Introduction to Transmission Lines

Outline

- Objectives of transmission lines
- Applications
- Types
- Transmission line theory

Why it is needed?

- Transmission of signal (and power)
- Circuit analysis where operating frequency is high, i.e., circuit size large compared to the wavelength or "electrically large".
- Very important for RF or microwave circuits, digital circuits (very high clock rate)

Applications

- Telephone
- Cable TV (CATV, or Community Antenna Television)
- Broadband network
- High frequency (RF) circuits, e.g., circuit board, RF circuits, etc.
- Microwave applications, e.g., radar system, global positioning system (GPS).

Transmission Lines

- Used for guiding electromagnetic (EM) waves
- Point-to-point "guided" transmission of power and information from "source" to "receiver", e.g., data signal. (unguided=antenna)
- Transverse EM (TEM) waves applied to most transmission lines except waveguides.
- TEM waves -> uniform plane waves

Types classified by materials

- Metallic Transmission Lines (Conductor)
- Hollow or Dielectric-filled Waveguides (Conductor and dielectric)
- Optical Fiber (dielectric)

Transmission Lines

Two fundamental types

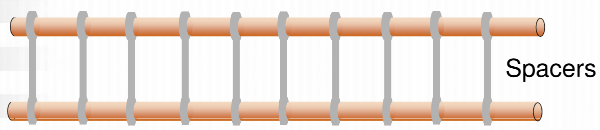
- Low Frequency
  - used for power transmission
- High Frequency
  - used for RF transmission
    "wavelengths are shorter than or comparable to the length of cable"

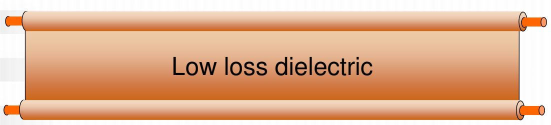
Note - transmission line = conductor - but only use "surface"

Types of Metallic Transmission Lines

- Parallel Line
- Twisted Pair (Shielded & Unshielded)
- Coaxial
- Microstrips
- Strip Line

Parallel Pair



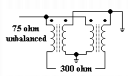


Parallel Line (aka Ribbon Cable)

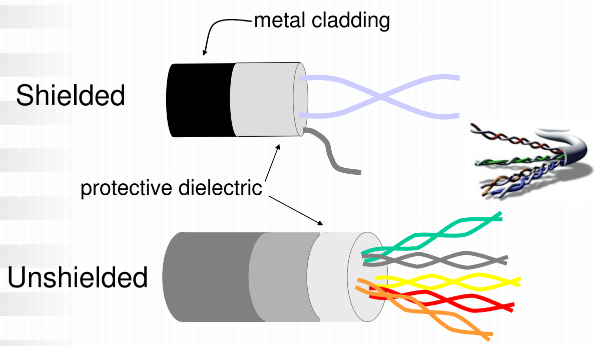
- Simple Construction
- Used primarily for power lines, rural telephone lines or TV antenna cable
- Freq up to 200MHz over short distances
- High Radiation Loss
  - moving current = Ae
  - need to be aware of other metallic conductors

Twin Lead Cable

- Balanced
  - 300 Ω $Z_0 = 276\log(D/r)$
- Balun
  - Balanced to unbalance transformer



Twisted Pair



coating is paper, rubber, PVC…
can also have single pair, each wrapped individually

Twisted Pair

- Twists tend to cancel radiation loss
- Helps reduce crosstalk
- Still fairly inexpensive
- Frequency < 100MHz
- Generally short distances
  - analog ~5-6 km
  - digital ~2-3 km

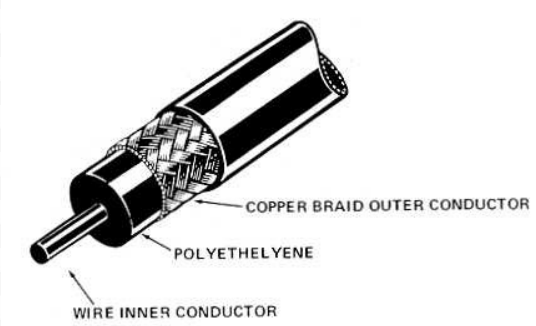
- Note - power line interference

CAT5 Cable

- UTP
- 4 pair
- terminating in RJ45
- 100MHz max frequency
- 1000 Mbps transmit rate

- Aside: Wire Gauge (smaller is bigger)

Coaxial Cable

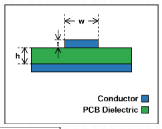


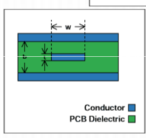
Coaxial Cable

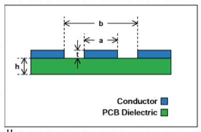
- Geometry creates a "shielded" system
  - no EM energy outside the cable
- Can support frequencies > 100MHz
- Can support data rates > 1GHz
- Low self-inductance allows greater BW
- Used for long-distance telephone trunks, urban networks, TV cables
- Expensive + must keep dielectric dry

Striplines

- Micro Stripline
- Embedded Stripline
- Coplanar Stripline



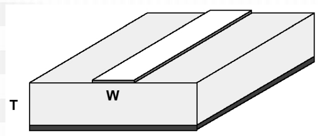


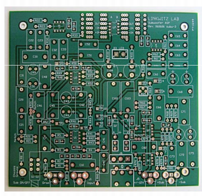


- Loss
  - Metallic
    - Skin depth
    - Localized current flow
  - Dielectric
    - Loss tangent $\varepsilon = \varepsilon' - j\varepsilon'' \Rightarrow Tan\delta = \frac{\varepsilon''}{\varepsilon'}$
  - Surface roughness

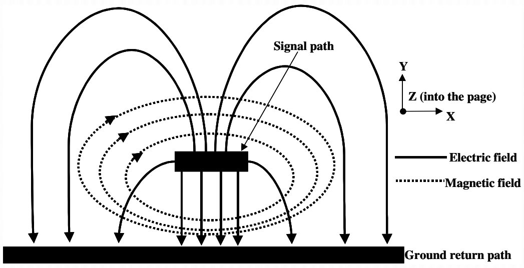
Microstrips

- Used for very high frequencies in semi-conductors





E & H Fields – Microstrip Case



The signal is really the wave propagating *between* the conductors

Transmission Line Theory

- Current and Voltage change with time along the line (the signal)
  - superposition of waves in both directions
  - but over short distances (<λ) are constant
- Energy is lost (heat - resistance) or stored (magnetic - inductance) / (capacitive - capacitance)

$$v = Ri \qquad v = L\frac{di}{dt} \qquad i = C\frac{dv}{dt}$$

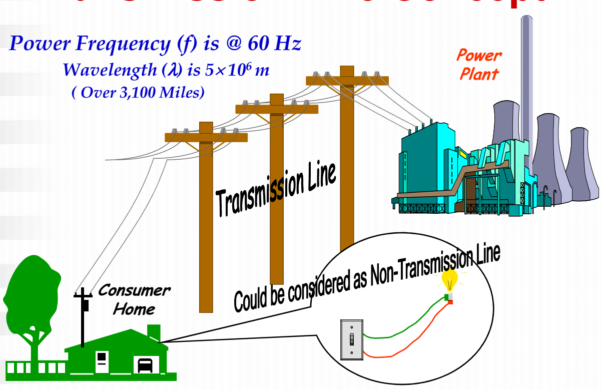
= Attenuation Losses

Transmission Line Concept

Power Frequency (f) is @ 60 Hz

Wavelength (λ) is 5×10^6 m

(Over 3,100 Miles)

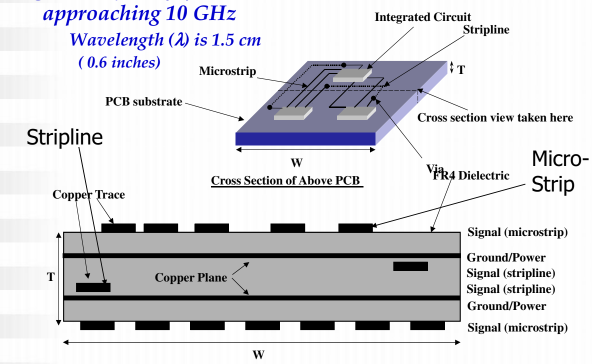


PC Transmission Lines

Signal Frequency (f) is approaching 10 GHz

Wavelength (λ) is 1.5 cm

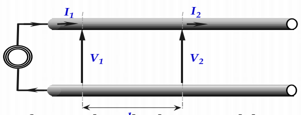
(0.6 inches)



Key point about transmission line operation

Voltage and current on a transmission line is a function of both time and *position*.

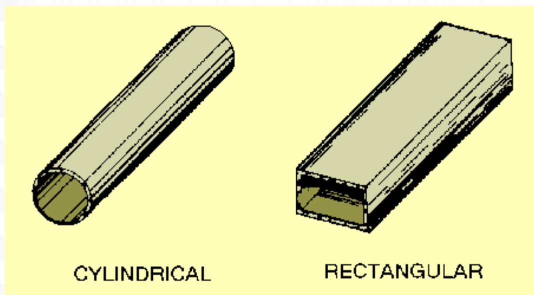
$$V = f(z,t)$$
$$I = f(z,t)$$



The major deviation from circuit theory with transmission line, distributed networks is this positional dependence of voltage and current!

- **Must think in terms of position and time to understand transmission line behavior**
- **This positional dependence is added when the assumption of the size of the circuit being small compared to the signaling wavelength**

Waveguides aka plumbing



- width is ~ wavelength

Waveguides

- Uses a different transmission method
- “Ducting” not “conducting”
- >1GHz
- Expensive
- May need to be filled
- Cannot turn sharp corners
- Any defects will cause significant attenuation (sparking)

What to discuss next?

- Transmission line theory
- Analysis of wave propagation on a transmission line
- Field analysis
- The main objective is to analyze how signals propagate on transmission lines, e.g.,
  – Attenuation
  – Distortion

Analysis for Digital Pulse