EE2025

Lecture 2

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“The unreasonable effectiveness of mathematics”

- E. Wigner

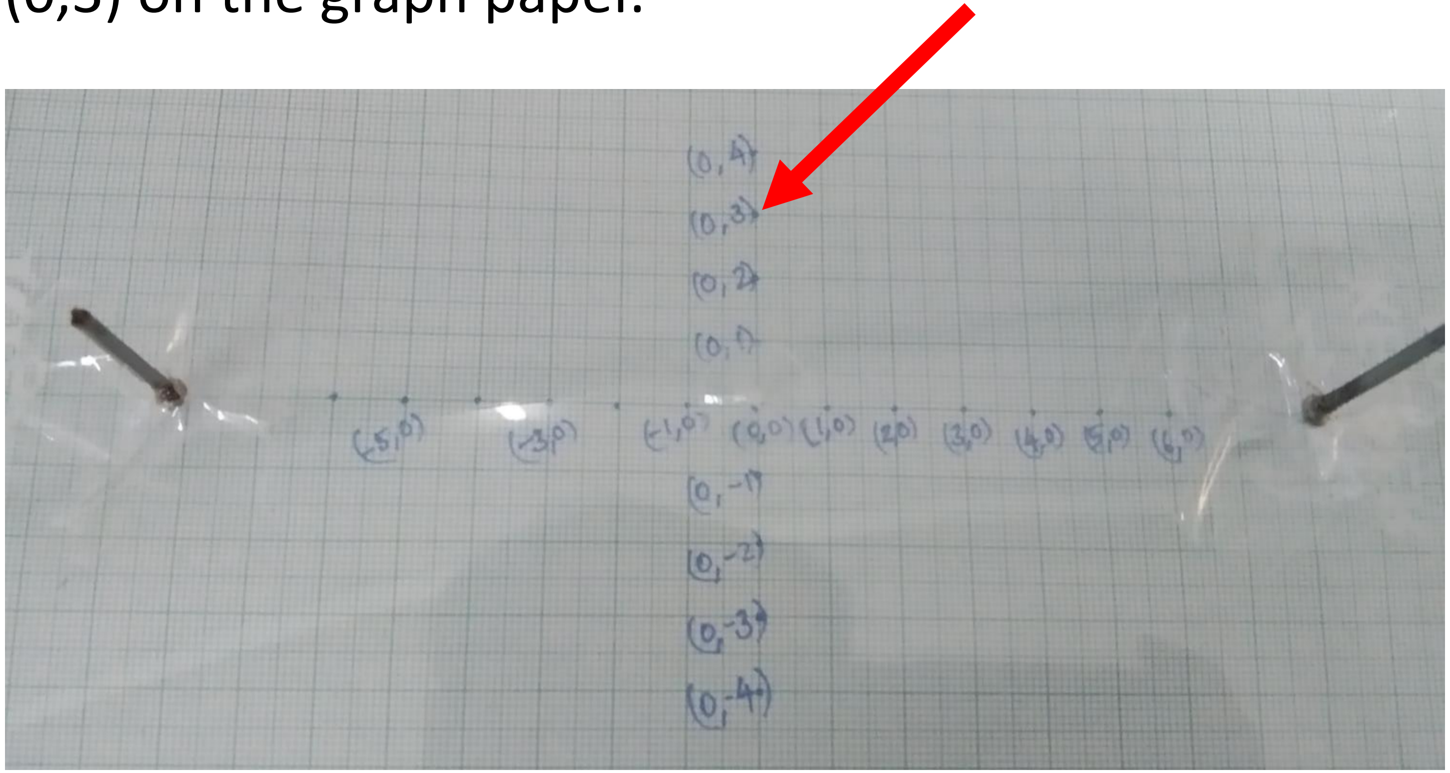
Gauss honored on a German banknote

In 1623 Galileo crafted a famous metaphor that is still often cited by scientists. Nature, he wrote, is a book written in “the language of mathematics”. If we cannot understand that language, we will be doomed to wander about as if “in a dark labyrinth”.

Estimate the electric field (V/m)

TASK

- Estimate the electric field at (0,3) on the graph paper.



See, Think, Wonder

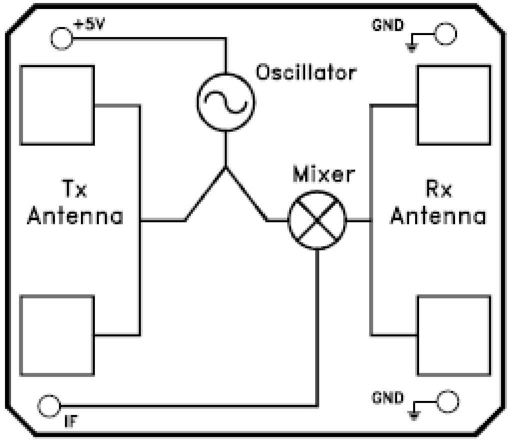
I see… a girl with her head down, she's frowning, and markers on the table.

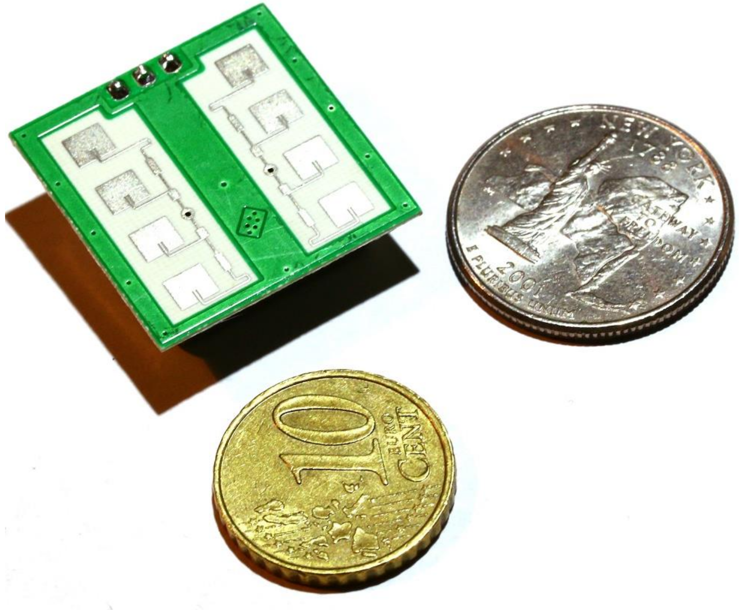
I think… she's sad and wants to make a picture for someone she is missing.

I wonder… where is she? Who is she missing?

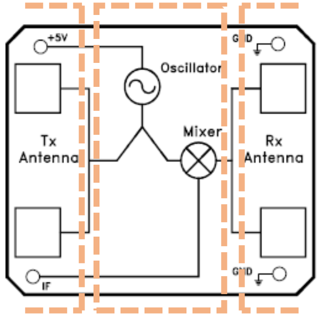
Doppler radar

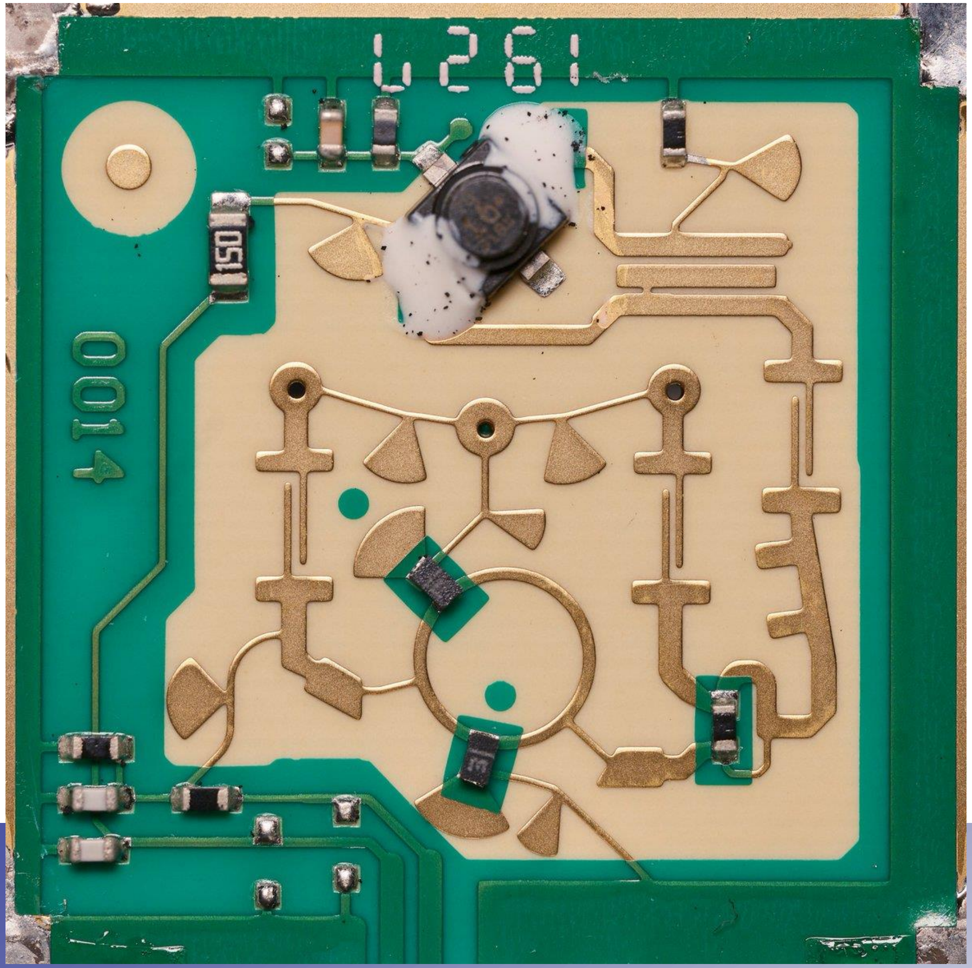
A movement and velocity sensor – cheap and mass producible

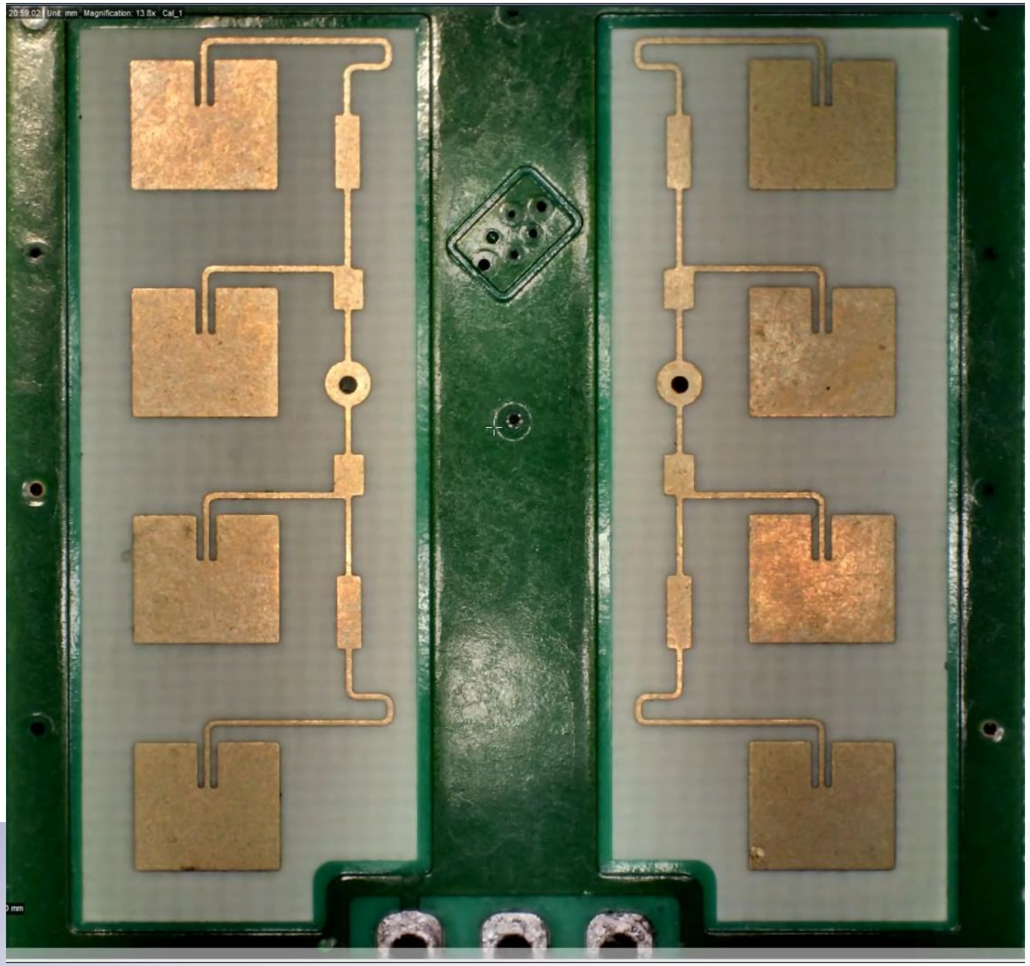




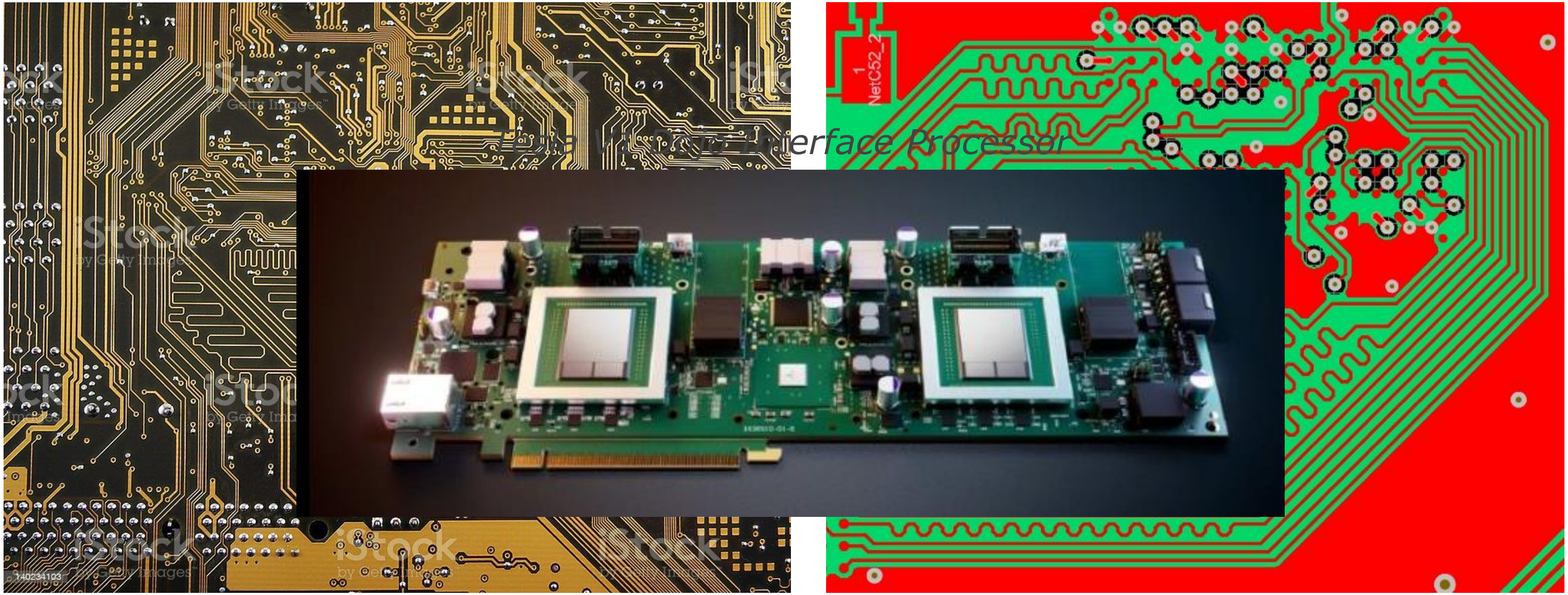
See, Think, Wonder







Digital data communication



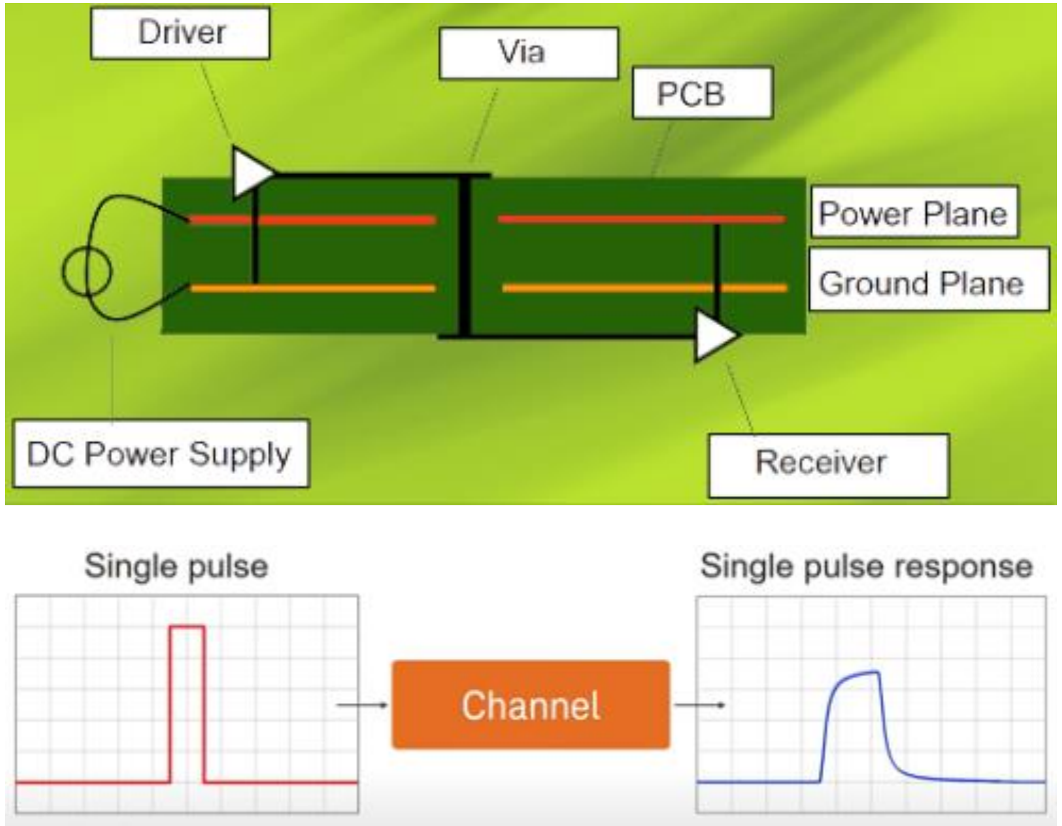
Tesla V1 Dojo Interface Processor

Why are the traces so wavy?

https://www.servethehome.com/tesla-dojo-custom-ai-supercomputer-at-hc34/

https://www.istockphoto.com/photo/motherboard-detail-close-up-gm140234103-2269342
https://www.integrasources.com/blog/high-speed-pcb-design-guidelines/

High-speed data transport



What are the consequences of a pulse response as shown below?

- Loss
- Ground Bounce
- Reflection noise
- Crosstalk

https://www.protoexpress.com/blog/understanding-signal-integrity/

Kirchhoff's law

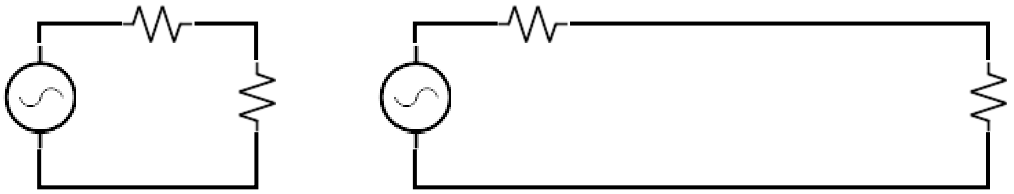
$$\nabla \cdot \varepsilon_0 \boldsymbol{E} = \rho$$

$$\nabla \cdot \mu_0 \boldsymbol{H} = 0$$

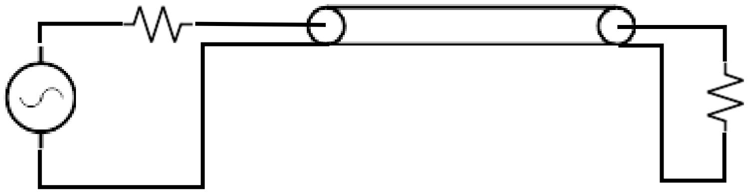
$$\nabla \times \boldsymbol{E} = -\mu_0 \frac{\partial \boldsymbol{H}}{\partial t} \xrightarrow{\mu_0 = 0} \oint \boldsymbol{E} \cdot d\boldsymbol{l} = \oint (-\nabla \phi) \cdot d\boldsymbol{l} = 0 \qquad \text{KVL}$$

$$\nabla \times \boldsymbol{H} = \boldsymbol{J} + \varepsilon_0 \frac{\partial \boldsymbol{E}}{\partial t} \xrightarrow{\varepsilon_0 = 0} \nabla \cdot \boldsymbol{J} = \nabla \cdot (\nabla \times \boldsymbol{H}) = 0 \qquad \text{KCL}$$

Transmission lines



Are these the same?
(Maybe not at RF)

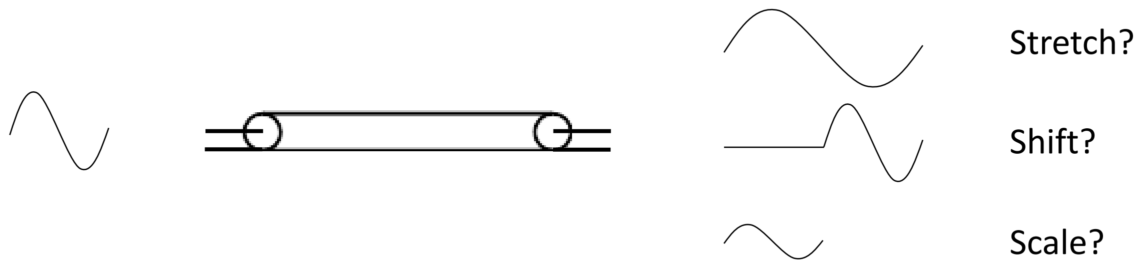


We use the transmission line model when we want to indicate we care about the speed of the signal.

Rule of thumb: Signal wavelength is more than ~1/10th the length of the transmission line.

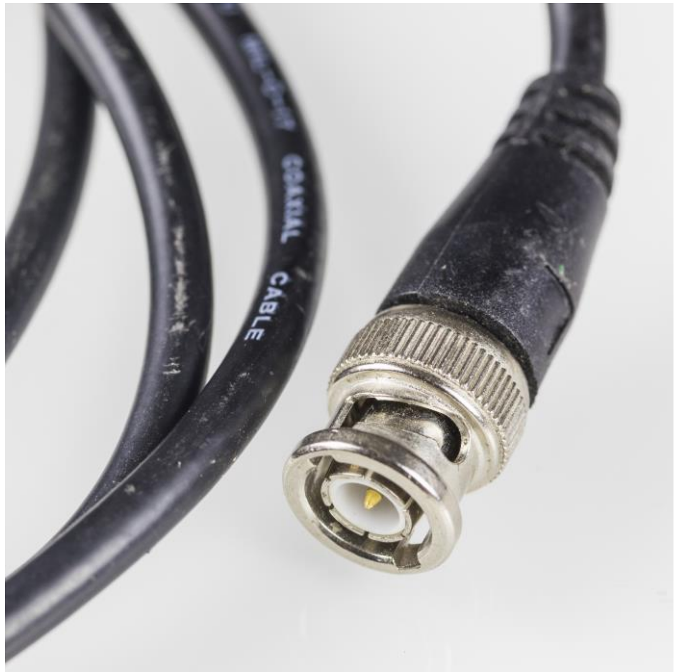
Models of wires

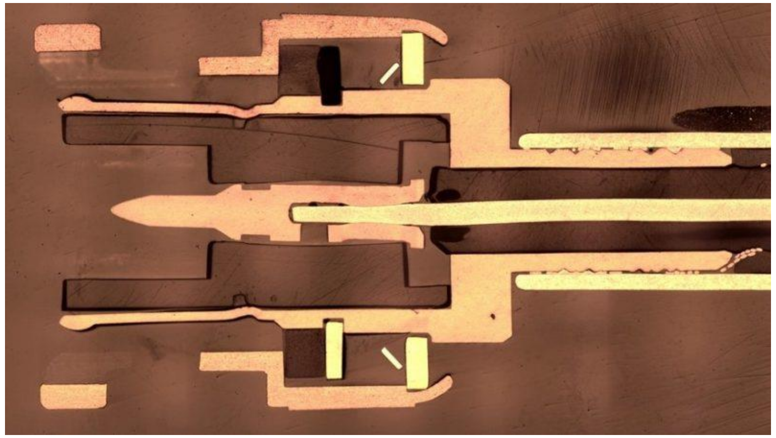
How do transmission lines affect our signals?



Let’s try making a model by looking at the transmission line construction

Coaxial cable

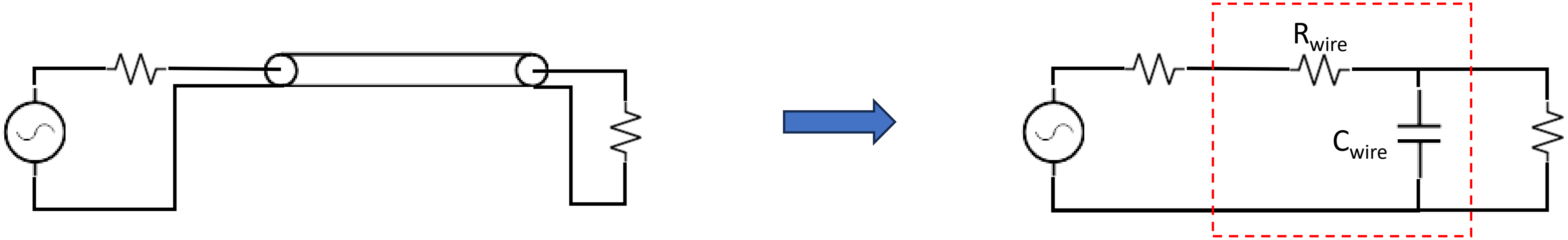




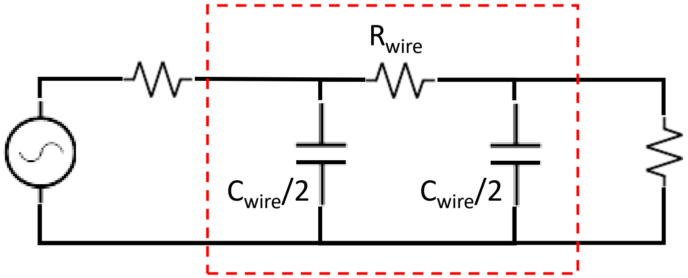
How about a series R and a shunt C?

https://hackaday.com/2018/10/19/the-bnc-connector-and-how-it-got-that-way/
https://en.wikipedia.org/wiki/10BASE2

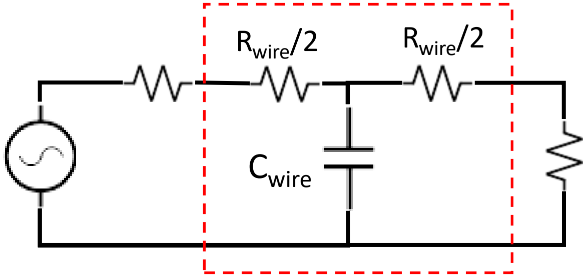
Simple model



- Used for digital design
- You can do even better by adding more segments

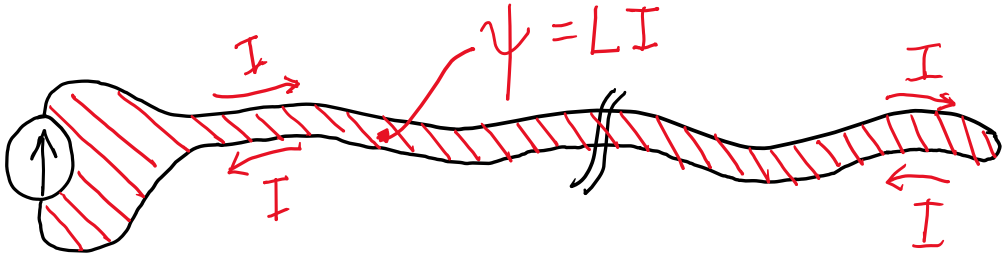


1-segment π-model

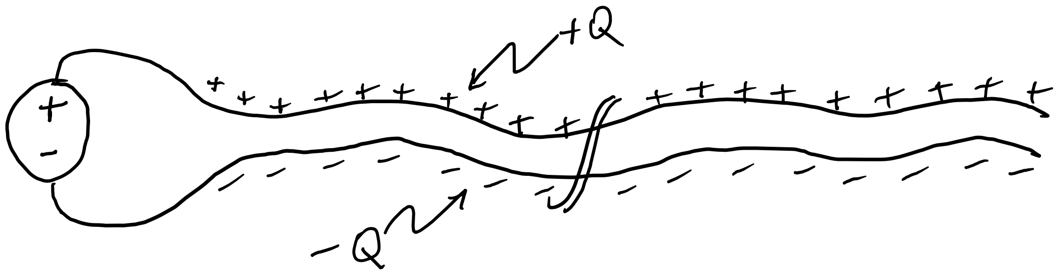


1-segment T-model

Some more insight

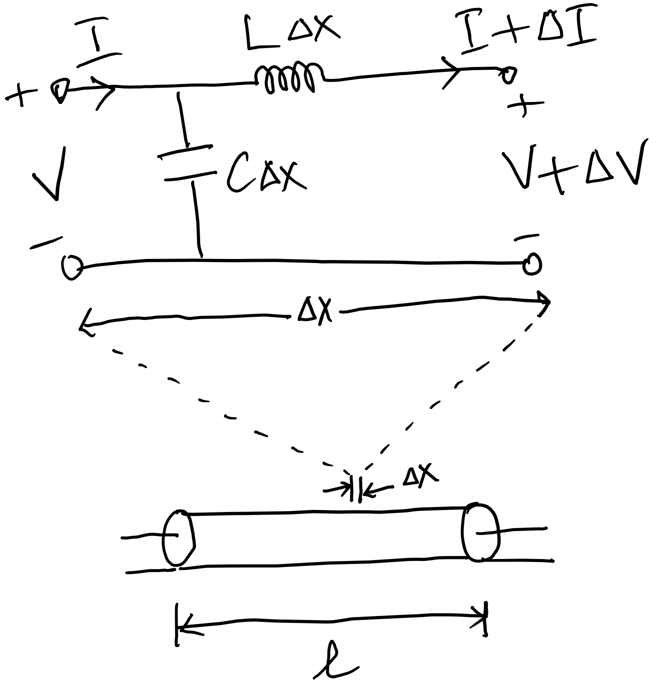


Shorted line: Cannot neglect the flux in long lines



Open line: Substantial capacitance as we anticipated

Telegraph equations



$$\Delta V = -L\Delta x \frac{\partial I}{\partial t} \Rightarrow \frac{\Delta V}{\Delta x} = -L\frac{\partial I}{\partial t}$$

$$\Delta I = -C\Delta x \frac{\partial V}{\partial t} \qquad \frac{\Delta I}{\Delta x} = -C\frac{\partial V}{\partial t}$$

In the limit $\Delta x \to 0$

$$\frac{\partial V}{\partial x} = -L\frac{\partial I}{\partial t}$$

$$\frac{\partial I}{\partial x} = -C\frac{\partial V}{\partial t}$$

Telegraph Equations

Distributed model