EE 5200 - Lecture 17

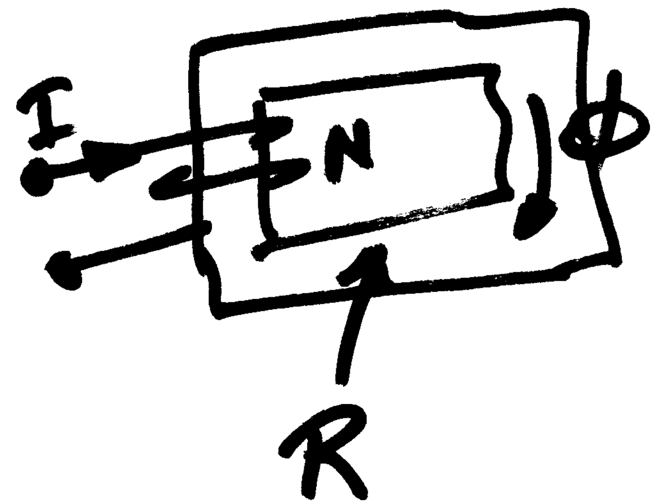
Wed Oct 9, 2019

Topics for Today:

- Announcements
  - Matlab to be incorporated in some upcoming Hmwks.
  - E-mail/help forum: ee5200-l@mtu.edu
  - Office: EERC 614. Phone: 906.487.2857
  - Recommended problems from Ch.4,5 solutions posted
  - Next: Transmission Line C Parameters, Chapter 6

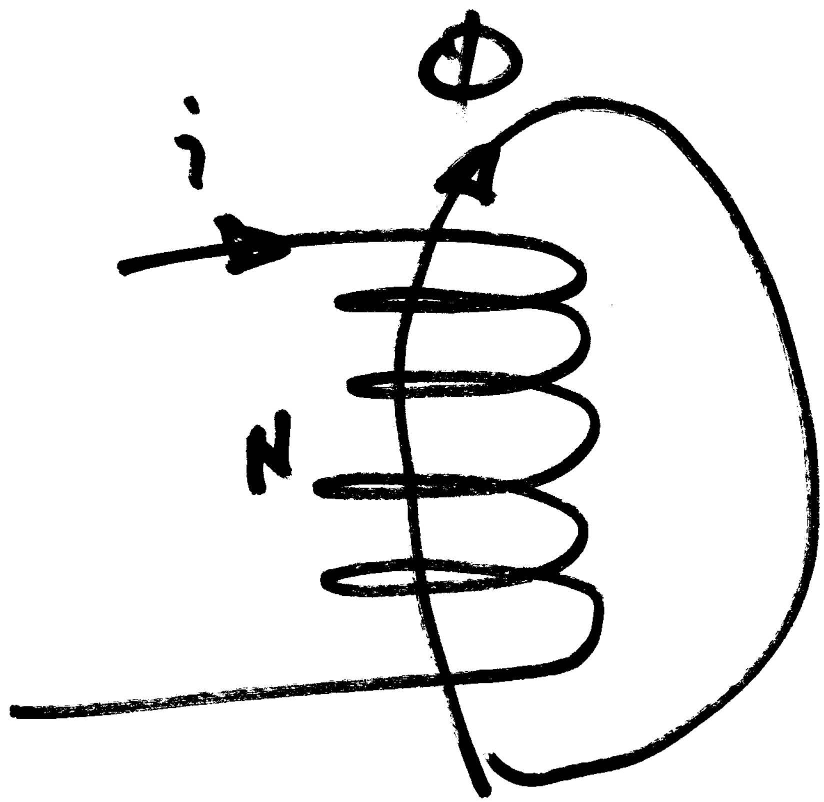
Chapter 5 - Series Impedance of Transmission Lines

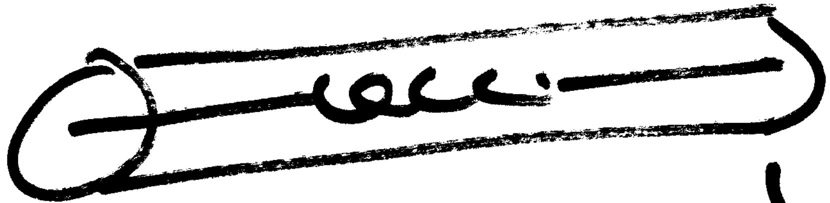
- Resistivity, resistance
- Self inductance of a conductor - recap
- Mutual inductance between 2 conductors
- Inductance matrix for group of conductors
- ATPDraw Line Constants
- Traditional methods for per-phase parameters
  - Geometric mean “averaging” of effective radius and phase spacing. Single-circuit, double-circuit.
  - Use of tables - standard 1-foot phase spacing.



$$NI = \Phi R$$

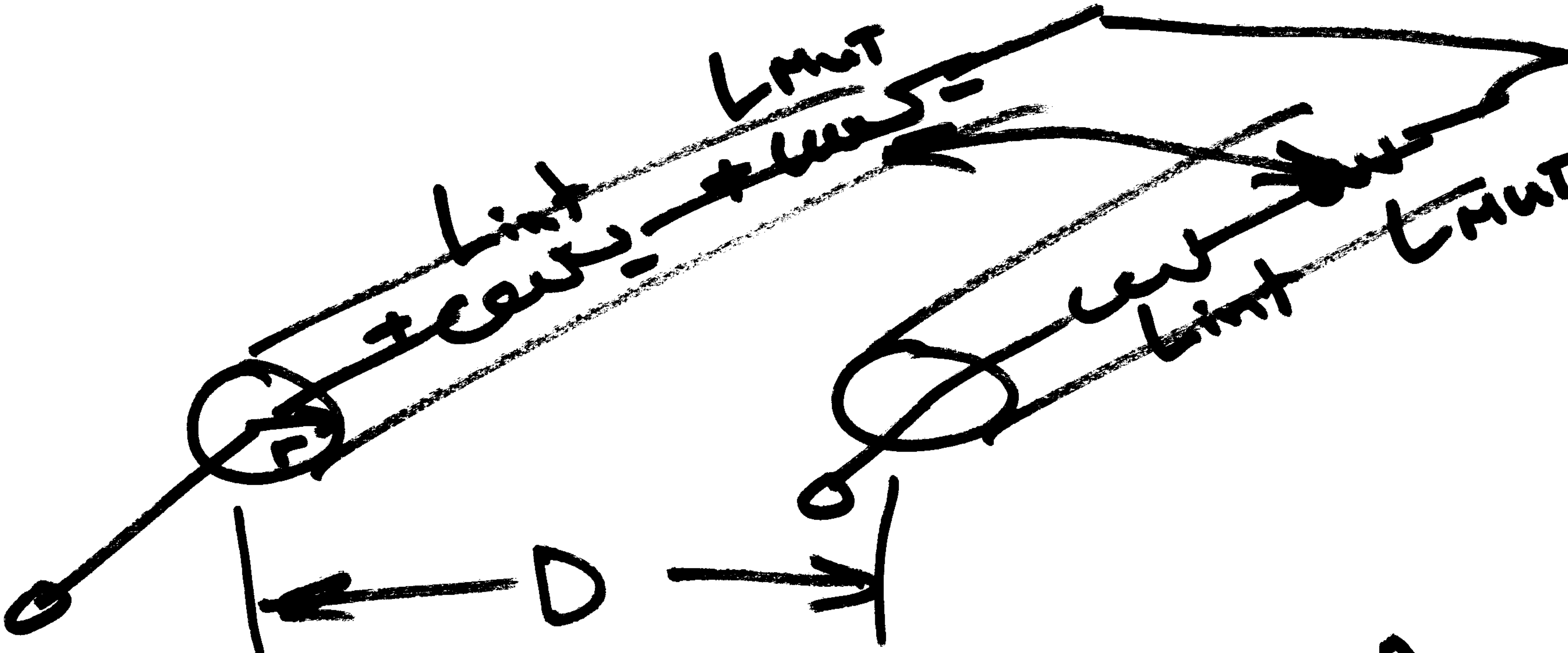
$$L = \frac{\lambda}{i} = \frac{N\Phi}{i}$$



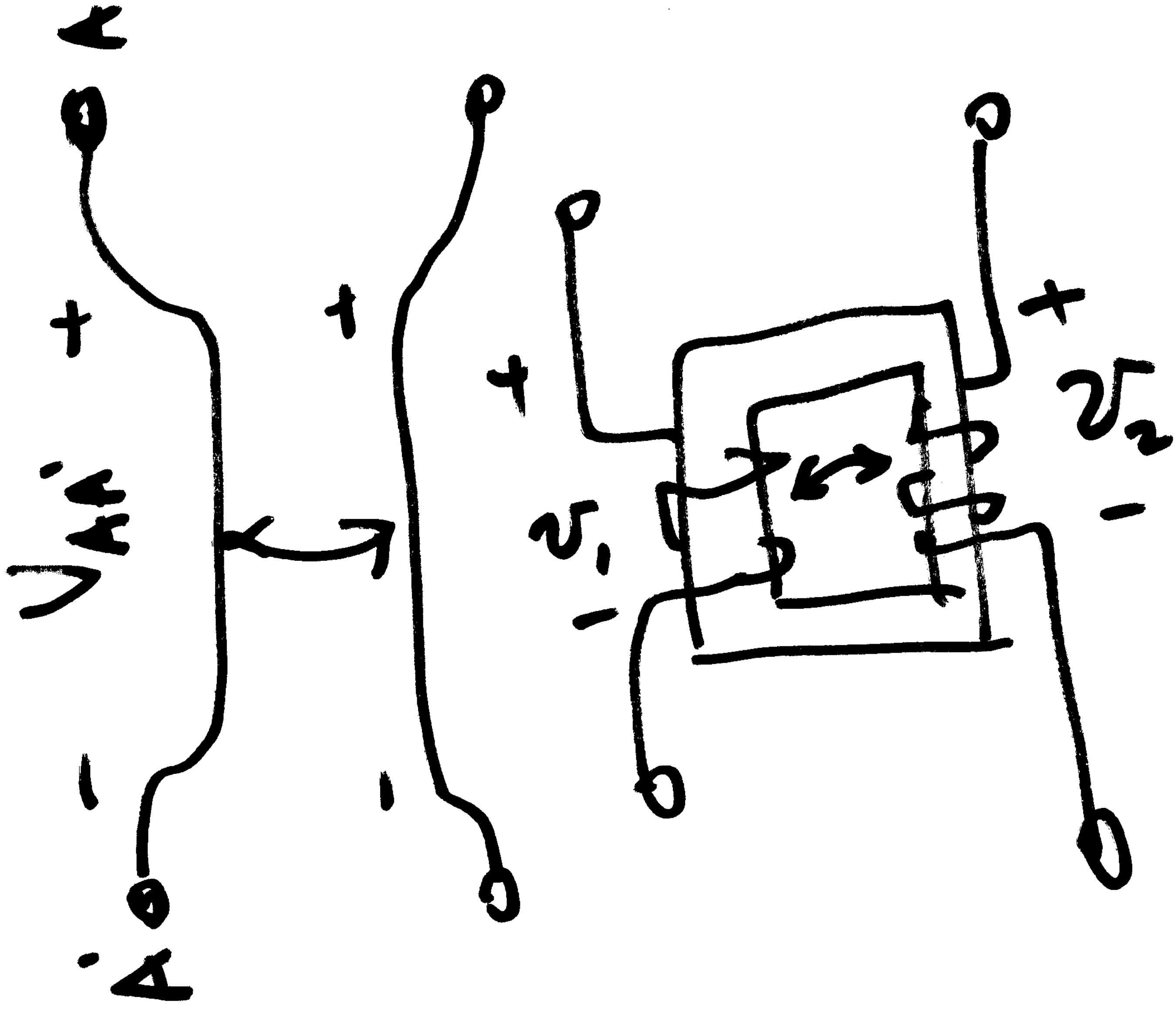


$$L_{int} = \frac{1}{2} \times 10^{-7}\ H/m$$

μ_0



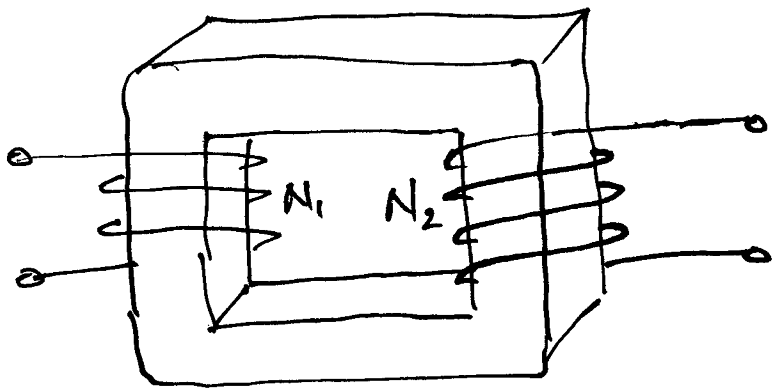
$$L_{mut} = 2 \times 10^{-7} \ln \frac{D}{r}$$



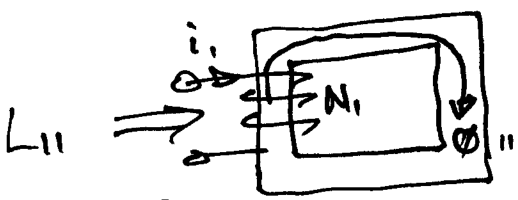
v1
v2

MUTUAL INDUCTANCE

- Section 4.4 in text, pp. 73-77.
- see also handout on Basic Magnetic Circuits

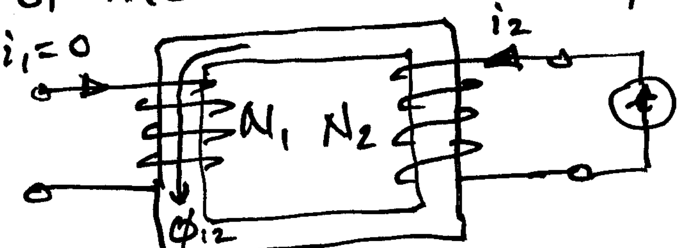


- Fundametal definition of inductance: $L = \frac{\lambda}{i} = \frac{N\phi}{i}$



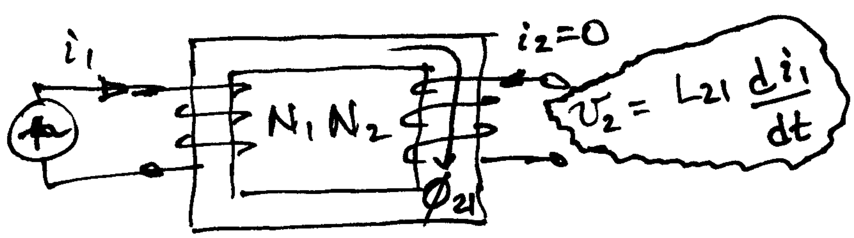
Self-Inductance

$$L_{11} = \frac{N_1 \phi_{11}}{i_1} = \frac{\lambda_{11}}{i_1} = \frac{N_1^2}{R}$$



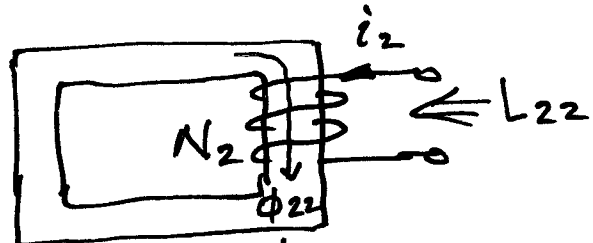
Mutual Inductance

$$L_{12} = \frac{N_1 \phi_{12}}{i_2} = \frac{\lambda_{12}}{i} = \frac{N_1 N_2}{R}$$



$$L_{21} = \frac{N_2 \phi_{21}}{i_1} = \frac{\lambda_{21}}{i} = \frac{N_2 N_1}{R}$$

Mutual Inductance

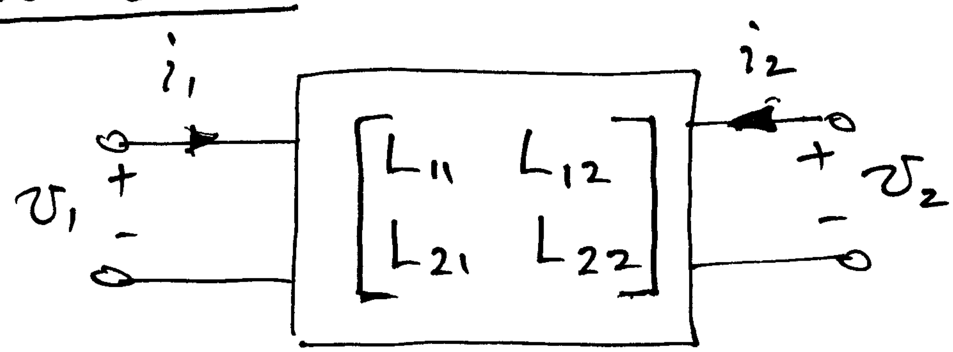


Self Inductance

$$L_{22} = \frac{N_2 \phi_{22}}{i_2} = \frac{\lambda_{22}}{i_2} = \frac{N_2^2}{R}$$

How to Use the Concept of Mutual Inductance

Two-Port Device:



Note: Reference direction of currents is into terminals at (+) side of voltage.

In time domain:

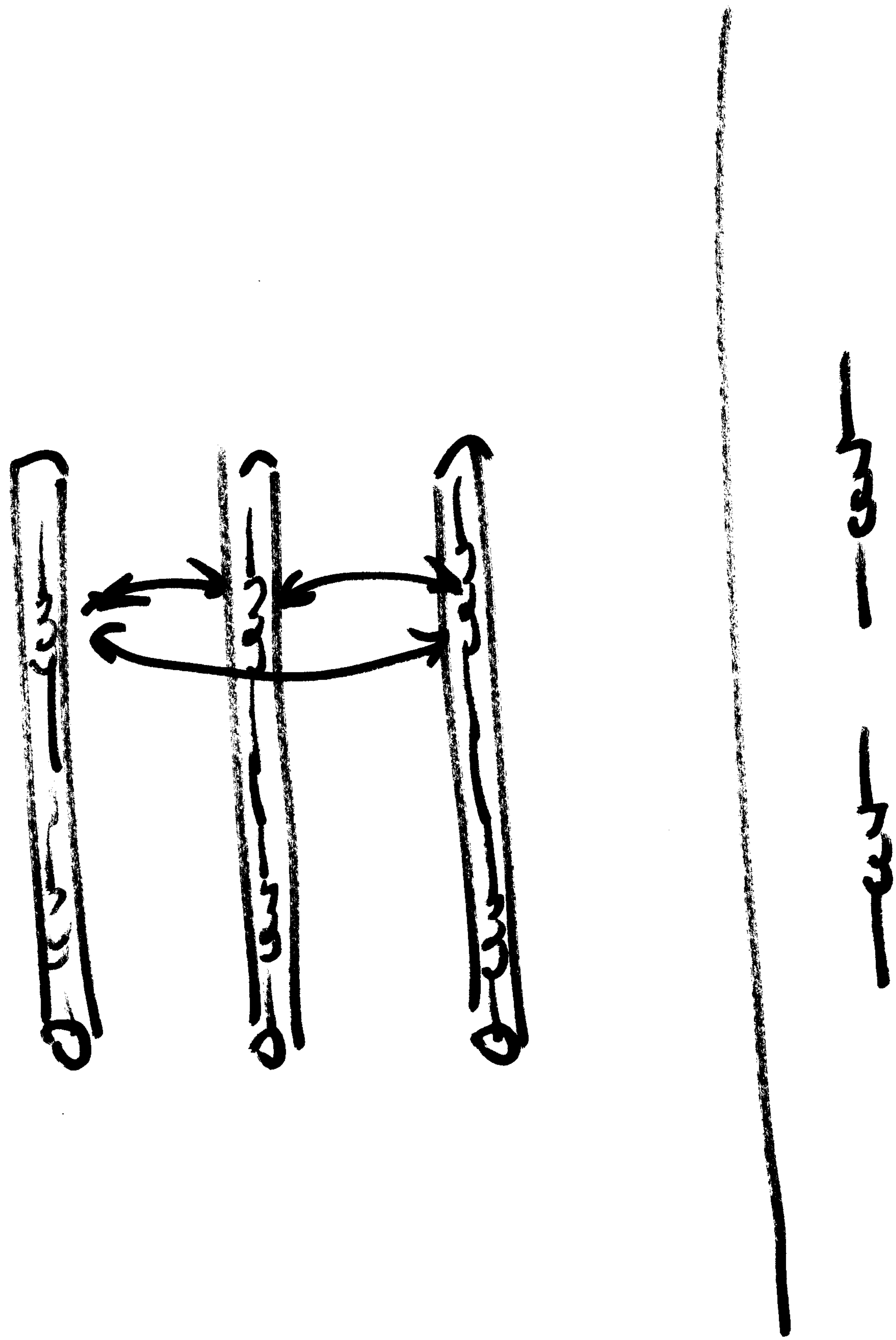
$$\begin{bmatrix} v_1 \\ v_2 \end{bmatrix} = \begin{bmatrix} L_{11} & L_{12} \\ L_{21} & L_{22} \end{bmatrix} \begin{bmatrix} \frac{di_1}{dt} \\ \frac{di_2}{dt} \end{bmatrix}$$

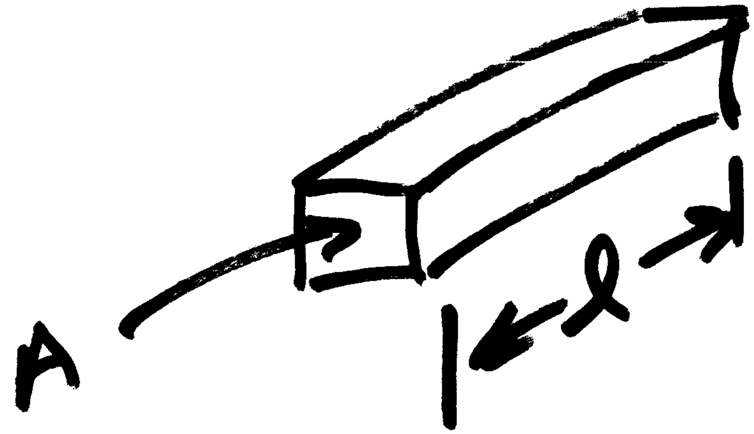
In phasor domain:

$$\begin{bmatrix} \tilde{V}_1 \\ \tilde{V}_2 \end{bmatrix} = \begin{bmatrix} j\omega L_{11} & j\omega L_{12} \\ j\omega L_{21} & j\omega L_{22} \end{bmatrix} \begin{bmatrix} \tilde{I}_1 \\ \tilde{I}_2 \end{bmatrix}$$

Also of note:

In some texts, since L_{12} and L_{21} are mutal inductances, they are called M_{12} and M_{21}. Same thing.





ρ = resistivity

Ω-m

$$R = \frac{\rho \ell}{A} \; \Omega$$

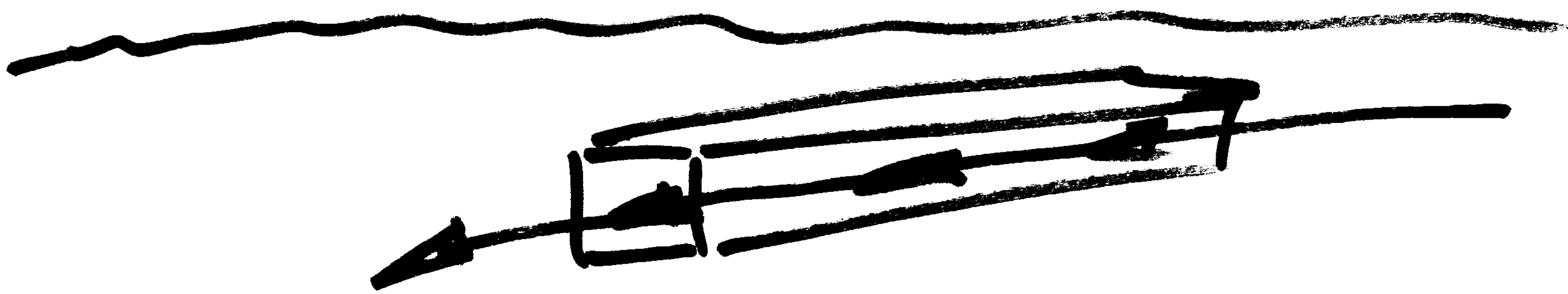
$$\frac{\frac{\Omega\text{-}m^2}{m} \, m}{m^2} \; \Omega$$

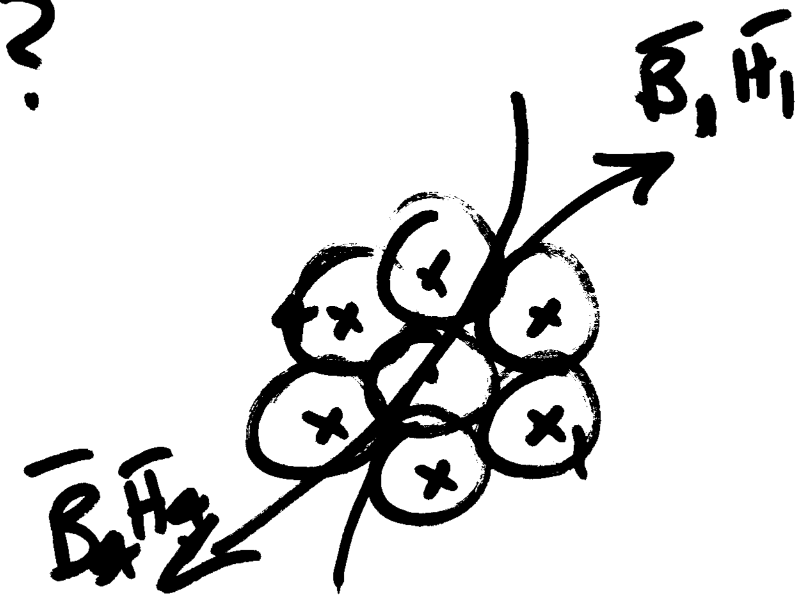
Earth Resistivity

Dry Rocks

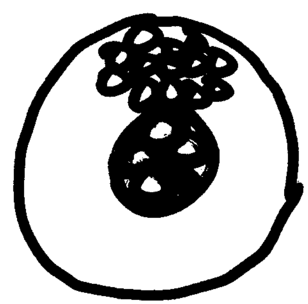
$\rho = 1000 \; \Omega\text{-}m$

wet





- R of strands
- AC vs. DC ?
- Temp
- If AC, - skin effect
  - proximity effect.



$$\frac{j\omega}{2}\begin{bmatrix} C_{AA} & C_{AB} & C_{AC} \\ C_{BA} & C_{BB} & C_{BC} \\ C_{CA} & C_{CB} & C_{CC} \end{bmatrix}\begin{bmatrix} \tilde{V}_A \\ \tilde{V}_B \\ \tilde{V}_C \end{bmatrix} = \begin{bmatrix} \tilde{I}_A \\ \tilde{I}_B \\ \tilde{I}_C \end{bmatrix}$$

$$j\left[\frac{B}{2}\right] \qquad [V] = [I_{inj}]$$

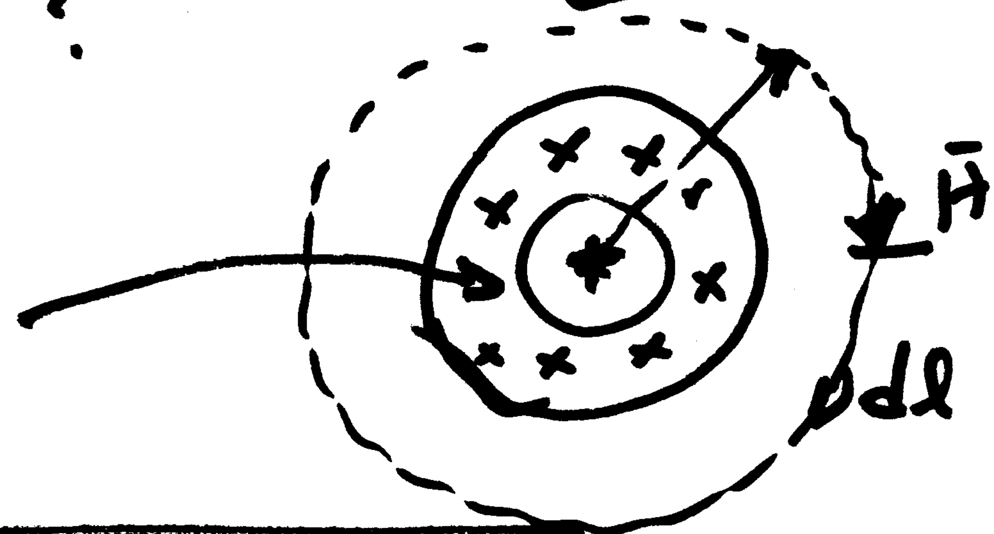
Ampere's Law

- MOCTs
- Hall-Effect Probe
- Clip-on meter

$NI = \Phi R$

$\equiv$?

$$\bar{H} = \frac{I_{ENCL}}{2\pi r}$$

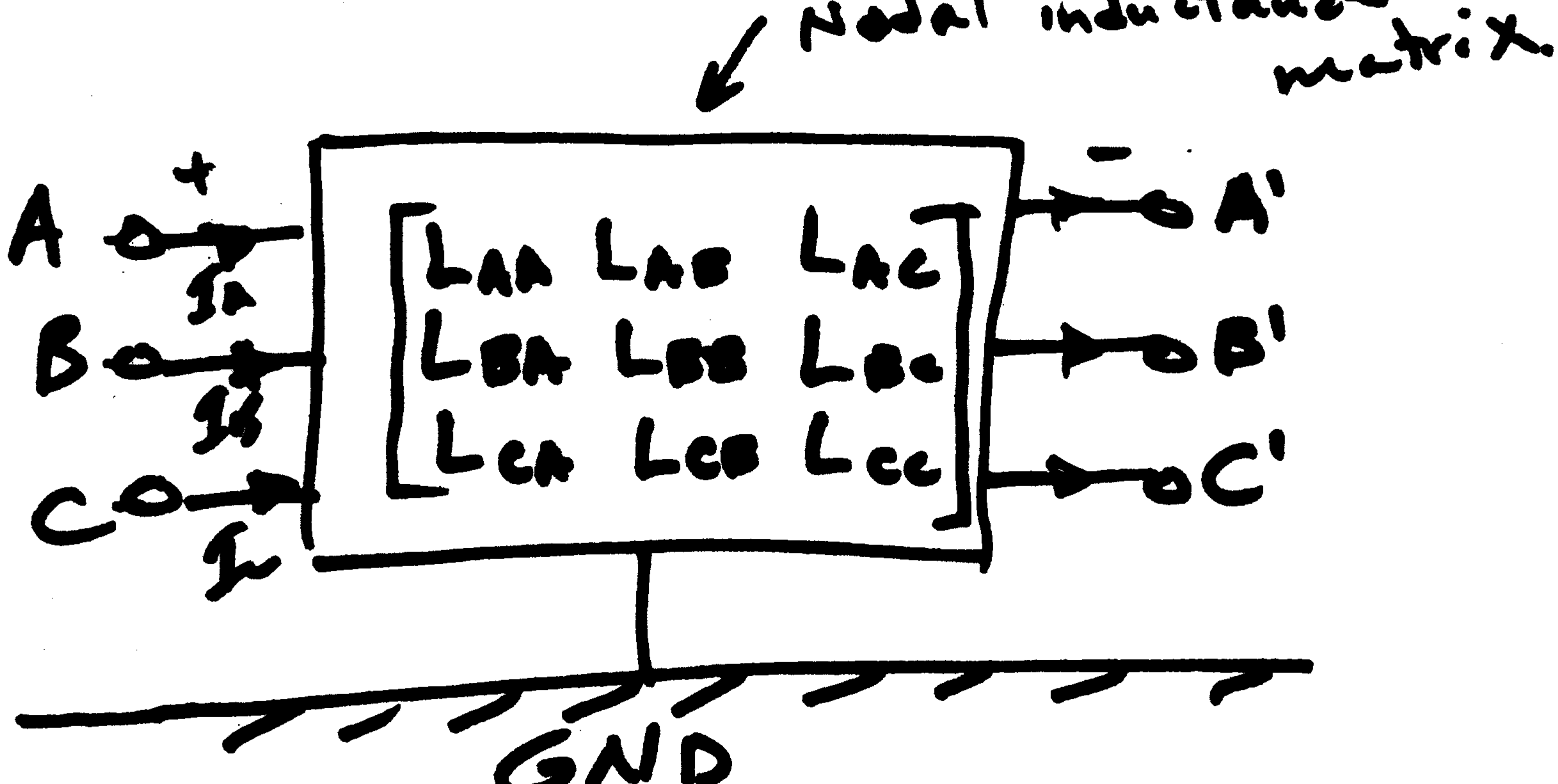


$$I_{ENCL} = \oint_0^{2\pi} \bar{H} \cdot dl$$

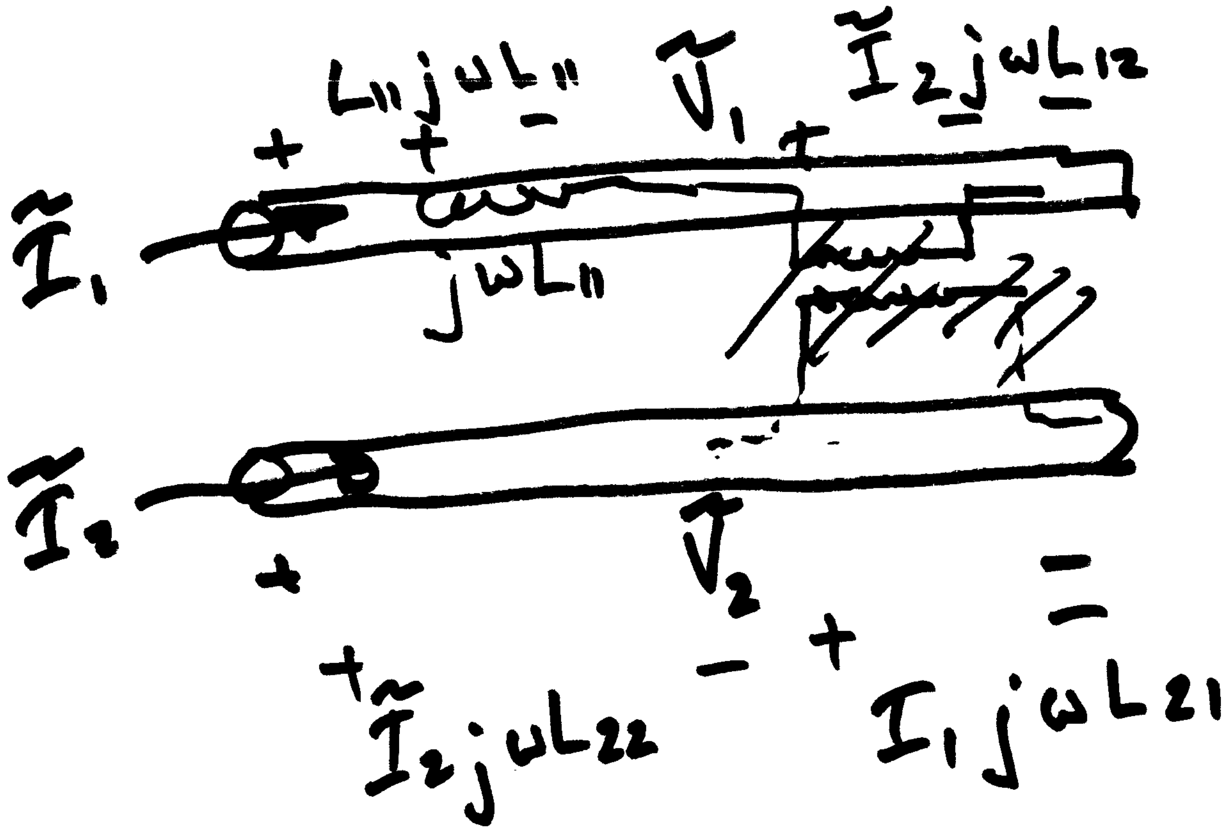
Clamp-on ammeter or current probe.

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

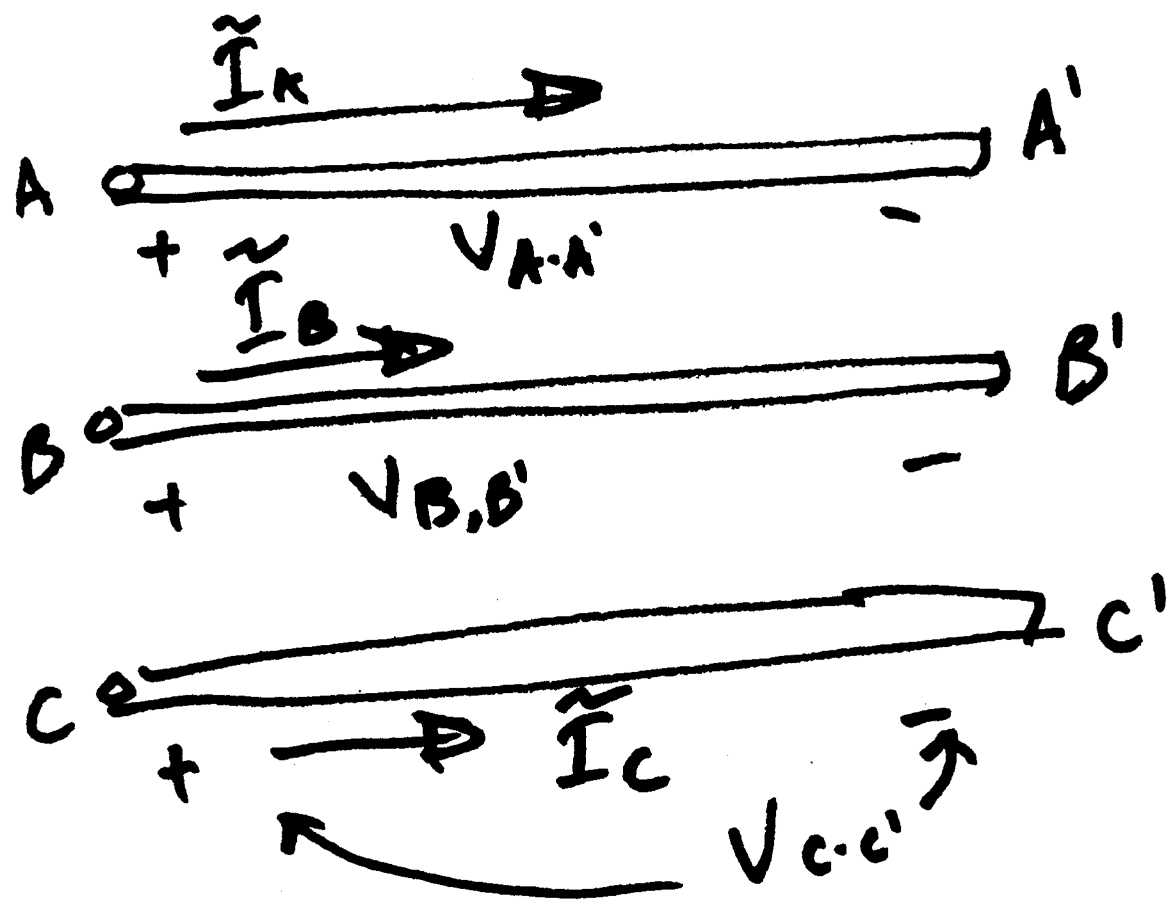
$$+ \begin{bmatrix} R_{AA} & 0 & 0 \\ 0 & R_{BB} & 0 \\ 0 & 0 & R_{CC} \end{bmatrix} \begin{bmatrix} I_A \\ I_B \\ I_C \end{bmatrix}$$



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



L11 jωL11
Ṽ1
Ĩ2 jωL12
Ĩ1
jωL11
Ĩ2
Ṽ2
Ĩ2 jωL22
I1 jωL21



$$\tilde{V}_{B \cdot B'} = \tilde{I}_A j\omega L_{BA} + \tilde{I}_B j\omega L_{BB} + \tilde{I}_C j\omega L_{BC}$$

Bare "OHD" lines.

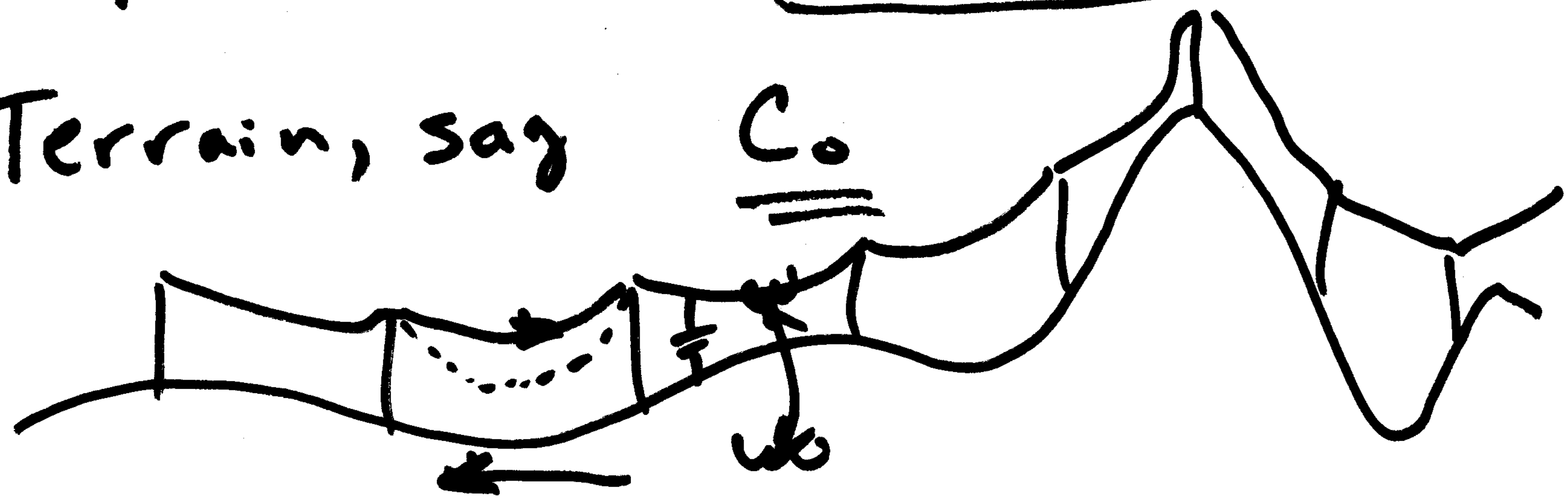
5-10% parameter variation

- Wind - L & C (transient)
- Temp, Sag ⇒ C to gnd. (C_o)

- Rainfall, seasonal variations in ρ of earth.

  Rule of thumb $\rho = 100\ \Omega\text{-m}$.

- Terrain, sag $\underline{\underline{C_o}}$



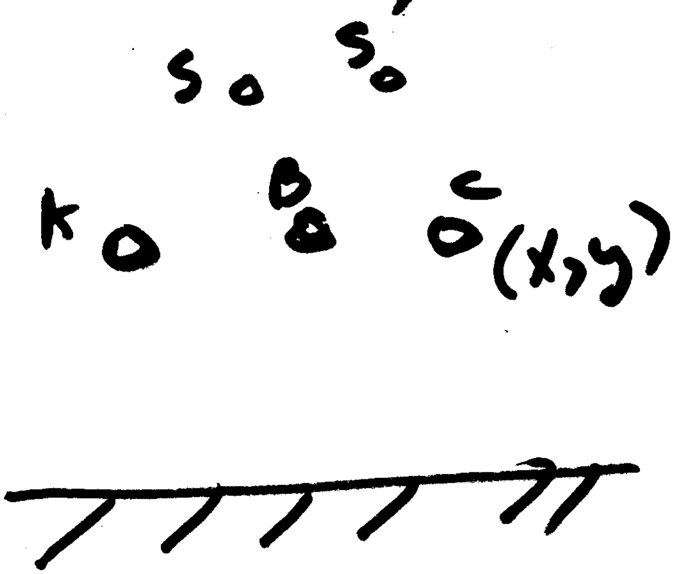
Computational Tools:

- Aspen
- ATP/EMTP

"Line Constants"

$$\Downarrow$$

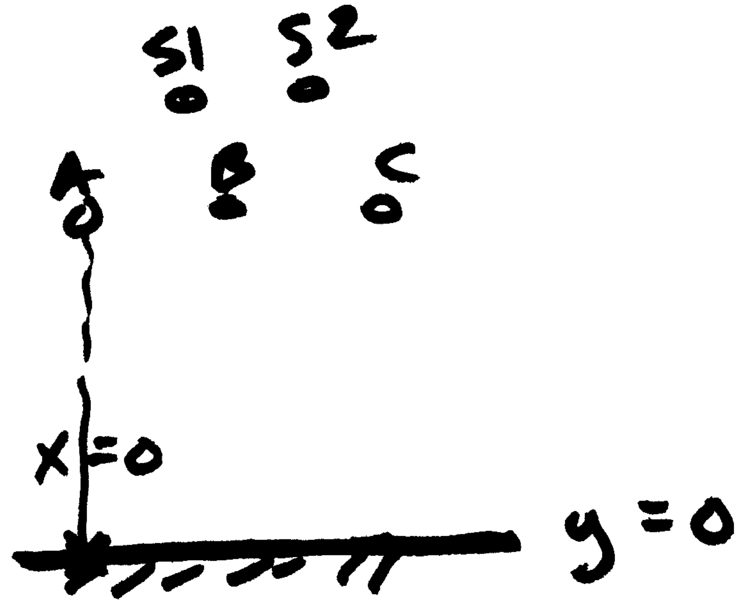
$$R, \; [L] \; [C]$$



Line Constants

- ATP Draw GUI
- ASPEN
- CAPE
- others

⋮



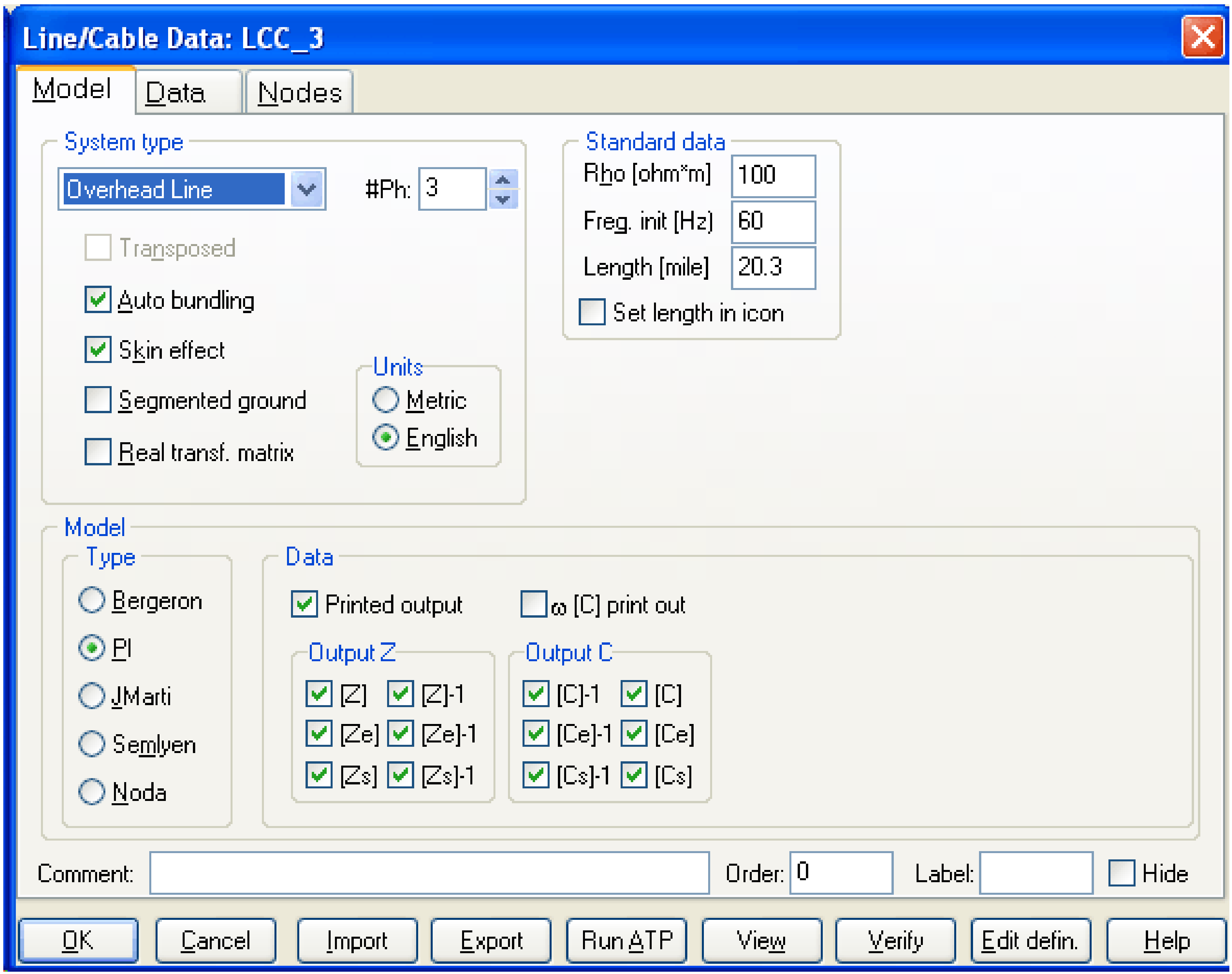
$\rho = 100\ \Omega\text{-m}$?

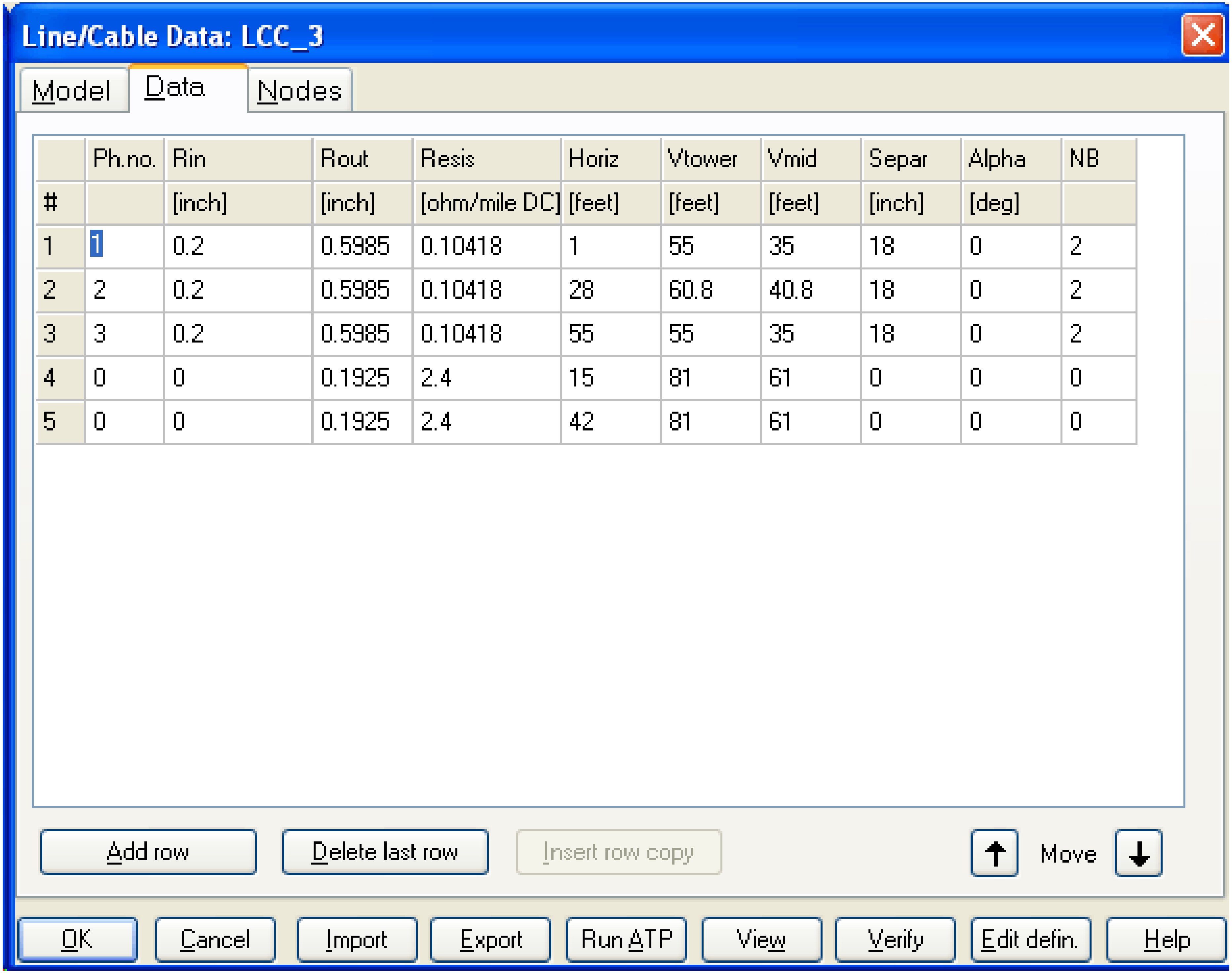
⇓

Line Constants

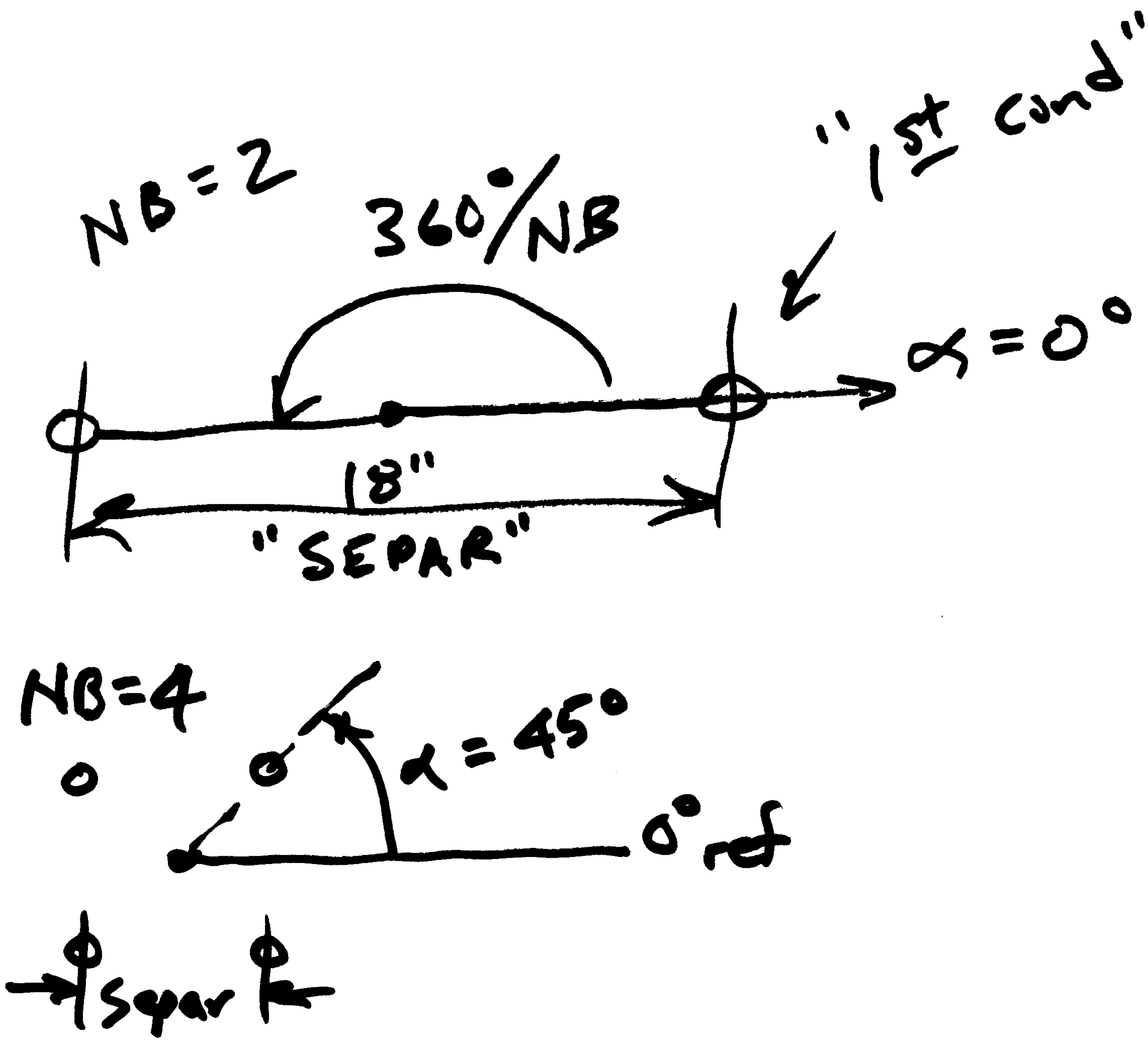
⇓

[R] {L} [C]


Line/Cable Data: LCC_3
Model
Data
Nodes
System type
Overhead Line
#Ph: 3
Transposed
Auto bundling
Skin effect
Segmented ground
Real transf. matrix
Units
Metric
English
Standard data
Rho [ohm*m] 100
Freq. init [Hz] 60
Length [mile] 20.3
Set length in icon
Model
Type
Bergeron
PI
JMarti
Semlyen
Noda
Data
Printed output
ω [C] print out
Output Z
[Z] [Z]-1
[Ze] [Ze]-1
[Zs] [Zs]-1
Output C
[C]-1 [C]
[Ce]-1 [Ce]
[Cs]-1 [Cs]
Comment:
Order: 0
Label:
Hide
OK
Cancel
Import
Export
Run ATP
View
Verify
Edit defin.
Help



	Ph.no.	Rin	Rout	Resis	Horiz	Vtower	Vmid	Separ	Alpha	NB
#		[inch]	[inch]	[ohm/mile DC]	[feet]	[feet]	[feet]	[inch]	[deg]	
1	1	0.2	0.5985	0.10418	1	55	35	18	0	2
2	2	0.2	0.5985	0.10418	28	60.8	40.8	18	0	2
3	3	0.2	0.5985	0.10418	55	55	35	18	0	2
4	0	0	0.1925	2.4	15	81	61	0	0	0
5	0	0	0.1925	2.4	42	81	61	0	0	0



NB=2
360°/NB
"1st cond"
α=0°
18"
"SEPAR"
NB=4
α=45°
0° ref
separ