EE 5200 - Lecture 23

Wed Oct 23, 2019

Topics for Today:

- Announcements
  - Software: We will be opening EERC 134 Lab to this class. Aspen, ATP will be installed there (to reduce IT issues with support).
  - Learning Center next week: require you and your partner to visit!
  - Office: EERC 614.   Phone: 906.487.2857
  - Book exercises from Ch.6,7 solutions posted
  - Next homework: Transmission Lines as 2-port networks. Matlab.

Chapter 6 - Transmission Lines

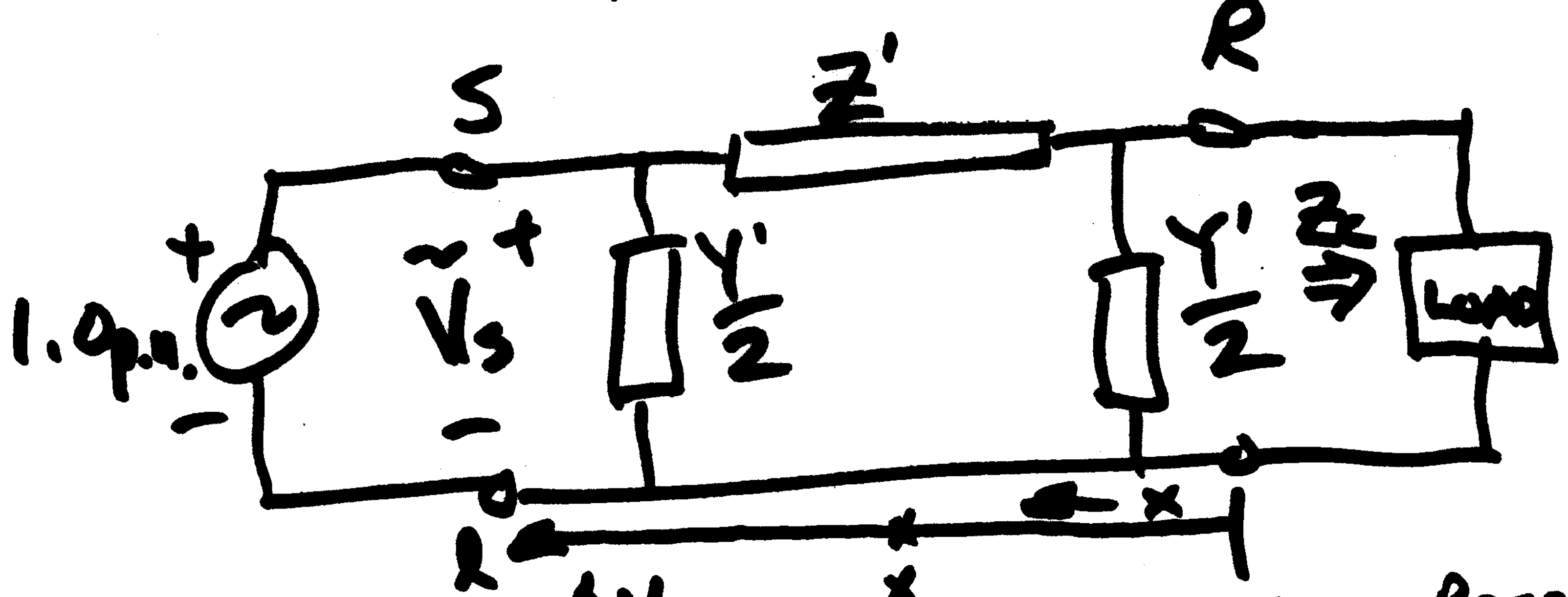
- Using the T-Line models
  - Short Transmission Lines - up to 50 miles (80 km)
  - Voltage Regulation, phasor diagrams
  - Per-phase impedance diagrams (positive seq only)
  - Medium-Length Lines (50 - 150 miles)
  - ABCD parameters for Medium-lines, power flow
  - Long Lines - more than 150 miles (240 km)
  - Derivation of long-line equations, meaning of equations
  - Characteristic Impedance Z_C
  - Propagation Constant $\gamma = \alpha + j\beta$
  - Surge-Impedance Loading (SIL)
  - Wavelength, velocity, Traveling waves, reflections

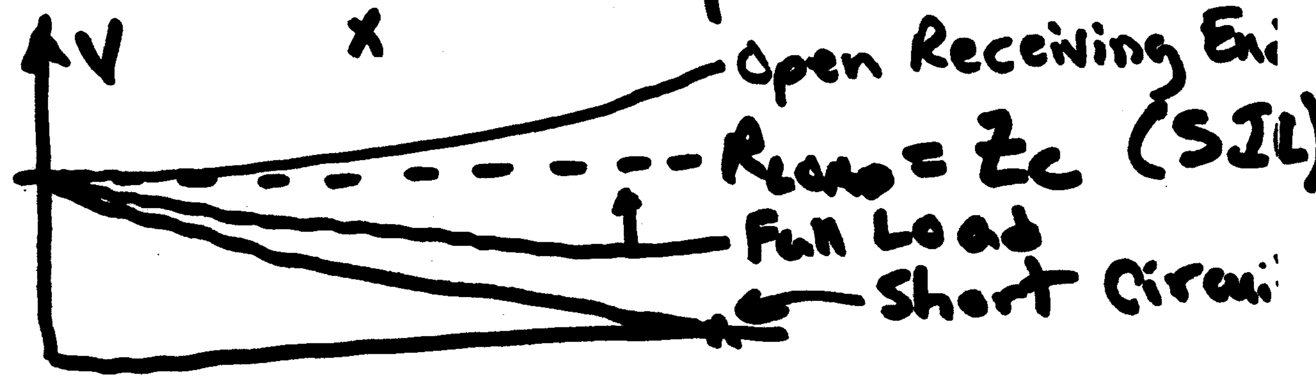
$Z_c = \sqrt{\frac{z}{y}}$ ← Imp per unit length
← Admit " " "

$\gamma = \sqrt{z\,y} = \alpha + j\beta$ ← phase angle rotation

attenuation (α)

How a wave travels down line.



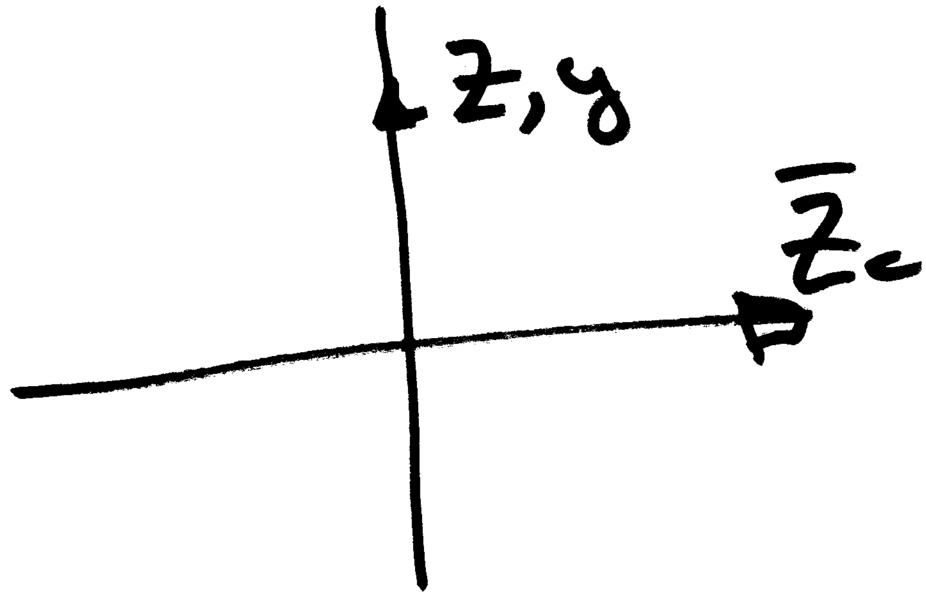


Another Point:

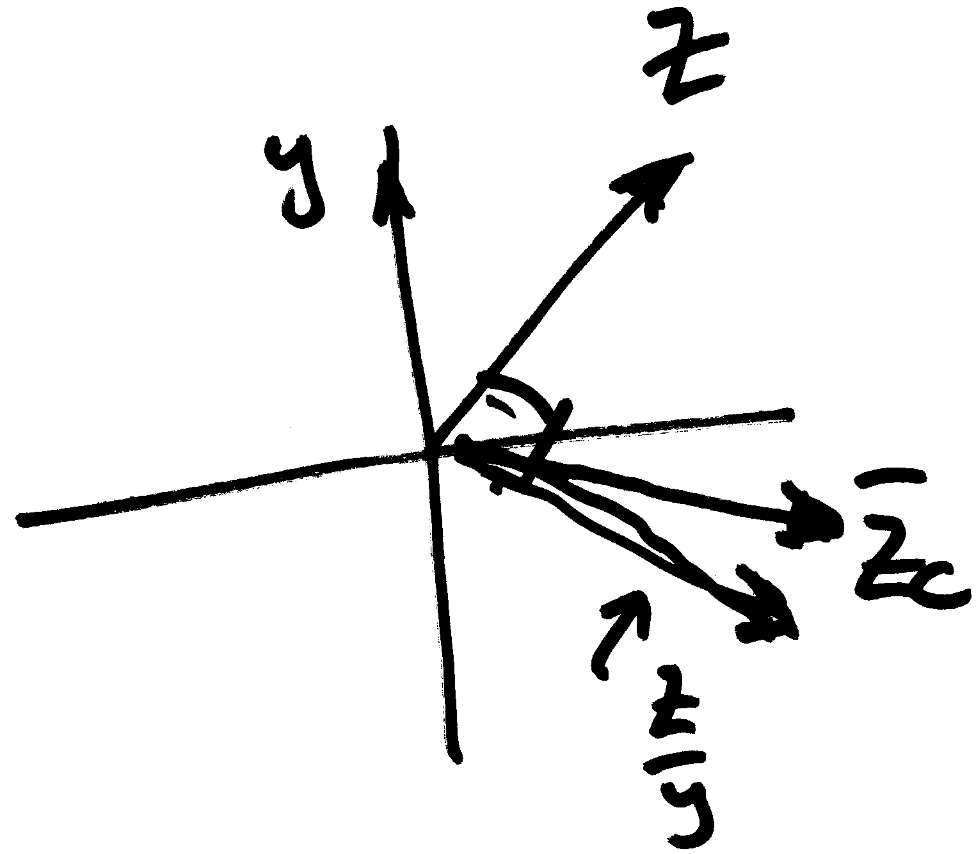
- SIL = Surge Impedance Loading
  - $R_{LOAD} = |Z_c|$
  - Total Reactive Power Consumed in Line = 0.
  - → "Flat" Line or flat voltage profile.
  - $SIL = \frac{V^2}{Z_c} = \frac{V_S^2}{Z_c} = \frac{V_R^2}{Z_c}$

High X/R:

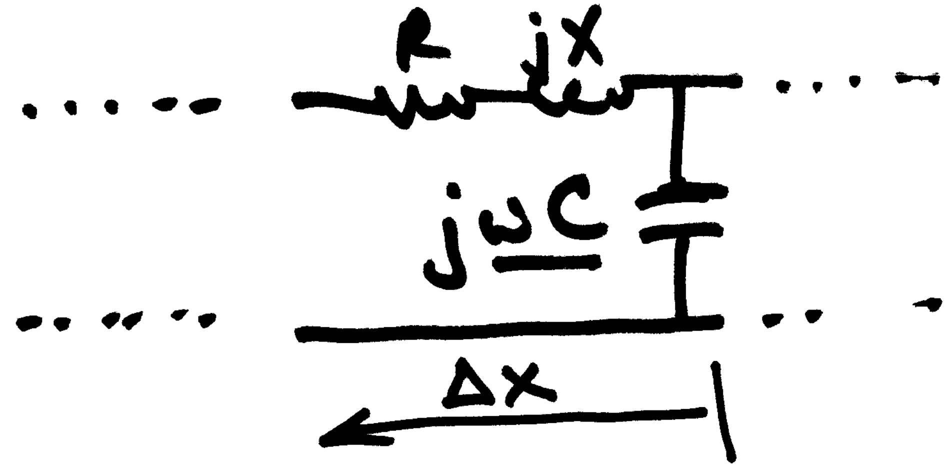
$$\bar{Z}_c = \sqrt{\frac{z}{y}}$$



Low X/R:



$$\bar{Z}_c = \sqrt{\frac{\bar{Z}}{\bar{y}}}$$



$$Z = R + jX_L \quad \text{per unit length}$$

$$y = jB_c = j\omega C \quad \text{" " "}$$

<u>Observations:</u> for high X/R ratio:

$\bar{Z}_c \approx$ Real $\Rightarrow$ 100's kV: $X/R = 10\text{-}20$

$\Rightarrow$ 10's kV: $X/R \leq 1$

$\bar{Z}_c$

Propagation Wavelength λ

λ = distance req'd to change $\angle V$ by 360°.

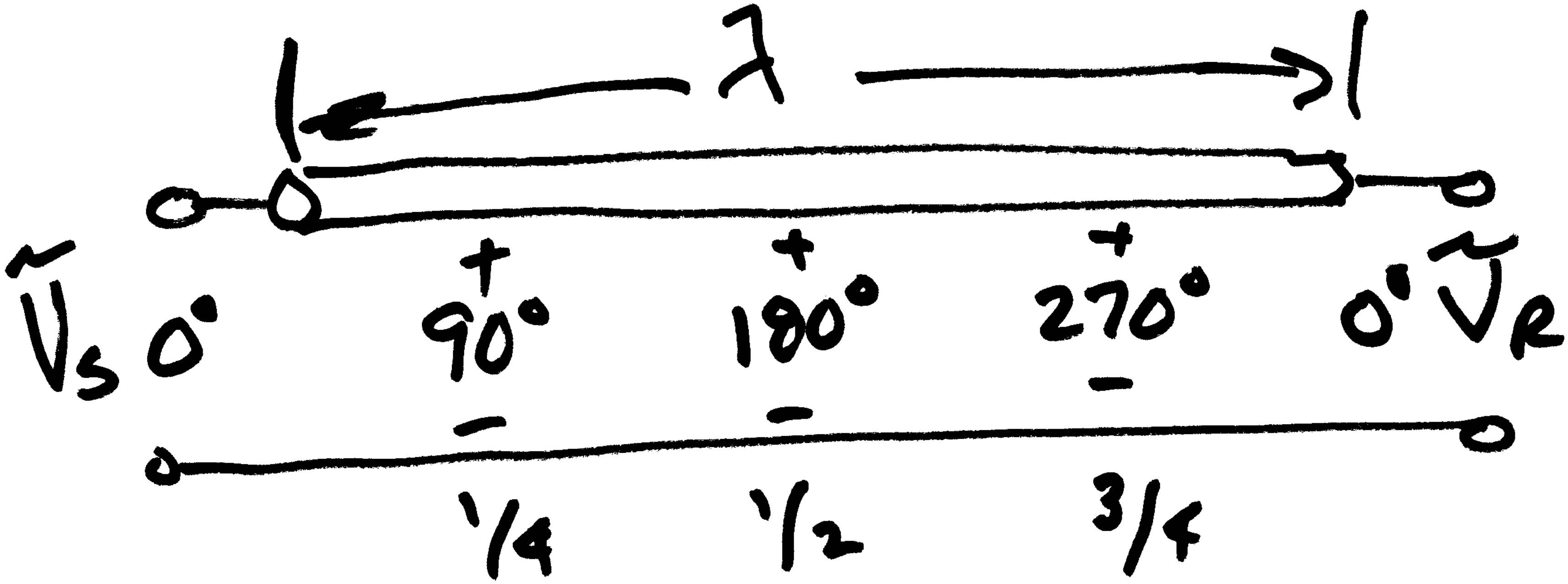
$$\gamma = \sqrt{zy} = \underbrace{\cancel{\alpha}_{\to 0} + j\beta}_{\text{per unit length}} \quad \text{(Assume Lossless)}$$

$e^{j\beta x}$: term provides phase rotation in each term of $I(x)$, $V(x)$.

$$\lambda = x = \frac{2\pi}{\beta} \Rightarrow \lambda = \frac{2\pi}{\omega\sqrt{LC}} = \frac{2\pi}{2\pi f\sqrt{LC}}$$

$$\boxed{\lambda = \frac{1}{f\sqrt{LC}}}$$

$$\boxed{v = f\lambda} = \frac{1}{\sqrt{LC}} = 3\times10^8 \text{ m/s} = \frac{1}{\sqrt{\epsilon_0\mu_0}}$$


λ
Ṽs 0°
90°
180°
270°
0° ṼR
1/4
1/2
3/4

@ 60 Hz, $\lambda = \dfrac{v}{f} = \dfrac{3\times10^8 \text{ m/s}}{60}$

$\cong 5000$ Km

<u>BPL</u>: <u>2-40 MHz</u> $\cong 3100$ miles

@ 2 MHz, $\lambda = \dfrac{3\times10^8}{2\times10^6} =$ 150 m [redacted] [redacted]

- Side Comments (later) on
[redacted] T-line loading limits

1) - Thermal
2) - Voltage Limits, V_s & $V_R \Rightarrow VR$
$.95 < V < 1.05$
3) - Stability Limits

(From Lecture 15)

$$\overset{v}{V(x)} = \overset{v^+}{\left(\frac{V_R + Z_c I_R}{2}\right)} e^{\gamma x} + \overset{v^-}{\left(\frac{V_R - Z_c I_R}{2}\right)} e^{-\gamma x}$$

$$\overset{i}{I(x)} = \overset{i^+}{\left(\frac{V_R + Z_c I_R}{2}\right)} e^{\gamma x} - \overset{i^-}{\left(\frac{V_R - Z_c I_R}{2}\right)} e^{-\gamma x}$$

best for trav. waves.

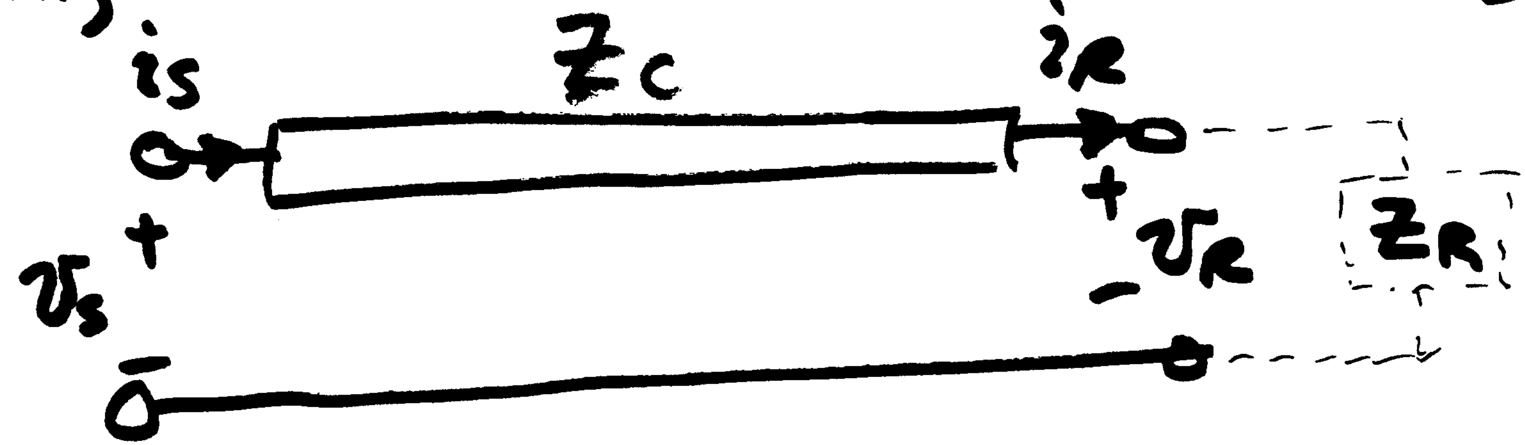
$$Z_c = \sqrt{\frac{z}{y}} = \text{Characteristic Impedance.}$$

$$\gamma = \sqrt{zy} = \alpha + j\beta = \text{Propagation Coefficient}$$

α = attenuation constant

β = angular propagation constant

Travelling Waves

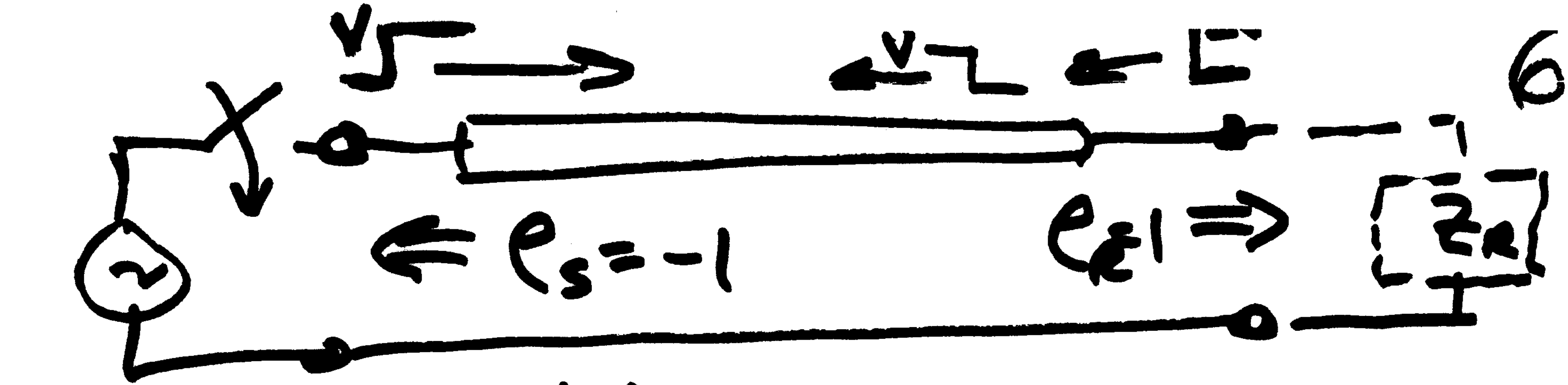


Impedance at receiving end:

$$Z_R = \frac{v_R}{i_R} = \frac{v_R^+ + v_R^-}{i_R^+ + i_R^-} = \frac{v_R^+ + v_R^-}{\frac{v_R^+}{Z_C} - \frac{v_R^-}{Z_C}} = Z_R$$

$$\frac{v_R^-}{v_R^+} = \boxed{\frac{Z_R - Z_C}{Z_R + Z_C} = \rho_R}$$

Reflection Coefficient



If receiving end is...

- Open-ckt (i.e. $Z_R = \infty$)

$$\rho_R = \frac{\infty - Z_c}{\infty + Z_c} = +1$$

$$\therefore \; v_R^- = v_R^+ \rho_R = v_R^+$$

- Short-ckt (i.e. $Z_R = 0$)

$$\rho_R = \frac{0 - Z_c}{\infty + Z_c} = -1$$