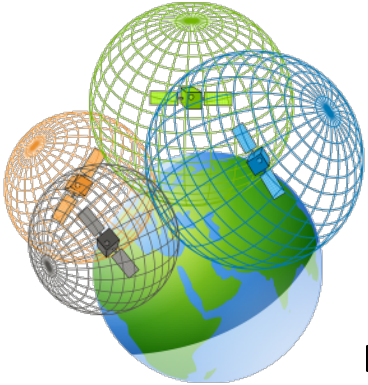
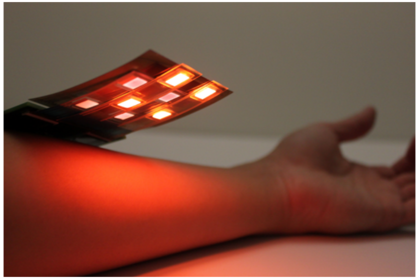




# Welcome to EECS 16A!

## Designing Information Devices and Systems I


**Ana Claudia Arias and Miki Lustig**


**Fall 2021**

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

# Last Lecture

- Solve circuits for the currents and node potentials
- Set up a matrix problem of the form A $\vec{x} = \vec{b}$

  *where*

  $\vec{x}$ consists of the unknown currents and potentials

  $\vec{b}$ contains the independent current and voltage sources

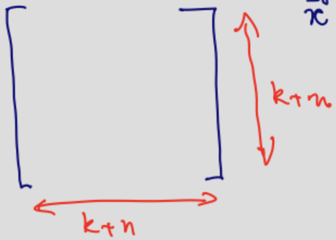
  A describes the relationship between them.

$A\vec{x} = \vec{b}$

$\vec{x}$ : unknowns

$\vec{b}$ : knowns / constants

A : knowns / constants




$$\vec{x} = \begin{bmatrix} i_1 \\ \vdots \\ i_k \\ v_1 \\ \vdots \\ v_n \end{bmatrix} \qquad \vec{b} = \begin{bmatrix} b_1 \\ \vdots \\ b_{k+n} \end{bmatrix}$$

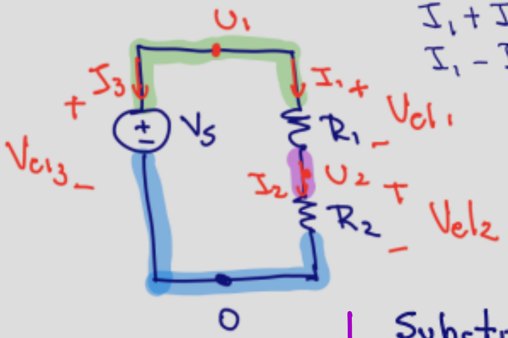
**Rules:**

- KVL
- KCL
- Element definitions
- I x V relationship

* Started Voltage Divider Analysis

# Node Voltage Analysis – Voltage Divider

Step 7 – Use the IV relationships of each of the non-wire elements to fill in the remaining rows of A and




$I_1 + I_3 = 0$ (1)

$I_1 - I_2 = 0$ (2)

$V_{el_1} = U_1 - U_2$

$V_{el_2} = U_2 - 0 = U_2$

$V_{el_3} = U_1 - 0 = U_1$

$$\begin{bmatrix} I_1 \\ I_2 \\ I_3 \\ U_1 \\ U_2 \end{bmatrix}$$

$V_{el_1} = R_1 \cdot I_1$

$V_{el_2} = R_2 \cdot I_2$

$V_{el_3} = V_s$

Substitution:

$El_1 \therefore \; U_1 - U_2 = R_1 \cdot I_1 \Rightarrow R_1 I_1 - U_1 + U_2 = 0$ (3)

$El_2 \therefore \; U_2 = R_2 I_2 \Rightarrow R_2 I_2 - U_2 = 0$ (4)

$El_3 \therefore \; U_1 = V_s$ (5)

# Node Voltage Analysis – Voltage Divider

Step 8 – Solve the system of equations to determine values of unknown variables.

$I_1 + I_3 = 0$ (1)

$-I_1 + I_2 = 0$ (2)

$R_1 I_1 - U_1 + U_2 = 0$ (3)

$R_2 I_2 - U_2 = 0$ (4)

$U_1 = V_S$ (5)

$$\underbrace{\begin{bmatrix} 1 & 0 & 1 & 0 & 0 \\ -1 & 1 & 0 & 0 & 0 \\ R_1 & 0 & 0 & -1 & 1 \\ 0 & R_2 & 0 & 0 & -1 \\ 0 & 0 & 0 & 1 & 0 \end{bmatrix}}_{A} \underbrace{\begin{bmatrix} I_1 \\ I_2 \\ I_3 \\ U_1 \\ U_2 \end{bmatrix}}_{\vec{x}} = \underbrace{\begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ V_S \end{bmatrix}}_{\vec{b}}$$

$$I_1 = \frac{V_S}{R_1 + R_2}, \quad I_2 = \frac{V_S}{R_1 + R_2}, \quad I_3 = -\frac{V_S}{R_1 + R_2}$$

$$U_1 = V_S \qquad U_2 = \frac{R_2}{R_1 + R_2} \cdot V_S$$

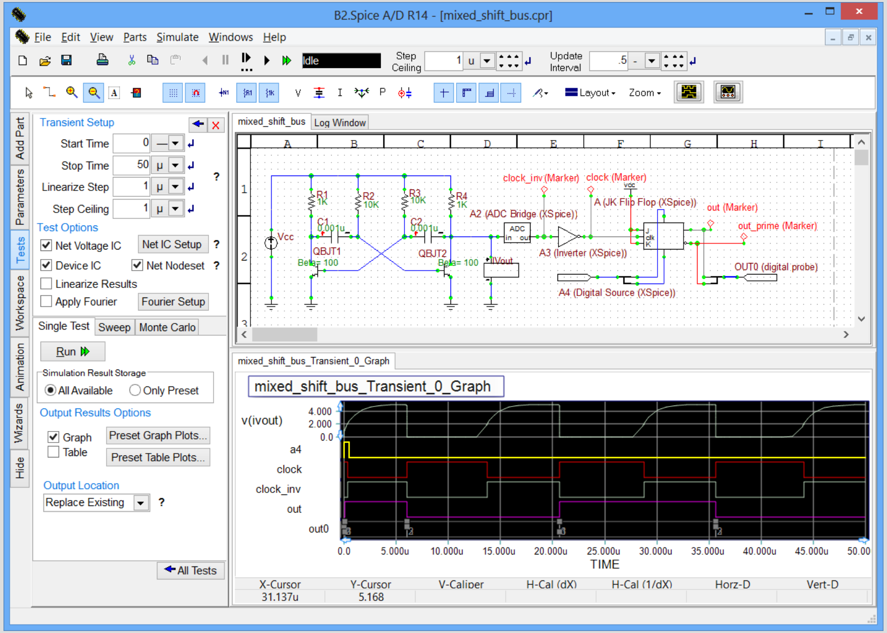
$\frac{R_2}{R_1+R_2} \to \alpha < 1$

$\alpha$ is an operator

# Electrical Circuit Analysis Algorithm (tool)

SPICE (Simulation Program with Integrated Circuit Emphasis): started as a student project at Berkeley!

Now the basis for open-source electronic circuit simulation, to design and model device characteristics and check circuit boards

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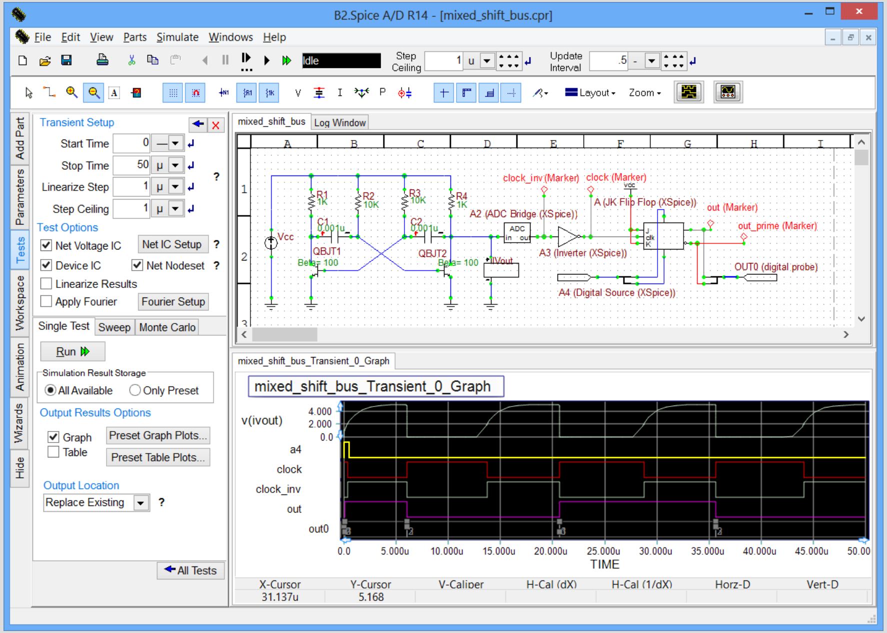
Prof. Alberto L. Sangiovanni-Vincentelli

# Electrical Circuit Analysis Algorithm (tool)

# 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 → B ⇒ Voltage

$$V_{AB} = \frac{dE}{dq}$$

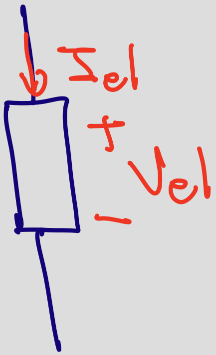
**Power**: is the rate of change of energy

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

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

# Energy and Power

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




if element is a resistor

$$P = V \cdot I = R \cdot I \cdot I = R \cdot I^2 \geq 0$$

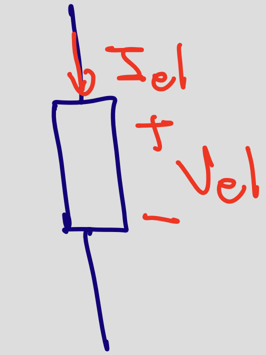
Power dissipated is positive

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

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

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

# Energy and Power

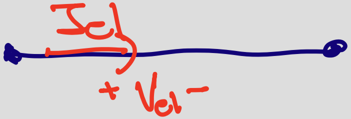



$$P_{el} = V_{el} \cdot I_{el}$$

Open circuit

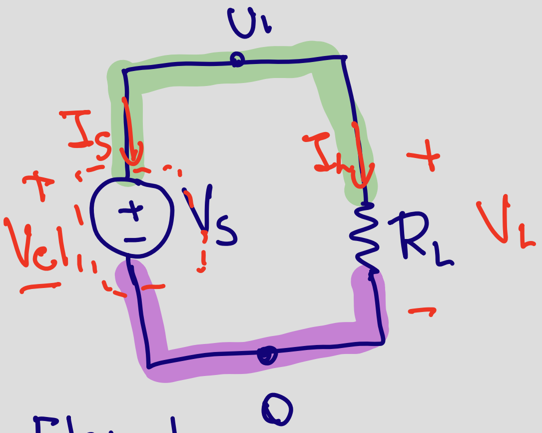

$$P_{el} = V_{el} \cdot I_{el} = 0 \quad (I_{el} \to 0)$$

wire




$$P_{el} = V_{el} \cdot I_{el} = 0 \quad (V_{el} \to 0)$$

# Example




Elem 1

$P_s = I_s \cdot V_{el_1}$ (def.)

$P_s = I_s \cdot V_s$

* Conservation of Energy

KCL : $I_L + I_s = 0$

KVL : $U_1 - 0 = V_L$

$U_1 - 0 = V_{el_1} = V_s$

Power : Elem L

$P_L = I_L \cdot V_L$ (def.)

$P_L = (-I_s) \cdot V_L$

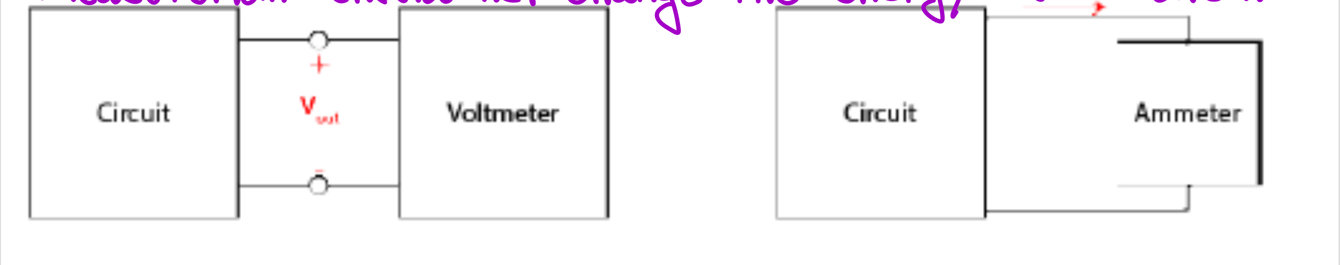
$P_L = (-I_s) \cdot V_s$

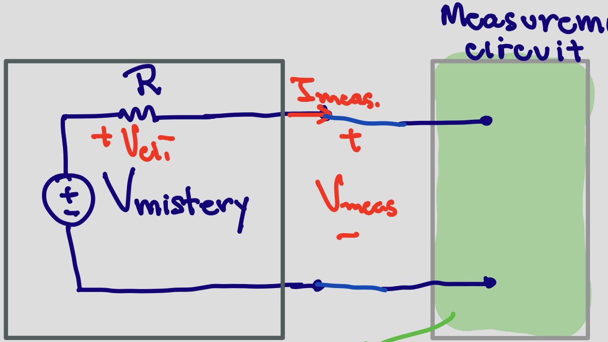
* $P_L = -P_s$

$P_L + P_s = 0$

# How to measure Voltage and Current?

Measurement should not change the energy of the circuit




Must behave as an open-circuit

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

$V_{el_1} = I_{meas} \cdot R$

KVL: $V_{mistery} - V_{el_1} - V_{mea} = 0$

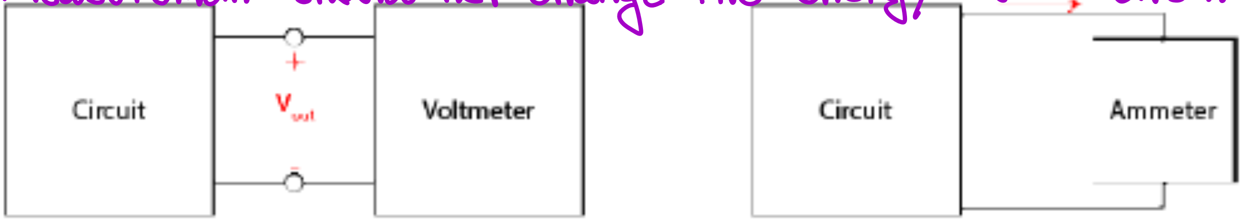
$V_{mistery} = V_{el_1} + V_{meas}$

$V_{mistery} = I_{mea} \cdot R + V_{meas}$ ($I_{mea} \to 0$)

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

# How to measure Voltage and Current?

Measurement should not change the energy of the circuit




Task/Goal:

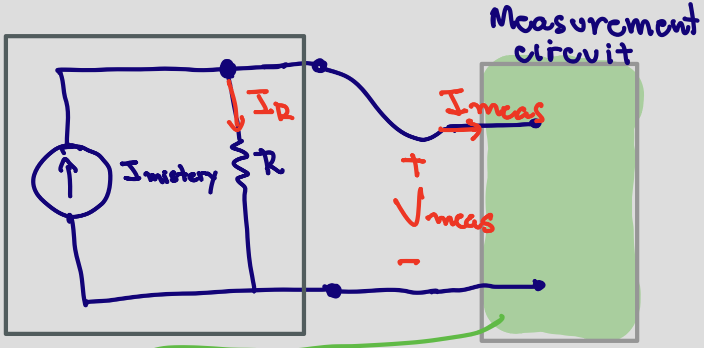
Measure $I_{mistery}$

KCL: $I_{mistery} = I_R + I_{meas}$

$I_{mistery} = I_{meas}$ | if $I_R = 0$

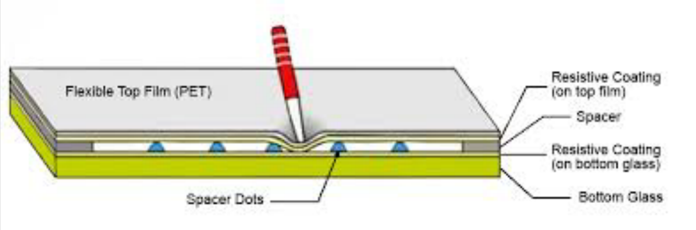
$I_R = \frac{V_{meas}}{R}$

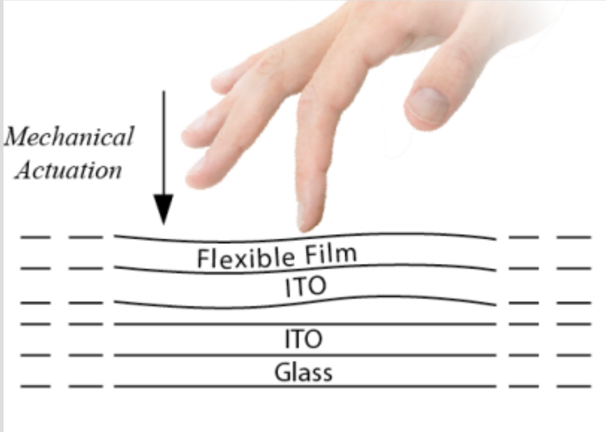
$I_R = 0$ ; is $V_{meas} = 0$



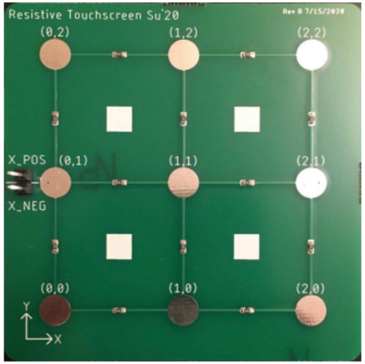

Must behave as a wire

# Resistive Touch Screen

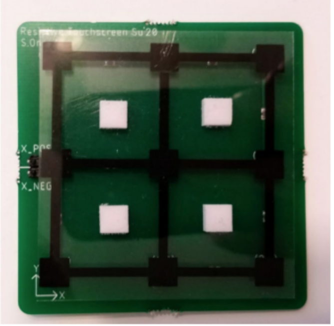


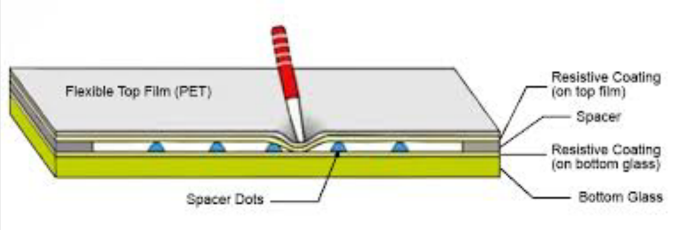

## Bottom Layer: Resistive Layer

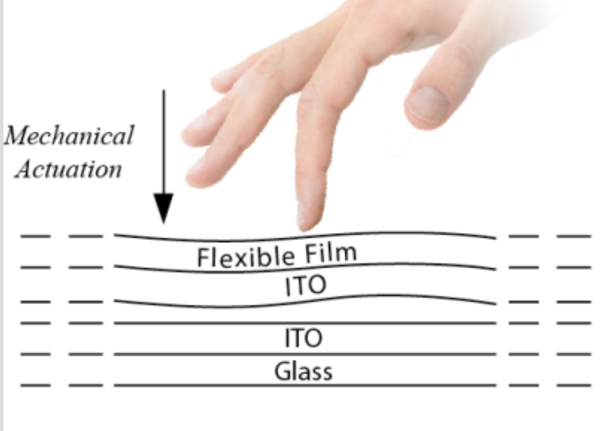


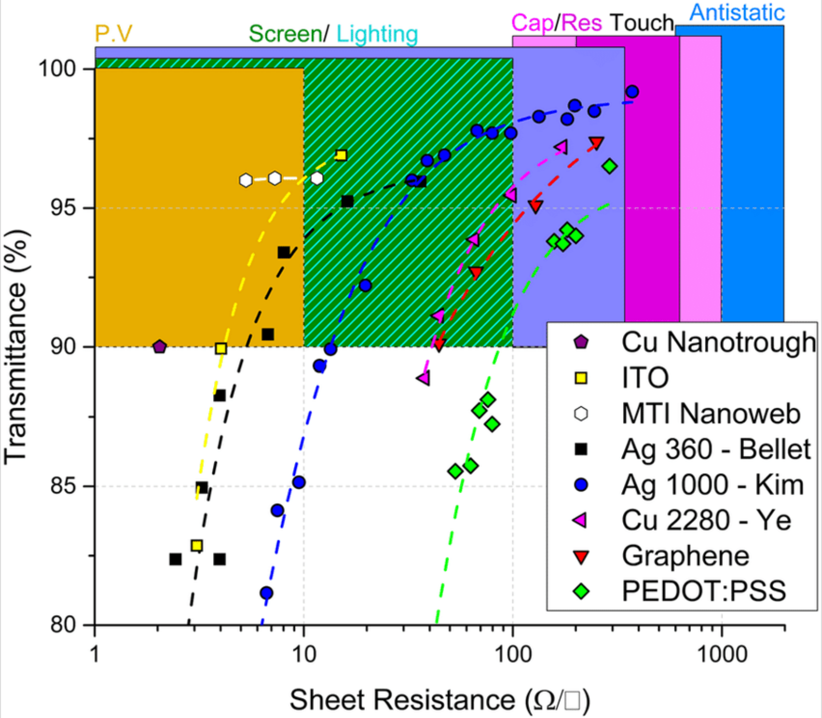

## Top Layer: Flexible Resistive Layer



# Resistive Touch Screen



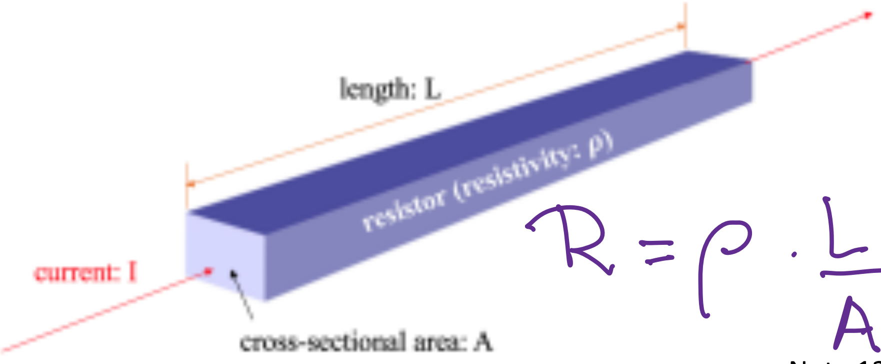




https://doi.org/10.1038/s41598-019-47777-2

# Resistance, Resistivity, Conductivity – Properties of Materials

| Material | Electrical characteristics | |
|---|---|---|
| | Electrical Resistivity (Ω x cm) | Electrical Conductivity (Ω$^{-1}$ x cm$^{-1}$) |
| Cu | 0.034 x10$^{-5}$ | 29 x 10$^{5}$ |
| Fe | 32.54 x 10$^{-5}$ | 0.031 x 10$^{5}$ |
| Ag | 0.36 x 10$^{-5}$ | 2.8 x 10$^{5}$ |
| Al | 0.03 x 10$^{-5}$ | 33.3 x 10$^{5}$ |
| Ni | 0.046 x 10$^{-5}$ | 21.7 x 10$^{5}$ |
| Cu-Fe | 33.37 x 10$^{-5}$ | 0.030 x 10$^{5}$ |
| Cu-Ag | 2.71 x 10$^{-5}$ | 0.37 x 10$^{5}$ |
| Al-Ni | 0.564 x 10$^{-5}$ | 1.77 x 10$^{5}$ |




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

Note 12

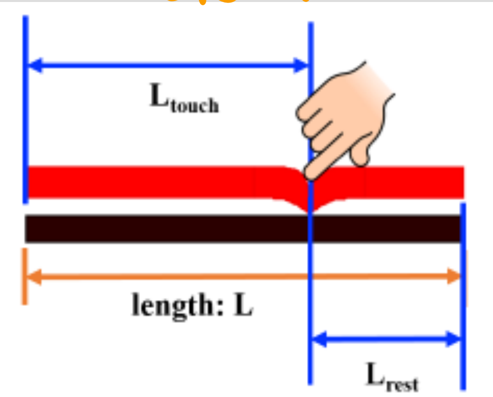
- Longer the wire → the more E is lost
- Wide wires → lower resistance
- Wire properties depend on materials choice.

$\rho$ = resistivity (property of materials)

$\frac{L}{A}$ : geometric parameters (property of the wire)

# Resistive Touch Screen

Problem: to find the location of touch.



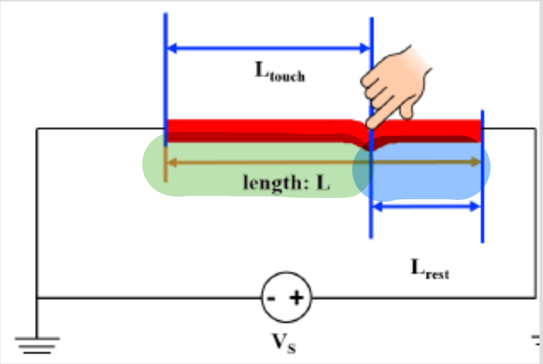

Go from mechanical to electrical quantity.

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

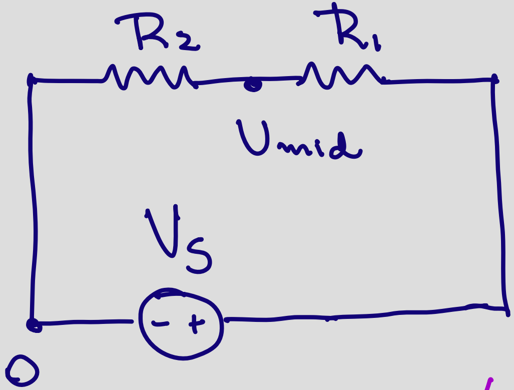
$L_{touch}$ is unknown

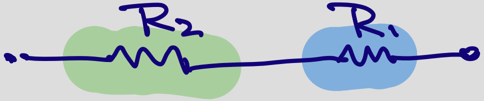
# Resistive Touch Screen – First model

$U_{mid} = ?$




$\Rightarrow$




$$U_{mid} = \frac{R_2}{R_2 + R_1} \cdot V_S \quad \text{(Voltage Divider)}^*$$

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

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

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

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