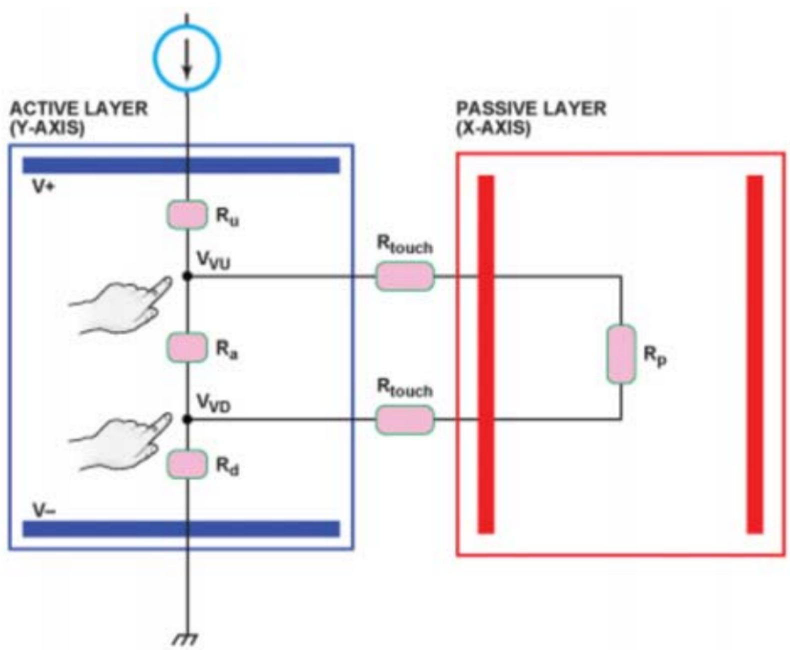
Lecture notes by Nikhil Sharma (03/05/2015)

Multitouch

Recall that in a resistive touchscreen, we drive a voltage across the terminals of the touchscreen's resistive layers and use the split in resistance caused by a touch to determine position. Also recall that for resistors in parallel, the equivalent resistance always drops, as it is a reciprocal of a sum of reciprocals. For multitouch, we drive a current through resistors in parallel, and the magnitude of the resistance drop across the parallel resistors is determined by the relative positions of the fingers. Hence, we can use this property to detect various gestures. Let's express this in more mathematical terms. First, observe the following diagram of a resistive touchscreen:



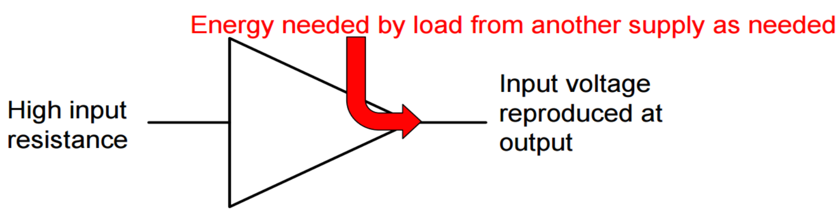
We can observe that the passive layer resistance is in parallel with the active layer resistance, that the passive layer resistance equals $R_{touch} + R_p + R_{touch}$, and that the active layer resistance is R_a. Furthermore, when there is no touch, the voltage difference between the positive and negative plates, $V^+ - V^-$, equals the current flowing from one end to to the other, times the equivalent resistance by Ohm's law: $I \cdot (R_u + R_a + R_d)$. Using this information, we can derive a formula for the effective voltage across the active layer during a multitouch:

$$\begin{aligned} V_+ - V_- &= I \cdot (R_u + R_d + R_a || (2R_{touch} + R_p)) \\ &= I(R_u + R_d + \frac{R_a(2R_{touch} + R_p)}{R_a + 2R_{touch} + R_p}) \end{aligned}$$

Buffering

Similar to how a parallel resistor lowers the equivalent voltage of a circuit, a voltage measurement device with a non-infinite resistance does the same (due to the internal resistance of the device), and so we would like a method by which to connect a voltmeter to measure voltage across a touchscreen without loading the system and lowering the voltage.

We can accomplish this using a buffer, a circuit component with a high input resistance, but with the capacity to source the current needed by the load. Buffers successfully nearly reproduce the input voltage without loading the input. They need to be connected to their own independent power source to function since they can't produce energy themselves, and this external power source provides power to output a voltage nearly equal to that of input.

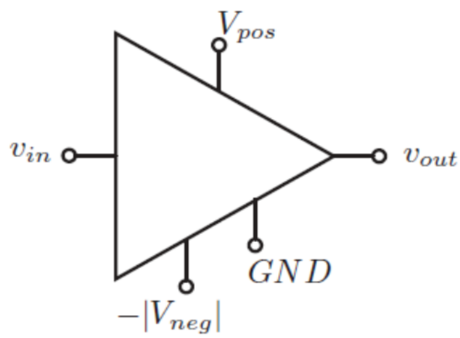


Amplifier Integrated Circuits

Now, let us introduce the concept of an integrated circuit. An integrated circuit in circuit design is analogous to an abstraction barrier in computer programming. The internal workings of the integrated circuit can be ignored - we only need to worry about the circuit's function and not its implementation details. In general, an amplifier integrated circuit takes an input signal (which we will denote as V_{in}) and multiplies it by a fixed amount to produce an output signal. Hence, a typical amplifier integrated circuit satisfies the following equation:

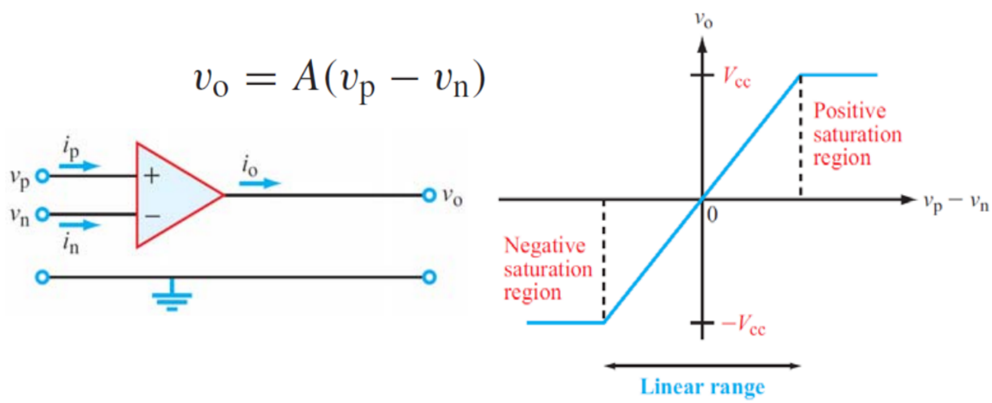
$$V_{out} = A_V V_{in}$$

where A_V is the multiplier, and is called the voltage gain of the circuit. Similar to a buffer, an amplifier integrated circuit also needs energy to operate, and so also must be connected to an external power supply. A circuit diagram representation of an amplifier integrated circuit is depicted below:



Operational Amplifier "Op Amp"

The operational amplifier, better known as the "op amp", is a special integrated circuit that is used extremely commonly in electrical engineering and has limitless possibilities for applications. The op amp has two input terminals, a positive, non-inverting terminal and a negative, inverting terminal, an output terminal, and a power supply. The op amp has a high voltage gain, typically on the order of 10^8.



As we can observe in the diagram above, the op amp takes two voltages, v_p and v_n, as input, and generates an output voltage that is the voltage difference between v_p and v_n scaled by a factor A. The op amp also has positive and negative saturation regions, meaning that the voltage levels off to the voltages of the external power supply (either V_{cc} or $-V_{cc}$) in these ranges regardless of further changes in the input. Hence, by computing the difference between v_p and v_n and amplifying it by a large factor, we receive as output either a voltage equal to V_{cc} or $-V_{cc}$.

Now that we have established that the op amp takes in two voltages as input and outputs a single voltage that is usually restricted to one of two values, we can see that the op-amp can be used as a boolean comparator - it outputs V_{cc} if $v_p > v_n$ and $-V_{cc}$ if $v_n > v_p$. It's easy to see how such a comparator can have widespread uses in many wide-ranging forms of electronic devices.

Capacitance

A capacitor is essentially an electrical component with two terminals that stores electrical charge (and hence electrical energy). Before we cover one of the most useful applications of capacitors in electronic devices - capacitive touch screens - we'll first introduce a few properties of capacitance in circuits. For n capacitors wired in series, we are able to use the following equation to compute the equivalent capacitance, C_{eq}:

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

Similarly, an equation for the equivalent capacitance of n capacitors wired in parallel can also be determined, and is computed using the following equation:

$$C_{eq} = C_1 + C_2 + C_3 + \ldots + C_n$$

On an intuitive level, this relationship makes logical sense - with capacitors wired in parallel, the charge accumulated on each individual capacitor is independent of the others; however, if they're wired in series, then the current buildup on each independent capacitor is dependent on the charge of the capacitors around it. These same intuitive results can be derived more concretely in the form of the two above equations using Kirchoff's Voltage Law and Kirchoff's Current Law, respectively.

Capacitive Touch Screens

Now that we have established a couple mathematical rules with regard to capacitance in circuitry, we shall explore capacitive touch screens, a very modern application of capacitors that takes advantage of the fact that fingers provide a natural capacitive path to ground.

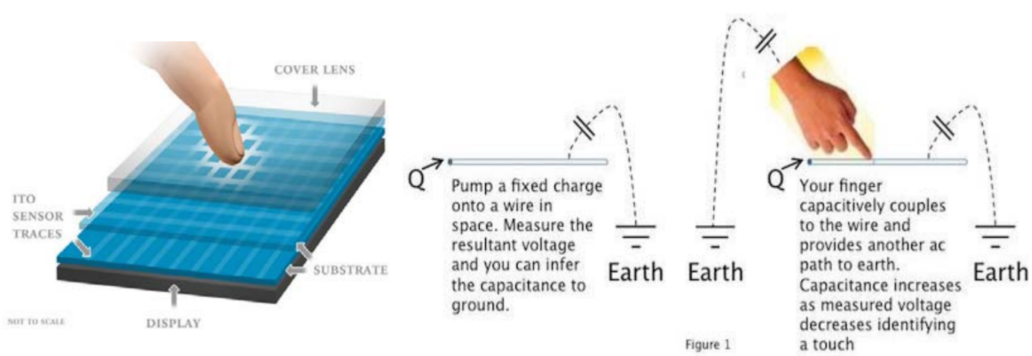
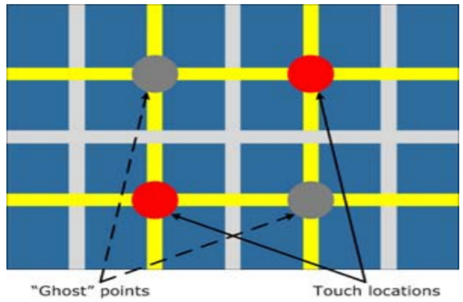


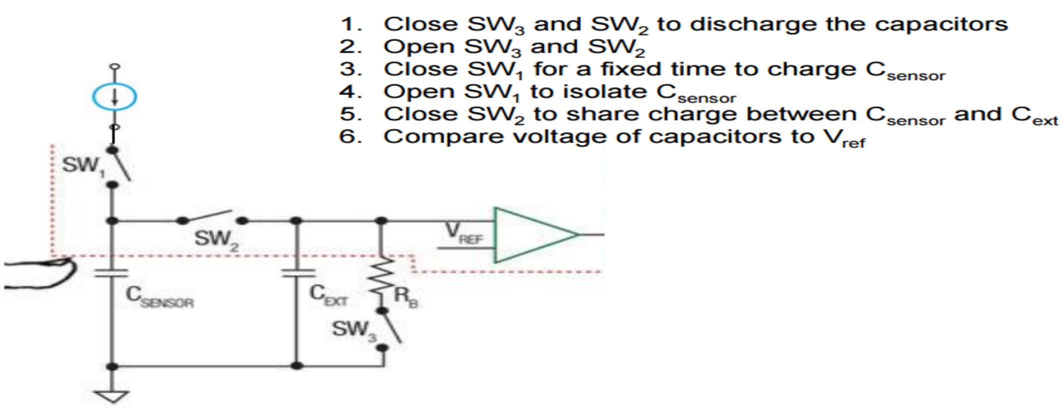
Figure 1

When you touch a capacitive touchscreen, some of the charge running across the screen is redirected into your hand which, serving as a capacitor, both increases the measured capacitance and decreases the measured voltage. These measurements can then be used to identify the position of the touch. However, "ghosting" becomes an issue when multitouch becomes involved - if you touch a capacitive touchscreen at multiple points, the sensor then detects additional "ghost" touch points. This is depicted pictorially as follows:



“Ghosting” effect with self-capacitive touchscreens

This flaw can be avoided by constructing capacitive touchscreen with an array of electrodes. This setup is known as mutual capacitance, and allows sensors to detect multitouch. With multitouch enabled through this setup, capacitive touchscreen become an attractive alternative to resistive touchscreens - they can register a touch any time they come into contact with a conductive object, and so are highly responsive and don’t require any pressure to register a touch unlike resistive touchscreens, they can be made from glass, which makes them very durable, easy to clean, and resistant to scratches, and are considered to be capable of faster typing speeds. We now look at the internal structure of how the circuit whithin a capacitive touchscreen works:



The above circuit diagram describes how a capacitive touchscreen detects touch and charges/recharges the capacitors within.