EE 5200 - Lecture 20

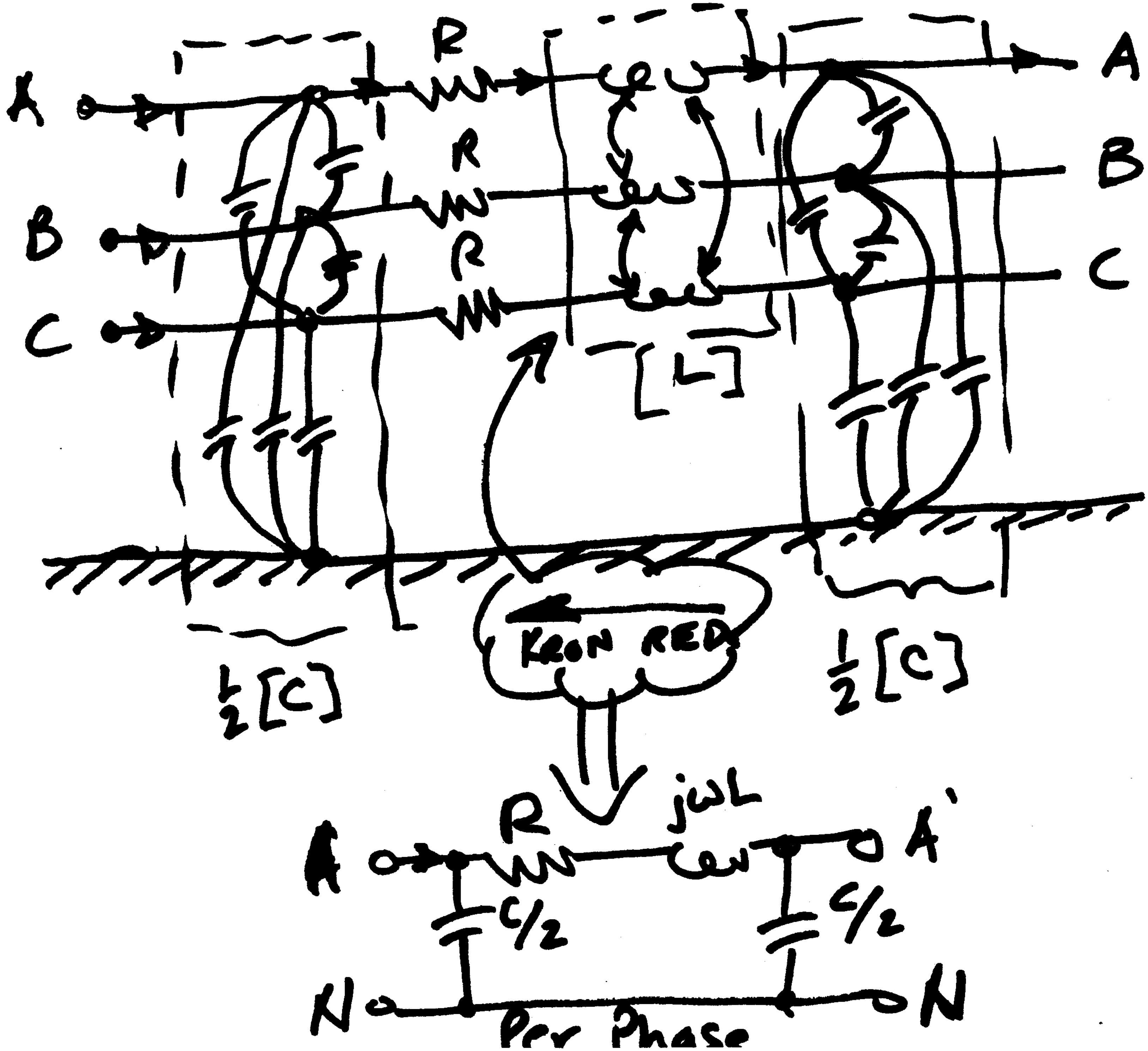
Wed Oct 16, 2019

Topics for Today:

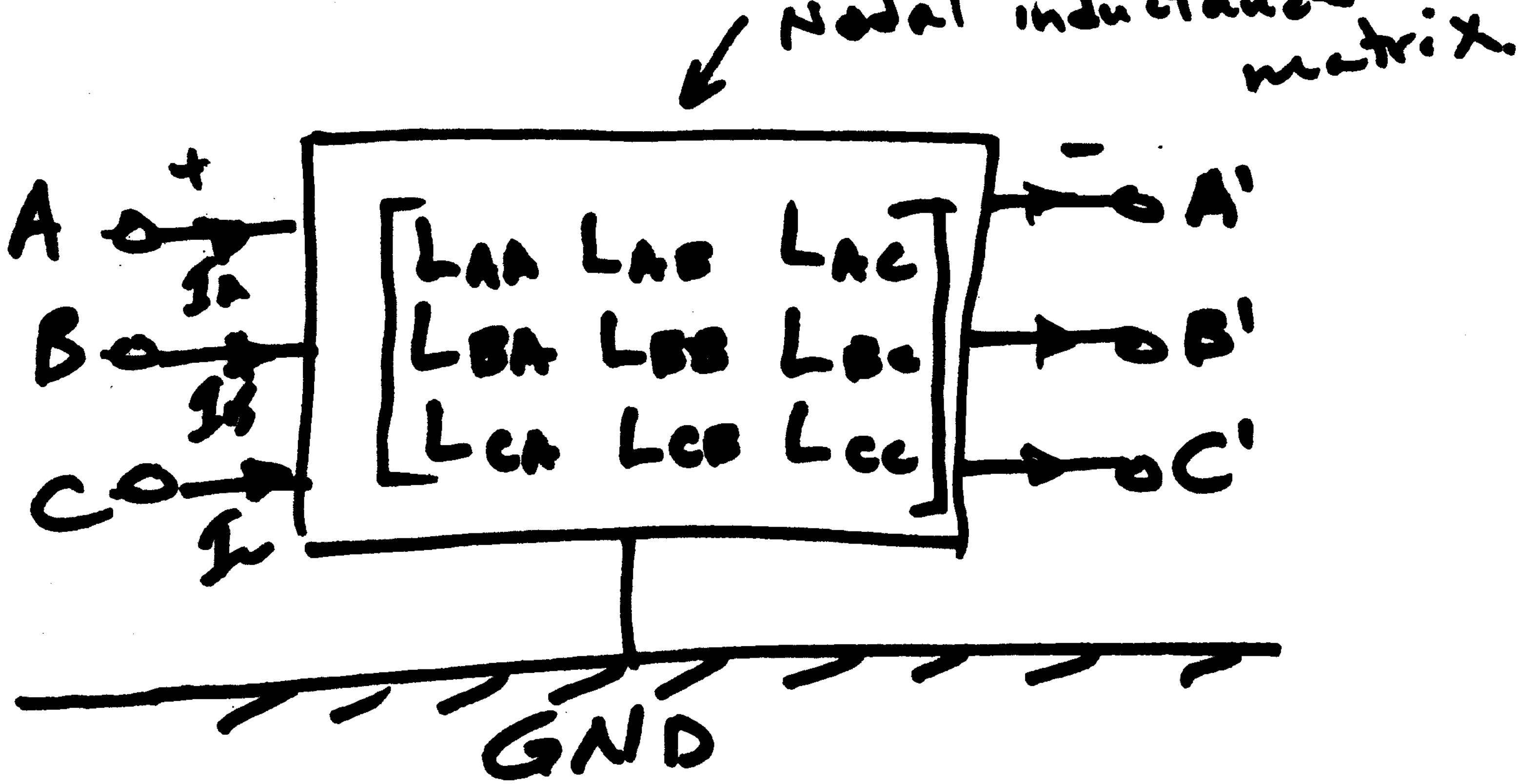
- Announcements - T-Line Hmwk due 9am Monday
  - ATP program: remote desktop to “remote.mtu.edu”
  - Office: EERC 614.   Phone: 906.487.2857
  - Recommended problems from Ch.6, solutions posted
  - Next: Transmission Lines as 2-port networks

Chapter 6 - Shunt Capacitance Transmission Lines

- Capacitance of 3-phase overhead lines, [C] matrix.
- Double-circuit 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 (L18).
  - Long Lines - more than 150 miles (240 km)
  - Derivation of long-line equations, meaning of equations
  - Characteristic Impedance Z_C
  - Propagation Constant $\gamma = \alpha + j\beta$



A
B
C
R
R
R
[L]
A'
B'
C'
½[C]
KRON RED
½[C]
R
jωL
A'
C/2
C/2
N
N
Per Phase

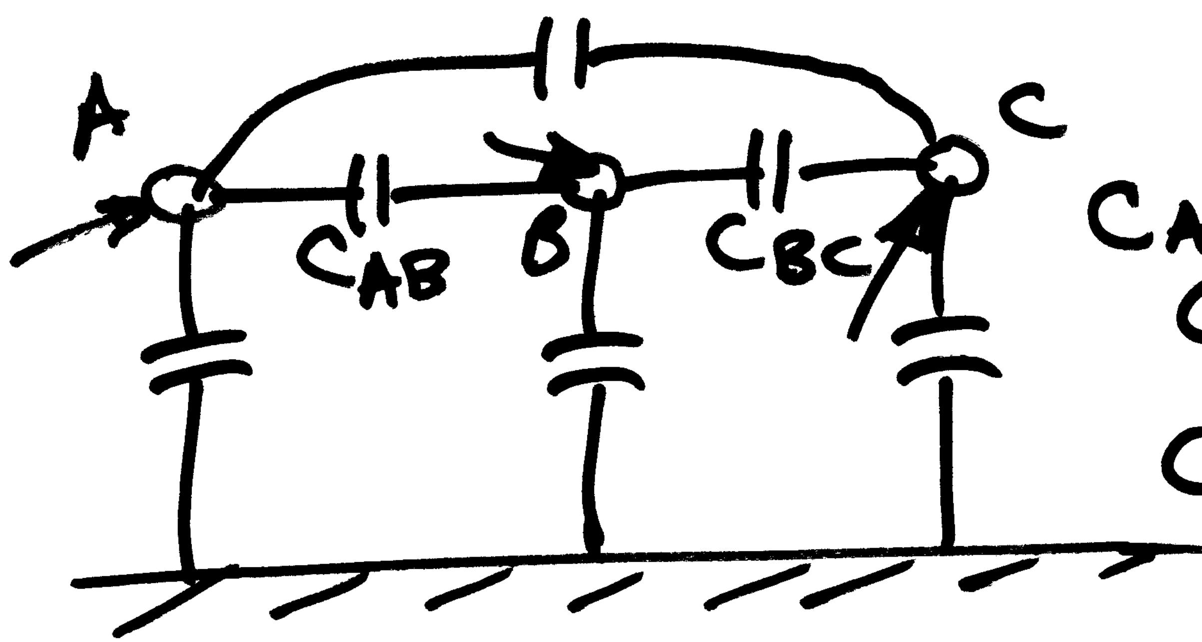


$$\begin{bmatrix} V_{A-A'} \\ V_{B-B'} \\ V_{C-C'} \end{bmatrix} = j\omega \begin{bmatrix} & & \\ & L & \\ & & \end{bmatrix} \begin{bmatrix} \tilde{I}_A \\ \tilde{I}_B \\ \tilde{I}_C \end{bmatrix}$$

$$\begin{bmatrix} V_{A-A'} \\ V_{B-B'} \\ V_{C-C'} \end{bmatrix} = j\omega \begin{bmatrix} L_{AA} & L_{AB} & L_{AC} \\ L_{BA} & L_{BB} & L_{BC} \\ L_{CA} & L_{CB} & L_{CC} \end{bmatrix} \begin{bmatrix} \tilde{\underline{I}}_A \\ \tilde{\underline{I}}_B \\ \tilde{\underline{I}}_C \end{bmatrix} + \begin{bmatrix} R_{AA} & 0 & 0 \\ 0 & R_{BB} & 0 \\ 0 & 0 & R_{CC} \end{bmatrix} \begin{bmatrix} I_A \\ I_B \\ I_C \end{bmatrix}$$

Capacitance

$C \propto \ln \frac{r}{D}$



$C_{AC} < C_{AB}$ or C_{BC}

$[C]$

$[B] = \omega [C]$

$[Y] = j\omega [C]$
$= j [B]$

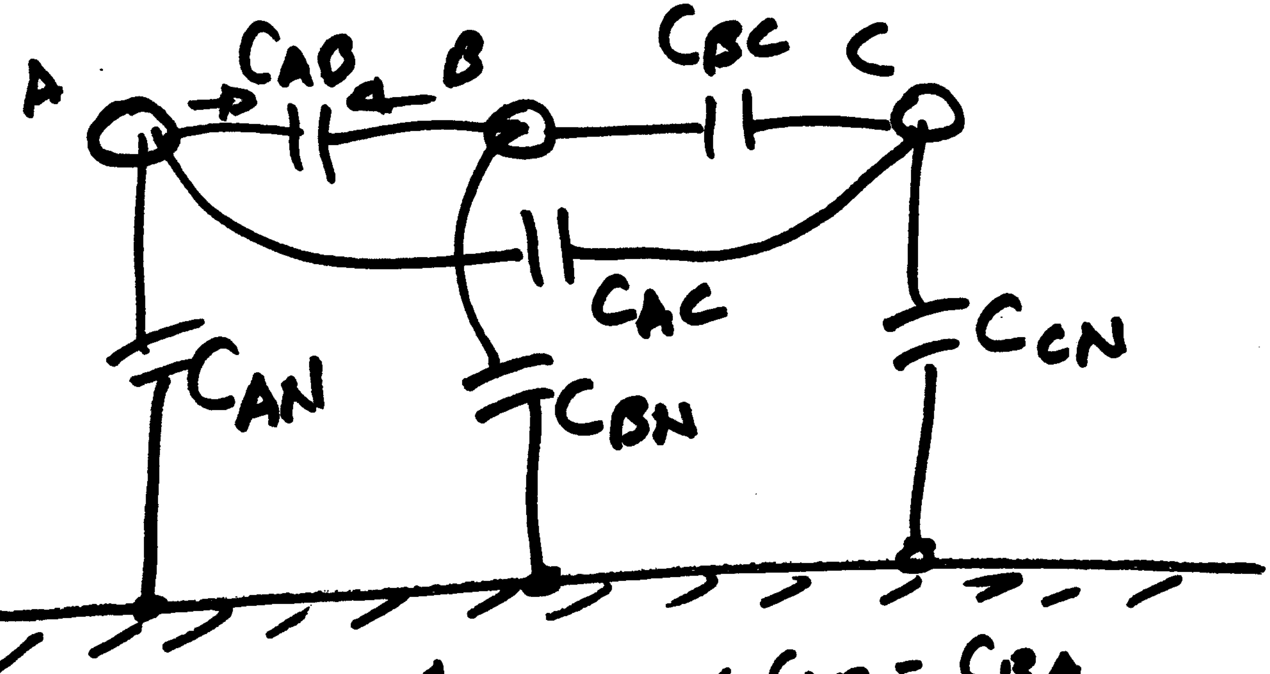
Full-Line
vs.
Half-Line (Pi-Equiv)

Line Charging Current

C_y Effects:

Note: $C_{AC} < C_{AB}, C_{BC}$

$y_{AB} = j\omega C_{AB}$

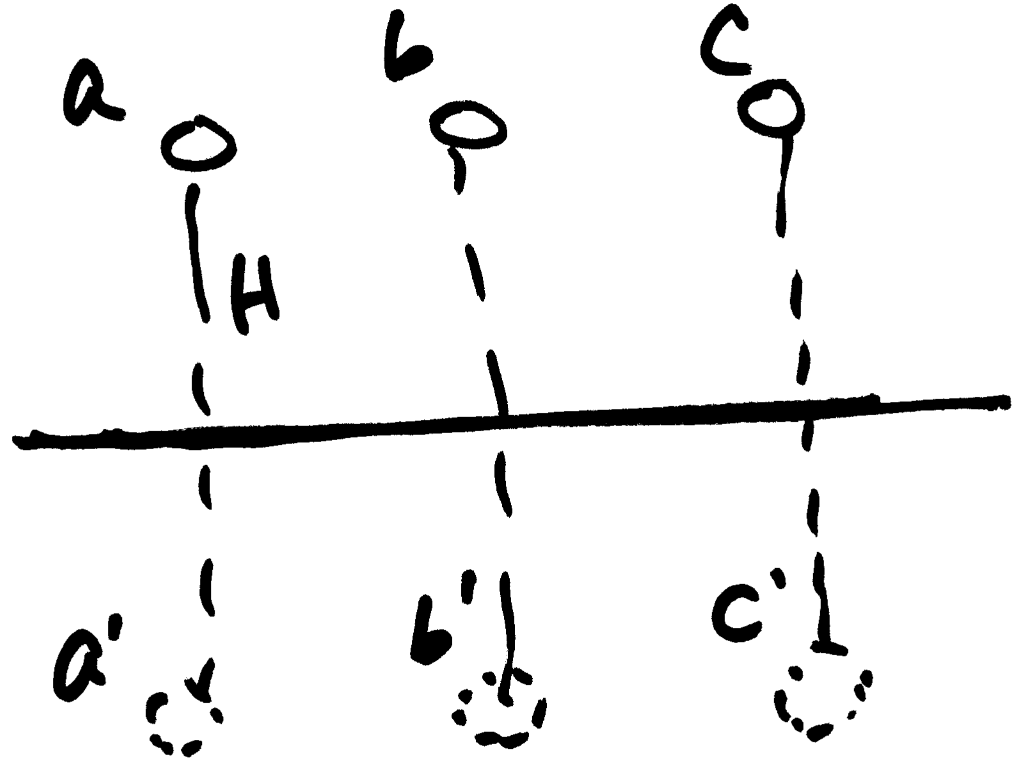


Full-Line Chg. Capacitance

$C_{AB} = C_{BA}$

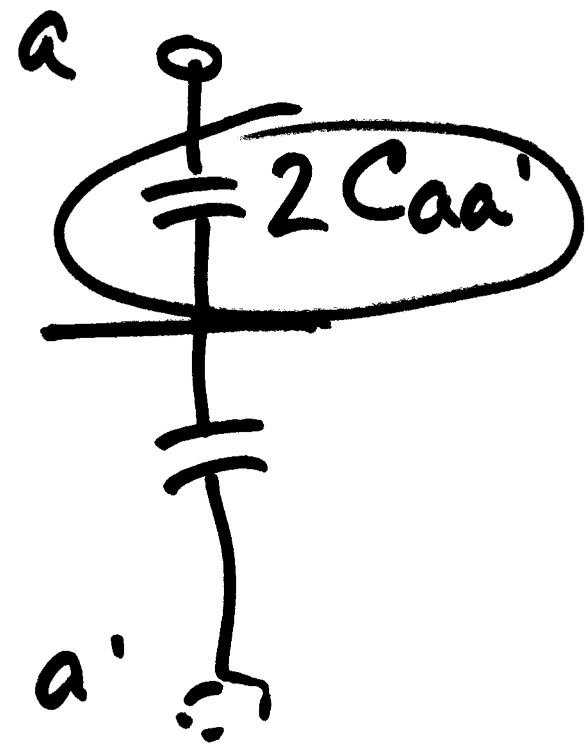
$$[C] = \begin{bmatrix} C_{AB}+C_{AC}+C_{AN} & -C_{AB} & -C_{AC} \\ -C_{BA} & C_{AB}+C_{BC}+C_{BN} & -C_{BC} \\ -C_{CA} & -C_{CB} & C_{BC}+C_{AC}+C_{CN} \end{bmatrix}$$

(C_{AA} = $C_{AB}+C_{AC}+C_{AN}$)

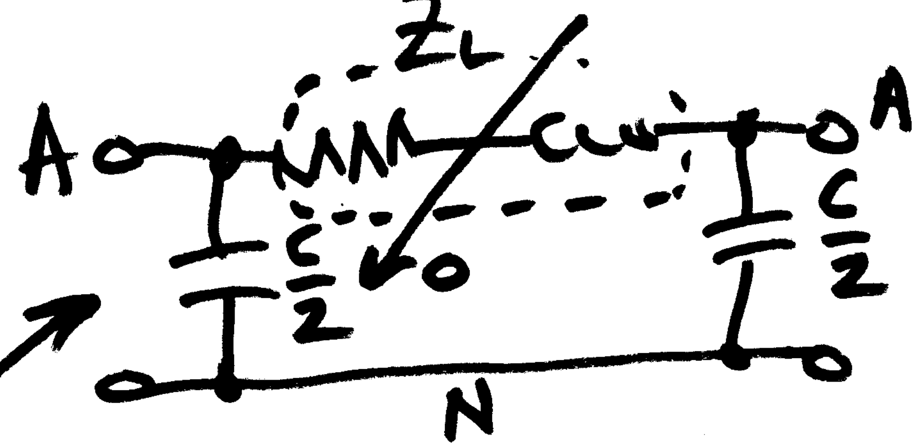


method of images.

$\Longrightarrow [C]$



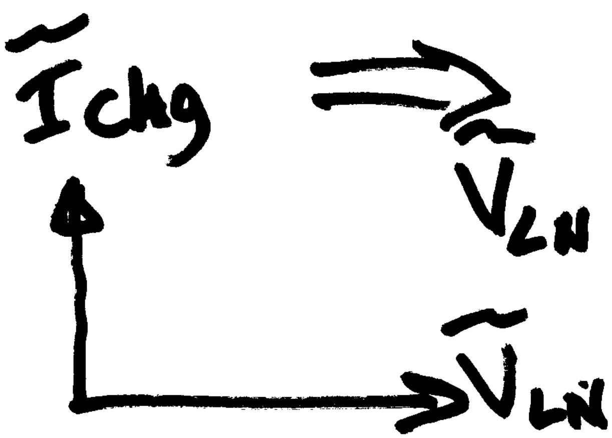
$$C_{aa'} = \frac{\pi \epsilon_0}{\ln \frac{2H}{r}} \text{ F/m}$$

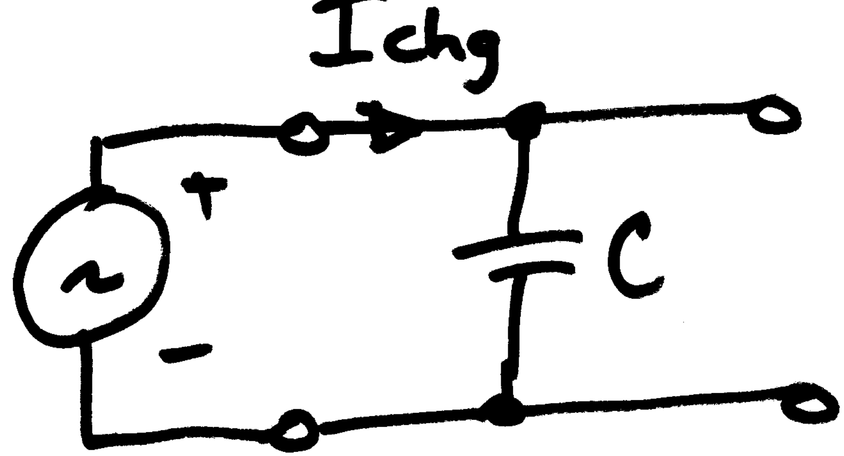


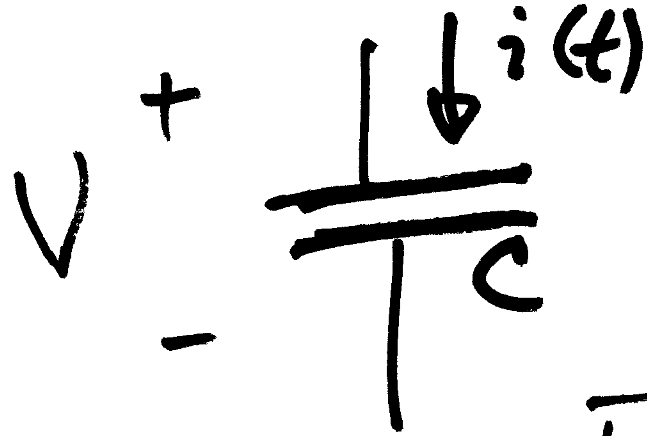
$+jB_c$

$$Z = \frac{1}{j\omega C/2} = -jX_c$$

$$\left|-jX_c\right| >> \left|Z_L\right|$$

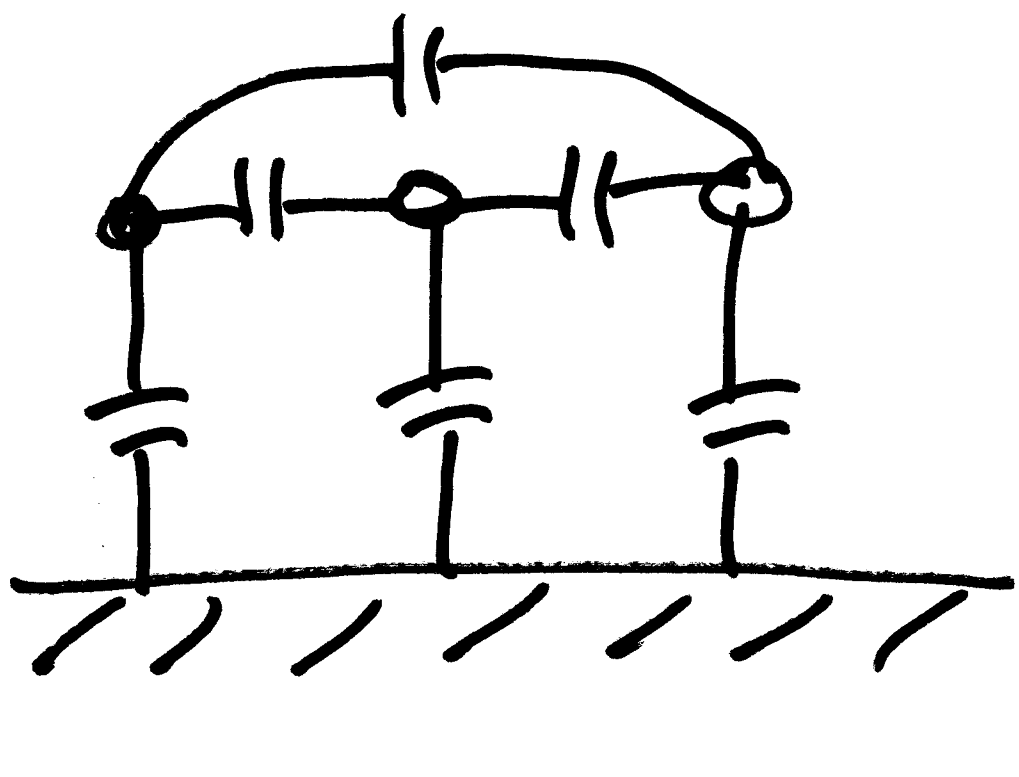






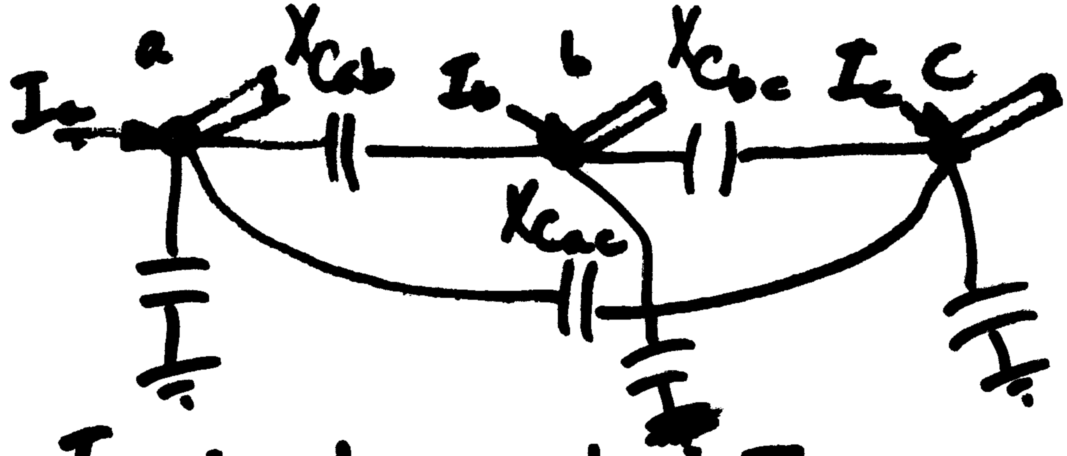
$$C = \frac{Q}{V}$$

$$i(t) = C\frac{dv(t)}{dt}$$



$Z = \frac{1}{j\omega C}$

Apply Bal. 3φ Source Voltage.



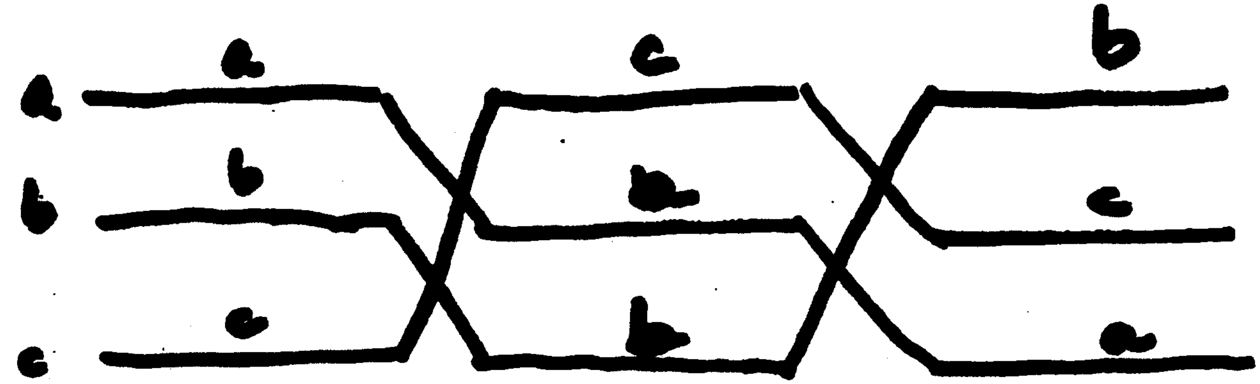
$C \propto \ln \frac{r}{D}$.

$L \propto \ln \frac{D}{r'}$.

I_b is larger than I_a or I_c

$|I_a| = |I_c|$ .... 120° phase shift.

Solution: Transposition, then all $I_{a,b,c}$ are equal.

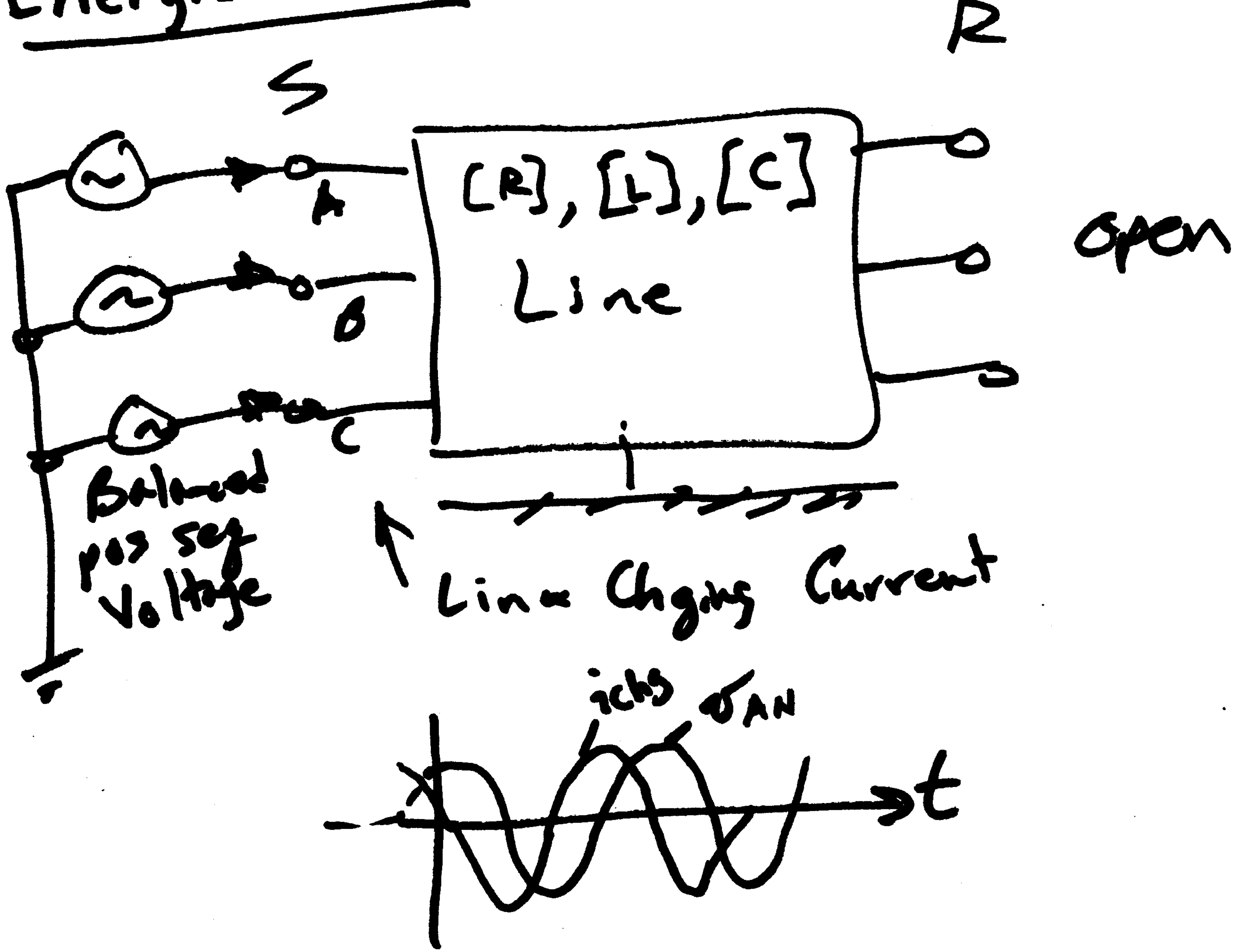


D = phase spacing
r = radius

$$C \propto \ln \frac{r}{D} \Rightarrow \{C_{AB} \text{ or } C_{BC}\} > C_{AC}$$

$$L \propto \ln \frac{D}{r}$$

Energize Line:

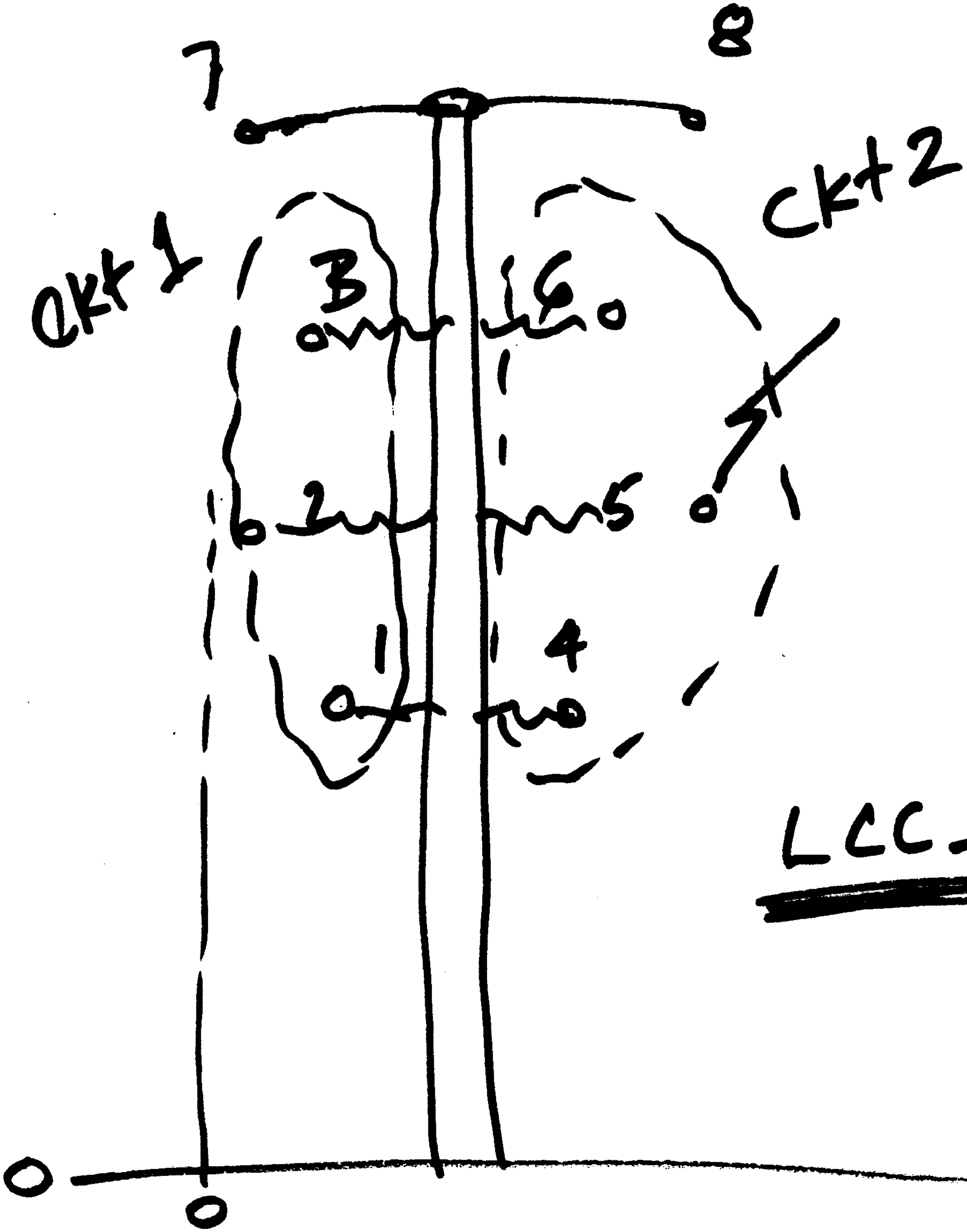


$$[Z_p] = \begin{bmatrix} Z_{AA} & Z_{AB} & Z_{AC} \\ Z_{BA} & Z_{BB} & Z_{BC} \\ Z_{CA} & Z_{CB} & Z_{CC} \end{bmatrix}$$

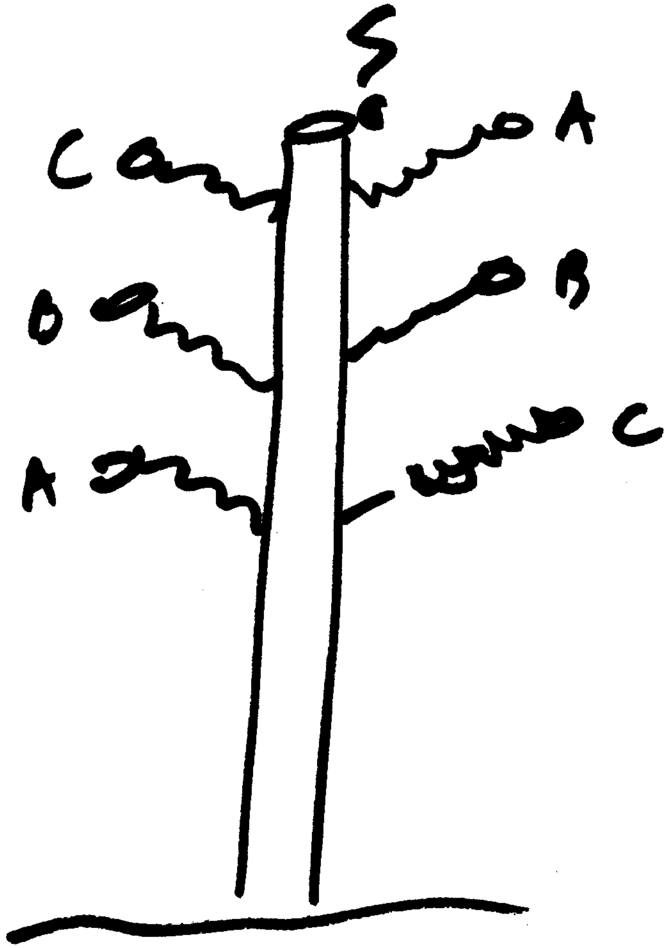
$$[Z_s] = A^{-1}[Z_p]A$$

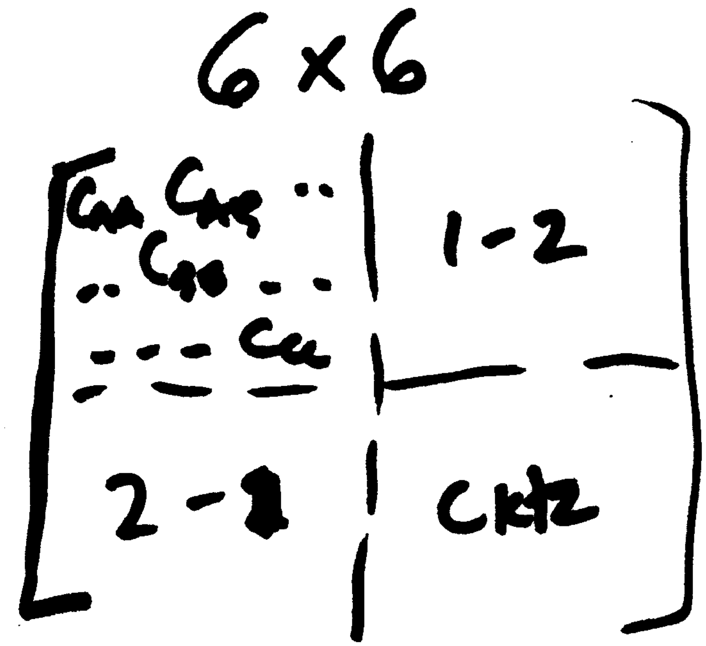
$$[Z_p] = A[Z_s]A^{-1}$$

$$\Rightarrow [Z_s] = \begin{bmatrix} Z_{00} & Z_{01} & Z_{02} \\ Z_{10} & Z_{11} & Z_{12} \\ Z_{20} & Z_{21} & Z_{22} \end{bmatrix}$$



LCC_6.alc





Double-Circuit Lines

$$[C] = \begin{bmatrix} \otimes & \times & \times \\ \times & \otimes & \times \\ \times & \times & \otimes \end{bmatrix}$$

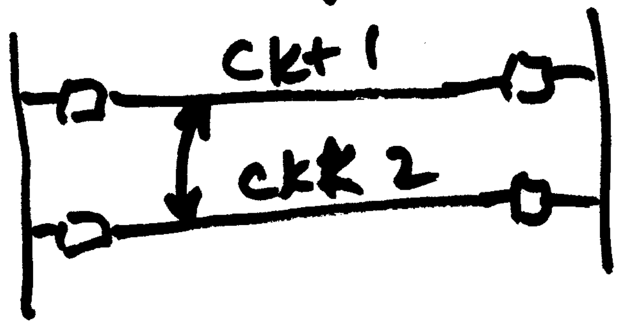
Fully Decoupled:

$$[Z_s] = \begin{bmatrix} Z_{00} & 0 & 0 \\ 0 & Z_{11} & 0 \\ 0 & 0 & Z_{22} \end{bmatrix}$$

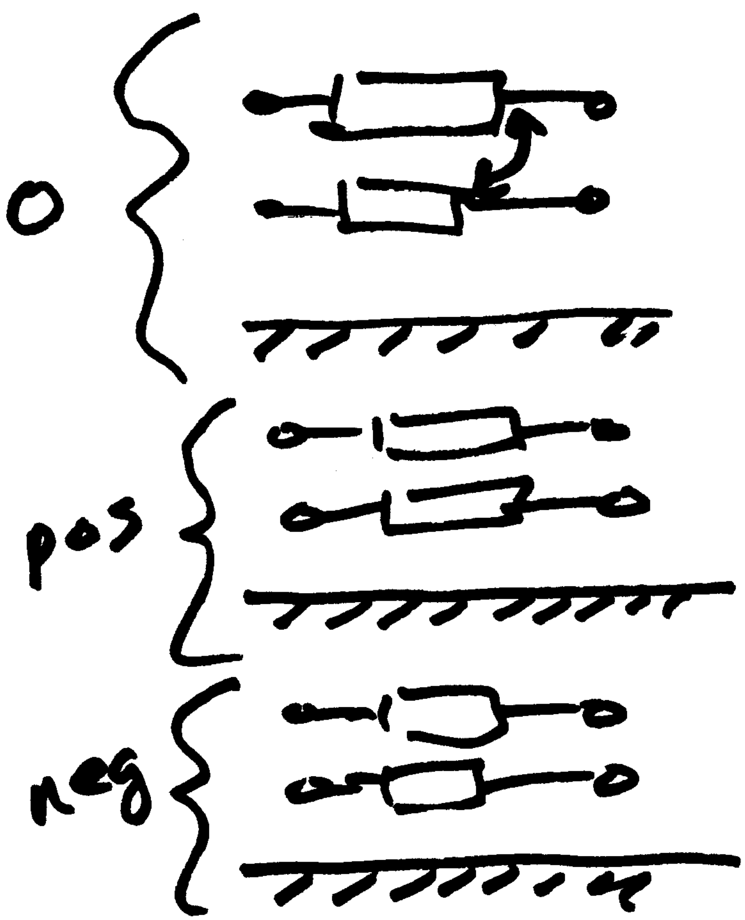
$Z_{00} = Z_0$, $Z_{11} = Z_1$, $Z_{22} = Z_2$

only if Z_A, Z_B, Z_C are equal (Balanced)

Series Impedance
$R + j\omega L$

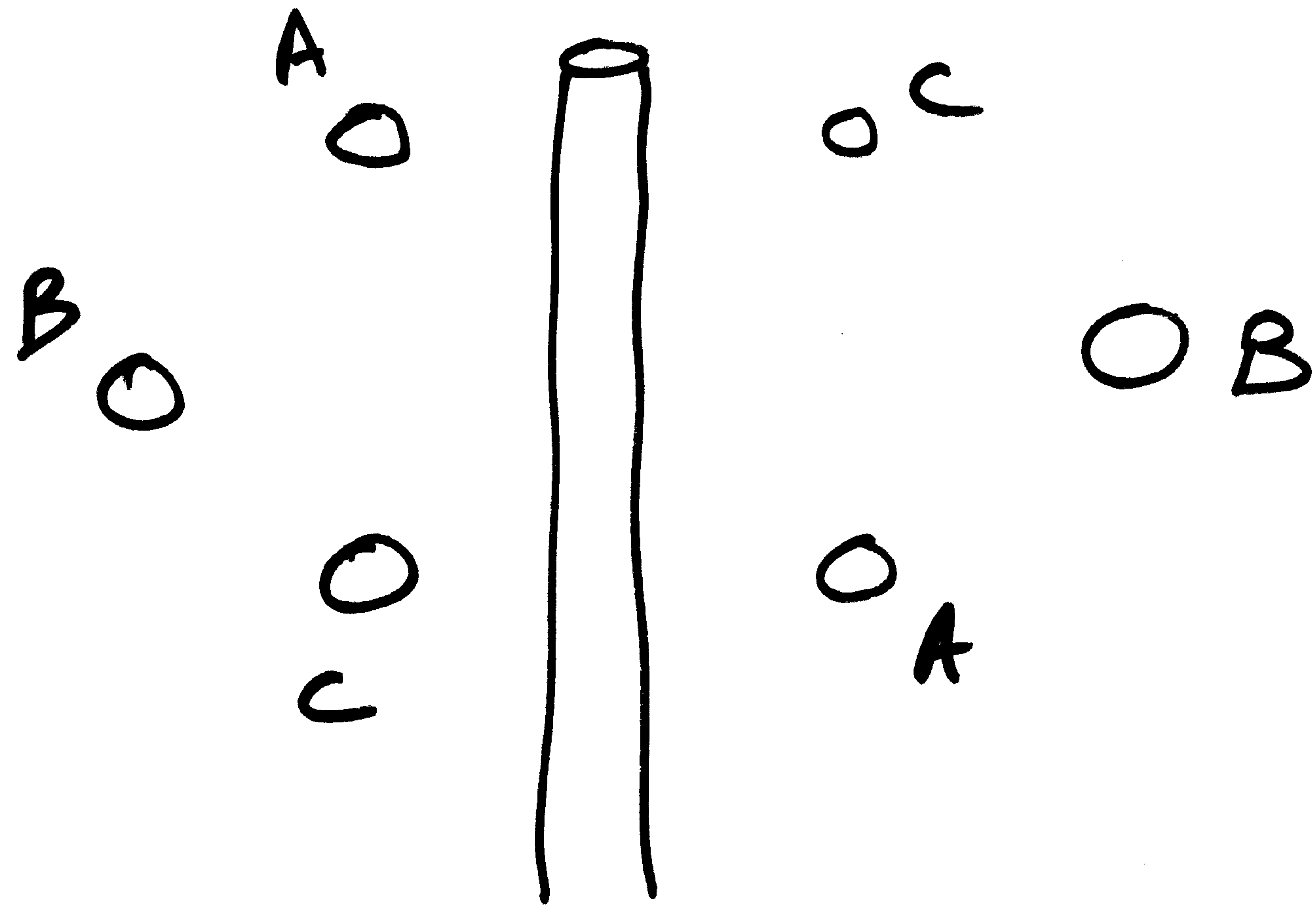


$$\begin{bmatrix} Z_{AA} & & & & 1\text{-}2 & \\ & Z_{BB} & & & & \\ & & Z_{CC} & & & \\ & & & Z_{AA} & & \\ & 2\text{-}1 & & & Z_{BB} & \\ & & & & & Z_{CC} \end{bmatrix}$$

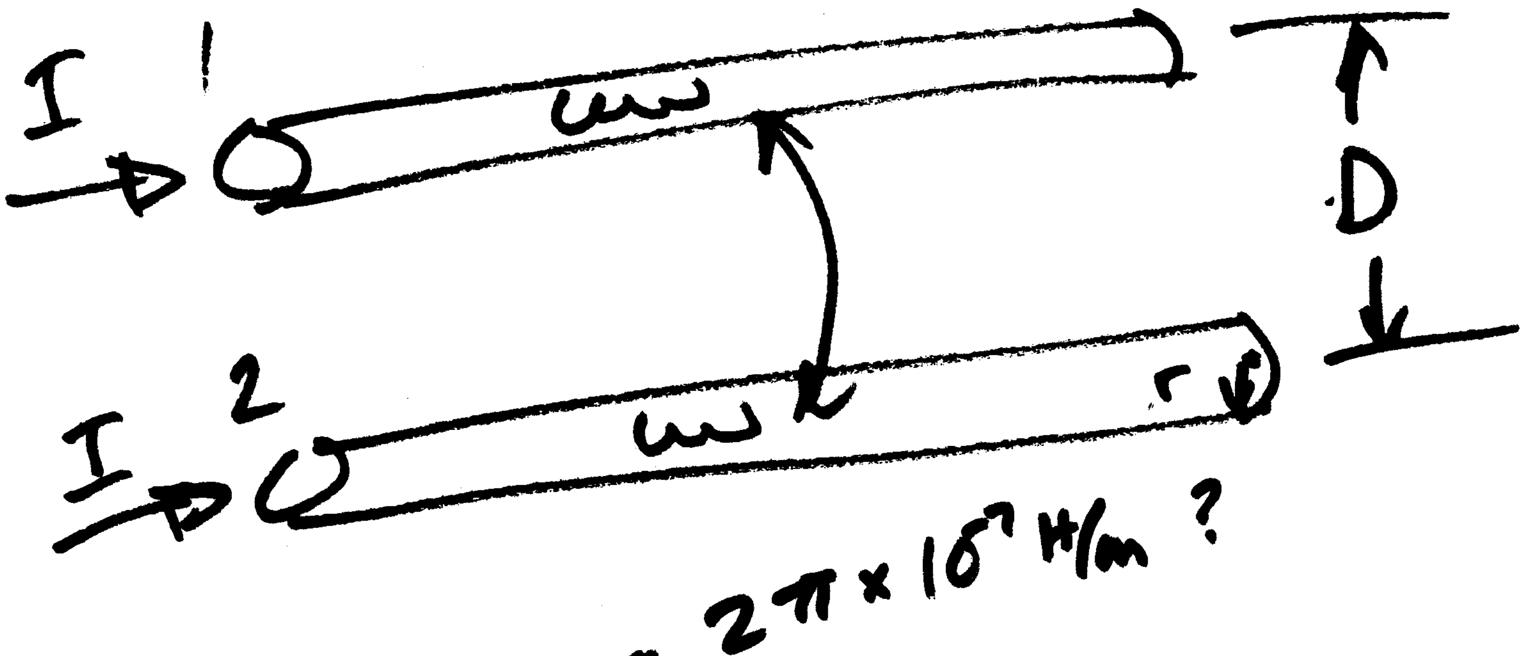


$\Downarrow$ phase [redacted] to seq transformation.

$$\begin{bmatrix} Z_{00} & 0 & 0 & Z_{00}^{1-2} & 0 & 0 \\ 0 & Z_{11} & 0 & 0 & 0 & 0 \\ 0 & 0 & Z_{22} & 0 & 0 & 0 \\ Z_{00}^{2-T} & 0 & 0 & Z_{00} & 0 & 0 \\ 0 & 0 & 0 & 0 & Z_{11} & 0 \\ 0 & 0 & 0 & 0 & 0 & Z_{22} \end{bmatrix}$$



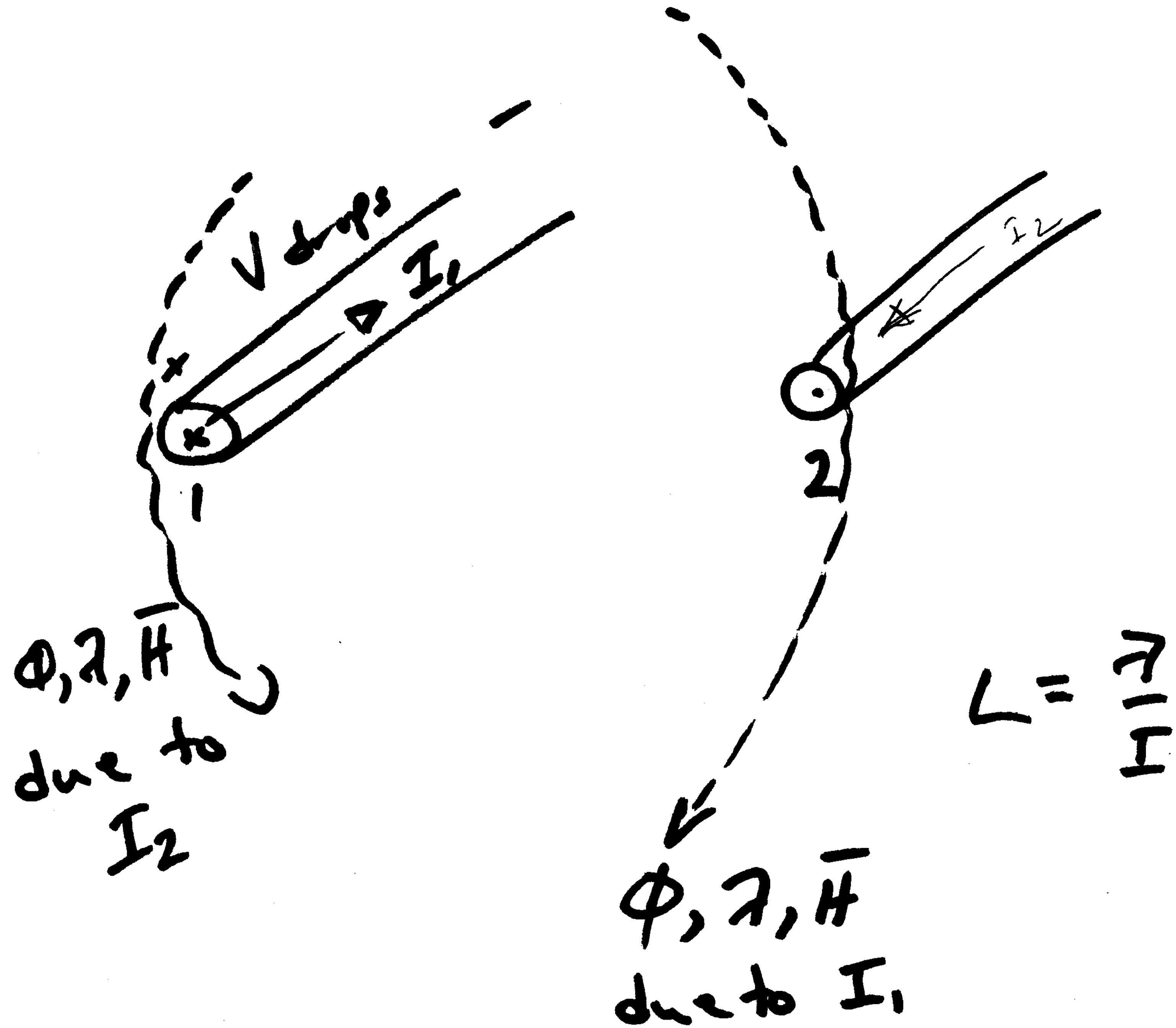
Transposition: $[Z_p] \Rightarrow [Z_s]$

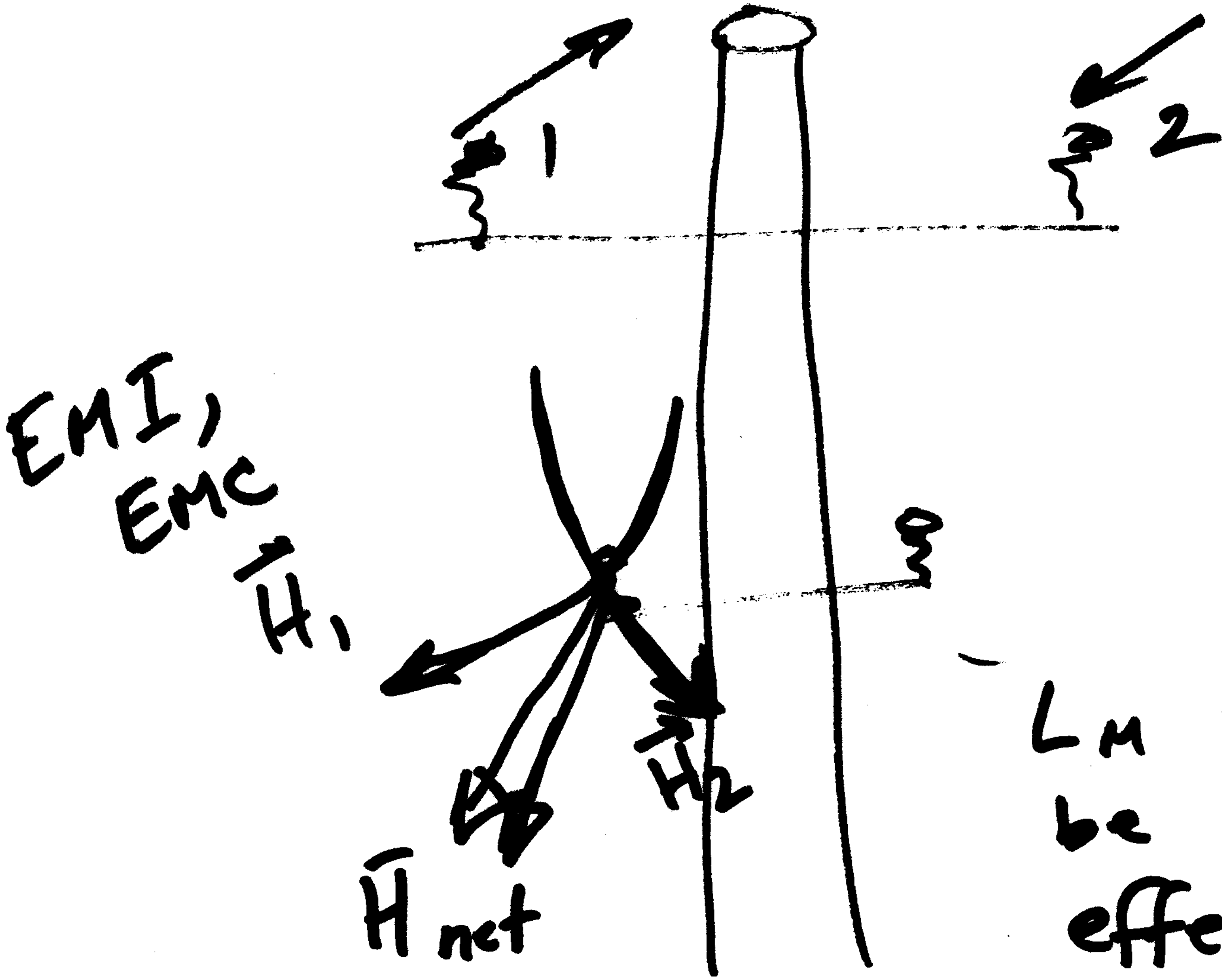


$$L_1 = L_{INT} + L_{MUT}$$

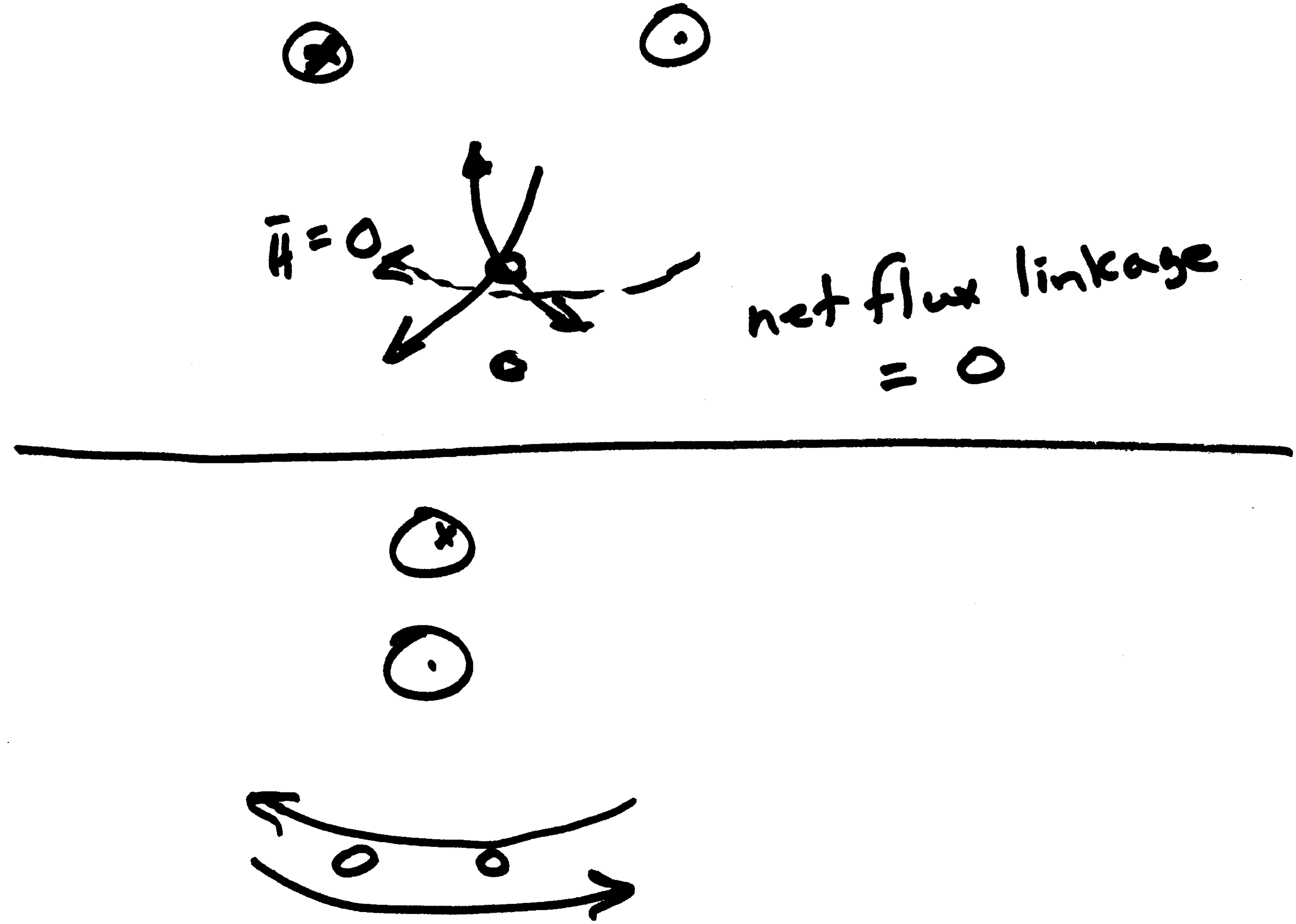
$$= 2 \times 10^{-7} \ln \frac{D}{r'} \text{, or}$$

$$= 2 \times 10^{-7} \ln \frac{D}{GMR}$$


V drops
I_1
I_2
1
2
$\Phi, \lambda, \overline{H}$
due to
I_2
$\Phi, \lambda, \overline{H}$
due to I_1
$L = \frac{\lambda}{I}$



L_M should ideally be zero, or effects of $\vec{H}$ should cancel.


$\bar{H} = 0$
net flux linkage = 0