How does this relate to touch screens?

- When we press at some point on the screen, we “tap” into the middle of a long resistor.
- We can model this as a tap on a series connection of lots of resistors.
- We need to determine the voltage on the tap point and use this for position determination.
1\textsuperscript{st} design tool: Kirchhoff’s Current Law (KCL)

Sum of currents entering a node is zero
Also holds for closed boundary

\[ \sum_{n=1}^{N} i_n = 0 \quad \text{(KCL)}, \]

\[ i_1 - i_2 - i_3 + i_4 = 0 \]
\[ i_1 + i_4 = i_2 + i_3 \]

2\textsuperscript{nd} Design tool: Kirchhoff’s Voltage Law (KVL)

Sum of voltages around a closed path is zero
Sum of voltage drops = sum of voltage rises

\[ \sum_{n=1}^{N} v_n = 0 \quad \text{(KVL)}, \]

\[-4 + V_1 - V_2 - 6 + V_3 - V_4 = 0 \]

Sign Convention

- Add up the voltages in a systematic clockwise movement around the loop.
- Assign a positive sign to the voltage across an element if the (+) side of that voltage is encountered first, and assign a negative sign if the (−) side is encountered first.
Combining Resistors – Series

For equivalence, currents and voltages must be the same

- Do a KVL:
  Top Circuit

Bottom Circuit

Equating:

Combining Resistors - Parallel

- Do a KCL

- In other words:

- More generally:
Useful Videos

- KVL and KCL: [http://youtu.be/MlwYUBe16C0](http://youtu.be/MlwYUBe16C0)

Going back to that touch screen...

If the stripes are very conductive, does the voltage vary laterally?
Exercise: Find $I$

![Diagram with 24V source, resistors, and current $I_0 = 0$]

Exercise: Find $I_0$

![Diagram with series resistors and current $I_1 = 1\, \text{A}$]
Going back to that touch screen…

- The “tapped” electrode line is called a voltage divider

![Circuit Diagram]

For now, let’s ignore the resistor on the tap and simplify / generalize to:

- Let’s try a KVL:

So we’ve found the voltage. Now to relate this to position….

What about that assumption?

- We just assumed

![Circuit Diagram]

- What does this say about the voltage sensing circuitry?
Position determination

- A touch screen system drives the top and detects on the bottom, and vice versa to find X and Y positions

- Problems:
  - Requires “hard” contact
  - Cannot do multi-touch, since only one voltage is measured on the sensing plate

Exercise: Calculate voltages sensed

- Assume
  - Resistance is 1kΩ/cm of electrode line
  - Screen is 40cm × 30cm
  - $V_{\text{applied}} = 5V$

- What is $V_x, V_y$ for touch at:
  - Center of screen
  - Center of top-left quadrant
Exercise: Simultaneous $X$, $Y$ determination

- Suppose I were to try to apply voltages on both layers to try to determine $X$ and $Y$ in one measurement, would this work?

Exercise: Find $I_1$, $I_2$, $I_3$, $I_4$
Independent Sources

• We can achieve multi-touch if we drive with a current rather than a voltage.
• In general, we can define independent sources as:

<table>
<thead>
<tr>
<th>Ideal Voltage Source</th>
<th>Realistic Voltage Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_s$ or $V_s'$</td>
<td>$V_s$</td>
</tr>
<tr>
<td>Battery</td>
<td>Any source</td>
</tr>
</tbody>
</table>

The resistance represents the fact that realistic sources “droop” when the load is increased (for example, car headlights often dim as you crank the engine to start.

Exercise: Realistic voltage source

• When I turn on my car headlights, my effective voltage of the 12V battery drops to 11.5V. What is the internal resistance of the battery?
  – Assume the bulb wattage is 50W per bulb
**Exercise: Convert from \( V_s \) to \( I_s \)**

![Source Transformation Diagram]

**Useful Videos**

- Transformations: [http://youtu.be/6Ujq1SeLhU8](http://youtu.be/6Ujq1SeLhU8)
- Mesh: [http://youtu.be/yzJl-KufYNg](http://youtu.be/yzJl-KufYNg)
- Equivalence: [http://youtu.be/hNsZJKowd34](http://youtu.be/hNsZJKowd34)