Topics for Today:

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

- HW#8 - Probs. 9.6, 9.12 due Mon Mar 21st 9am.
- HW#9 - Probs. 9.2, 9.3, 9.4 due date TBA.
- Term Project - Mar 18th - a) complete reference list and b) fully-detailed table of contents according to format given in Term Project Guidelines, e-mail grader and Mork.
- Transmission line modeling, cascaded PI sections
- Transformer modeling - Section 11.1 of text, plus lecture notes
  - Review pre-req matls on mag circuits (as posted under Pre-Req Mat’ls)
    - Ampere’s Law, Lenz’ Law, magnetic circuit parameters
  - Example of single-phase transformer, Excitation
    - Waveforms for voltage, $I_{EX}$, $I_R$, $I_C$, $\lambda$
- Next - take stock of available ATP transformer models
Steady-State Excitation of Single Phase Transformer
Rated voltage applied to primary, Open-circuited secondary
ATP Pointers - Lighting Surges
"Type-15"
Actual Lightning or Switching Surges:

"Virtual Origin"

Standard Reference:

\[ t_f \times t_t \]

\[ t_f = 1.6(X_2 - X_3) \]

\[ t_t = (X_4 - X_0) \]

Stds:

1.2 x 50 ms (Lightning Surges)
5 x 200 ms (Impulse)
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
- ATP Sim Pointer
- Concept...

Cascading Line Section

How to model?

See Figs 11.32 → 11.35

Options:
- Cascading Pi Section (TNA)
- Distributed parameter "long line" models.
consisting of three sections as shown in Figure 3.2. In this case the line is energized at one end and open at the far end. For this example we consider the very first time step when \( t = t_1 \) and \( t-\Delta t = t_0 = 0 \).

![Diagram of transmission line divided into three sections](image)

**Figure 3.2** Transmission line divided into three sections.

Equations (3.18)-(3.23) are a set of six equations (two for each section) which describe the current and voltage relations along the line. They are listed here as follows:

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Figure 3.1 Detailed Representation of a transmission line element
$E_{\text{eff}} = E$

near-singular

How does $\Delta t$ affect $G_z$?

function of $\Delta t$
size in the stable range is much larger than required for most transient studies.

Figure 4.4 Variation of the coefficient matrix condition number with time step size.

Cond \((Y)\)
Note: Therefore, at a given value of \( \omega \), can exactly represent a T-line by equin \( \frac{\omega}{\omega_1} \).

Error at other frequencies depends on parts of eqn that are in the brackets.

\[
\text{If } \frac{\sinh j\omega \sqrt{L/C}}{j\omega \sqrt{L/C}} = 1 \approx \frac{\tanh \frac{1}{2} j\omega \sqrt{L/C}}{\frac{1}{2} j\omega \sqrt{L/C}}
\]

then error is small. (Happens when \( \sqrt{L/C} \) is small)

\[
\text{if } \sqrt{L/C} = x \sqrt{LC} \quad (L + C \text{ are } \frac{f}{m} < \frac{F}{m})
\]

then freq error is related to length \( x \) of line.

\( \times \) (Error is usually small if \( x \leq \frac{\lambda}{4} \) for highest freq being considered.)

<table>
<thead>
<tr>
<th>( f )</th>
<th>( \frac{f}{4} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 Hz</td>
<td>745 km</td>
</tr>
<tr>
<td>1000 Hz</td>
<td>74.5 km</td>
</tr>
<tr>
<td>3 kHz</td>
<td>24.8 km</td>
</tr>
<tr>
<td>10 kHz</td>
<td>74.5 km</td>
</tr>
<tr>
<td>30 kHz</td>
<td>24.8 km</td>
</tr>
<tr>
<td>100 kHz</td>
<td>74.5 km</td>
</tr>
<tr>
<td>1 kHz</td>
<td>74.5 km</td>
</tr>
</tbody>
</table>

To increase accuracy, we can cascade T-epsilon sections. (p. 368). (fig 11.33) Practical soln if using TNA.

\[
I_{in} = E_2o \cdot (t - t) \text{ i.e. step function.}
\]
Fig. 11.35 - 8 π-sections ⇒ 8 resonances.

Only valid up to about 2 kHz.
for a true line, in the absence of losses, a step travels along the line undistorted. In Section 9.1 we pointed out in connection with Fig. 9.1b that when a ladder network is energized, some influence, no matter how slight, is felt at the remote end immediately after energization. The question is, how big is this effect? Carslaw and Jaeger [32] have addressed themselves to this problem.

They consider a step of voltage $E$ applied to a line with $n$ sections per unit length. A line of length $x$ will therefore have $nx$ sections. If the inductance

![Graph showing $\frac{\sinh \theta}{\theta}$ plotted against $\theta$](image)

Fig. 11.32. Function $\sinh \theta/\theta$ plotted against $\theta$, illustrating distortion correction for $Z$. 
are perhaps better illustrated in Fig. 11.34, which shows the response of an artificial transmission line made up of \( \pi \) sections to a step of voltage applied.

![Graph showing current vs. vt/x with annotations]

**Fig. 11.33.** Current leaving the \( n \)th section of an artificial line as a consequence of a step stimulus.

\[ I_{nx} \left( \frac{L}{C} \right)^{1/2} \quad \frac{1}{2} E \]

\[ vt/x \]
Fig. 11.34. Voltage at the remote end of a 200 km artificial line made up of \( \pi \) sections, following the application of a voltage step at the sending end: (a) 2\( \pi \) sections, (b) 4\( \pi \) sections, (c) 8\( \pi \) sections, (d) 16\( \pi \) sections (courtesy of Augusto Brandão).
Admittance versus Frequency plot for a 200 km single phase transmission line (q) model comprising eight sections.
Electric Circuit

Controls

- MODELS
  - Language

- TACS
  - S-Block
  - Functional blocks

V
I
Switch Pos
Switch Pos
Controlled Source