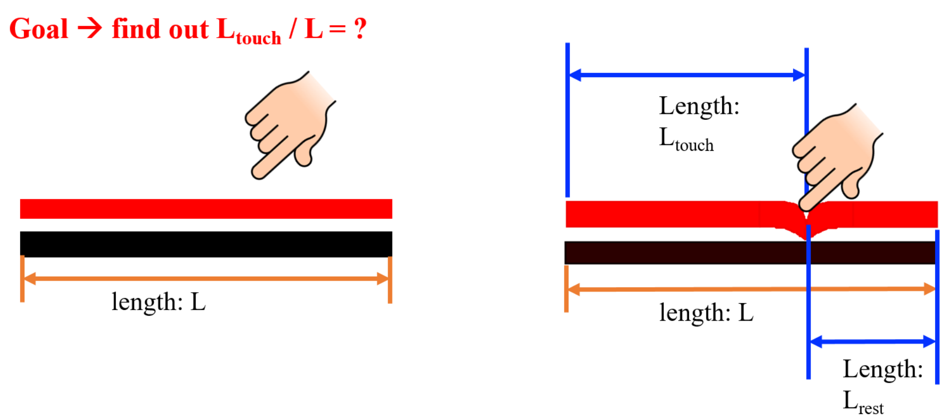
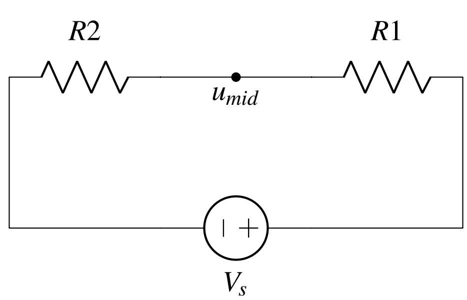
14.1 Resistive Touchscreen - expanding the model

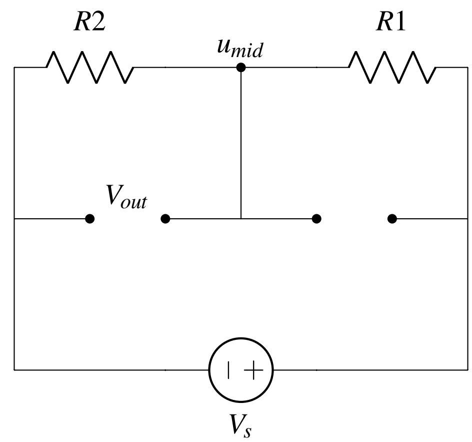
Recall our "real world" view of the simple resistive touchscreen:



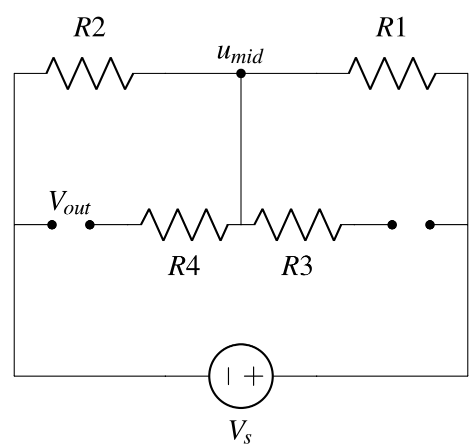
We have previously either ignored the black "bottom plate" or stated it was a perfect conductor. But why do we want it at all? Let's return to the circuit schematic of our touchscreen and build off of it. The simple version is shown below, where u_{mid} represents the point where the finger is touching:



Schematically, if the bottom plate is a perfect conductor the circuit will look like this:



Note that this addition does not change the voltage u_{mid}. We see that with a perfect conductor (analogous to our ideal wire), $V_{out} = u_{mid}$. What about if the bottom plate is not a perfect conductor? Note that this means that the bottom plate would also have an associated resistance, calculated just like the resistance of the touched electrode. Our new circuit schematic would look like this:



We note that a voltage, V_x, will develop across R_4. Another voltage, V_y, will develop across R_3. However, both of these resistors are followed by an open circuit. From the definition of an open circuit, we know that zero current will flow through it. Therefore, from Ohm's Law, the voltage across these new resistors will be 0. This means that, even with an imperfectly conductive bottom plate, the voltage V_{out} will still be equal to u_{mid}, even with the addition of these new resistors.

Clearly if we want to measure an output voltage, things are easiest when our measurement point is an "open circuit". In the prior case, it allowed us to neglect the non-idealities of our bottom plate. This extends to an important and common question: **how to guarantee that whatever I connect to my circuit to measure V_{out} or i_{out} does not influence/change the circuit itself.** To seek a general answer, we will have to introduce a new quantity: power.

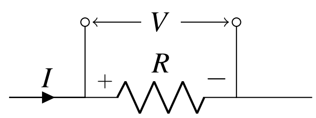
14.2 Power

Note our two fundamental measurement types, voltage and current. We can draw an abstracted diagram that looks like these for each case:

It turns out that the most complete and concise way of guaranteeing these measurement tools do not influence the circuit is to state that **they do not allow any power dissipated through the measurement device**. So what exactly IS power? Power P is the time rate of change of energy. Let $\frac{dE}{dt}$ be the change in energy. Recall that voltage V is the amount of energy needed to move a unit charge between two points, i.e., $V = \frac{\frac{dE}{dt}}{\frac{dQ}{dt}}$ (see Discussion 6B worksheet). Hence, we have

$$P = \frac{dE}{dt} = \frac{V\,dQ}{dt} = V \times \frac{dQ}{dt} = V \times I. \tag{1}$$

The power dissipated (positive) or supplied (negative) by a component with voltage V and current I is thus equal to their product $V \times I$. Note that according to passive sign convention, positive current goes into the positive terminal of the component.



When $P = IV$ is positive, power is being dissipated; when $P = IV$ is negative, power is being generated/delivered. Being able to tell when power is dissipated versus delivered using the sign is the reason why passive sign convention was introduced in the first place! Note that, once we have completed nodal analysis, we should therefore be able to solve for power delivered/dissipated in every circuit element using this relationship.

$P = IV$ is a fundamental relationship that will be used repeatedly and is worth memorizing. It can also take other useful forms through combination with Ohm's Law, given here for reference:

$$P = I \times V \tag{2}$$

$$P = \frac{V^2}{R} \tag{3}$$

$$P = I^2 \times R \tag{4}$$

Returning to our measurement tool question with our newfound relationship for power, this means that a voltmeter has to have 0 current going into it to ensure $P = IV = 0$, because we know that the voltage can be non-zero. The ammeter needs V across it to equal zero, because we know that the current through it can be non-zero. In practice it is often enough to ensure that these quantities are just extremely small compared to our measured quantity so that we can **approximate** the power dissipated to be zero.