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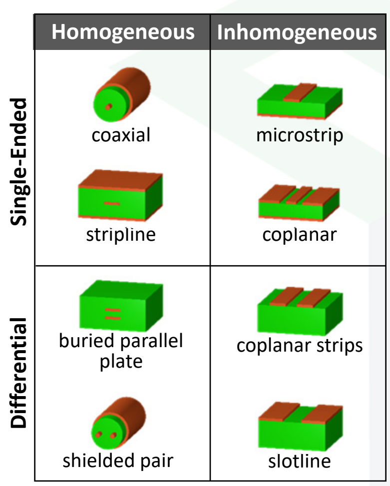
Computational Science:
Computational Methods in Engineering

Transmission Lines

What Are Transmission Lines?



Transmission lines are essentially high-frequency electrical cables composed of two or more metal wires.

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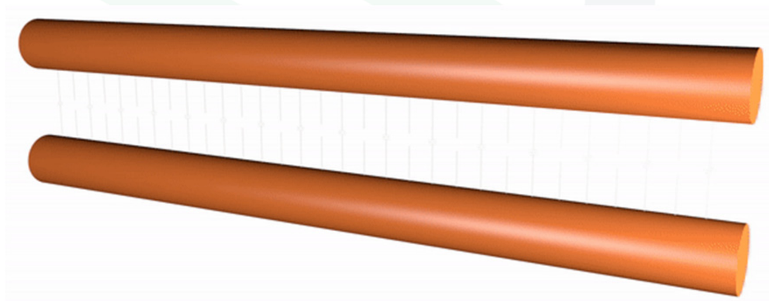
Transmission Line Parameters RLGC

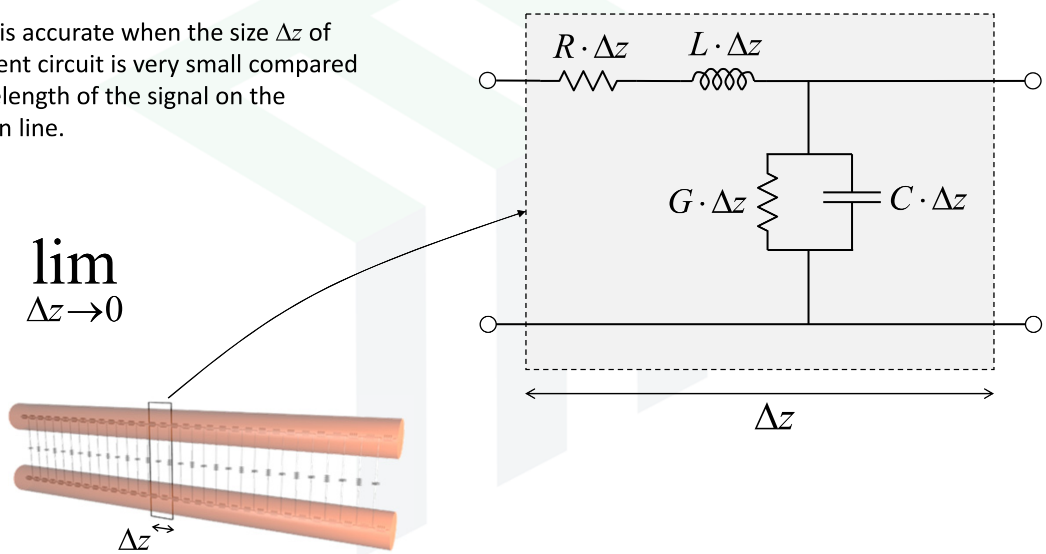
Think of transmission lines as being composed of millions of tiny little circuit elements that are distributed along the length of the line.



In fact, these circuit element are not discrete, but continuous along the length of the transmission line.

RLGC Circuit Model

This model is accurate when the size Δz of the equivalent circuit is very small compared to the wavelength of the signal on the transmission line.



Distributed TL Parameters

Distributed Circuit Parameters

R (Ω/m)
Resistance per unit length. Arises due to resistivity in the conductors.

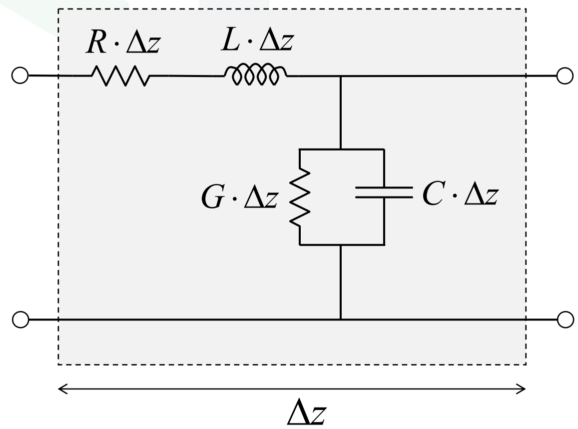
L (H/m)
Inductance per unit length. Arises due to stored magnetic energy around the line.

G (1/Ω·m)
Conductance per unit length. Arises due to conductivity in the dielectric separating the conductors.

$$G \neq \frac{1}{R}$$

C (F/m)
Capacitance per unit length. Arises due to stored electric energy between the conductors.

There are many possible circuit models for transmission lines, but most produce the same equations after analysis.



Characteristic Impedance, Z_0

The characteristic impedance is the voltage divided the current at any point along the transmission line.

$$Z_0 = \frac{V}{I}$$

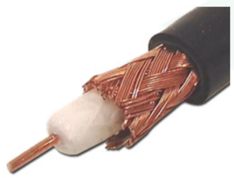
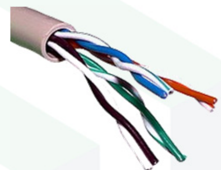
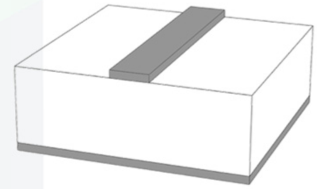
After analyzing the equivalent circuit, the characteristic impedance is derived to be

$$Z_0 = \sqrt{\frac{R + j\omega L}{G + j\omega C}}$$

When loss is ignored (usually very accurate to do this), the above equation reduces to

$$Z_0 = \sqrt{\frac{L}{C}}$$

Example RLGC Parameters

RG-59 Coax	CAT5 Twisted Pair	Microstrip
		
$R = 36\ \text{m}\Omega/\text{m}$	$R = 176\ \text{m}\Omega/\text{m}$	$R = 150\ \text{m}\Omega/\text{m}$
$L = 430\ \text{nH/m}$	$L = 490\ \text{nH/m}$	$L = 364\ \text{nH/m}$
$G = 10\ \mu\mho/\text{m}$	$G = 2\ \mu\mho/\text{m}$	$G = 3\ \mu\mho/\text{m}$
$C = 69\ \text{pF/m}$	$C = 49\ \text{pF/m}$	$C = 107\ \text{pF/m}$
$Z_0 = 75\ \Omega$	$Z_0 = 100\ \Omega$	$Z_0 = 50\ \Omega$

Surprisingly, almost all transmission lines have parameters very close to these values.

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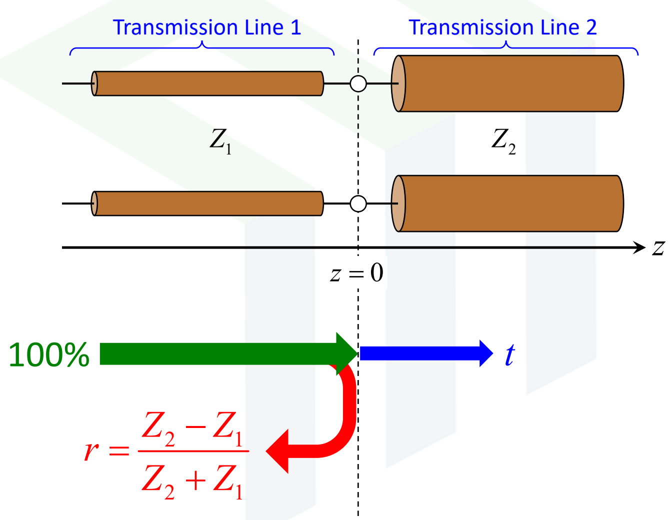
Reflections From Impedance Discontinuities



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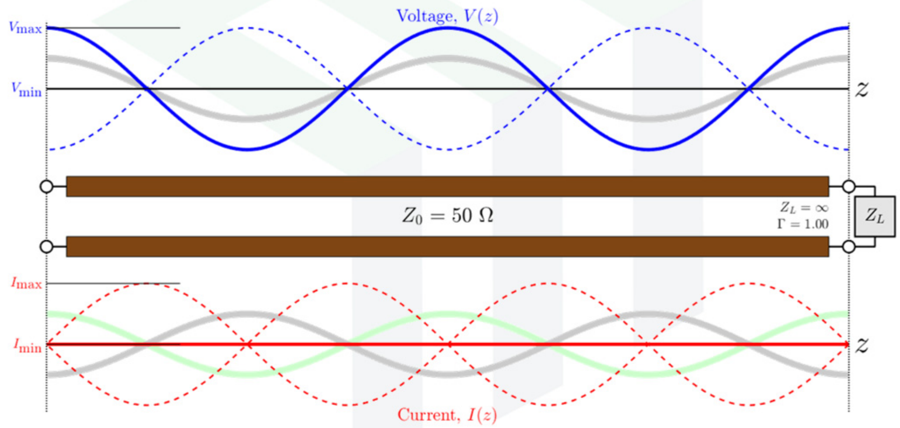
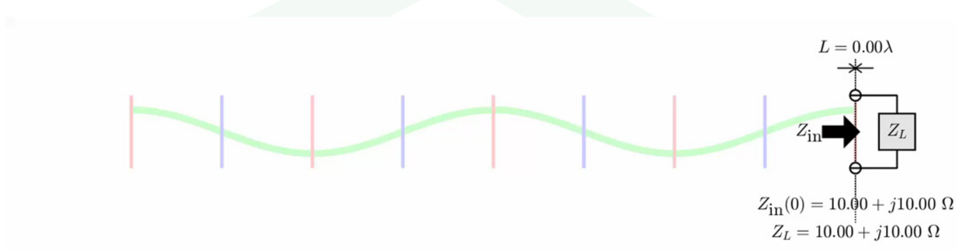
Voltage Standing Wave Ratio (VSWR)



Impedance Transformation



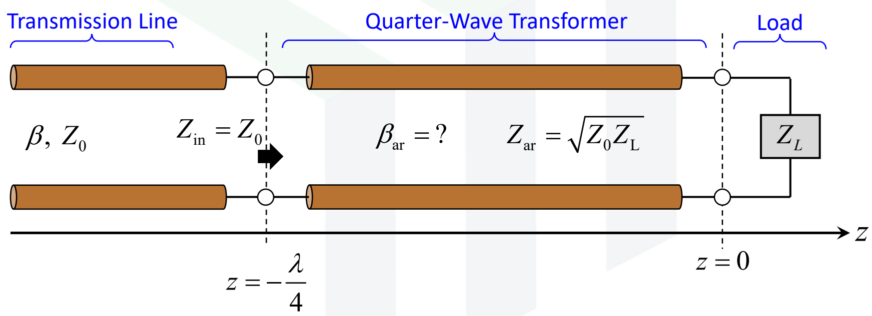
The impedance experienced by the source changes with distance away from the load!

Short circuits can look like open circuits, open circuits can look like short circuits, inductors can look like capacitors, capacitors can look like inductors,…its crazy!

$$Z_{in}\left(-\ell\right) = Z_0 \frac{Z_L + jZ_0 \tan\left(\beta\ell\right)}{Z_0 + jZ_L \tan\left(\beta\ell\right)}$$

Impedance Matching

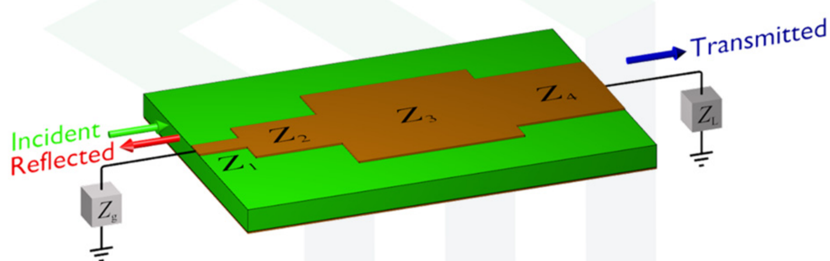
A quarter-wavelength section of transmission line can be inserted between the main transmission and load to eliminate reflections.



An electromagnetic analysis of the transmission line must be performed in order to determine β_{ar}.

$$\ell = \frac{\lambda}{4} = \frac{\pi}{2\beta_{\text{ar}}}$$

Multi-Segment Circuits



It becomes possible to design filters, pulse shapers, impedance matching circuits and much more.