INTRODUCTION TO TRANSMISSION LINES

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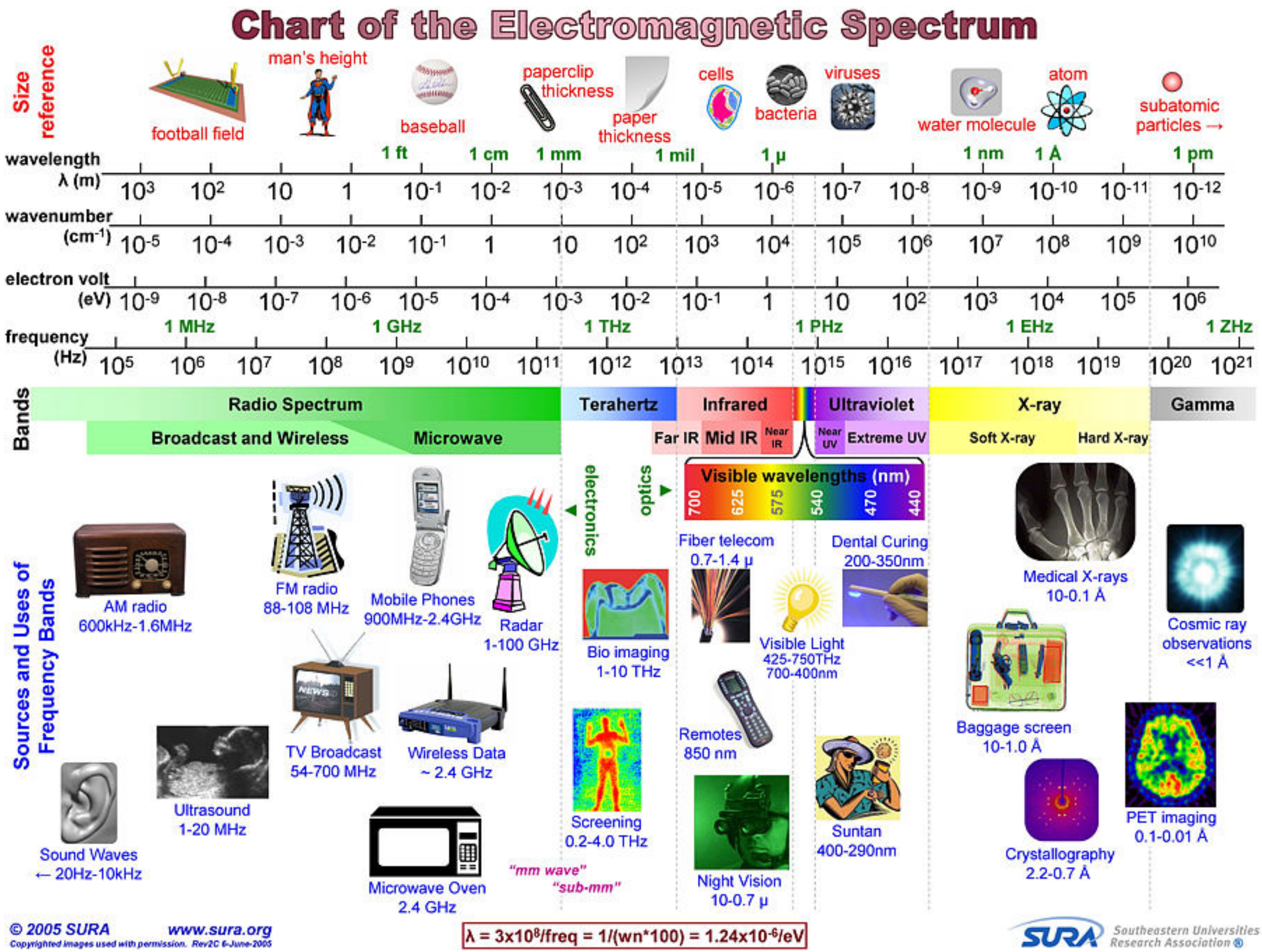
http://www.empowermentresources.com/stop_cointelpro/electromagnetic_warfare.htm



RF Design

- In RF circuits RF energy has to be transported
  - Transmission lines
  - Connectors
- As we transport energy energy gets lost
  - Resistance of the wire → lossy cable
  - Radiation (the energy radiates out of the wire → the wire is acting as an antenna

We look at transmission lines and their characteristics

Transmission Lines

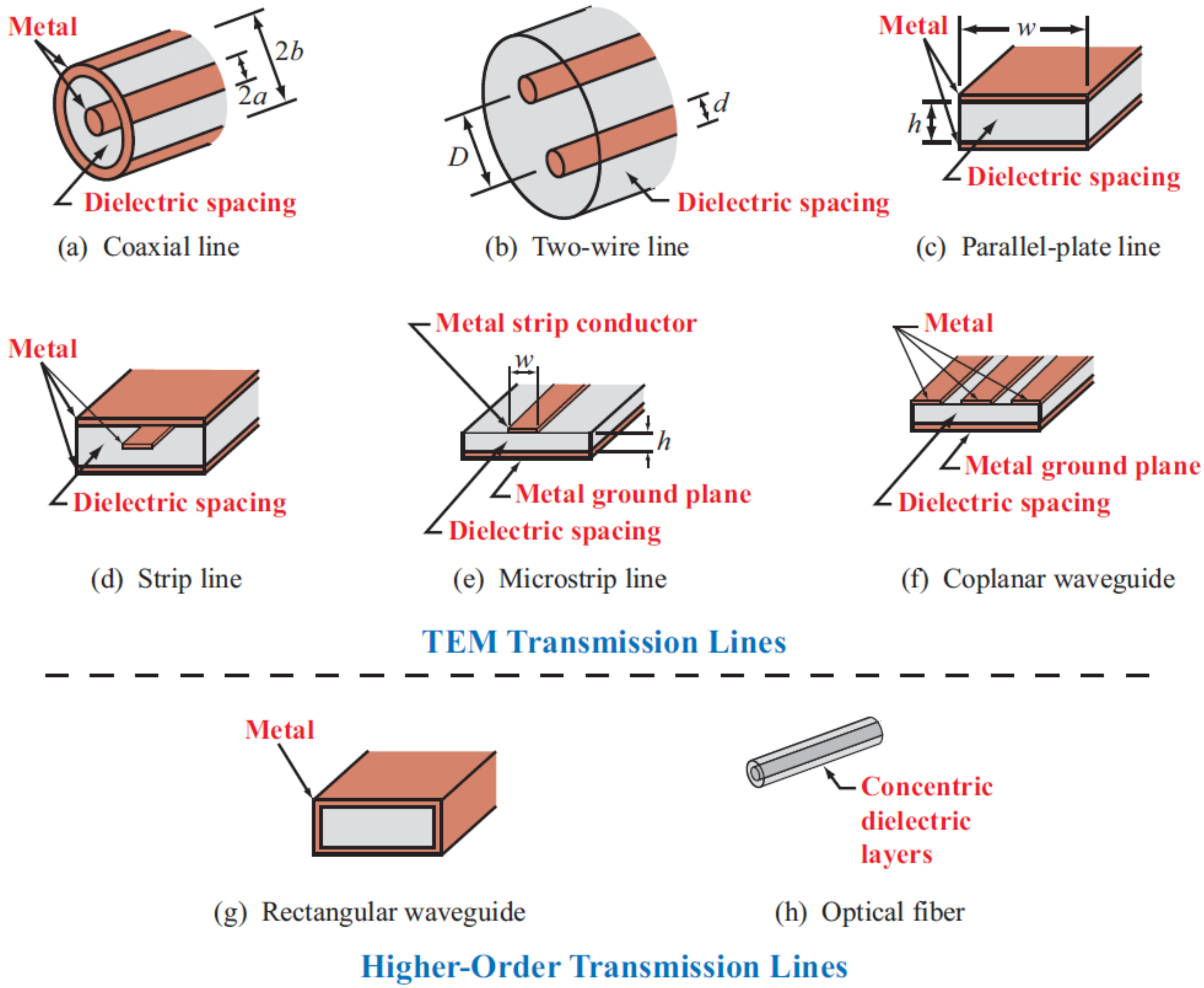
A transmission line connects a generator to a load – a two port network

Transmission lines include (physical construction):

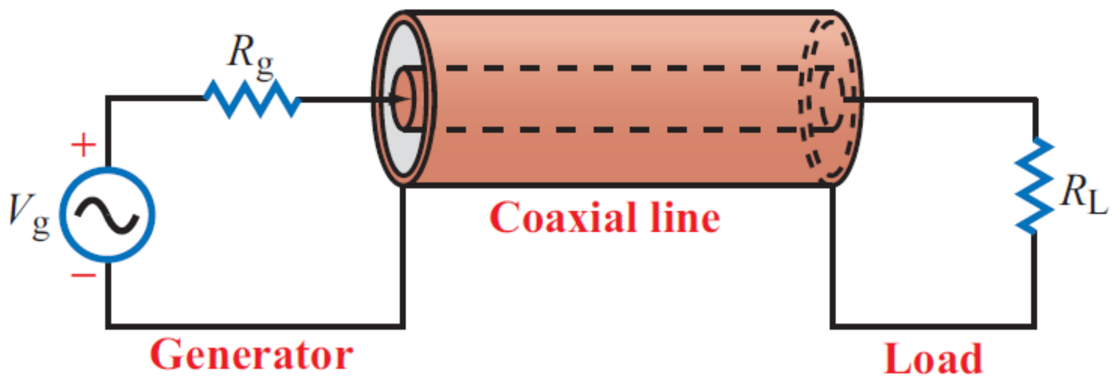
- Two parallel wires
- Coaxial cable
- Microstrip line
- Optical fiber
- Waveguide (very high frequencies, very low loss, expensive)
- etc.

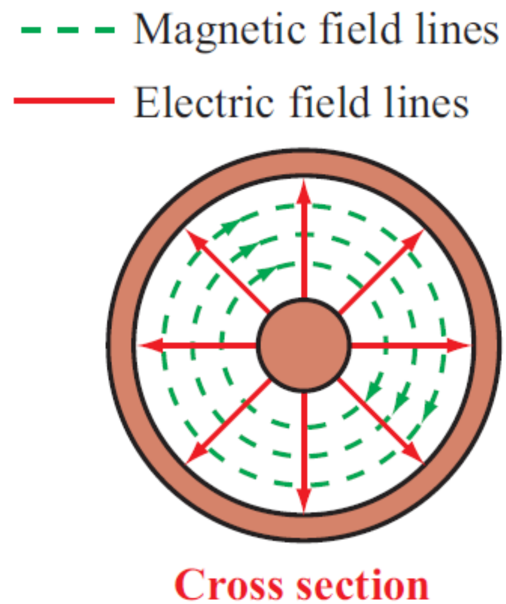
Types of Transmission Modes

TEM (Transverse Electromagnetic): Electric and magnetic fields are orthogonal to one another, and both are orthogonal to direction of propagation



Example of TEM Mode





Electric Field E is radial
Magnetic Field H is azimuthal
Propagation is into the page

Examples of Connectors

Connectors include (physical construction):

BNC

UHF

Type N

Etc.

Connectors and TLs must match!

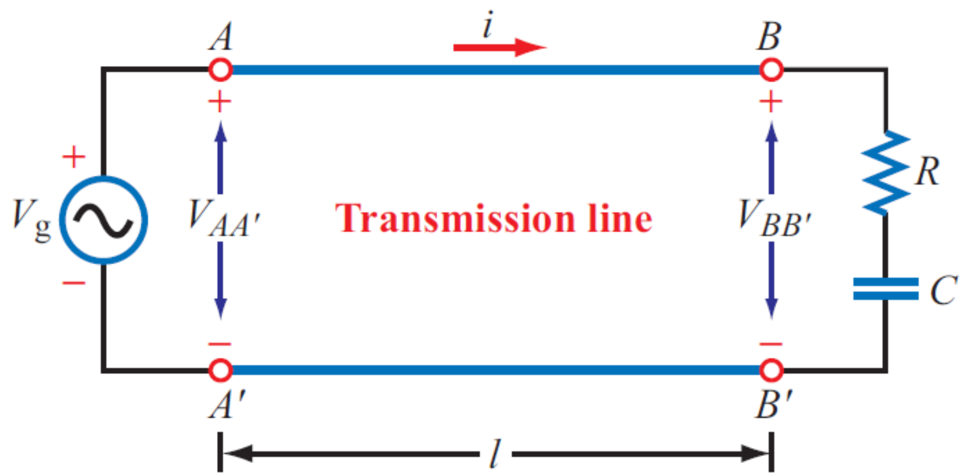
Transmission Line Effects

$$V_{AA'} = V_g(t) = V_0 \cos \omega t \qquad \text{(V)}$$

$$V_{BB'}(t) = V_{AA'}(t - l/c)$$ Delayed by l/c

$$= V_0 \cos[\omega(t - l/c)]$$

$$= V_0 \cos(\omega t - \phi_0),$$



At $t = 0$, and for $f = 1$ kHz , if:

(1) $l = 5$ cm:

$$V_{BB'} = V_0 \cos(2\pi f l/c) = 0.999999999998\, V_0$$

(2) But if $l = 20$ km:

$$V_{BB'} = 0.91 V_0$$

Properties of Materials (constructive parameters)

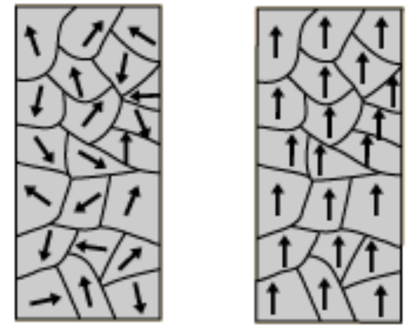
Remember: **Homogenous** medium is medium with constant properties

- Electric Permittivity ε (F/m)
  - The higher it is, less E is induced, lower polarization
  - For air: 8.85xE-12 F/m; $\varepsilon = \varepsilon o * \varepsilon r$

Relative permittivity and permeability (for air they are 1)

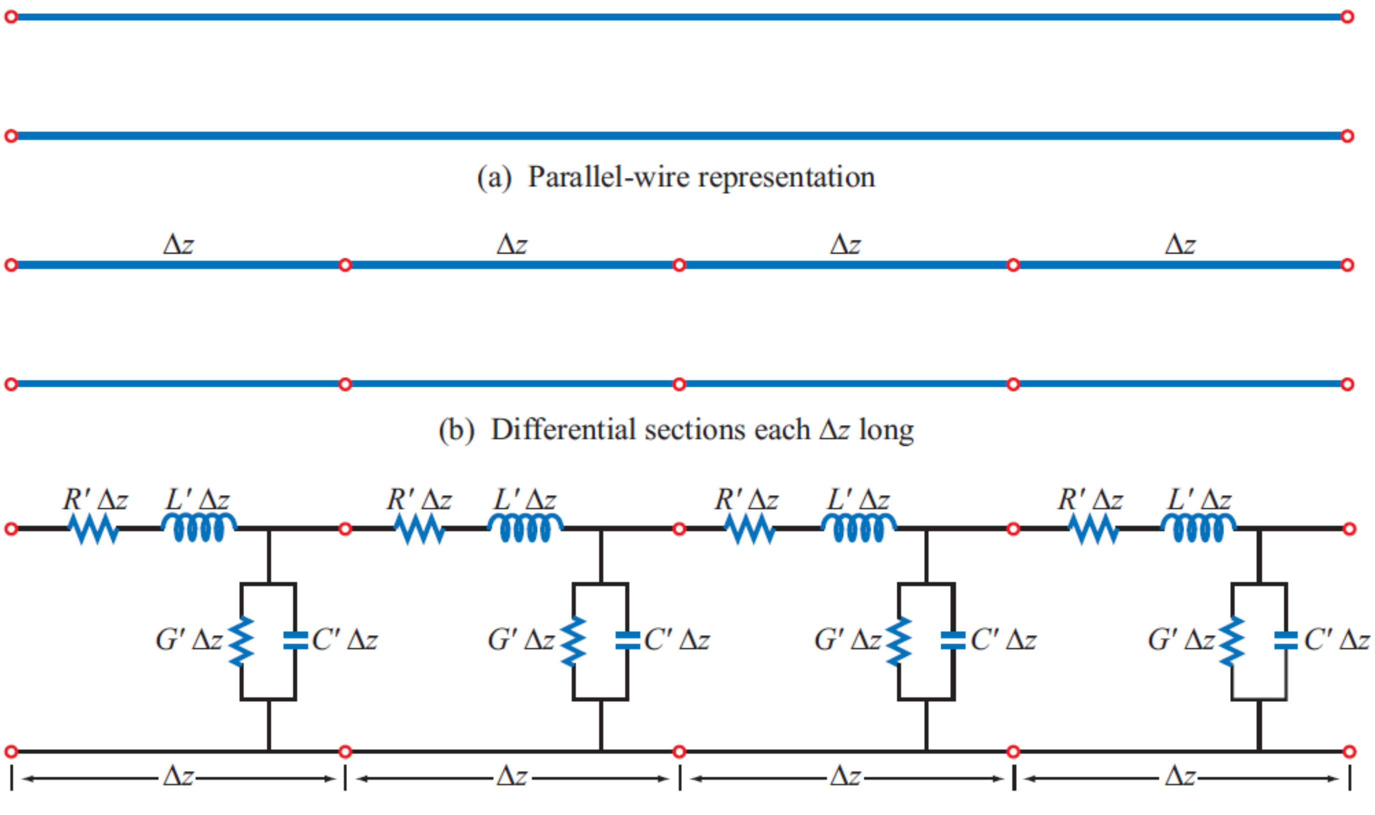
- Magnetic Permeability μ (H/m)
  - For air: 4piE-7 H/m
  - Higher value → **more** retention of magnetic property can be experienced in the material after removing B field
    - For ferromagnetic materials (Nickel, Cobalt)
  - If diamagnetic (gold) and paramagnetic (air) μ ~1
- Conductivity (S/m = Siemens/meter)
  - σ = INF → perfect conductor
  - σ = 0 → perfect dielectric

Properties of Materials



- Ferromagnetic materials (Nickel, Cobalt, pure Iron) – magnetic material
  - Retain magnetic property
  - Higher $\mu r \rightarrow$ more retention
  - Electrons are unpaired orbiting around
- Diamagnetic materials (Gold, Copper) – non-magnetic material
  - Composed of atoms which have no net magnetic moments (i.e., all the orbital shells are filled and there are no unpaired electrons) - no net magnetic moment
  - When exposed to a field, a negative magnetization is produced
  - $\mu r=1$ (slightly less than 1)
- Paramagnetic materials (Air, Aluminum) – non-magnetic material
  - some of the atoms or ions in the material have a net magnetic moment due to unpaired electrons in partially filled orbitals
  - Magnetization is zero when the B field is removed
  - In the presence of a B field, there is a partial alignment of the atomic magnetic moments in the direction of the field, resulting in a net positive magnetization
  - $\mu r=1$ (slightly more than 1)

Transmission Line Model



(c) Each section is represented by an equivalent circuit

- R': The combined ***resistance*** of both conductors per unit length, in Ω/m,
- L': The combined ***inductance*** of both conductors per unit length, in H/m,
- G': The ***conductance*** of the insulation medium between the two conductors per unit length, in S/m, and
- C': The ***capacitance*** of the two conductors per unit length, in F/m.

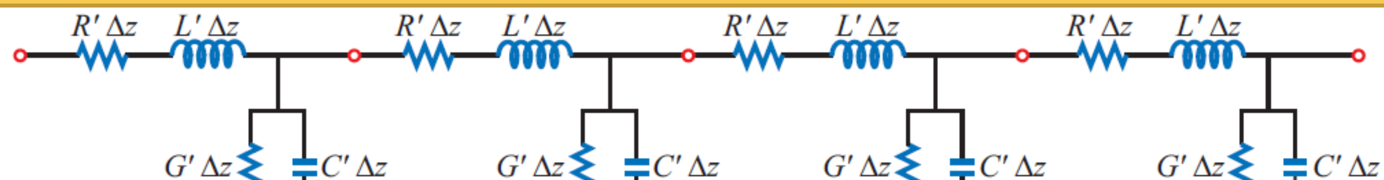
Transmission Line Model

Three Basic Properties:

Resistance: impacts the flow of current; controlled by the cross section area

Inductance: due to magnetic field; thus impacted by magnetic object

Capacitance: generally impacted by the grounding



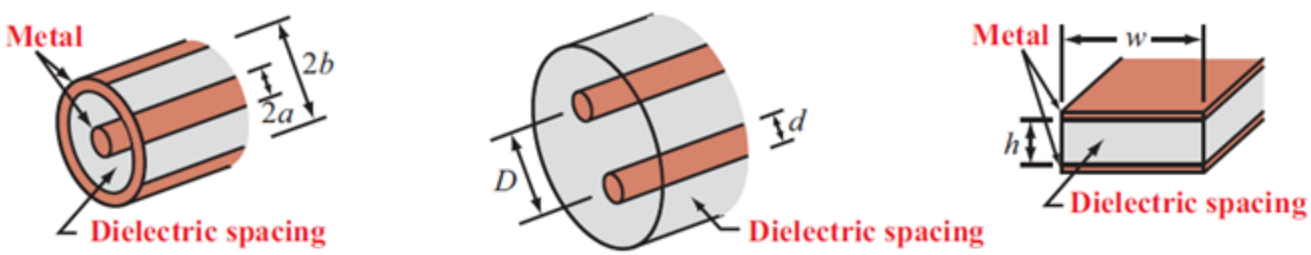
Note that these parameters are very low when the input voltage is DC or operating at low frequency, thus they can be ignored!

- R': The comb… length, in … um between the … d
- L': The combi… length, in H/m,
- C': The capacitance of the two conductors per unit length, in F/m.

Transmission-line parameters R', L', G', and C' for three types of lines.

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

Notes: . (2) μ, ε, and σ pertain to the insulating material between the conductors. (3) $R_s = \sqrt{\pi f \mu_c/\sigma_c}$. (4) μ_c and σ_c pertain to the conductors. (5) If $(D/d)^2 \gg 1$, then $\ln\left[(D/d)+\sqrt{(D/d)^2-1}\right] \simeq \ln(2D/d)$.



(a) Coaxial line (b) Two-wire line (c) Parallel-plate line

Perfect Conductor and Perfect Dielectric (notes)

TEM Transmission Line

- For all TEMs:

$$L'C' = \varepsilon\mu$$

$$Perfect\_Conductor : \sigma = \infty; Rs \approx 0 \quad G'/C' = \sigma/\varepsilon$$

$$Perfect\_Dielectric : \sigma = 0; G' \approx 0$$

- If the TL is lossless:

$$Z_o = \sqrt{L'/C'}$$

$$c = 1/\sqrt{\varepsilon_o \mu_o}$$

$$v_p = \lambda.f = 1/\sqrt{L'C'} = c/\sqrt{\varepsilon_r \mu_r} = \omega/\beta$$

$$V(t,x) = A\cos(\omega t - \beta x + \varphi_o)$$

Sinusoidal traveling wave representation

Wave Propagations

- Propagation Velocity
  - Assuming lossless line

$$v_p = \lambda . f = 1 / \sqrt{L^{'} C^{'}}$$

- Velocity Factor VF = vp/C (less than one)
  - Where C = 3x10E-8 m/s
- Dispersion effect is due to Vp variations due to frequency differences
  - Remember any composite signal is made up of many difference frequency components (cf., Fourier Analysis)
  - The result is a narrowed pulse!

The speed of light = 299 792 458 m / s

EA1

Energy Loss

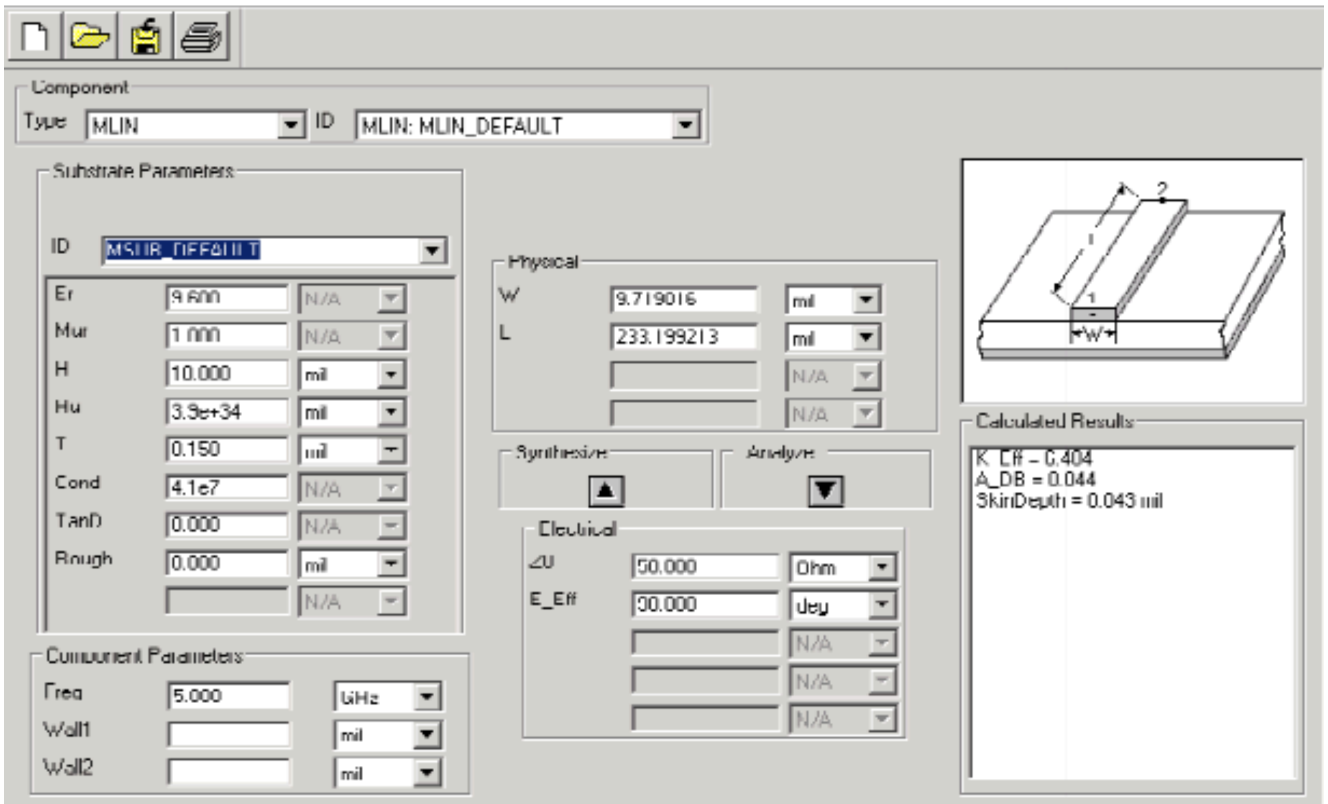
- As the wave propagates it may looses energy
  - Ohmic Loss: Due to resistance of the wire; at high frequency current flows outside the surface of the conductor → Skin Effect (thus circumference is critical)
  - Dielectric Loss: Energy is lost in dielectric → converted to heat! The best dielectric is air!
- How much energy is lost
  - Measured in dB/unit_of_length

$$dB_{gain} = 10\log(P_{out} / P_{in})$$

ADS LineCalc Tutorial – (1)

Tutorial Available at:
http://newport.eecs.uci.edu/eceware/ads_docs/pdf/linecalc.pdf

- ADS has many other tools built into it. A popular one is LineCalc. This tool calculates impedances and dimensions for the much different geometry of wave-guides and microstrip lines. To start the tool, there must already be a schematic open. Use the quarter-wave circuit just built. From the schematic at the top choose Tools → LineCalc →Start LineCalc. A window such as that below will appear.

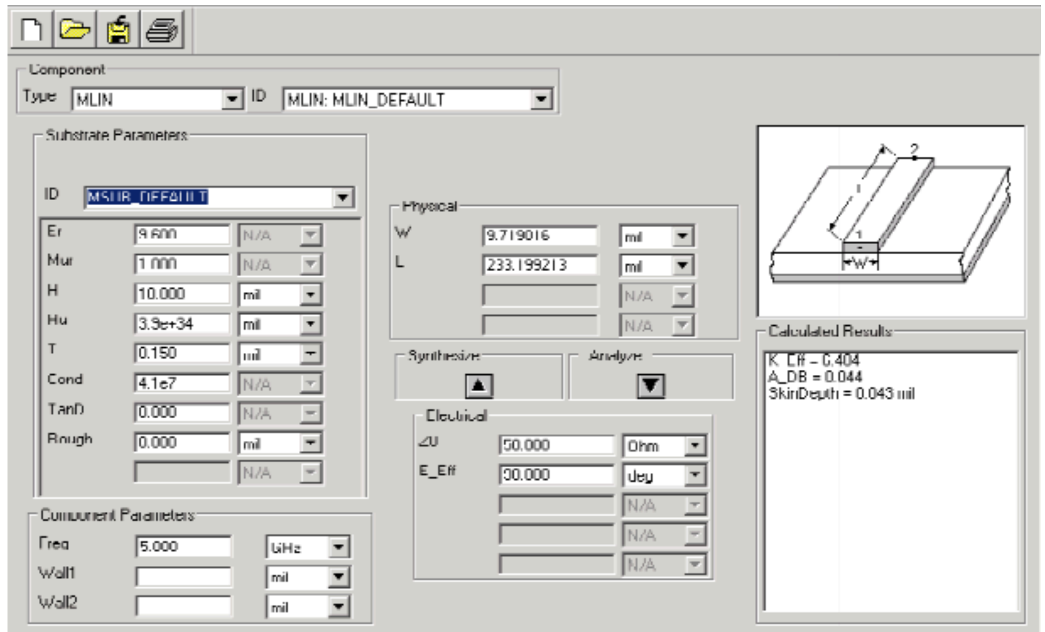


ADS LineCalc Tutorial – (2)

- At the top is the Type of structure to be analyzed. The program defaults to microstrip. Take a look at some of the other available such as COAX and CPW. The ID is the name of the defaults being viewed. This has initial parameter values and an initial Type. You can make your own ID if you wish. For the microstrip the parameters stand for:
- Er – relative permitivity
- Mur – relative permeability
- H – height of the substrate
- Hu – if the design was covered by a metal box, this would be its height
- T – conductor thickness
- Cond – conductivity of the conductor
- TanD – dielectric loss tangent
- Rough – RMS surface roughness of the dielectric
- W – width of conductor
- L – length of line
- Z0 – characteristic impedance of line
- E_Eff – effective electrical length
- K_Eff – effective dielectric permitivity of the system
- A_DB – total attenuation of the system

ADS LineCalc Tutorial – (3)

Let's go through an example. Set all but the Physical parameters (W and L) to those as in the Fig. Notice there are two arrows. Clicking the arrow pointing up will calculate W and L of the microstrip while clicking the down arrow will calculate Z0 and E_Eff. Push the up arrow. The simulator will run and the W and L will be calculated as in the Fig. Let's go the other way. Set W = 50 mil and click the down arrow. Now Z0 = 17.806900 and E_Eff = 98.733400. A wider conductor gives lower impedance as would be expected.



For more information use the online help command!

http://my.ece.ucsb.edu/bobsclass/144A/Handouts/ADS_Tutorial.pdf

Practice:

- Estimate the impdance of a coaxial cable assuming permeability is 1. You must simplify the expression as much as possible.
- Assuming E(x,t) = 2cos(3x10^15t – 10^7x) calculate the wave velocity. What is the amplitude of the wave at the distance of 200 m?
- Assume we have a transmission line in which air separated the two conductors. Assume the impedance of the line is 50 ohm, phase constant is 20 (rad/m) and the operating frequency is 700MHz. Calculate the line inductance/meter and capacitance/meter
- Learn about EEsof LineCalc