Topics for Today:

- Announcements
  - Software: online students - apply for ATP/ATPDraw license, verify licensing when you receive it by e-mail, and we will mail you the install CD.
  - Office hrs: 2-3pm M,W,F
  - Office: EERC 614. Phone: 906.487.2857
  - Book exercises from Ch.6,7 solutions posted

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
\[ Z_c = \sqrt{\frac{\Xi}{Y}} \quad \text{Imp per unit length} \]

\[ X = \sqrt{Z \cdot Y} = \alpha + j\beta \]

Phase angle rotation

Has a wave travels down line.

Attenuation

Diagram of a circuit with labels:
- \( S \)
- \( V_s \)
- \( Y' \)
- \( R \)
- \( Z' \)

Open Receiving End

\( \text{Reac} = Z_c \quad \text{(SIC)} \)

Full Load

Short Circuit
Another Point:

- $SIL = \text{Surge Impedance Loading}$

- $R_{\text{Load}} = |Zc|$

- Total Reactive Power Consumed in Line = 0.

$\rightarrow \text{"Flat" Line or flat voltage profile}$

- $SIL = \frac{V^2}{Zc} = \frac{V_s^2}{Zc} = \frac{V_k^2}{Zc}$
High: \( x = \sqrt{\frac{y}{2}} \)
\[ Z_c = \sqrt{\frac{Z}{jy}} \]

\[ Z = R + jX_c \] per unit length

\[ y = jB_c = j\omega C \]

Observations: for high \( X/R \) ratio:

\[ \bar{Z}_c \approx \text{Real} \implies 100\text{ s KVAR}: \frac{X}{R} = 10-20 \]

\[ \bar{Z}_c \implies 10\text{ s KVAR}: \frac{X}{R} \leq 1 \]
Propagation Wavelength $\lambda$

$\lambda = \text{distance req'd to change } \phi \text{ by } 360^\circ$

$T = \sqrt{2y} = \alpha + j\beta$ (Assume Lossless)

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

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

$v = \frac{1}{f \sqrt{LC}}$

$\omega = \frac{1}{\sqrt{LC}} = 3 \times 10^8 \text{ m/s} = \frac{1}{\sqrt{\varepsilon_0 \mu_0}}$
\[ \vec{V} \quad 0^\circ \quad 90^\circ \quad 180^\circ \quad 270^\circ \quad 0^\circ \vec{V_R} \]

\[ \frac{1}{4} \quad \frac{1}{2} \quad 3/4 \]
@ 60 Hz, \( \lambda = \frac{\nu}{f} = \frac{3 \times 10^8 \text{m/s}}{60} \)

**BPL:** 2-40 MHz \( \approx 5000 \text{ Km} \)
\( \approx 3100 \text{ miles} \)

@ 2 MHz, \( \lambda = \frac{3 \times 10^8}{2 \times 10^6} = 150 \text{ m} \)

- Side Comments (later) on T-line loading limits:
  1. Thermal
  2. Voltage Limits, \( V_s \& V_R \rightarrow \)_
  3. Stability Limits

\[ .95 < V < 1.05 \]
\[ V(x) = \left( \frac{V_R + Z_c I_R}{2} \right) e^{\gamma x} + \left( \frac{V_R - Z_c I_R}{2} \right) e^{-\gamma x} \]

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

\[ Z_c = \sqrt{\frac{\gamma}{y}} = \text{Characteristic Impedance} \]

\[ \gamma = \sqrt{\frac{1}{y}} = \alpha + j\beta = \text{Propagation Coefficient} \]

\[ \alpha = \text{Attenuation constant} \]

\[ \beta = \text{Angular propagation constant} \]
Travelling Waves

Impedance at receiving end:

\[ Z_R = \frac{V_R}{i_R} = \frac{V_R^+ + V_R^-}{i_R^+ + i_R^-} = \frac{V_R^+}{i_R^+} - \frac{V_R^-}{i_R^-} = Z_R \]

\[ \frac{V_R^-}{V_R^+} = \frac{Z_R - Z_c}{Z_R + Z_c} = \rho_R \]

Reflection Coefficient
If receiving end is open-circuit (i.e., \( Z_{e} = 0 \)),

\[
\text{If receiving end is open-circuit (i.e., } Z_{e} = 0 \text{),}
\]

\[
E_{r} = \frac{\Delta V}{8} = \frac{1}{8} (V_{r} + E_{r})
\]

\[
E_{r} = V_{r} - 2V_{r} + E_{r} = 2V_{r}
\]

\[
E_{t} = \frac{V_{t}}{r + 2e}
\]

- Short-circuit (i.e., \( Z_{e} = 0 \))

\[
E_{r} = \frac{V_{r}}{r - 2e}
\]