EE 5200 - Lecture 20 **Friday Oct 20, 2006**
(Taken from Fall ‘03 Archive, Lecture 14)

Topics for Today:

- Announcements
  - Expanded Term Project outline (i.e. Table of Contents + List of references (suggest about half a dozen to start with) by end of week.
  - Software: online students - apply for ATP/ATPDraw license, verify licensing when you receive it by e-mail, and we will mail you the install CD.
  - Office: EERC 623. Phone: 906.487.2857
  - Recommended problems & all solutions: Ch.6 solns posted.

- Chapter 6 - Using the T-Line models
  - Pi-Equivalent circuit for long-line
  - Characteristic Impedance Z_C
  - Propagation Constant $\gamma = \alpha + j\beta$
  - Surge-Impedance Loading (SIL)
  - Wavelength, velocity
  - Traveling waves, reflections

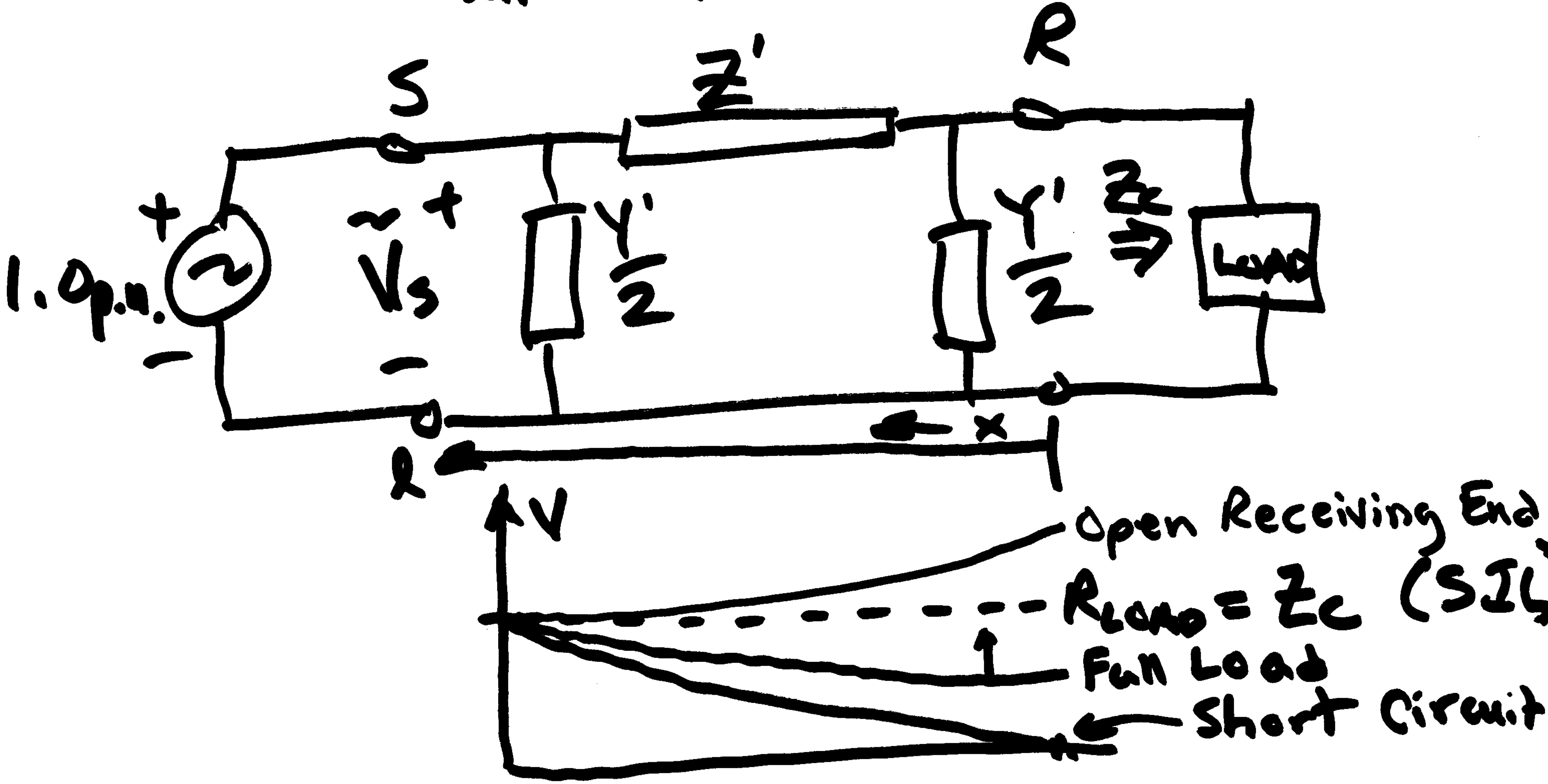
$$Z_c = \sqrt{\frac{z}{y}}$$

phase angle rotation

$$\gamma = \sqrt{zy} = \alpha + j\beta$$

How a wave travels down line.

attenuation



Another Point:

- SIL = Surge Impedance Loading
  - $R_{LOAD} = |Z_c|$
  - Total Reactive Power Consumed in Line = 0.

→ "Flat" Line or flat voltage profile.

- $SIL = \dfrac{V^2}{Z_c} = \dfrac{V_S^2}{Z_c} = \dfrac{V_R^2}{Z_c}$

Propagation Wavelength λ

λ = distance req'd to change $\angle V$ by 360°.

$$\gamma = \sqrt{zy} = \underbrace{\cancel{\alpha}_{0} + j\beta}_{\text{per unit length}} \quad \text{(Assume Lossless)}$$

$e^{j\beta x}$: term provides phase rotation in each term of $I(x)$, $V(x)$.

$$\lambda = x = \frac{2\pi}{\beta} \Longrightarrow \lambda = \frac{2\pi}{\omega\sqrt{LC}} = \frac{2\pi}{2\pi f\sqrt{LC}}$$

$$\boxed{\lambda = \frac{1}{f\sqrt{LC}}}$$

$$v = f\lambda = \frac{1}{\sqrt{LC}} = 3\times10^{8}\ \text{m/s} = \frac{1}{\sqrt{\epsilon_0 \mu_0}}$$

@ 60 Hz, $\lambda = \dfrac{v}{f} = \dfrac{3\times10^{8}\ m/s}{60}$

$\cong$ 5000 Km

$\cong$ 3100 miles

@ 2 MHz, $\lambda = \dfrac{3\times10^{8}}{2\times10^{6}} = $ 150 m

[redacted] [redacted]

- Side Comments (later) on

[redacted] T-Line loading limits

  - Thermal
  - Voltage Limits, V_S & V_R $\Rightarrow$ VR
    $.95 < V < 1.05$
  - Stability Limits

$$\overset{v}{V(x)} = \overset{v^+}{\left(\frac{V_R + Z_c I_R}{2}\right) e^{\gamma x}} + \overset{v^-}{\left(\frac{V_R - Z_c I_R}{2}\right) e^{-\gamma x}} \quad (10)$$

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

best for Trav. Waves?

(From Lecture 13)

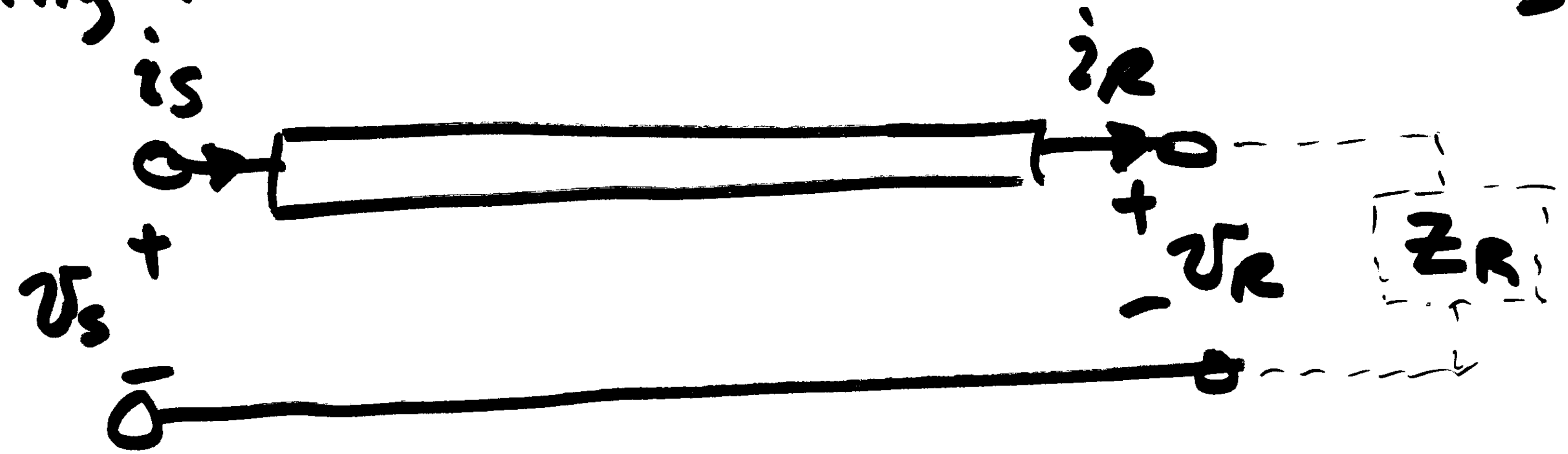
$$\boxed{Z_c = \sqrt{\frac{z}{y}} = \text{Characteristic Impedance.}}$$

$$\boxed{\gamma = \sqrt{zy} = \alpha + j\beta = \text{Propagation Coefficient}}$$

α = attenuation constant

β = angular propagation constant.

Travelling Waves



Impedance at receiving end:

$$Z_R = \frac{v_R}{i_R} = \frac{v_R^+ + v_R^-}{i_R^+ + i_R^-} = \frac{v_R^+ + v_R^-}{\frac{v_R^+}{Z_c} - \frac{v_R^-}{Z_c}} = Z_R$$

$$\frac{v_R^-}{v_R^+} = \boxed{\frac{Z_R - Z_c}{Z_R + Z_c} = \rho_R}$$ Reflection Coefficient

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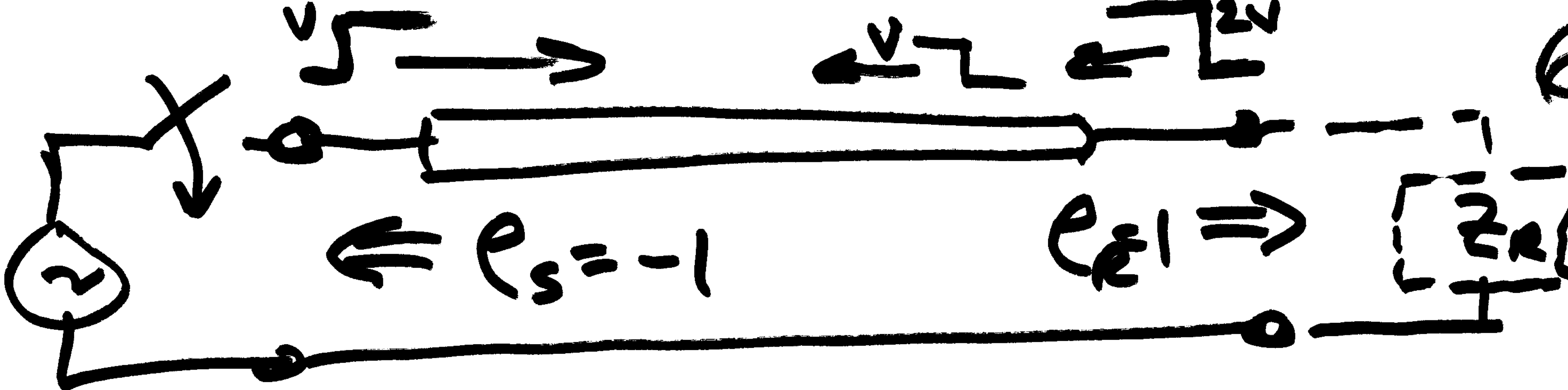


If receiving end is...

- Open-ckt (i.e. $Z_R = \infty$)

$$\rho_R = \frac{\infty - Z_C}{\infty + Z_C} = +1$$

$$\therefore \; v_R^- = v_R^+ \rho_R = v_R^+$$

- Short-ckt (i.e. $Z_R = 0$)

$$\rho_R = \frac{0 - Z_C}{\infty + Z_C} = -1$$

Traveling Wave Example (ATPDraw)

See page 14, Lecture 13

$Z_c = 294.3 \angle{-9.22^\circ}\ \Omega$

$\gamma = .00215 \angle{80.8^\circ} = \underbrace{0.00034}_{\alpha} + j\underbrace{0.00212}_{\beta}$

<u>250-miles long</u>

$$\left.\begin{array}{l} z = 0.2 + j0.6\ \Omega/\text{mi} \\ y = j7.3\ \mu S/\text{mi} \end{array}\right\} \Rightarrow \left.\begin{array}{l} L = 0.398\ H \\ C = 484\ \mu F \\ R = 50\ \Omega \end{array}\right\} \text{Total}$$

If losses are ignored,

$$\left[\begin{array}{l} Z_c = 286.69\ \Omega \\ \gamma = j0.00209\ \text{rad/mi} \\ (\alpha = 0) \quad \nwarrow \beta \end{array}\right.$$

$$\lambda = \frac{2\pi}{\beta} = \frac{2\pi\ \text{rad}}{.00209\ \text{rad/mi}}$$

$$= 3006\ \text{mi}$$

Before creating ATP example, let's predict behavior:

Lossless: $\lambda = \frac{2\pi}{\beta} = \frac{2\pi}{.00209} = 3006$ mi

$f\lambda = v = 2.9\times10^{8}$ m/s $(f = 60\,\text{Hz})$

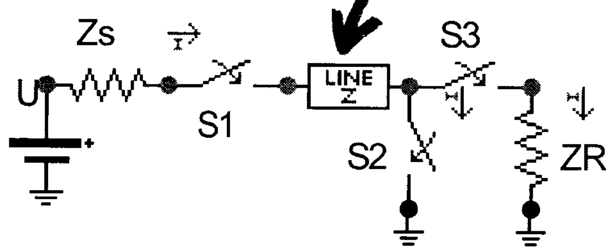
(should be 3×10^{8}.... rounding.)

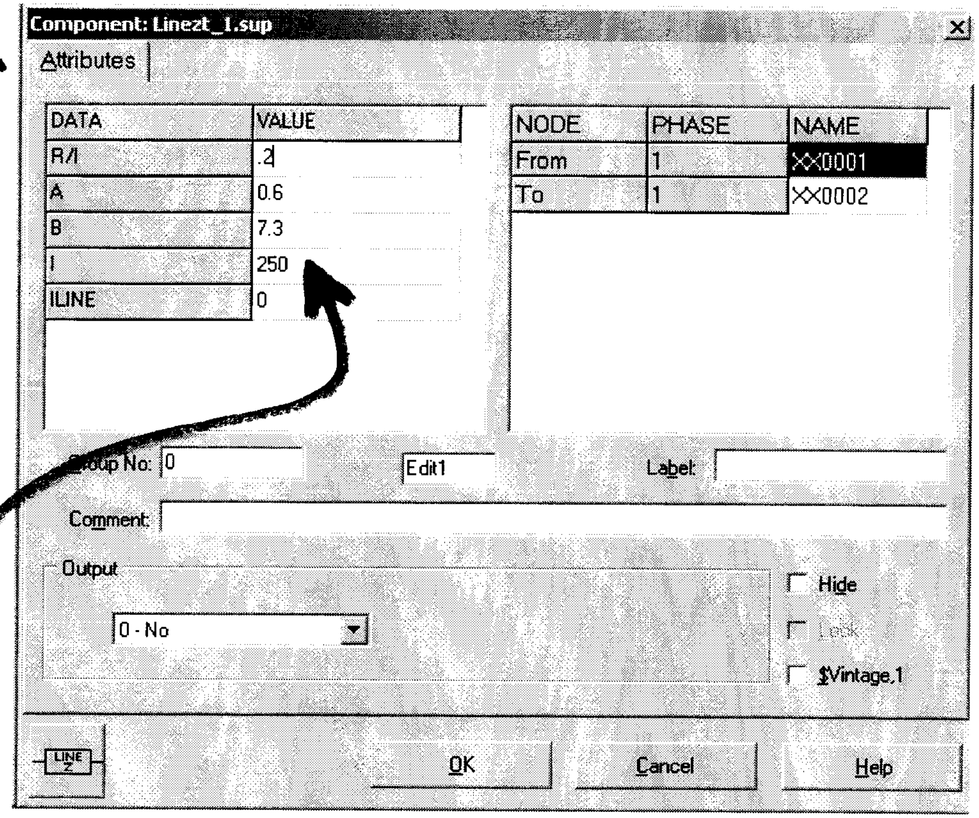
Propagation Time: ~~Approx~~:

$$t = \frac{x}{v} = \frac{(250\,\text{mi})(1.6\,\text{Km/mi})}{2.9\times10^{6}\,\text{Km/s}} = \boxed{138\,\mu s}$$

250-mile transmission line example - traveling wave model in ATP

TravWave.adp





Select Distributed 1-phase Clarke Line Model.

Input (click Help button):

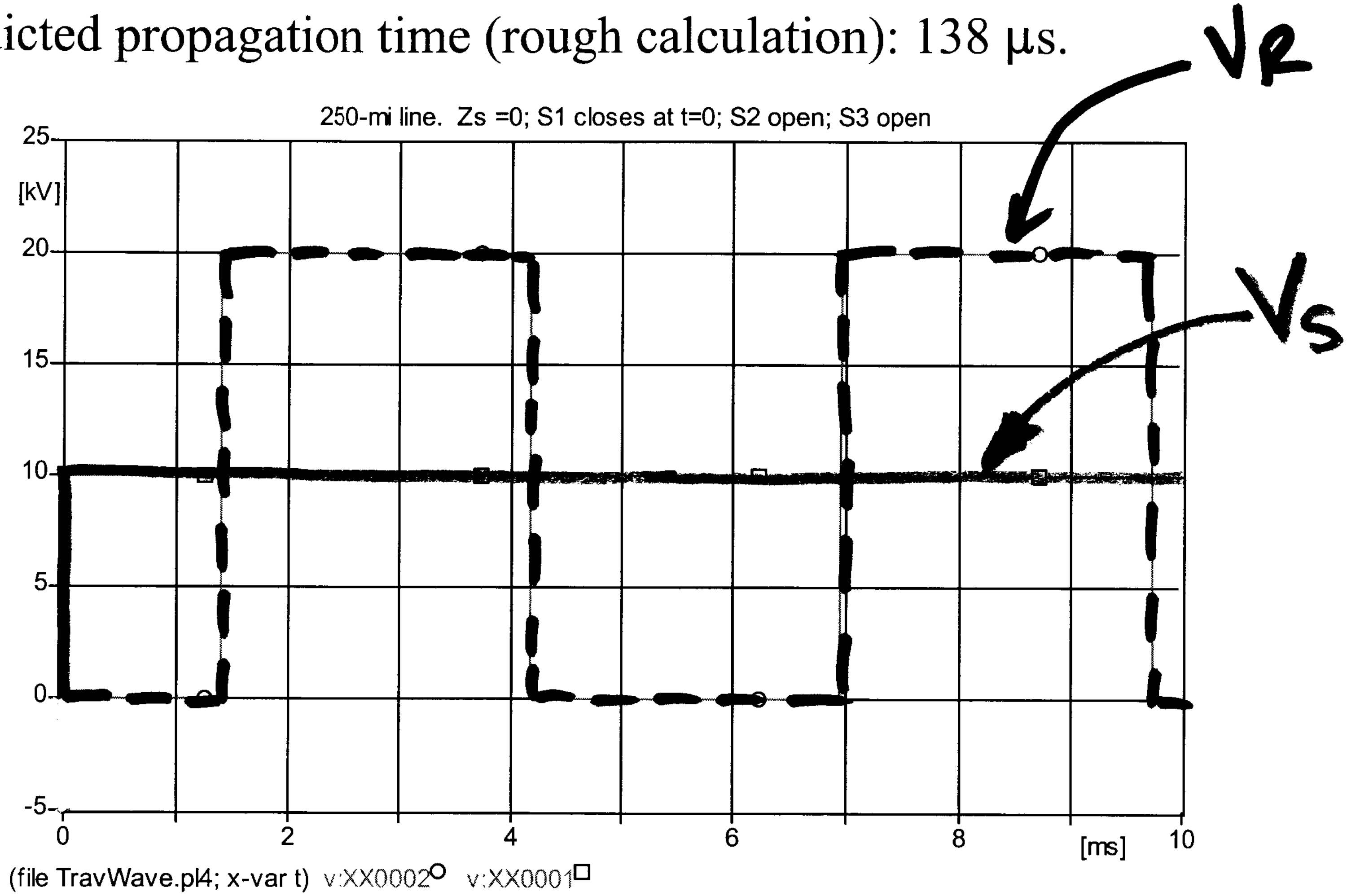
ILINE option: 0
$R/\ell = 0.2$ Ohms/mi
$A = j0.6$ Ohms/mi
$B = 7.3\ \mu S$/mi
ℓ (length) = 250 mi

$z = 0.2 + j0.6$ Ohms/mi
$y = j7.3\ \mu S$/mi
$Z_C = 294.3\ \underline{/-9.22^\circ}$ Ohms
$\gamma = 0.00215\ \underline{/80.8^\circ}$ /mi

Ref: EE5200 notes, Lectures 13 and 14.

First Case: Lossless. Zs = 0; Receiving end open-circuited.

Predicted propagation time (rough calculation): 138 µs.

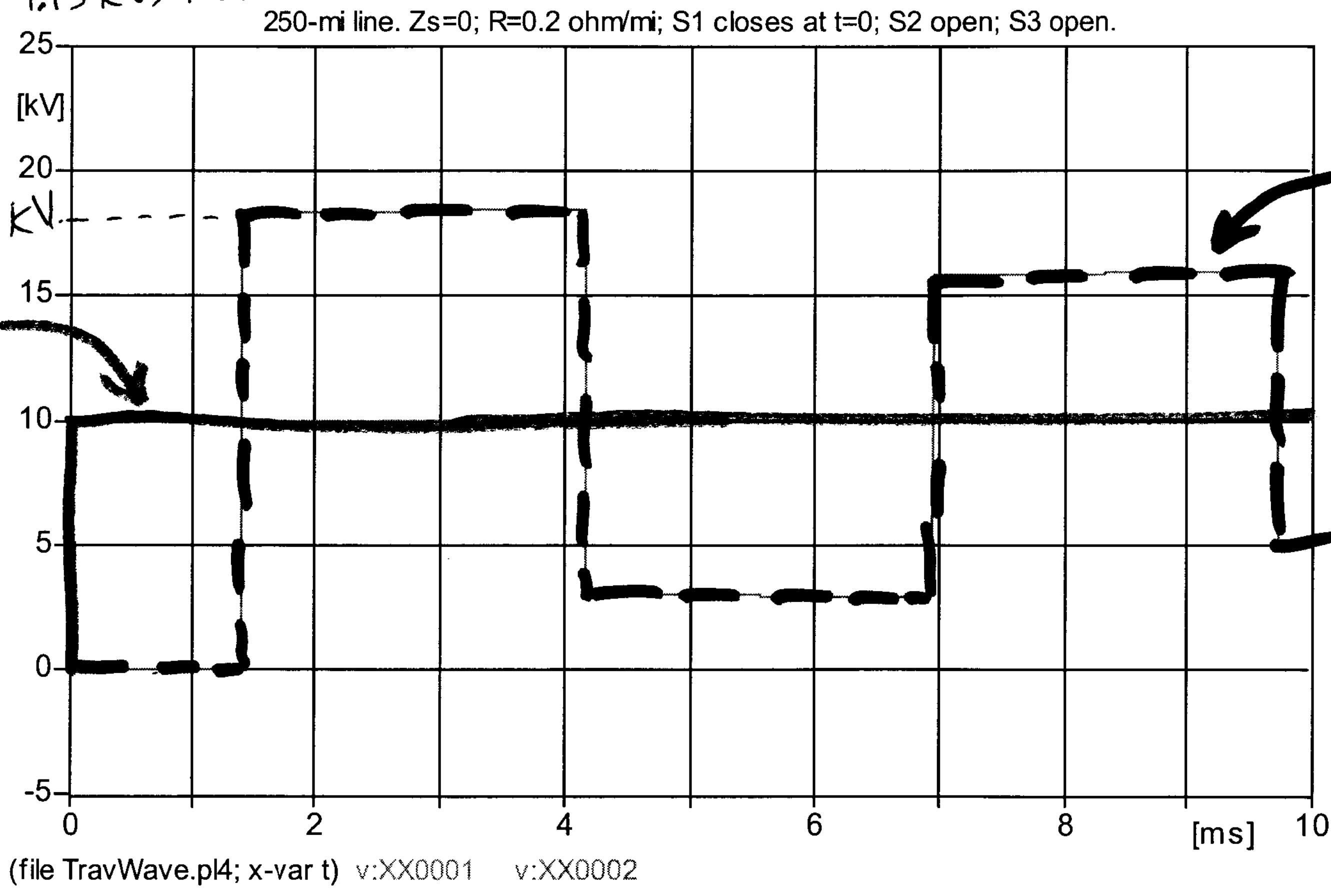


Actual propagation time: 139 µs.

$$\boxed{\rho_s = -1, \quad \rho_R = +1}$$

Second Case: R=0.2 Ohm/mi; Zs = 0; Receiving end open-circuited.

* 10-KV wave is attenuated 8.5%.
Arrives as 9.15 KV, reflection doubles it, to 18.3 KV.



$\rho_R = +1$

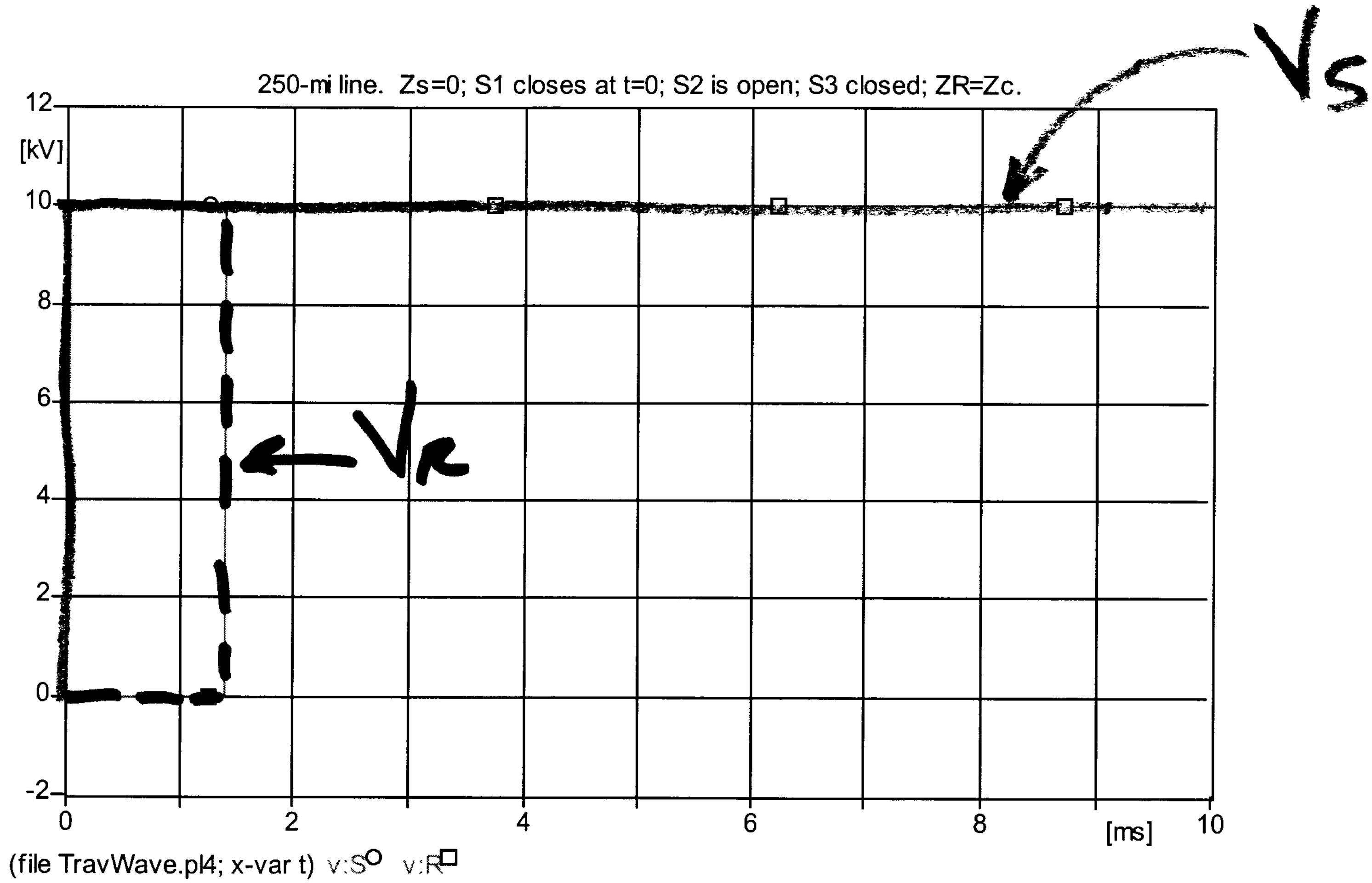
$\rho_S = -1$

*Note: Attenuation of voltage wave is $\alpha * l$

$= (0.00034/mi)(250\,mi) = 0.085$ or 8.5%

i.e. Mag at end of line is only 91.5%.

Third Case: Lossless line; Zs=0; $Z_R = Z_C$



Note: no reflection or voltage overshoot at receiving end !