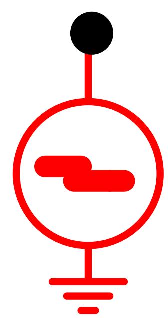
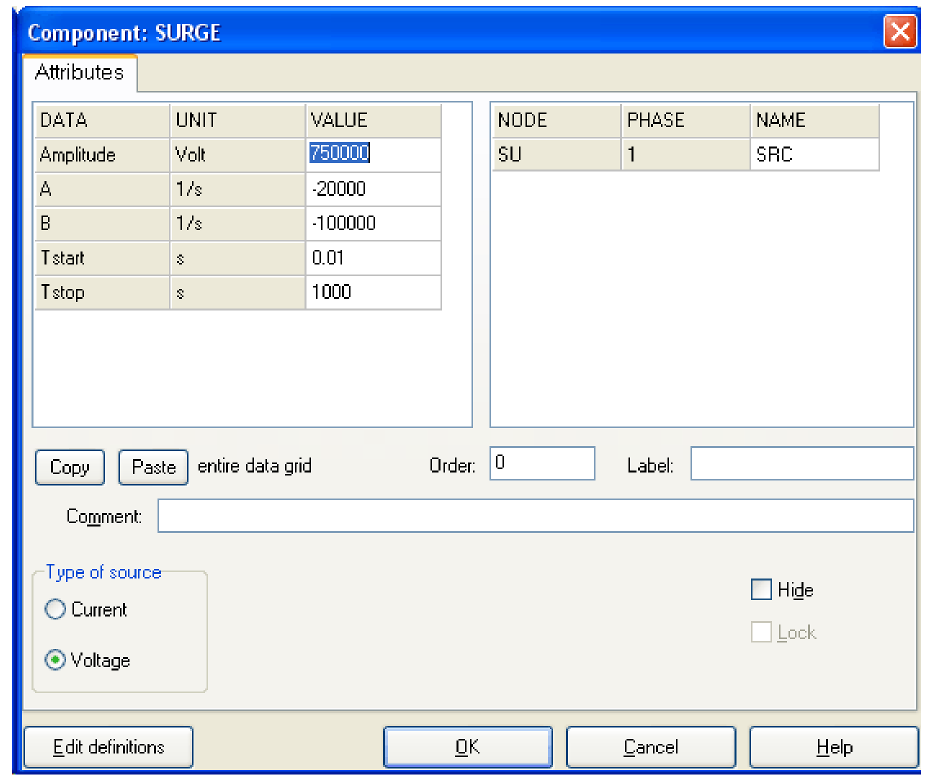
EE 5220 - Lecture 24 Fri Mar 4, 2022

Topics for Today:

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

- HW#7 - due Tues 9am Mar 15th.
- Upcoming: HW#8 - Probs. 9.6, 9.12 due ~Tues Mar 22nd 9am.
- HW#9 - Probs. 9.2, 9.3, 9.4 due date TBA.
- Term Project - Mar 21st - a) complete reference list and b) fully-detailed table of contents according to format given in Term Project Guidelines.
- Line Models implemented in ATP
- ATP Simulation pointers
  - Freq scan - used for T-line Verify, filter design at DC terminus, etc.
  - Surge waveforms - Type 15 Surge source: for lightning, switching
    - Example: Prob. 9.2 (HW#9); Chapters 14 and 15
- Coming next: Transformer modeling - Section 11.1 of text, plus lecture notes
  - Study pre-req matls on mag circuits
  - Example single-phase transformer, Excitation, Inrush
  - Take stock of available ATP transformer models





Name : SURGE - Surge function. Two exponentials. TYPE 15.

Card : SOURCE

Data : U/I= 0: Voltage source.

-1: Current source.

Amp= Constant in [A] or [V].

Does not exactly correspond to the peak value of surge.

A= Negative number specifying falling slope.

B= Negative number specifying rising slope.

Tsta= Starting time in [sec.]. Source value zero for T<Tsta.

Tsto= Ending time in [sec]. Source value zero for T>Tsto.

Node : SU= Positive node of exponential surge function.

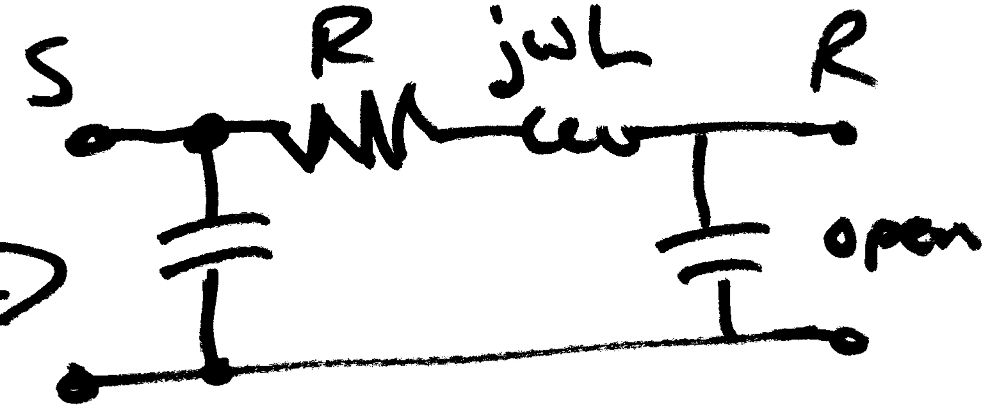
Negative node is grounded.

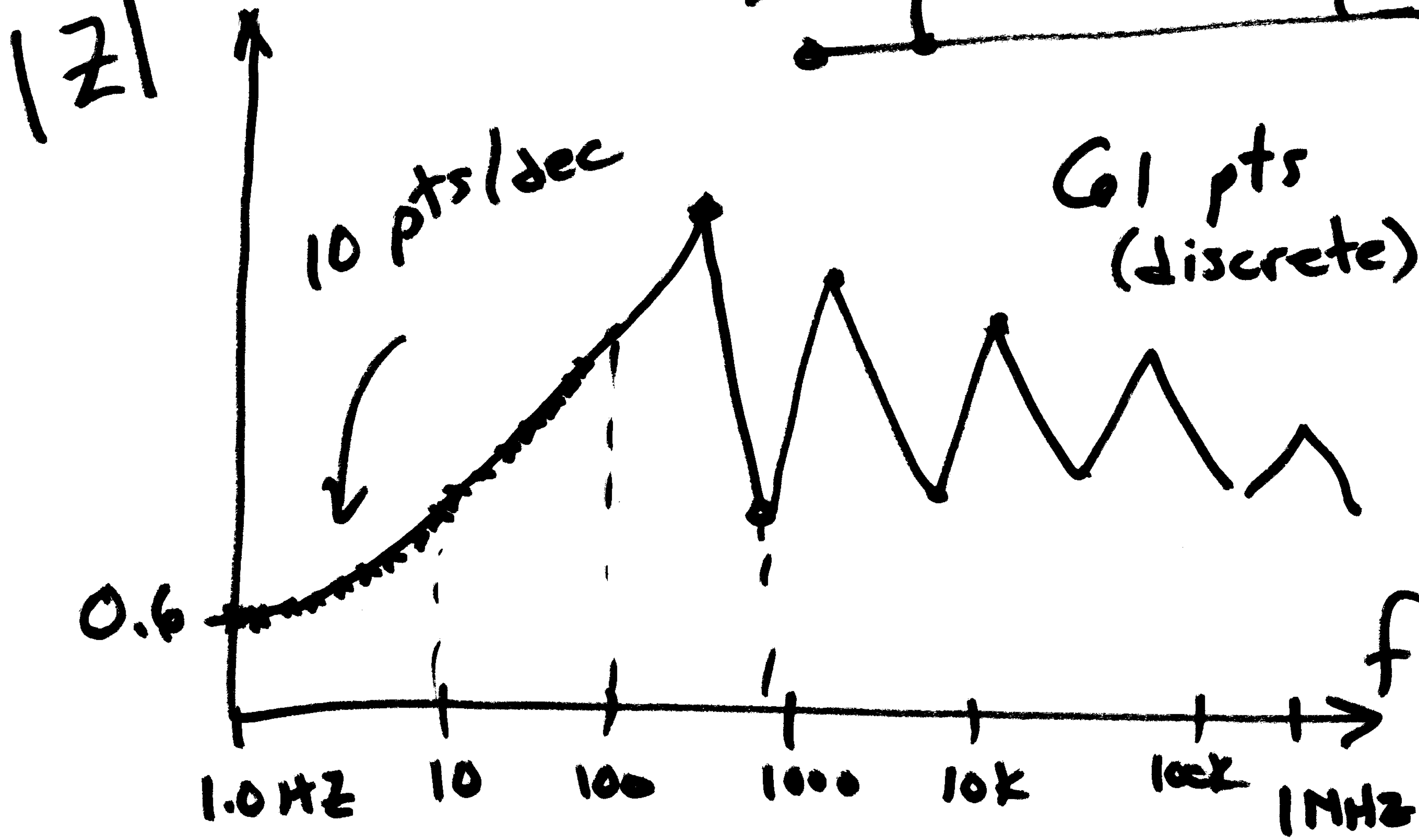
SU=Amp*(exp(A*t)-exp(B*t))

RuleBook: VII.C.5

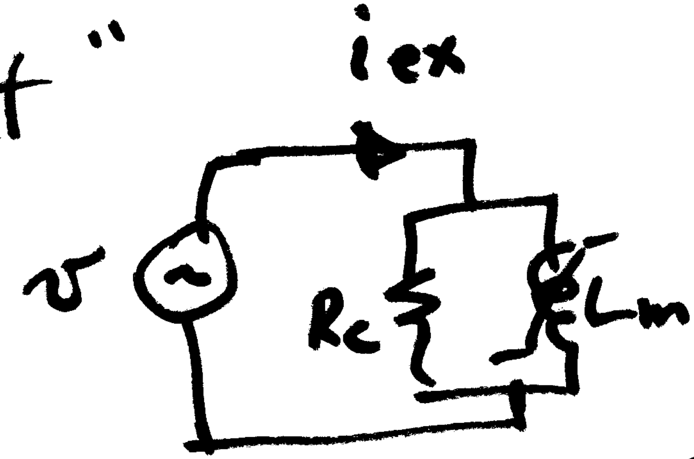
"**Exact**" Model?

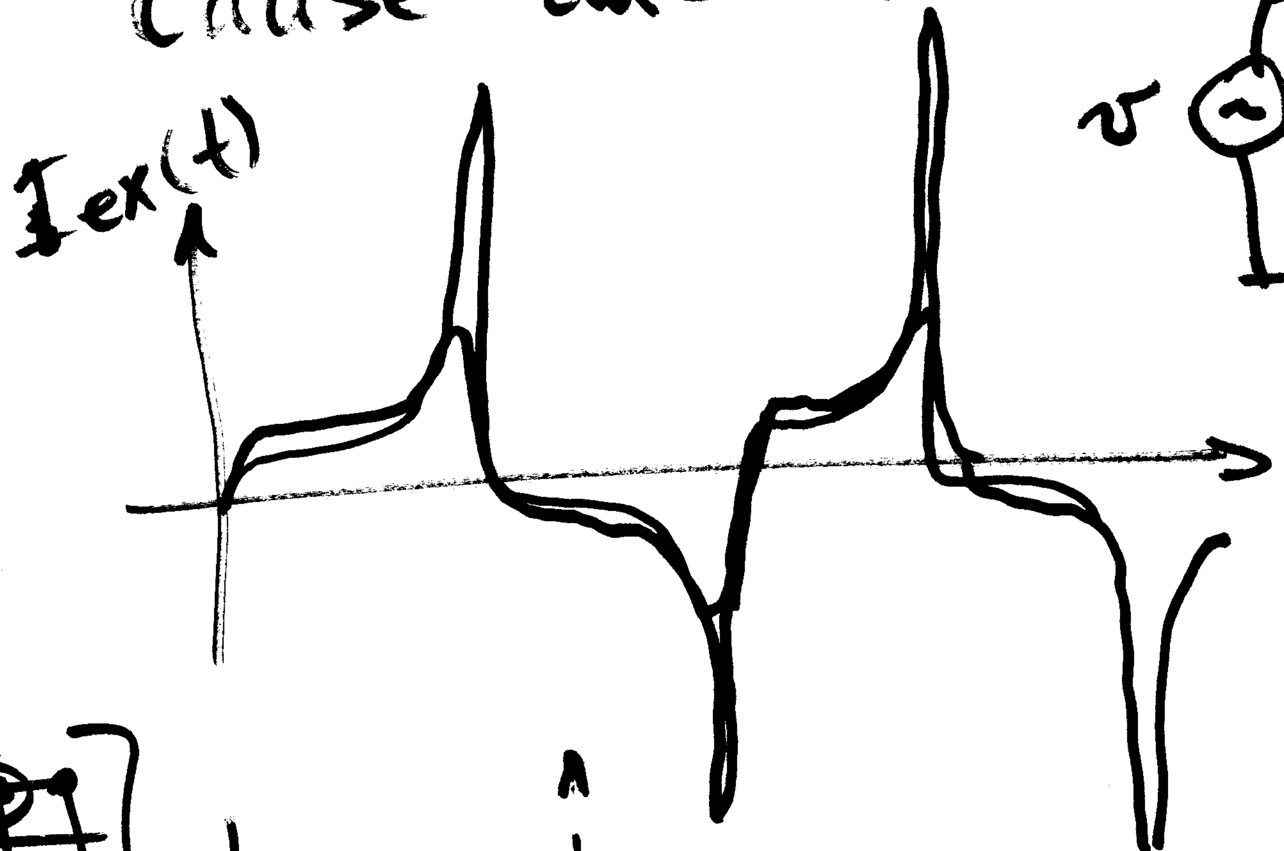
$\underline{\underline{\bar{Z}(f)}}$

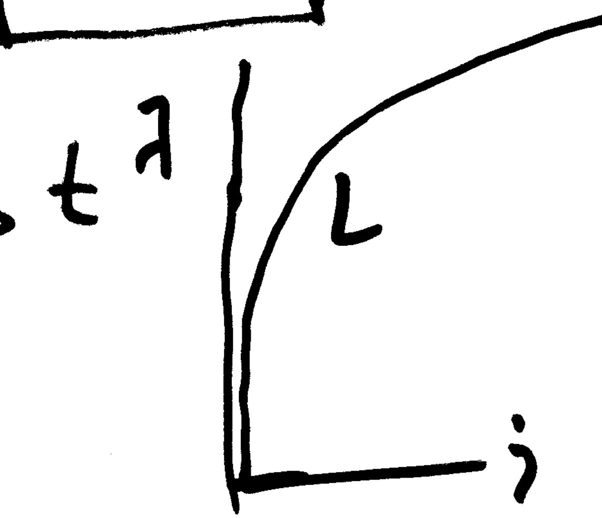


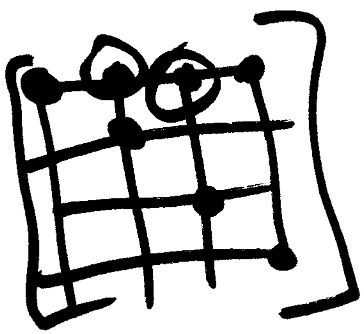


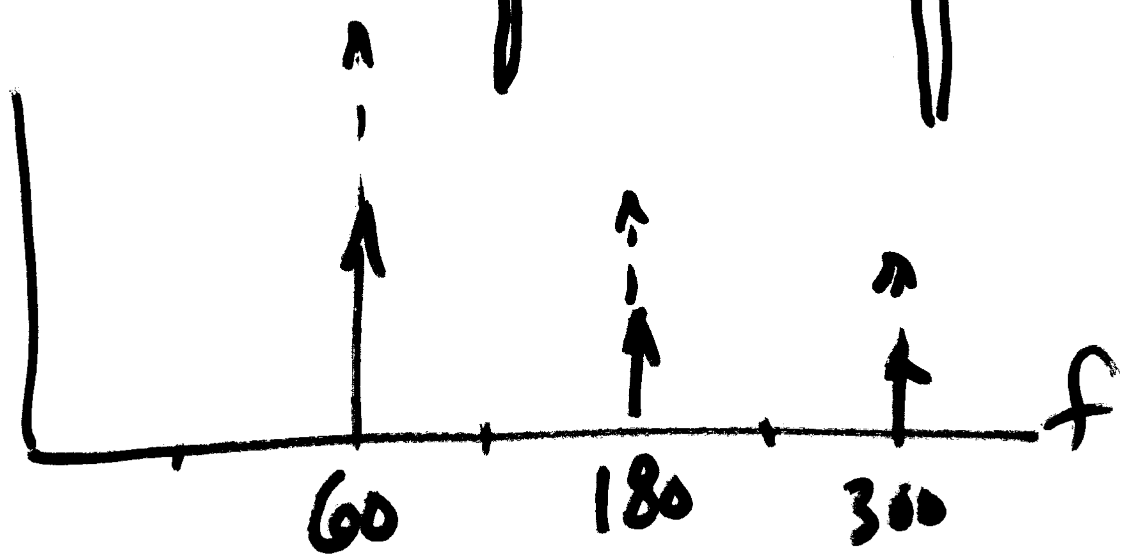
"Cause and effect"



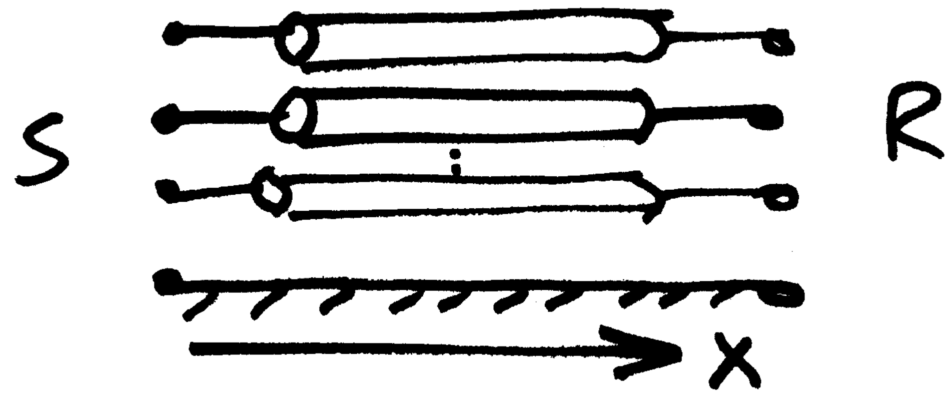




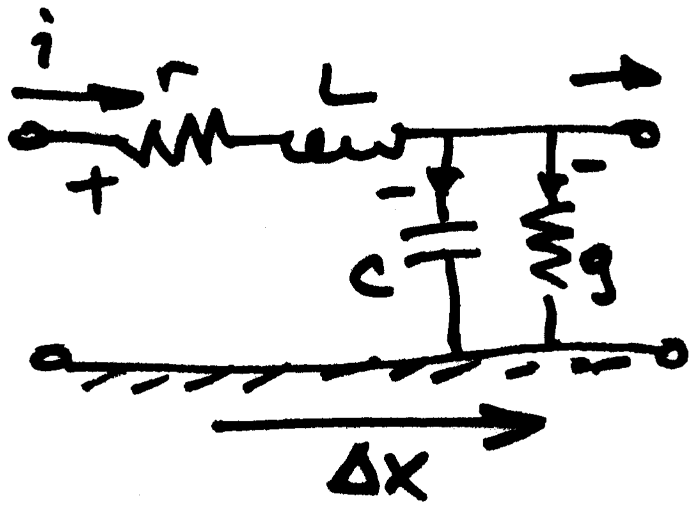




Multi-Cond Line Models:



$$v = \begin{bmatrix} v_{AG} \\ v_{BG} \\ v_{CG} \end{bmatrix}$$



$$\boxed{\begin{aligned} -\frac{\partial v}{\partial x} &= Z i \\ -\frac{\partial i}{\partial x} &= Y v \end{aligned}}$$

[Z] & [Y] are matrices

[i] & [v] are vectors

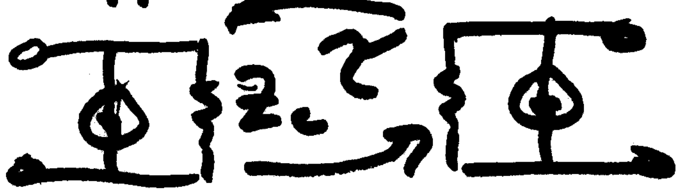
$$z_{ij} = R_{ij} + L_{ij}\frac{\partial}{\partial t}$$

$$y_{ij} = G_{ij} + C_{ij}\frac{\partial}{\partial t}$$

Problem:

- T-Line Eqns are developed in the frequency domain.
- Must pick one freq that model is valid for, or use some type of fitting technique.
  - Coupled Pi
  - Bergeron
  - J-Marti
- Freq Domain?
  - Can't use superposition for nonlinear or freq-dependent systems.

- Approach: Use convolution & deconvolution to move back & forth from Theo. freq-domain derived model to applied time-domain model.



Why continue in freq. domain?

- Tradition
- Numerical Efficiency

Approach - Choose a **freq** ω so $[Z]$ & $[Y]$ can be calculated. (convert to phasor domain).

$$-\frac{\partial V}{\partial x} = [Z][I] \qquad Z_{ij} = R_{ij} + j\omega L_{ij}$$

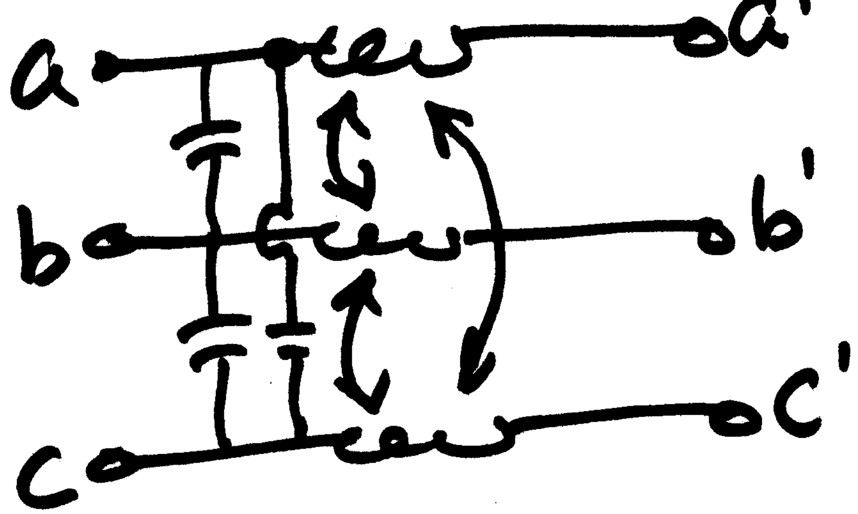
$$-\frac{\partial I}{\partial x} = [Y][V] \qquad Y_{ij} = G_{ij} + j\omega C_{ij}$$

$$\boxed{\begin{aligned} \frac{\partial^2 V}{\partial x} &= [Z][Y][V] \\ \frac{\partial^2 I}{\partial x} &= [Y][Z][I] \end{aligned}}$$

Consider structure of [Z] & [Y]

- ~~Sparse~~?

* - Full?



⇒ All equations are "coupled" to all other equations!

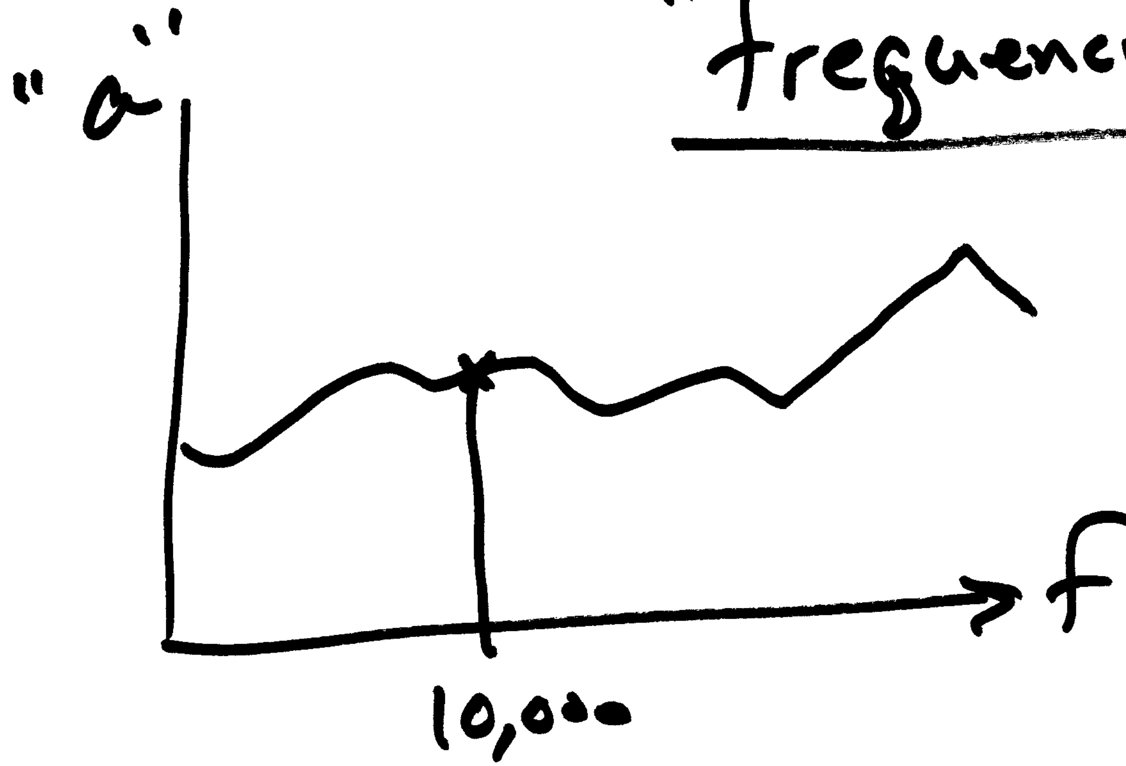
Solution is Compution-intensive

- Gauss Elim.
- Gauss-Jordan
- LU Factorization ⇐ ** EE5240

It would help to "decouple" the family of equations. (Also known as an "orthogonal" set of equations).

Structurally this means that all off-diagonal terms of [Z] & [Y] = 0

"frequency fitting"



- Marti
- Semlyen
- Noda
- Gustavsen

Freq weighting matrix

$$[Z_c][a] \Rightarrow [Z_c](f)$$

Method of decoupling:
<u>MODAL</u> Transformation

$$Ax = B$$

$$\begin{bmatrix} X & X & X \\ X & X & X \\ X & X & X \end{bmatrix} \begin{bmatrix} X_1 \\ X_2 \\ X_3 \end{bmatrix} = \begin{bmatrix} B_1 \\ B_2 \\ B_3 \end{bmatrix}$$

$\Downarrow$ Transform

$$\begin{bmatrix} X & - & - \\ - & X & - \\ - & - & X \end{bmatrix} \begin{bmatrix} X_{1,T} \\ X_{2,T} \\ X_{3,T} \end{bmatrix} = \begin{bmatrix} B_{1,T} \\ B_{2,T} \\ B_{3,T} \end{bmatrix}$$

$\Downarrow$ undo transform

Reclaim X_1, X_2, X_3

Types of Modal Transforms

- Symm Comp: $0, 1, 2$
- Park's Transf.: $d, q, 0$
- Clarke's Transf.: $\alpha, \beta, 0$

$\left.\right\}$ <u>3-PH</u>

- <u>Karrenbauers</u>: $0, 1, 2, \ldots$ <u>N-1</u>

General Idea

$$\underline{\underline{[V]}} = \underbrace{[T_v][V_m]}$$

V_m = modal voltages

$[T_v]$ = Transform Matrix

$$[T_v]\frac{\partial^2 V_m}{\partial^2 x} = [Z][Y][T_v][V_m]$$

$$\frac{\partial^2 V_m}{\partial^2 x} = [T_v]^{-1}[Z][Y][T_v][V_m]$$

$$\boxed{\text{To cut to the chase: choose } [T_v] \text{ as eigenvectors of } [Z][Y]}$$

$$[T_v]^{-1}[Z][Y][T_v] = [\Lambda] = \begin{bmatrix} \lambda_1 & 0 & \cdots & 0 \\ 0 & \lambda_2 & & \vdots \\ \vdots & & \ddots & \\ 0 & \cdots & & \lambda_N \end{bmatrix}$$