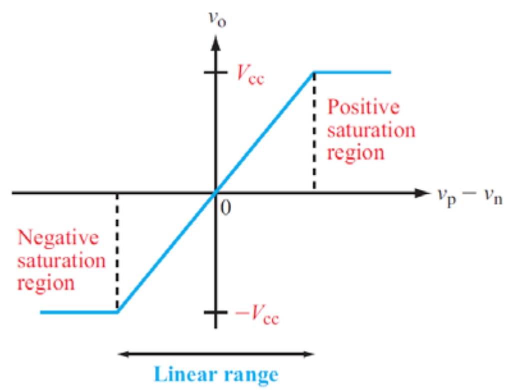
- In typical Op Amps, the gain is *really* high (e.g., ~10^8)

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 $v_n > V_p$?

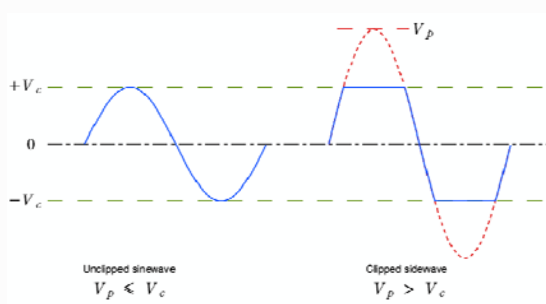
$$v_o = A(v_p - v_n)$$





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

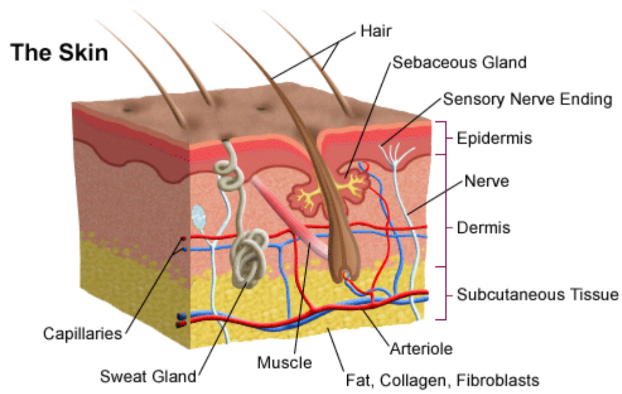
- Design an Op-Amp circuit that will light up an LED when an input voltage is above a value, V_{clip}

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

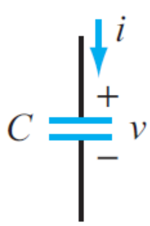
- Resistive touch screens suffer from:
  - Need for hard pressure
  - Complicated multi-touch implementation
- Capacitive touch screens address these problems.
- To begin, let's consider the electrical equivalent of human skin



How should we model this?

Capacitors

Passive element that stores energy in electric field

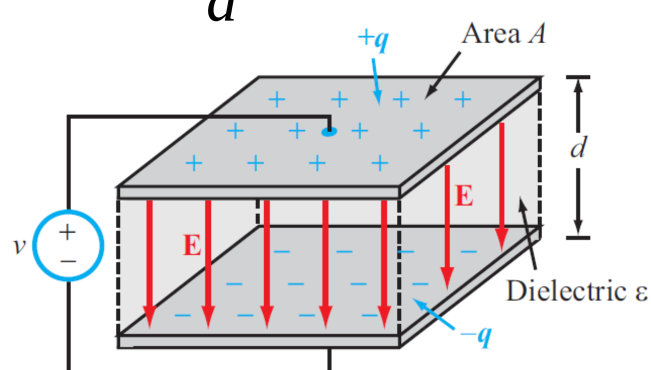


$$i = C\frac{dv}{dt} \qquad q = Cv$$

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

Parallel plate capacitor

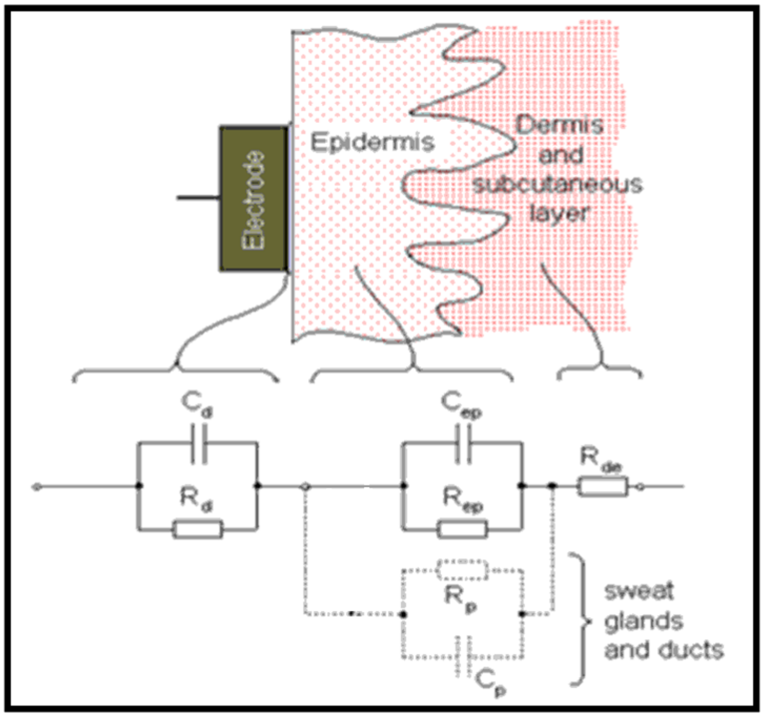
$$C = \frac{\varepsilon A}{d}$$ F (Farads)



To DC signals, capacitor looks like open circuit

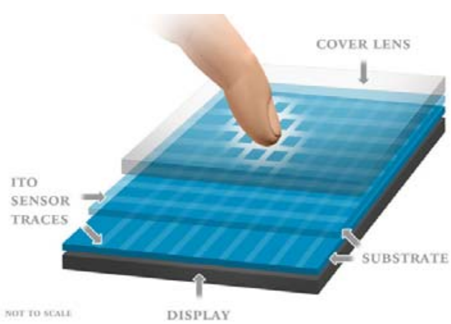
Voltage on capacitor must be continuous (no abrupt change)

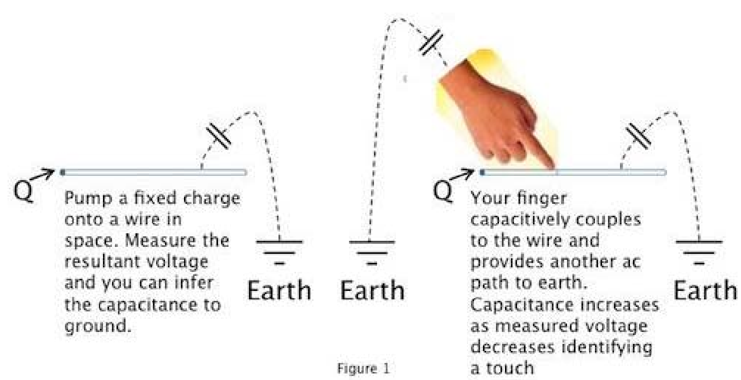
Modeling a touch



Self-capacitive touch screens

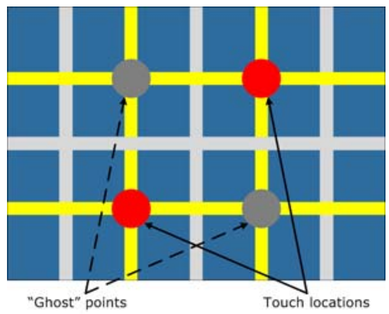
- By taking advantage of the fact that fingers provide a capacitive path to ground, touch location can be determined by detecting capacitance changes on X and Y electrode arrays





Self-capacitance: Multi-touch problems

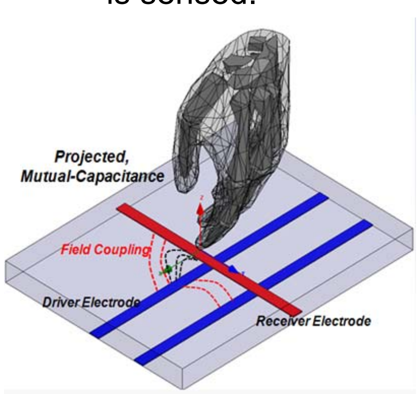
- Since self-capacitive systems only measure capacitance from the electrode to the earth, they have a problem with ghosting

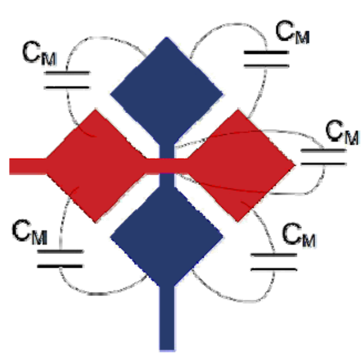


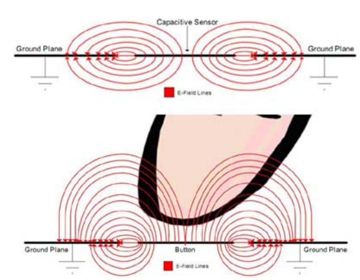
"Ghosting" effect with self-capacitive touchscreens

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.



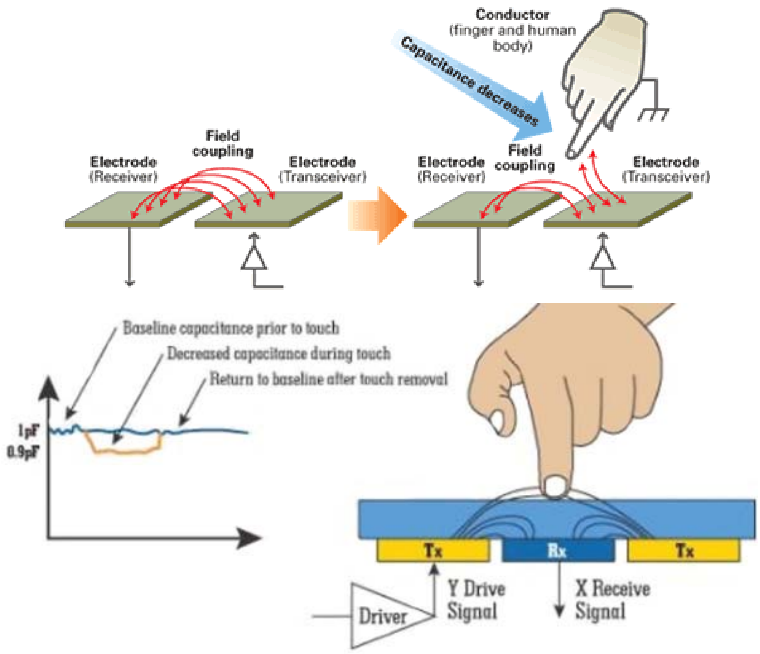




- The strong fringing fields between the planar electrodes interact with their local environment, including nearby fingers

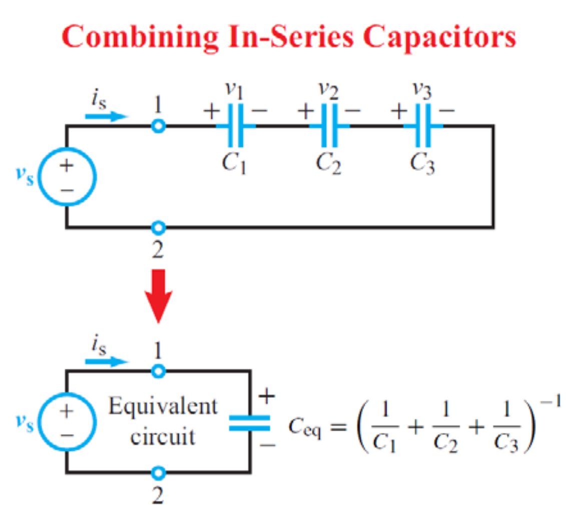
Response to touch

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



Capacitors in Series

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



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

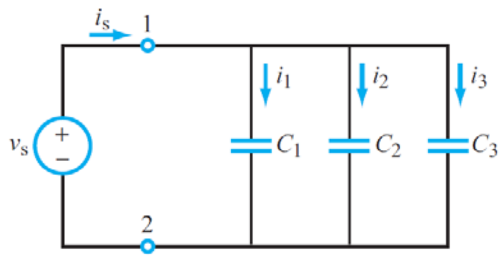
$$v_s = v_1 + v_2 + v_3.$$

$$i_s = C_{eq} \frac{dv_s}{dt} = C_{eq}\left(\frac{dv_1}{dt} + \frac{dv_2}{dt} + \frac{dv_3}{dt}\right) = C_{eq}\left(\frac{i_s}{C_1} + \frac{i_s}{C_2} + \frac{i_s}{C_3}\right),$$

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

Capacitors in Parallel

-use KCL
-voltage is the same across each capacitor



$$i_s = i_1 + i_2 + i_3$$

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

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

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

Useful Videos

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