EE 5220 - Lecture 14 Wednesday Feb 7, 2024

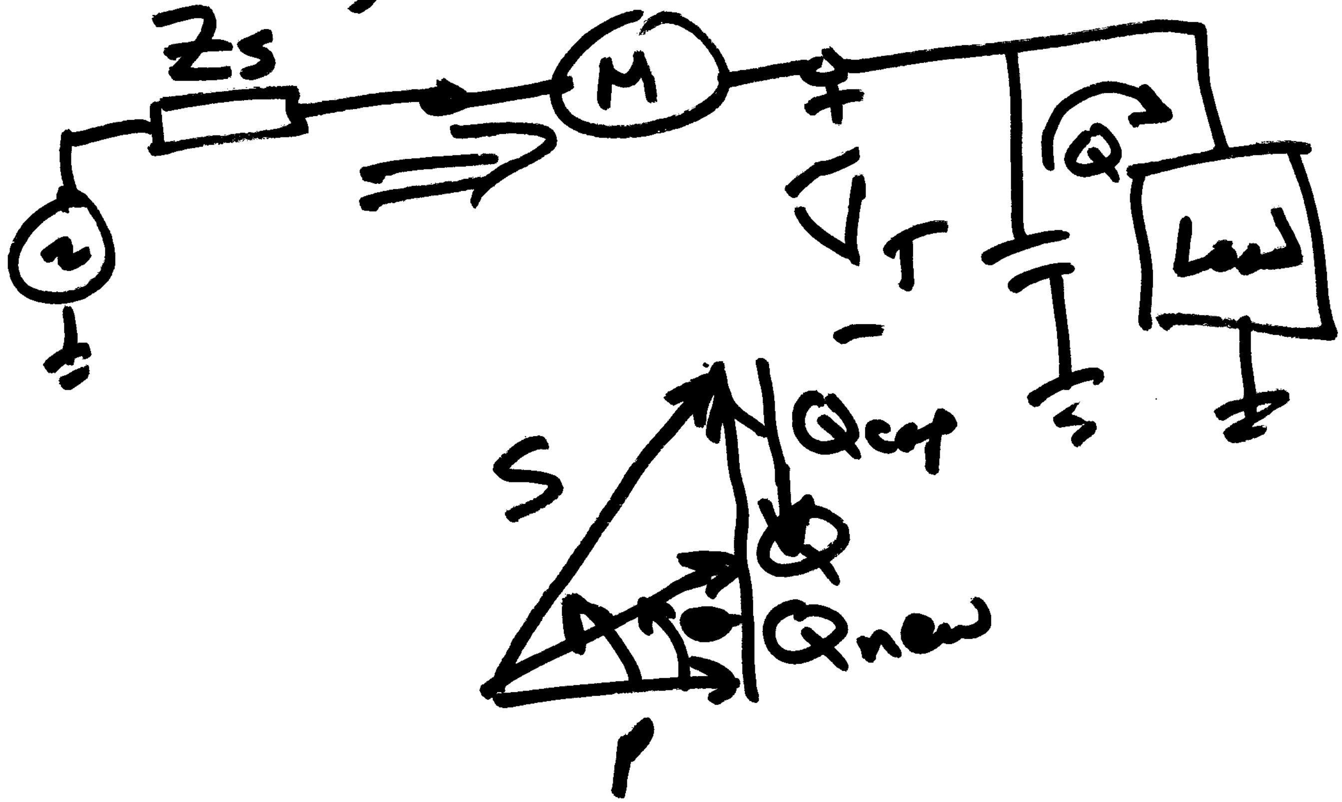
Topics for Today:

- Course Info:
    - Web page: https://pages.mtu.edu/~bamork/ee5220/index.htm
    - Software - Matlab. ATP/EMTP [License - www.emtp.org] ATP tutorials posted on our course web page
    - EE5220-L@mtu.edu (participation = min of half letter grade, 5%)

- HW#5 will be posted. Partnered exercise. Due latest Tues Feb 20th 9am.
    - Section 12.4 - detailed derivation for capacitor
    - Prob 5.3 - first do ATP simulation, then Hand Calculations
    - Prob 5.6
- Term Project - proposed topic(s) by end of next week, via short e-mail.
- Circuit Breakers - Interruption issues
    - Restrike
    - Reignition
- Cap and Reactor application (term projects similar to Hmwk4 are discouraged)
    - Dist system
    - Autotransformer tertiary
    - HV direct connection
- Transmission Lines - development of T-Line equations, traveling wave relays
- Transformers - hybrid model, inrush, GIC, ferroresonance

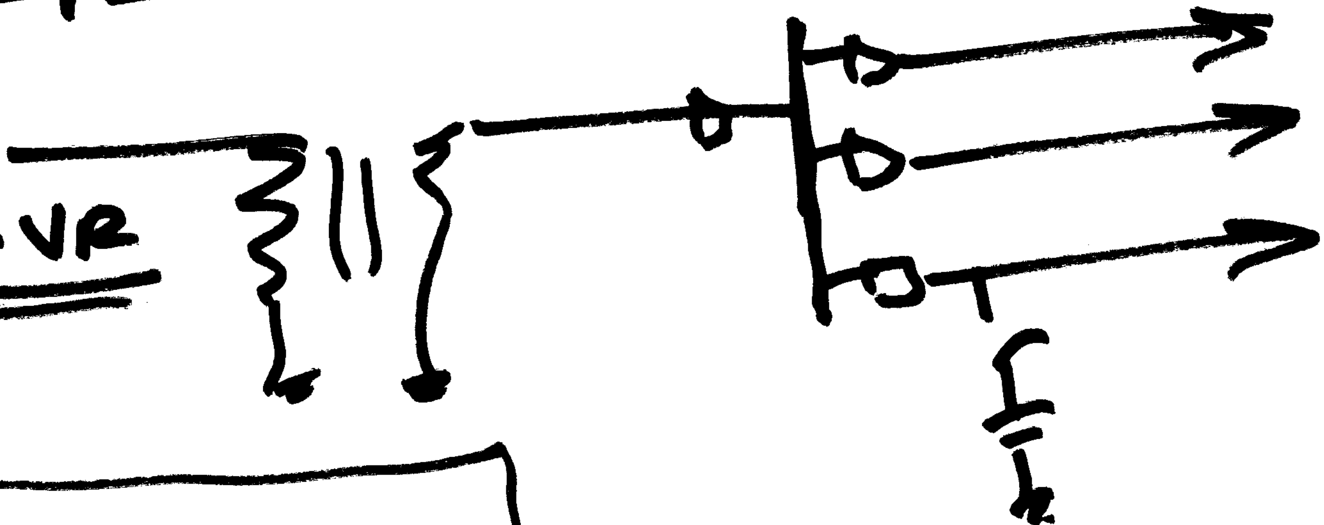
Cap Application

- LV, on customer side of meter
  ⇒ Penalty for Low P.F. ⇒ P.F. Correction



Compensation, VR.

Dist: VR



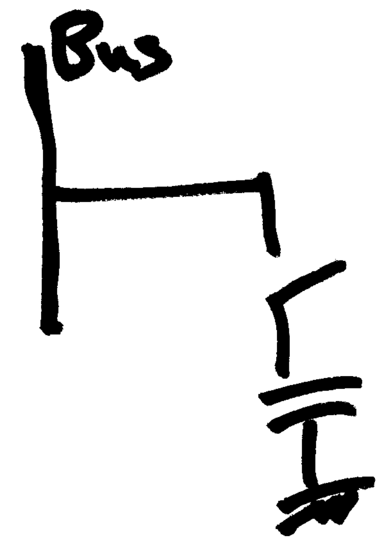
XFMR

Trans. Tie

L.V. Caps are cheaper to mfr.

Compensation

Shunt



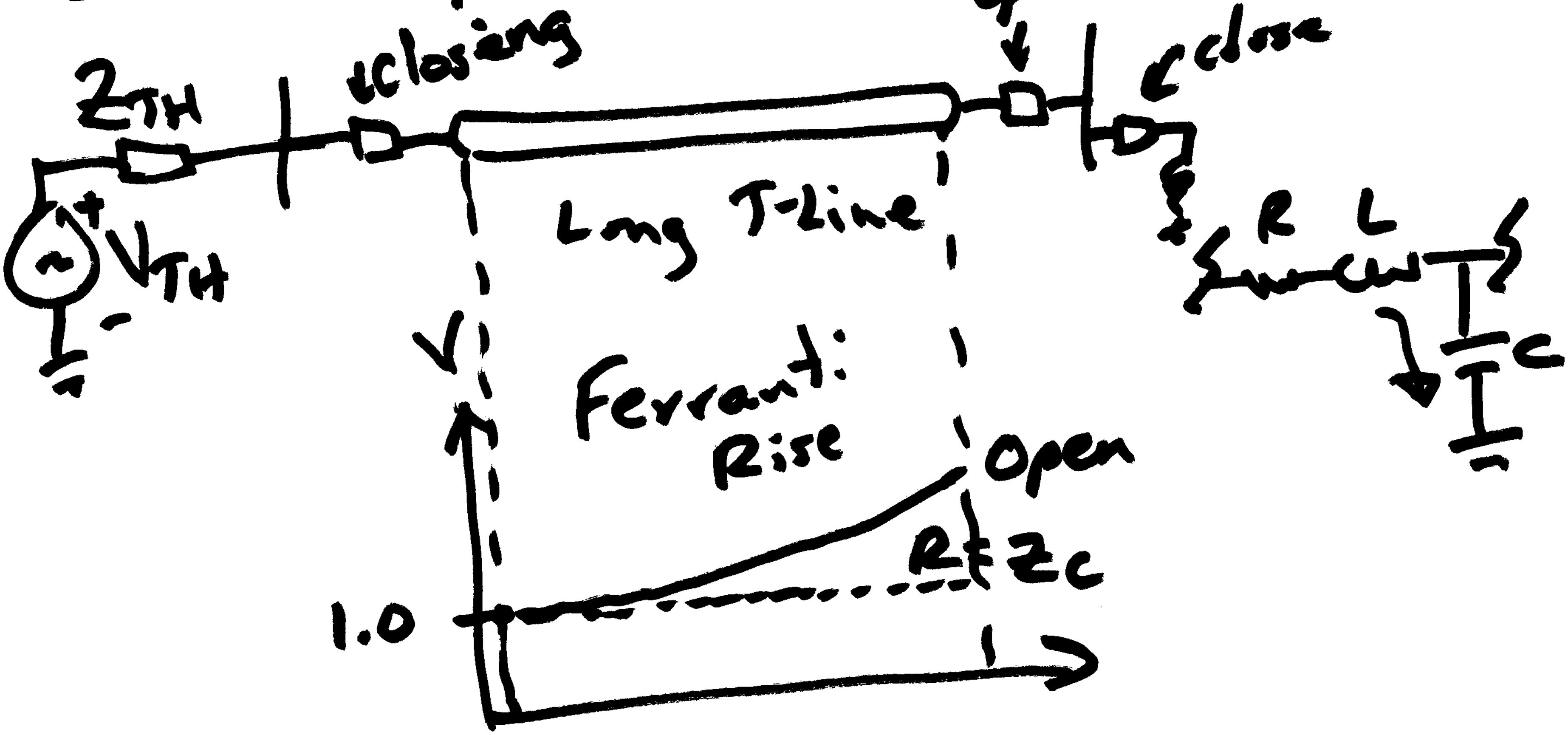
- Voltage Support
- Power Transfer

$$P_{1-2} = \frac{V_1 V_2}{X_{12}} \sin(\delta_1 - \delta_2)$$

21% increase
(.95 → 1.05 p.u. V)

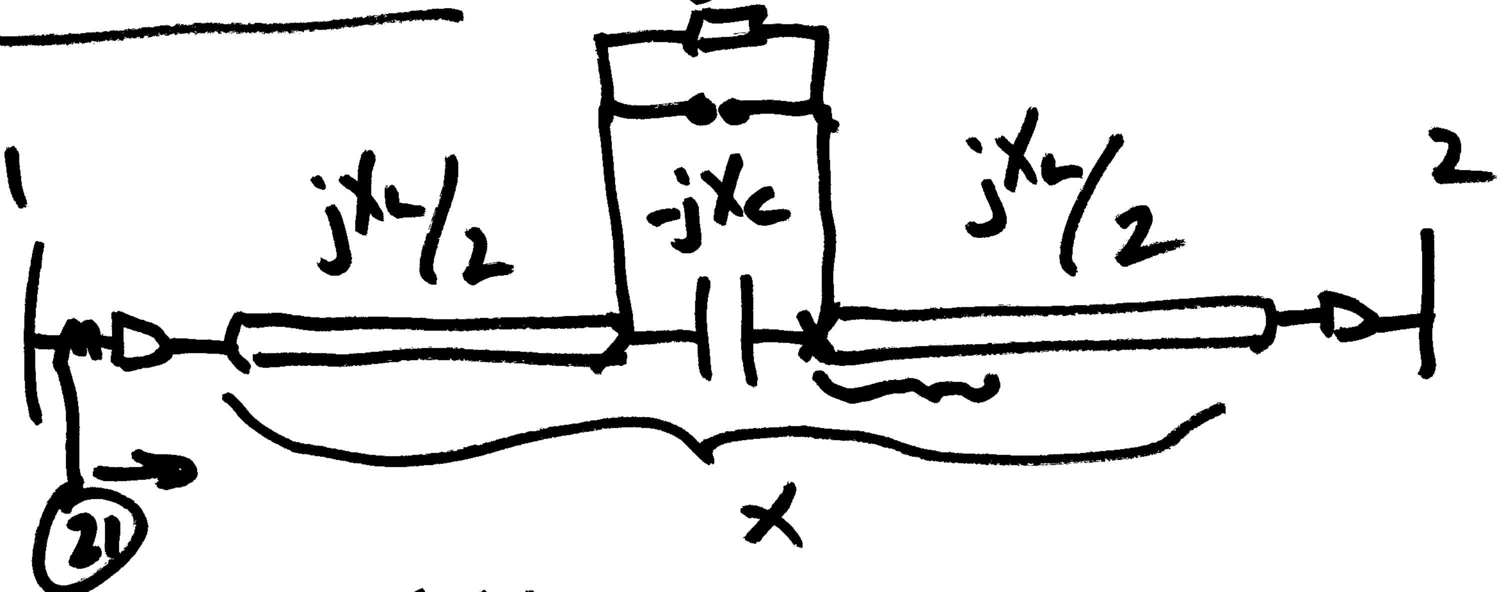
- Stability

Shunt Comp: Reactors



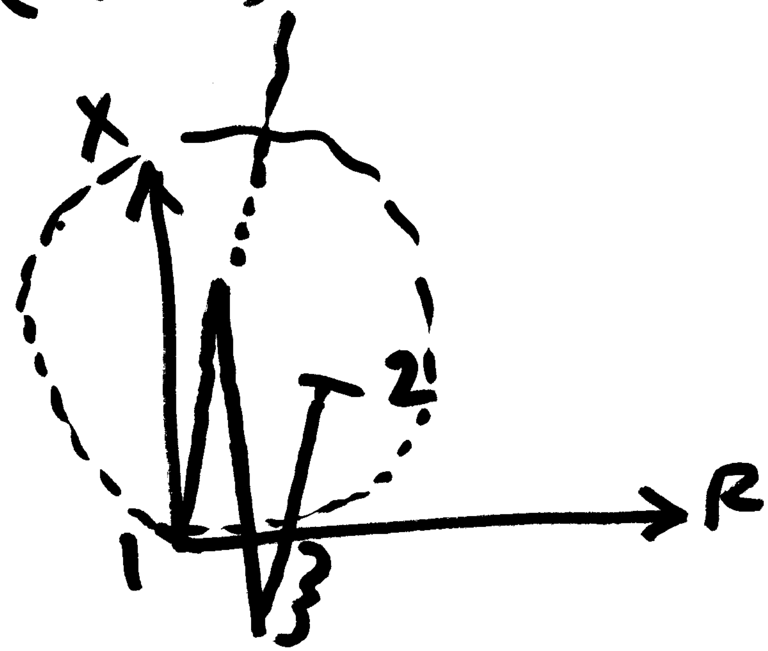
Ref: EE5200

Series Comp : C_{sa}

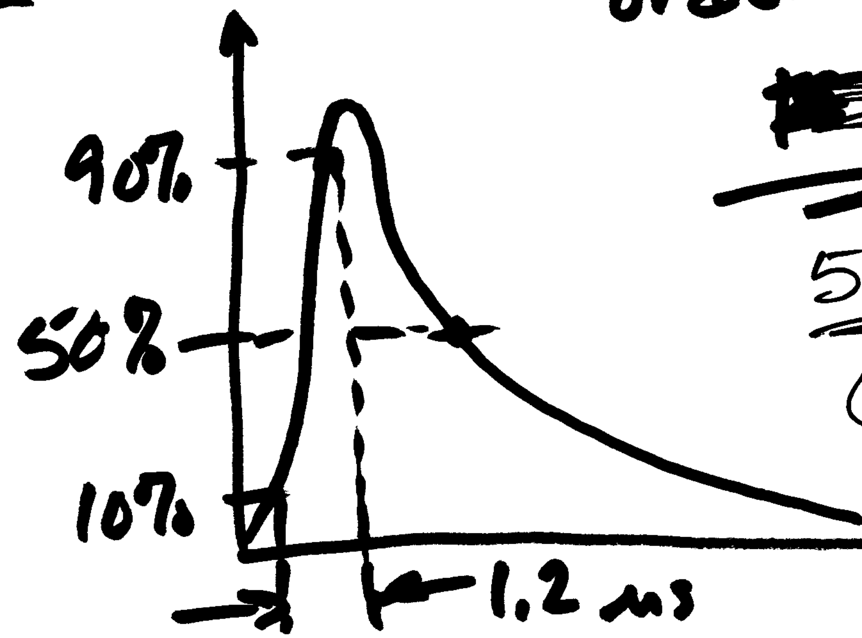


$$P_{1-2} = \frac{V_1 V_2}{X} \sin(\delta_1 - \delta_2)$$

X → $X_L - X_C$



Lightning –



order of ~~[illegible] MHz.~~

500 KHZ!

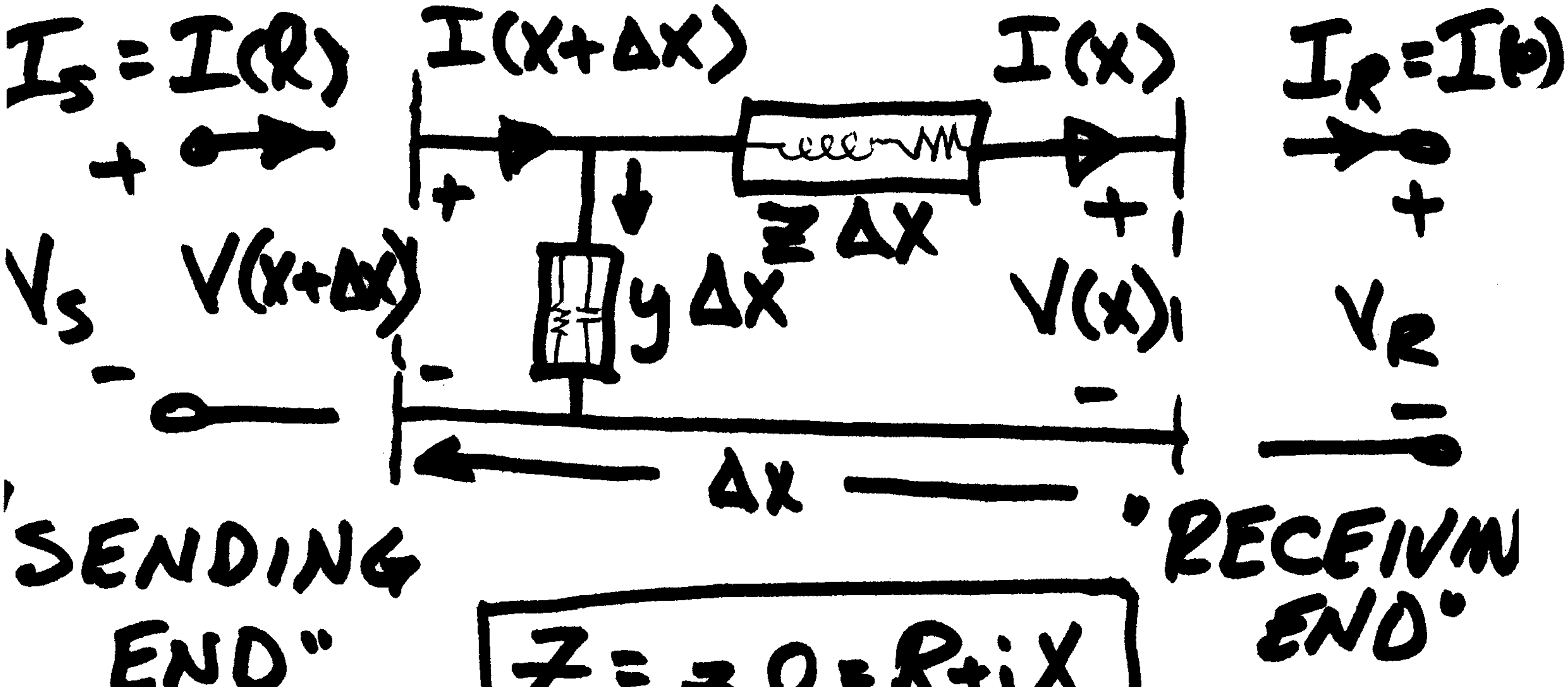
(half period ≅ 1 μs)

Switching –

DISTRIBUTED - PARAMER T-LINES

- "LONG LINES" (>250km @ 60Hz)
- FOR LIGHTNING, EVEN VERY SHORT LINES ARE MODELED AS DIST-PARAM.

FOR INCREMENTAL LENGTH:



$$Z = z\ell = R + jX$$
$$Y = y\ell = G + jB$$

Making ΔX very small,

(small Z)

$$\begin{cases} dV = IZ\,dx \\ dI = Vy\,dx \end{cases}$$

Rearranging,

$$\begin{cases} \dfrac{dV}{dx} = IZ & (1) \\ \dfrac{dI}{dx} = Vy & (2) \end{cases}$$

d/dx

Taking derivative of (1),

$$\frac{d^2V}{dx^2} = \frac{dI}{dx} Z$$

Substituting into (2)

$$\boxed{\frac{d^2 V}{dx^2} = V y z}$$

This implies gen'l sol'n:

$$\underline{V} = A_1 e^{\sqrt{yz}x} + A_2 e^{-\sqrt{yz}x}$$

Since $I = \frac{dV}{dx} / z$

$$I = A_1 \sqrt{\frac{y}{z}} e^{\sqrt{yz}x} - A_2 \sqrt{\frac{y}{z}} e^{-\sqrt{yz}x}$$

at $x = 0$, $V = V_R$, $I = I_R$

$$V(0) = V_R = A_1 + A_2$$

$$I(0) = I_R = \sqrt{\frac{y}{z}} A_1 - \sqrt{\frac{y}{z}} A_2$$

Defining $Z_c = \sqrt{\frac{z}{y}}$ = Char Imp.

$\gamma = \sqrt{yz}$ = Propagation Const.

$$V_R = A_1 + A_2$$

$$I_R = \frac{A_1 - A_2}{Z_c}$$

$\Rightarrow$

$$A_1 = (V_R + Z_c I_R)/2$$

$$A_2 = \frac{V_R - Z_c I_R}{2}$$

8

This form is best for traveling waves

Incident voltage — Reflected voltage

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

Incident current — Reflected Current

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

$$V_s = V(\ell) \leftarrow x = \ell$$

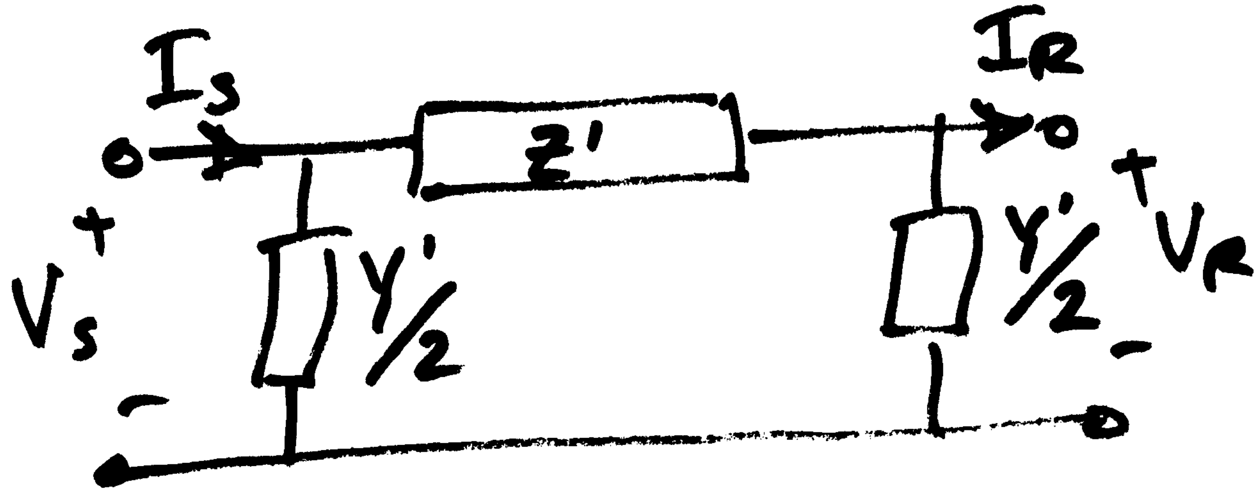
$$I_s = I(\ell)$$

This form is best for S-S 60 Hz using ABCD

$$V(x) = V_R \underbrace{\cosh(\gamma x)}_{A} + \underbrace{Z_c I_R \sinh(\gamma x)}_{B}$$

$$I(x) = \underbrace{\frac{V_R}{Z_c} \sinh(\gamma x)}_{C} + I_R \underbrace{\cosh(\gamma x)}_{D}$$

In hyperbolic form,



From EQNs:

$$\begin{bmatrix} V_S \\ I_S \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix}$$

If we match $\begin{bmatrix} A & B \\ C & D \end{bmatrix}$ with π-Equiv

$$Z' = Z\left[\frac{\sinh(\gamma l)}{\gamma l}\right]$$

$$\frac{Y'}{2} = \frac{Y'}{2}\left[\frac{\tanh(\gamma l/2)}{\gamma l/2}\right]$$