# TDT1: Introduction to Time-Domain Transmission Lines

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## *Why Study Electromagnetics?*

- Power – describes the operations of our technologies at the most fundamental levels
- Conceptual Ability – stretches visualization and analytical skills like no other
- Creativity – principle root of inventive contribution in our profession
- Magic – the ability to derive complex behavior with pencil and paper that corresponds to real physics
- Art – aspect of beauty and elegance in electromagnetic phenomena



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## Samuel Morse (1791-1872), the Artist

*Dying Hercules*

*The Chapel of the Virgin at Subiaco*



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## Samuel Morse (1791-1872), the Inventor

- 1825: wife dies before Morse returns home due to horse-sent message
- 1832: meets Prof. Charles Jackson, learns of the electromagnet
- 1844: first telegraphed message, Baltimore to Washington
- 1845: formed Magnetic Telegraph Company



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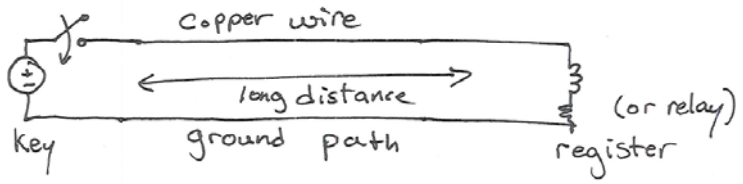
## Circuit Model of a Telegraph Network

Telegraph




Looks like a basic circuit, just a little lossy do to long distance.



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## Scaling with Frequency

Key Concept: In Emag, everything scales with frequency $\boxed{\lambda f = v_p}$

$\lambda$ = wavelength of sinusoid (m)
$f$ = frequency of a traveling sinusoid (Hz)
$v_p$ = velocity of propagation (m/s)



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## Analogy Based on Frequency Scaling

Frequency Content of telegraph signal
< 100 Hz

is to

Typical transmission line
10 km

< 10 GHz
Frequency of microprocessor

as

is to

Distance traveled on circuit board or in IC.
0.1 mm



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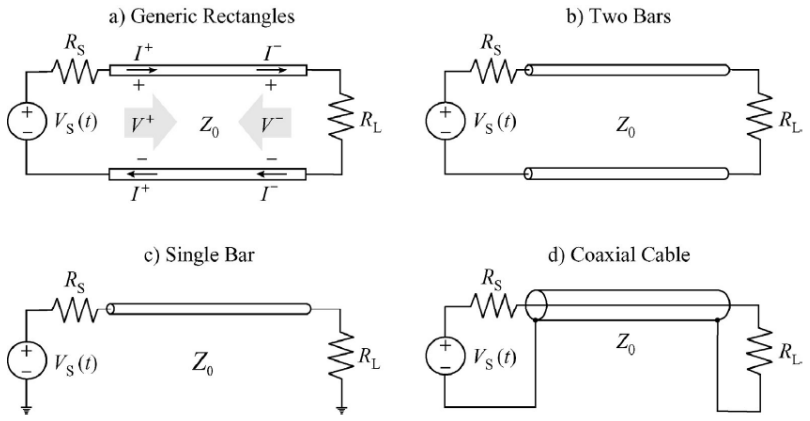
## Schematics for a Transmission Line



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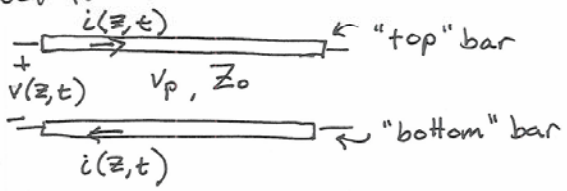
## Circuit Element for a Transmission Line

Our model for transmission line:




$v_p$ - velocity of propagation

$Z_o$ - intrinsic impedance ($\Omega$)

Important Concept: KVL and KCL still hold.



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## Where is Transmission Line Theory Important

Where are transmission lines used?

A. Long distance power transmission internet/
B. Long distance telecommunications (telephony)
C. Radio Frequency communications
D. High speed digital ~~con~~interconnects



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## When to Use Transmission Line Theory

When is Transmission Line theory important?

Rule-of-thumb: Use t-line theory when the line length is greater than 10% of a wavelength.

In a homogeneous material

$$v_p = \frac{1}{\sqrt{\epsilon \mu}}$$

$\epsilon = \epsilon_r \epsilon_0$ ($\epsilon_r$: relative permittivity)

$\mu = \mu_r \mu_0$ ($\mu_r$: relative permeability)

In Free Space

$\epsilon_0 = 8.85 \times 10^{-12}$ F/m

$\mu_0 = 4\pi \times 10^{-7}$ H/m

$v_p = c = 3.0 \times 10^8$ m/s



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