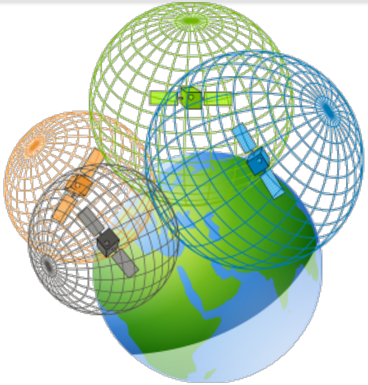

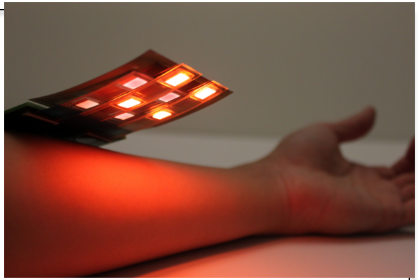

Welcome to EECS 16A!

Designing Information Devices and Systems I

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Fall 2021

Module 2
Lecture 3
Power and Voltage/Current Measurements
(Note 13)

How to think about Energy and Power in circuits?

Current : flow of charges (electrons moving from point A to B inside a material) $I = \frac{dQ}{dt}$

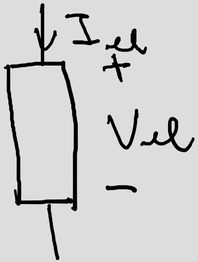
It takes energy to move charge from A to B $\Rightarrow$ Voltage $V_{AB} = \frac{dE}{dq}$

Power : is the rate of change of energy

$$P = \underbrace{\frac{dE}{dq}}_{V} \cdot \underbrace{\frac{dq}{dt}}_{I} = V \cdot I$$

$$(V) \cdot (A) = (W)$$

Energy and Power



$$\boxed{P_{el} = V_{el} \cdot I_{el}}$$

if el. is a resistor : $P = V \cdot I = R \cdot I \cdot I = RI^2 \geq 0$

↳ power dissipated is positive → ⊕

↳ $V_{el} = R I_{el}$

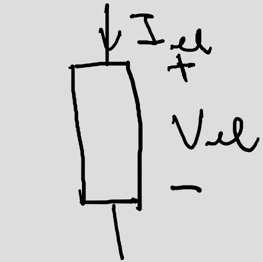
$I_{el} = \dfrac{V_{el}}{R}$

$P = V \cdot I = V_{el} \cdot \dfrac{V_{el}}{R} = \dfrac{V_{el}^2}{R} \geq 0$

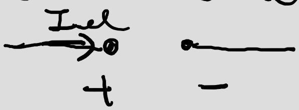
Passive-sign convention

Energy and Power

$$\boxed{P_{el} = V_{el} \cdot I_{el}}$$

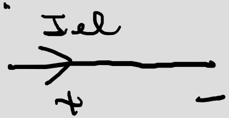


OPEN CIRCUIT



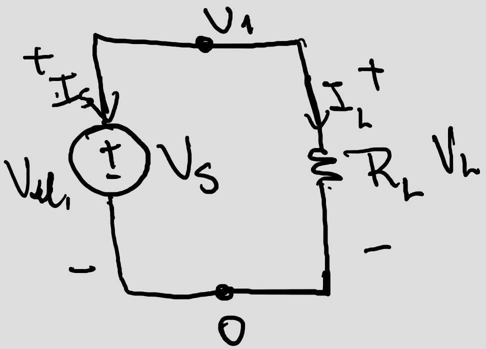
$$P_{el} = V_{el} \cdot \cancel{I_{el}}^{\to 0} = 0$$

Wire



$$P_{el} = \cancel{V_{el}}^{\to 0} \cdot I_{el} = 0$$

Example



KCL : $I_L + I_S = 0$

KVL : $V_1 - 0 = V_L = V_{el_1}$

$V_{el_1} = V_S$ (def)

Power :

$P_L = I_L \cdot V_L$ (def)

$P_S = I_S \cdot V_{el_1}$ (def)

$I_L = -I_S$

$P_L = (-I_S) \cdot V_L$

$P_S \leq 0$

$P_L = (-I_S) \cdot V_S$

* Conservation of Energy !

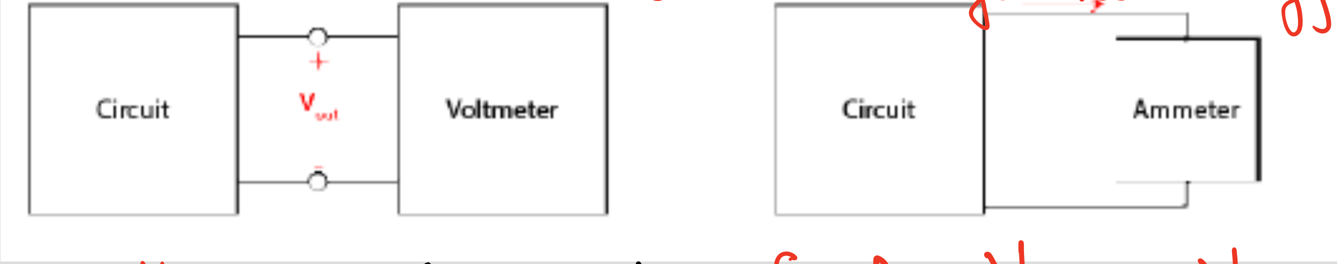
$P_L = -P_S$

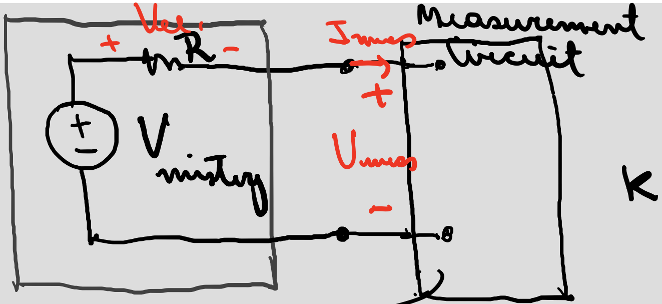
$P_L \geq 0$ (resistor)

$$\boxed{P_L + P_S = 0}$$

How to measure Voltage and Current?

Measurement should not change the energy of circuit





must behave as an open-circuit.

Goal : $V_{meas} = V_{mistery}$

$V_{el} = I_{meas} \cdot R$

KVL : $V_{mistery} = V_{meas} + V_{el}$

$V_{mistery} = V_{meas} + \cancel{I_{meas}}^{\,0} \cdot R$

$V_{mistery} = V_{meas} \Big|_{\text{if } I_{meas} = 0}$

How to measure Voltage and Current?

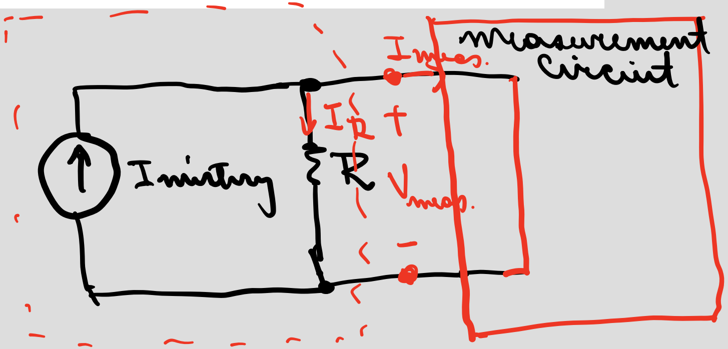
Task: measure $I_{mistery}$

(KCL) $I_{mistery} = I_R + I_{meas}$

$I_{mistery} = I_{meas} \Big|_{\text{if } I_R = 0}$

$I_R = \dfrac{V_{meas}}{R}$

if $V_{meas} = 0$

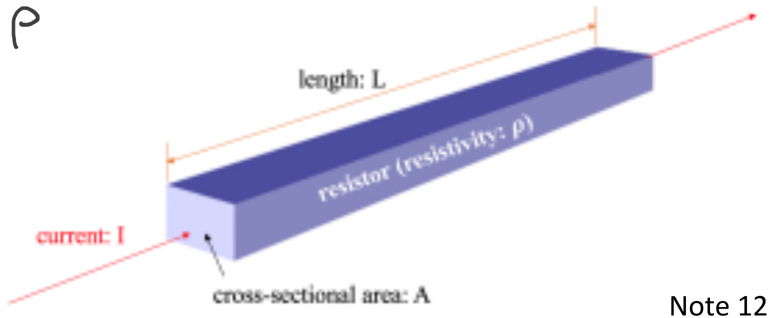


by definition meas. circuit should behave as a wire

Resistance, Resistivity, Conductivity – Physics and Materials…

Material	Electrical characteristics	
	Electrical Resistivity (Ω x cm)	Electrical Conductivity (Ω^{-1} x cm^{-1})
Cu	0.034×10^{-5}	29×10^{5}
Fe	32.54×10^{-5}	0.031×10^{5}
Ag	0.36×10^{-5}	2.8×10^{5}
Al	0.03×10^{-5}	33.3×10^{5}
Ni	0.046×10^{-5}	21.7×10^{5}
Cu-Fe	33.37×10^{-5}	0.030×10^{5}
Cu-Ag	2.71×10^{-5}	0.37×10^{5}
Al-Ni	0.564×10^{-5}	1.77×10^{5}

$\frac{1}{\rho}$



Note 12

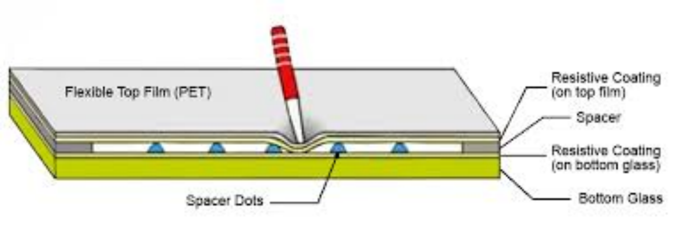
$$R = \rho \cdot \frac{L}{A}$$

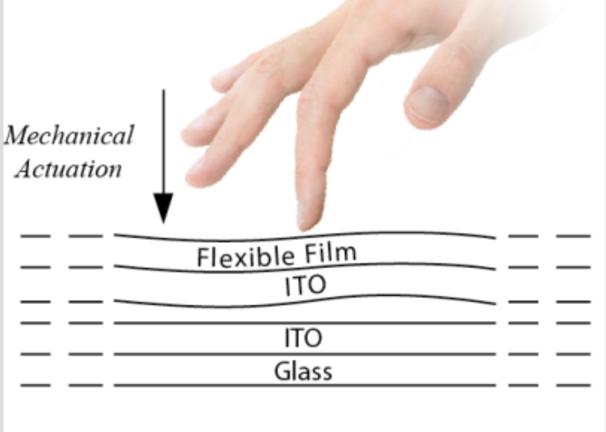
Longer the wire → the more energy is lost.

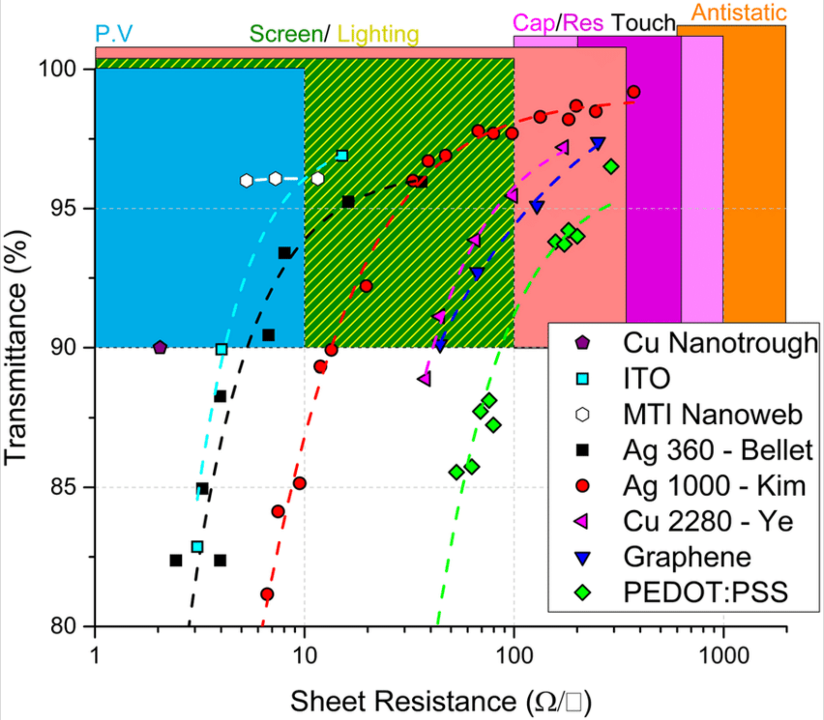
Wide wires → lower resistance

Wire properties depends on materials choice.

Resistive Touch Screen



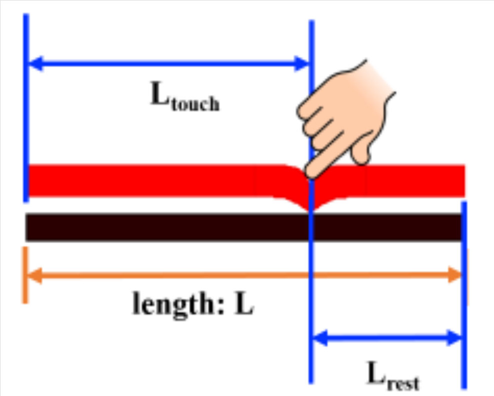




https://doi.org/10.1038/s41598-019-47777-2

Resistive Touch Screen

Problem: To find the location of touch.

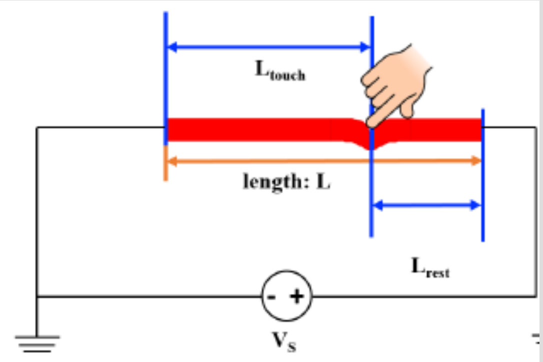


Go from mechanical to electrical quantity!

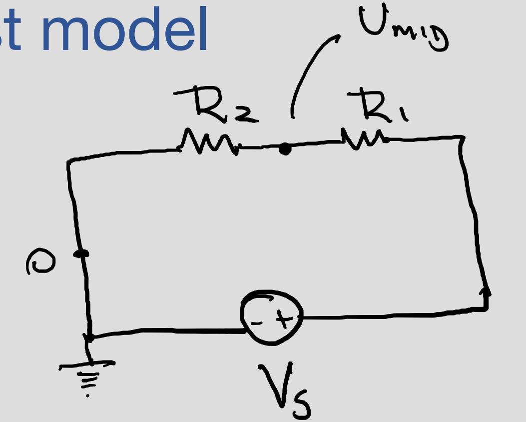
Want to measure $\frac{L_{touch}}{L}$

$\boxed{L_{touch} \text{ is unknown}}$

Resistive Touch Screen – First model



$\Rightarrow$



$$U_{MID} = \frac{R_2}{R_2+R_1} V_S$$ (Voltage Divider) ★

$$U_{mid} = \frac{\cancel{\rho}\,\frac{L_{touch}}{\cancel{A}}}{\cancel{\rho}\,\frac{L_{touch}}{\cancel{A}} + \cancel{\rho}\,\frac{L_{rest}}{\cancel{A}}} \cdot V_S$$

$$= \frac{L_{touch}}{L_{touch}+L_{rest}} \cdot V_S$$

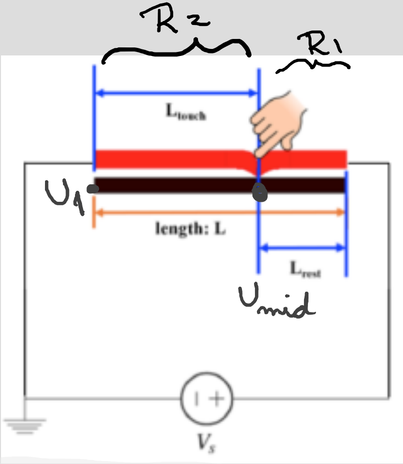
L

$$\boxed{U_{mid} = \frac{L_{touch}}{L} \cdot V_S}$$

$$R_1 = \rho \cdot \frac{-}{A} \quad (1)$$

$$R_2 = \rho \cdot \frac{L_{touch}}{A} \quad (2)$$

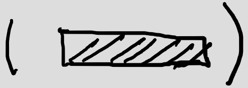
Resistive Touch Screen – More realistic model



$$R_2 = \rho \frac{L_{touch}}{A}$$

$$R_1 = \rho \frac{L_{rest}}{A}$$

⇒ Model 1



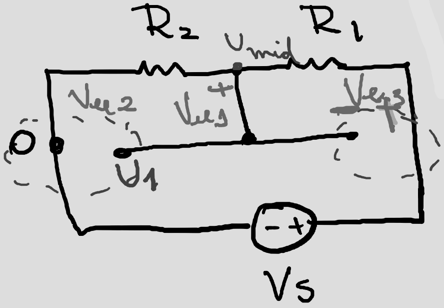
Ideal Wire

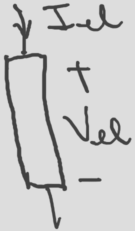
↳ Added:

el_1 : wire

el_2 : open-circuit (V_{el2})

el_3 : open-circuit (V_{el3})





Model ∅

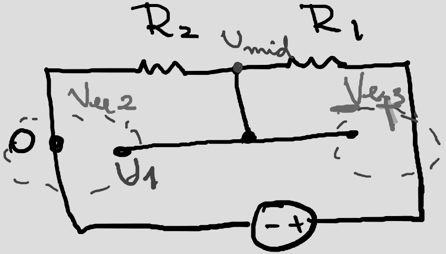
$$U_{mid} = \frac{R_2}{R_1 + R_2} \cdot V_s$$

(Voltage Divider)

Resistive Touch Screen – More realistic model

⇒ Model 1

(▨)
Ideal Wire
↳ Added:
el$_1$: wire
el$_2$: open-circuit (V_{el2})
el$_3$: open - circuit (V_{el3})



Model ∅

$$U_{mid} = \frac{R_2}{R_1+R_2} \cdot V_S$$

(Voltage Divider)

$$R_2 = \rho \frac{L_{touch}}{A}$$

$$R_1 = \rho \frac{L_{rest}}{A}$$

el 2:

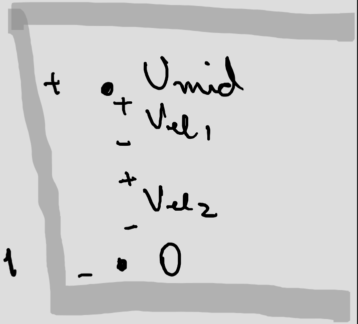
$$V_{el2} = U_1 - 0 \quad \text{(definition of elem. V)}$$

el 1:

$$V_{el1} = U_{mid} - U_1$$

KVL:

$$U_{mid} - 0 = V_{el2} + V_{el1}$$



Resistive Touch Screen – More realistic model

⇒ Model 1

(▨)

Ideal Wire

↳ Added:

- el_1 : wire
- el_2 : open-circuit (V_{el2})
- el_3 : open-circuit (V_{el3})

el 2:

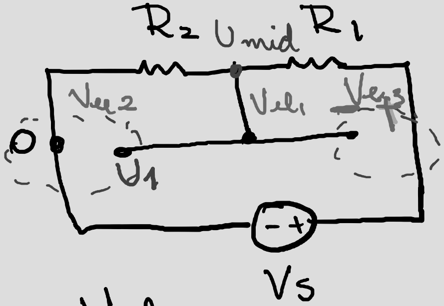
$$V_{el2} = U_1 - 0 \quad \text{(definition of elm. V)}$$

el 1:

$$V_{el1} = U_{mid} - U_1$$

KVL:

$$U_{mid} - 0 = V_{el2} + V_{el1}$$



$$\left.\begin{aligned} U_1 &= V_{el2} \\ U_{mid} - U_1 &= V_{el1} \end{aligned}\right\} +$$

$$U_{mid} - \cancel{U_1} + \cancel{U_1} = V_{el1} + V_{el2}$$

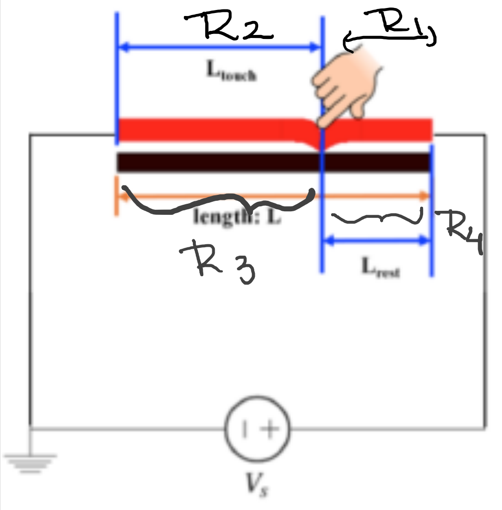
$$U_{mid} = V_{el1} + V_{el2}$$

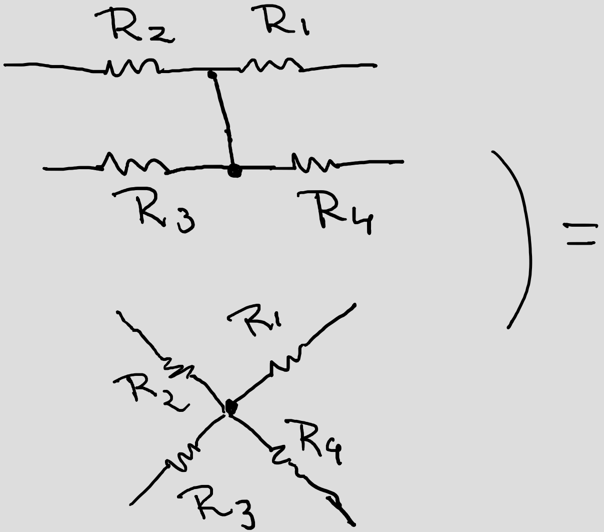
el 1 is a wire $\therefore V_{el1} = 0$

$$U_{mid} = 0 + V_{el2} = V_{el2} = U_1$$

* By measuring V_{el2} we get U_{mid} for any touch.

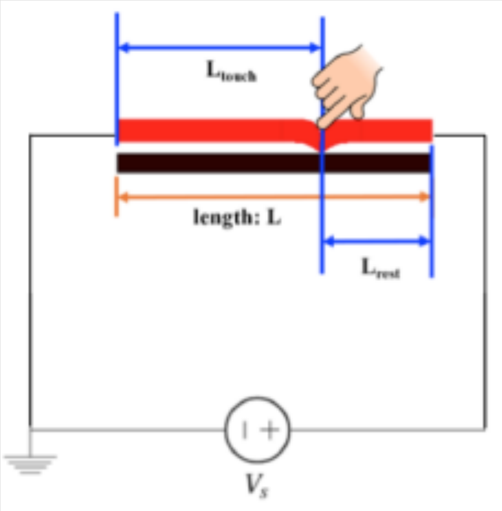
Resistive Touch Screen – More realistic model

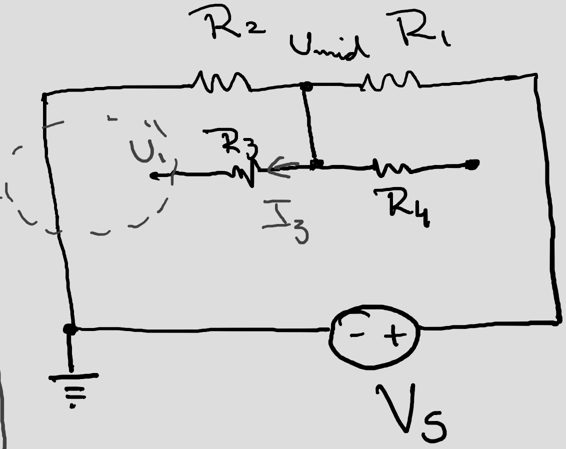




R_1, R_2, R_3 and R_4 are unknown.

Resistive Touch Screen – More realistic model





open circuit

$I = 0$

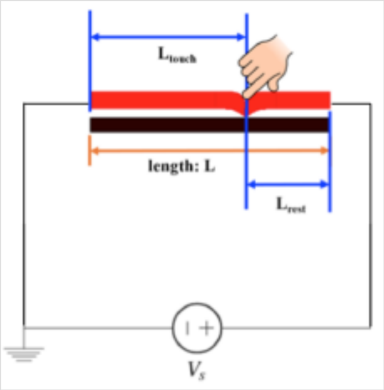
$I_3 = 0$

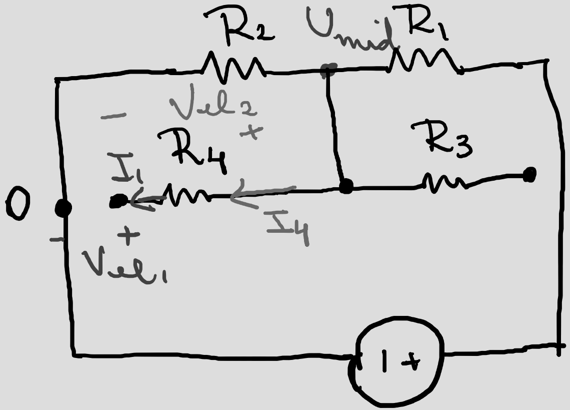
$U_1 = 0$

Read out is Voltage!

Resistive Touch Screen – More realistic model

Model 2 – imperfect conductor (resistor)





Added

el_1 : open-circuit $\Rightarrow$

el_2 : resistor (R_4)

$V_{el_2} = R_4 \cdot I_4$ (Ohm's Law)

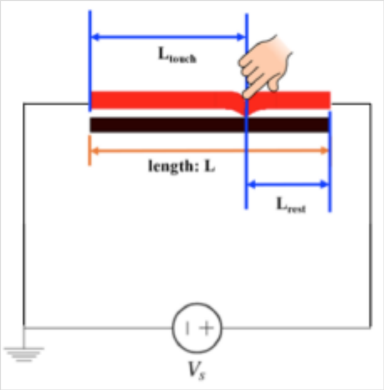
KCL : $I_1 = I_4$

$I_1 = 0 \quad \therefore \quad I_4 = 0$

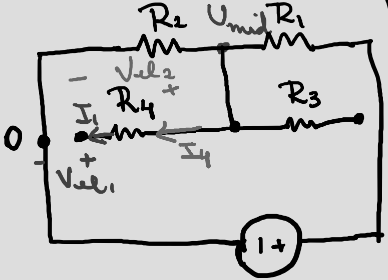
$U_{mid} = V_{el_1} + V_{el_2} = V_{el_1} + \cancel{R_4 \cdot I_4}^{\to 0}$

$$\boxed{U_{mid} = V_{el_1}}$$

Resistive Touch Screen – More realistic model



Model 2 – imperfect conductor (resistor)



KCL : $I_1 = I_4$

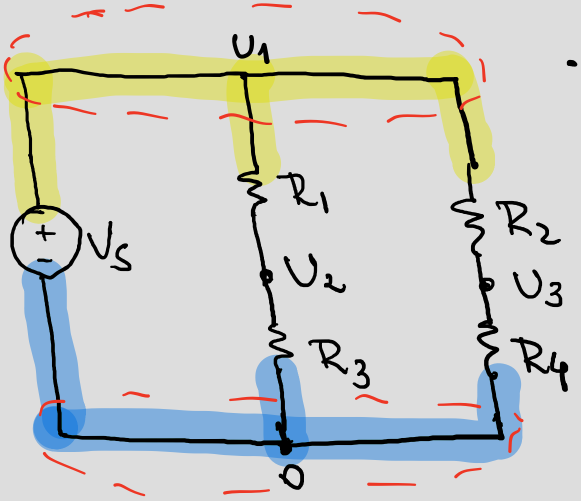
$I_1 = 0 \quad \therefore \quad I_4 = 0$

$U_{mid} = V_{el1} + V_{el2} = V_{el1} + \overset{\to 0}{\cancel{R_4 \cdot I_4}}$

$\boxed{U_{mid} = V_{el1}}$

We can: measure U mid at Vee1 regardless of backplane material and value of L touch

An interesting circuit



- What are U_2 and U_3?

$$U_2 = \frac{R_3}{R_1+R_3}\cdot V_S$$

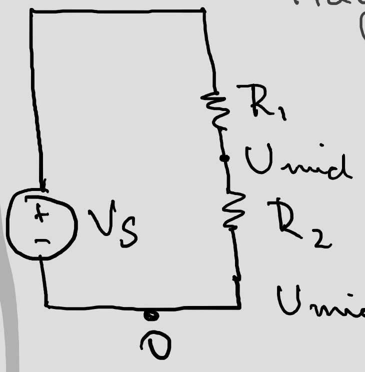
$$U_3 = \frac{R_4}{R_2+R_4}\cdot V_S$$

$$V_S = U_1 - 0$$

$$U_2 - 0 = \frac{R_3}{R_1+R_3}\cdot\left(\overset{V_S}{\cancel{U_1-0}}\right)$$

$$U_3 - 0 = \frac{R_4}{R_2+R_4}\cdot\left(\overset{V_S}{\cancel{U_1-0}}\right)$$

Voltage Divider



$$U_{mid} = \frac{R_2}{R_1+R_2}\cdot V_S$$

Operator!