

Stuff to Grok (wk 1)

Design / Analyze / Use electrical structures that allow us to deliver electrical waveforms to electrically distant loads while preserving their important characteristics and not interfere with, or be interfered by other signals.

Lossless T-lines do not exhibit DC resistance of any sort.

Square wave signals "contain" many odd harmonics of the fundamental signal. The less the rise and fall times, the more higher frequency signals there are.

In this class, waves traveling on a T-line exhibit linearity. The total amplitude of 2 waves is simply the sum of their individual amplitudes.

Lumped circuit: physical dimensions (length, frequency, wavelength) are such that the voltage across or the current through an element does not vary with distance.

Voltage or current on T-lines are functions of time & distance:

$$(1) \quad V(z, t) = V_0 \cos(\omega t - \beta z) \quad ; \quad \text{where } \beta = \frac{\omega}{v_p} \quad \text{is called the phase constant}$$

β tells us how quickly the phase of the signal changes with distance z .

$$\text{since } \lambda = \frac{v_p}{f} \quad ; \quad \text{by substitution, } \beta = \frac{2\pi}{\lambda} \quad \left(\text{Another representation for } \beta \right)$$

Thus we can write (1) as:

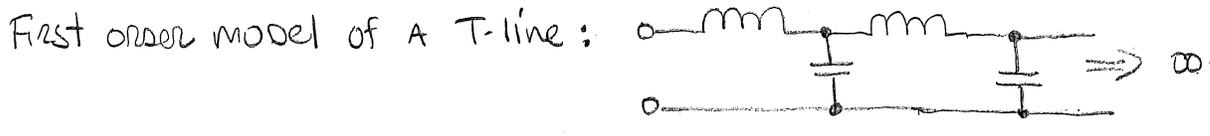
$$(2) \quad V(z, t) = V_0 \cos\left(\omega t - \boxed{2\pi \frac{z}{\lambda}}\right) \quad \leftarrow \text{electrical length in radians}$$

T-line criterion:

- | | | |
|------------------------|--|----------------|
| (a) rise time vs t_d | $\Rightarrow t_r > 6t_d$: lumped | } interconnect |
| | $t_r < 2.5t_d$: T-line | |
| (b) period vs t_d | $\Rightarrow t_d < 0.01T$: lumped | } interconnect |
| | $t_d > 0.1T$: T-line | |
| (c) size vs wavelength | $\Rightarrow \text{length} < 0.01\lambda$: lumped | } components |
| | $\text{length} > 0.01\lambda$: not lumped | |

The physical cross-section of conductor pairs is what determines their per unit inductance and capacitance; thus the Z_0 of the pair.

Z_0 of a T-line does not change with distance



Solution to one-dimensional wave equation implies the possibility of two waves traveling in opposite directions.

$$V(z,t) = \underbrace{V^+(z - v_p t)}_{\text{moving to right}} + \underbrace{V^-(z + v_p t)}_{\text{moving to left}}$$

Infinite bandwidth (BW) T-lines maintain the "shape" of the signal over time + space.

An infinite BW line can be lossy. (smaller amplitude, same shape)

We can fully define a T-line's characteristics with only $Z_0 + v_p$.

$$v_p = \frac{1}{\sqrt{LC}} \quad Z_0 = \sqrt{\frac{L}{C}} \Rightarrow \alpha = \frac{Z_0}{v_p} ; \epsilon = \frac{1}{Z_0 v_p}$$

$$t_{\text{delay}} = \underbrace{L \sqrt{\frac{L}{C}}}_{\substack{\text{per unit length} \\ C \text{ or } L}} \text{ or } \underbrace{\sqrt{LC}}_{\substack{\text{total } L \& C}}$$

$$v_p = \frac{c}{\sqrt{\epsilon_r}} \text{ (Another expression for } v_p \text{ derived from Maxwell's equations)}$$

On FR-4, $\epsilon_r \approx 4.5$ thus:

$$v_p = 1.41 \times 10^8 \text{ m/s or } 5.5 \text{ inches/ns}$$

Also 200 pS/inch

$$\text{Inductive reactance } X_L = 2\pi f L$$

At higher frequencies, signals follow the path of least impedance
Higher frequencies \Rightarrow 100kHz

Z_0 varies with cross sectional dimensions:

- loop AREA (L)
- parallel plate capacitance (C)