جامعة صحار
SOHAR UNIVERSITY

Fundamentals of Electromagnetic Fields and Waves

ELEC3100

Module -1: Transmission lines parameters and properties

Course Learning Outcomes

1. Calculate the transmission lines characteristic parameters.
2. Analyze the wave propagation and standing waves on a transmission line.

Lecturer Name: Dr. Hilal A. Fadhil

Academic Year: 2021-2022

Course Coordinator Name: Dr. Hilal Fadhil

Module 1: Delivery Plan

Week 1: Transmission Line Parameters

Week 2: Wave propagation on transmission line

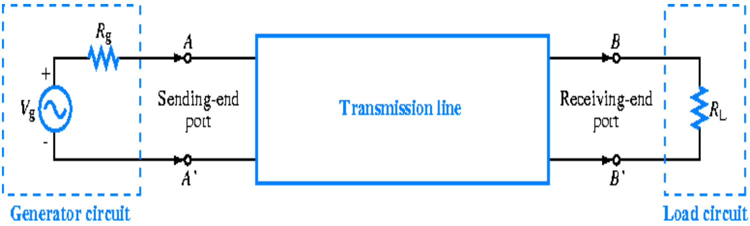
Week 3: Standing waves and power flow on transmission line

Teaching and Learning Activities

- Learning Materials
- Live Synchronous Session
- Exercises (Tutorials)
- Practical Component
- Discussion Forums

Introduction

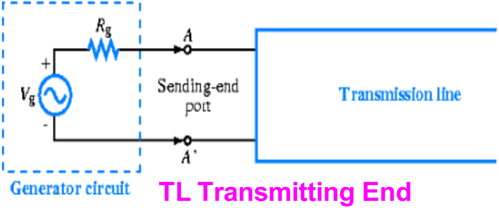
- **Transmission line (TL) is a two-port network; each port consisting of two terminals: The sending end and receiving end.**
- **Basically, TL consists of two parallel conductors to connect a SOURCE to a LOAD.**
- **The source connected to a sending end may be any circuit with an output voltage such as a radar transmitter, an amplifier or a computer terminal operating in transmitting mode.**



REF. Fawwaz T. Ulaby (2005). Electromagnetics for Engineers, Prentice Hall International, London.

General Considerations

- From circuit theory, any source can be represented by a Thevenin-equivalent generator circuit consisting of a generator voltage V_g in series with a generator resistance R_g.
- The generator voltage may consist of digital pulses, a modulated time-varying sinusoidal signal or any other signal waveform.
- In case of A.C signals, the generator circuit is represented by a voltage phasor V_g and an impedance Z_g.



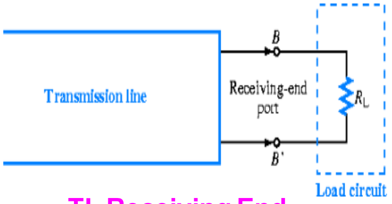
TL Transmitting End

REF. Fawwaz T. Ulaby (2005). Electromagnetics for Engineers, Prentice Hall International, London.

General Considerations

- The circuit connected to the receiving end of the transmission line is called the load. The load can be:

- An antenna in the case of a radar,
- A computer terminal operating in receiving mode,
- An input terminal of an amplifier, or
- Any output circuit whose input terminals can be represented by an equivalent load resistance R_L or a load impedance Z_L in the A.C. case.

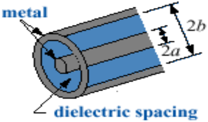


TL Receiving End

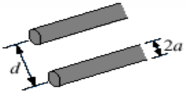
REF. Fawwaz T. Ulaby (2005). Electromagnetics for Engineers, Prentice Hall International, London.

Types of Transmission Lines

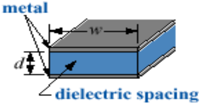
❖ TEM Transmission Lines



(a) Coaxial line

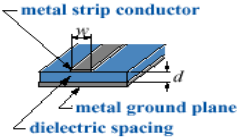


(b) Two-wire line



(c) Parallel-plate line

(d) Strip line



(e) Microstrip line

❖ Higher order Transmission Lines

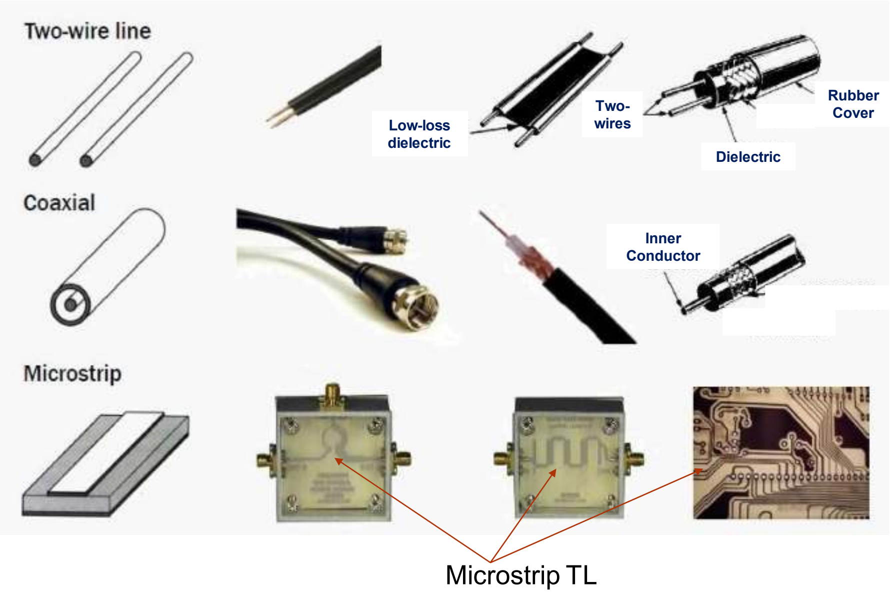
Coplanar waveguide

Optical fiber

Rectangular waveguide

REF. Fawwaz T. Ulaby (2005). Electromagnetics for Engineers, Prentice Hall International, London.

Common Types of Transmission Lines



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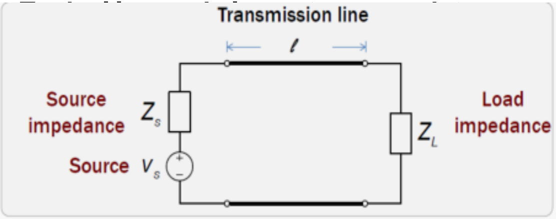
Lumped/Distributed Circuits of TL

Lumped circuits

- In lumped circuits, the entire circuit is at a single point. This means that the circuit components dimension are unimportant.
- Voltage & current do not vary across the component.
- Voltage applied at one point, the rest of the circuit reacts instantly.
- We don’t have to consider the travel time of the signal across components.
- …acitors, and inductors.



The load voltage V_L is given by

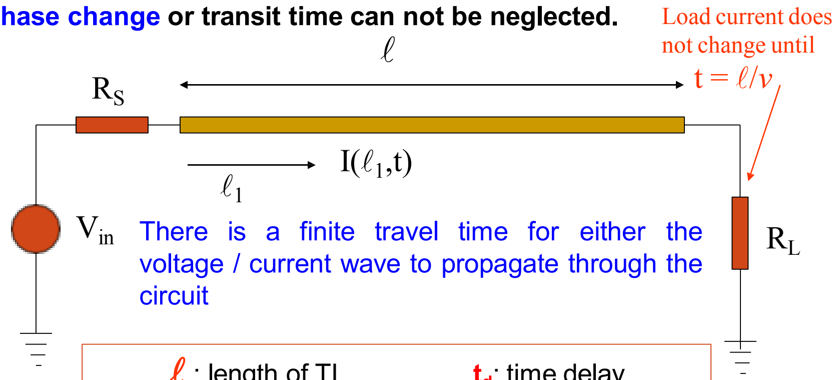
$$V_L = V_s \frac{Z_L}{Z_L + Z_{Ls}}$$

No effect of the TL on the voltage at the load (short TL length)

REF. Fawwaz T. Ulaby (2005). Electromagnetics for Engineers, Prentice Hall International, London.

Distributed circuits

- **In distribution circuits, the current and voltage varies along the transmission line (TL) elements.**
- **Voltages and currents along the TL cannot respond simultaneously to the excitation.**
- **Phase change or transit time can not be neglected.**



There is a finite travel time for either the voltage / current wave to propagate through the circuit

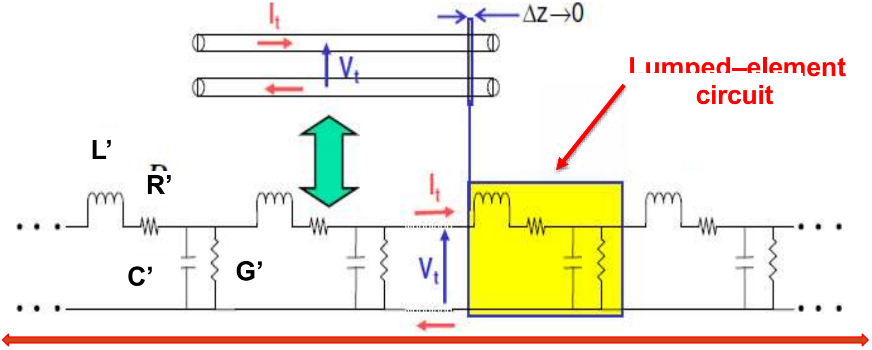
ℓ : length of TL, t_d: time delay

v : propagation velocity, R_s: resistance

R_L: load resistance

Lumped/ Distributed Element Model for a TL

A small segment of the TL can be modeled as a lumped–element circuit commonly known as Distributed RLGC circuit Model.



R' = series resistance per unit length for both conductors (Ω/m)
L' = series inductance per unit length for both conductors (H/m)
G' = shunt conductance per unit length (S/m)
C' = shunt capacitance per unit length (F/m)

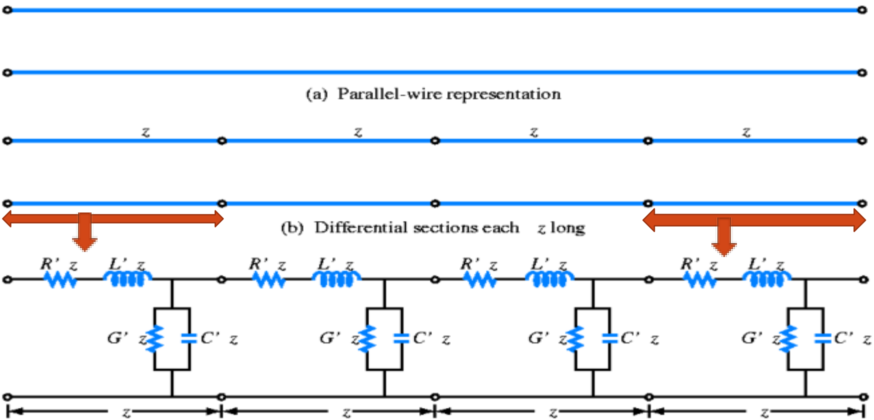
Transmission Line Parameters

- From the distributed circuit model of the transmission line, the transmission line has mainly four parameters, resistance, inductance, capacitance and shunt conductance.

- These parameters are uniformly distributed along the line. Hence, it is also called the distributed parameter of the transmission line.

- TL parameters are used to calculate characteristic impedance and propagation constant.

Representation/ Equivalent circuit of a two conductor line



(a) Parallel-wire representation

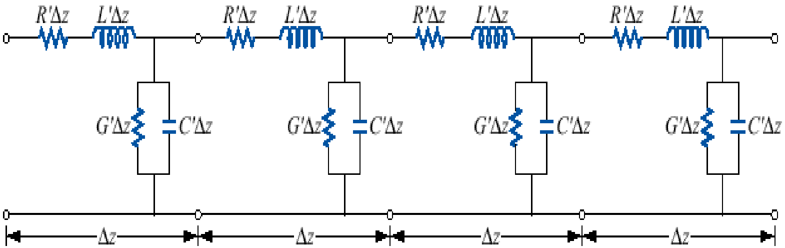
(b) Differential sections each z long

(c) Each section is represented by an equivalent circuit

Regardless of its actual shape, a transmission line is represented by the parallel-wire configuration shown in (a). To analyze the voltage and current relations, the line is subdivided into small differential sections (b), each of which is then represented by an equivalent circuit (c).

REF. Fawwaz T. Ulaby (2005). Electromagnetics for Engineers, Prentice Hall International, London.

Equivalent circuit



R' = resistance per unit length , *L'* = inductance per unit length
G' = conductance per unit length, *C'* = capacitance per unit length
Δz = increment of length

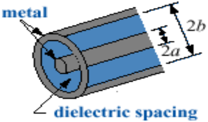
- Inductance and Capacitance are the most important parameters.

- **The current in the line sets up a field and induces a voltage VL=** $\left(L\,\frac{di}{dt} \right)$
- **The capacitance exists between the lines.**
- **Both L & C are distributed along the line.**
- **Both are not perfect, some attenuation (R' & G') always exists.**

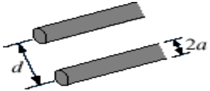
REF. Fawwaz T. Ulaby (2005). Electromagnetics for Engineers, Prentice Hall International, London.

Transmission-line parameters *R*`, *L*`, *G*` and *C*` for three types of lines

	Coaxial	Two Wire	Parallel Plate	Unit
R'	$\frac{R_s}{2\pi}\left(\frac{1}{a}+\frac{1}{b}\right)$	$\frac{R_s}{\pi a}$	$\frac{2R_s}{w}$	Ω/m
L'	$\frac{\mu}{2\pi}\ln(b/a)$	$\frac{\mu}{\pi}\ln\left[(d/2a)+\sqrt{(d/2a)^2-1}\right]$	$\frac{\mu d}{w}$	H/m
G'	$\frac{2\pi\sigma}{\ln(b/a)}$	$\frac{\pi\sigma}{\ln\left[(d/2a)+\sqrt{(d/2a)^2-1}\right]}$	$\frac{\sigma w}{d}$	S/m
C'	$\frac{2\pi\varepsilon}{\ln(b/a)}$	$\frac{\pi\varepsilon}{\ln\left[(d/2a)+\sqrt{(d/2a)^2-1}\right]}$	$\frac{\varepsilon w}{d}$	F/m



(a) Coaxial line



(b) Two-wire line

$$R_s = \sqrt{\pi f \mu_c / \sigma_c}$$

R_s: surface resistance of the conductors
f: frequency
μ_c: conductor permeability
σ_c: conductor conductivity
:ε_r **electrical** relative permittivity
μ_r: magnetic relative permeability

$$\varepsilon = \varepsilon_o \varepsilon_r$$

$$\mu = \mu_o \mu_r$$

Parameter	Units	Free-space Value
Electrical permittivity ε	F/m	$\varepsilon_0 = 8.854 \times 10^{-12}$ (F/m) $\simeq \frac{1}{36\pi} \times 10^{-9}$ (F/m)
Magnetic permeability μ	H/m	$\mu_0 = 4\pi \times 10^{-7}$ (H/m)
Conductivity σ	S/m	0

REF. Fawwaz T. Ulaby (2005). Electromagnetics for Engineers, Prentice Hall International, London.

Example

A coaxial air transmission line operate at frequency of **1 MHz**. The line has an inner conductor diameter of **0.6 cm** and outer conductor diameter of **1.2 cm**. The conductors are made of copper with permeability $\mu_C = \mu_0$ and conductivity $\sigma_C = 5.8 \times 10^7$ **S/m.**

Calculate the transmission line parameters, $R`$, $L`$, $G`$ and $C`$.

REF. Fawwaz T. Ulaby (2005). Electromagnetics for Engineers, Prentice Hall International, London.

Solution

Since the transmission line is Coaxial air line → the medium between the wires is air → *$\varepsilon=\varepsilon_o$, $\mu=\mu_o$* and *$\sigma=0$*

Given the line characteristics a=0.3 cm, b=0.6 cm, and μ_c=5.8x10⁷ S/m

The transmission line parameter *R`*

$$R' = \frac{R_s}{2\pi}\left(\frac{1}{a}+\frac{1}{b}\right)$$

$$R_s = \sqrt{\pi f \mu_c/\sigma_c}$$

$$= [\pi \times 10^6 \times 4\pi \times 10^{-7}/(5.8\times 10^7)]^{1/2} = 2.6\times 10^{-4}\ \Omega.$$

$$R' = \frac{R_s}{2\pi}\left(\frac{1}{a}+\frac{1}{b}\right) = \frac{2.6\times 10^{-4}}{2\pi}\left(\frac{1}{3\times 10^{-3}}+\frac{1}{6\times 10^{-3}}\right) = 2.08\times 10^{-2} \quad (\Omega/\text{m})$$

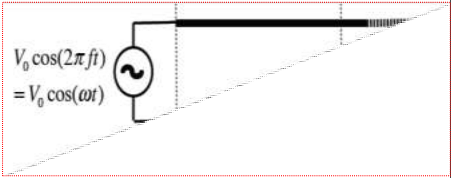
$$L' = \frac{\mu_0}{2\pi}\ln\left(\frac{b}{a}\right) = \frac{4\pi\times 10^{-7}}{2\pi}\ln 2 = 0.14 \quad (\mu\text{H/m})$$

$$G' = 0 \qquad \text{because } \sigma = 0$$

$$C' = \frac{2\pi\varepsilon}{\ln(b/a)} = \frac{2\pi\times 8.85\times 10^{-12}}{\ln 2} = 80.3 \quad (\text{pF/m}).$$

When do we use lumped/distributed analysis?

For steady state sinusoidal applications, we can look at the **one way propagation delay t_d**.



Say we have an input signal $V_{in} = V_0 \cos(\omega t)$

Then the voltage at a distance of ℓ is delayed by $t_d = \ell / v$,

This voltage is given as follow:

{v is the signal speed}

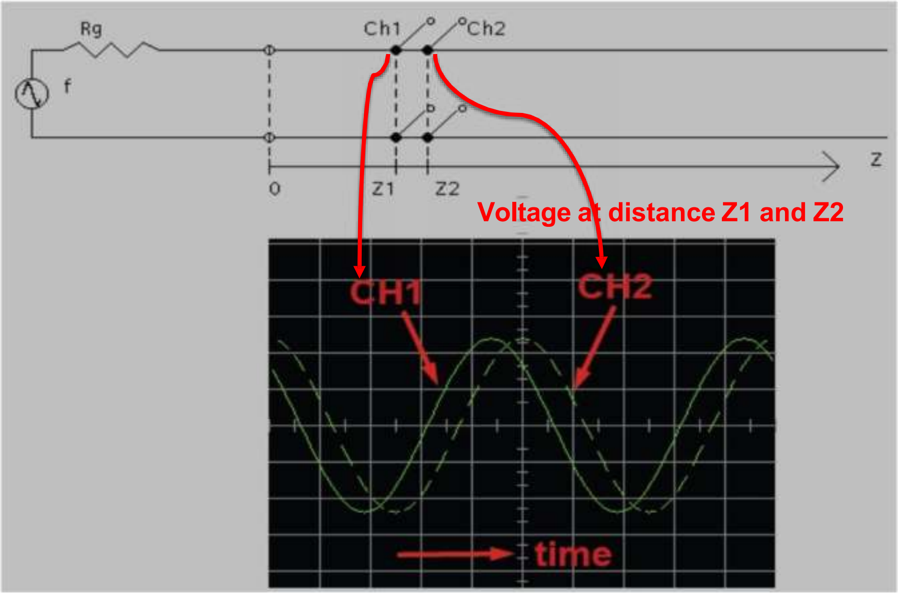
$$V_\ell(t) = V_0 \cos[\omega(t - t_d)]$$

$$= V_0 \cos\left[\omega t - 2\pi \frac{t_d}{T}\right]$$

$T = 1/f$

= period of the signal

Illustration of the delay



Two options

1. $t_d << T$ ($\ell << \lambda$)   (λ is the wavelength, t_d time delayed)

Then the voltage at ℓ distance is almost the same as the input voltage.

- Treat the line as a **lumped system**.

2. t_d comparable to T

In this case, the voltage down the line can be quite different e.g. at t_d = 0.5T, $V_\ell = -V_{in}$

- Treat the line as a **distributed system**.

So it depends on the **frequency.**

Rule of thumb: Use lumped analysis when $t_d < 0.1T$, or more stringently when $t_d < 0.01T$
($\ell << 0.01\lambda$)

Maximum lengths for lumped applications

Application	Frequency	Max length (based on t_d = 0.01T)
Power Transmission	50Hz	60km ($\ell = t_d \times v = 0.01T \times v$) $= 0.01/50 \times 3 \times 10^8 = 60$ km
Telephone	1kHz	3km ($0.01/1000 \times 3 \times 10^8 = 3$ km)
TV	150Mhz	2cm
Radar/Microwave	10GHz	0.3mm
Visible light	5×10^{14} Hz	6nm

Maximum transmission length depends on frequency of the signal

Dimensions, Units and Notation

Dimension	Unit	Symbol
Length	Meter	m
Mass	Kilogram	kg
Time	Second	s
Electric current	Ampere	A
Temperature	Kelvin	K

Prefix	Symbol	Magnitude
exa	E	10^{18}
peta	P	10^{15}
tera	T	10^{12}
giga	G	10^{9}
mega	M	10^{6}
kilo	k	10^{3}
milli	m	10^{-3}
micro	μ	10^{-6}
nano	n	10^{-9}
pico	p	10^{-12}
femto	f	10^{-15}
atto	a	10^{-18}

References

1. Fawwaz T. Ulaby (2005). Electromagnetics for Engineers, Prentice Hall International, London. Library code (QC760 .U488 2005).
2. Fawwaz T. Ulaby (2007). Fundamental of Applied Electromagnetics, Library code (QC760 .U49 2007).