**EE 5200 - Traveling Wave Example, Intro to ATP**

Referring to: Chapter 6 notes - T-Line models
T-Lines considering, distributed z,y, traveling waves
ATP Quick Start Handout

a. Pi-Equivalent circuit for long-line
b. Characteristic Impedance $Z_C$
c. Propagation Constant $\gamma = \alpha + j\beta$
d. Surge-Impedance Loading (SIL)
e. Wavelength, velocity
f. Traveling waves, reflections
g. Bounce diagrams (also called Bewley diagrams)

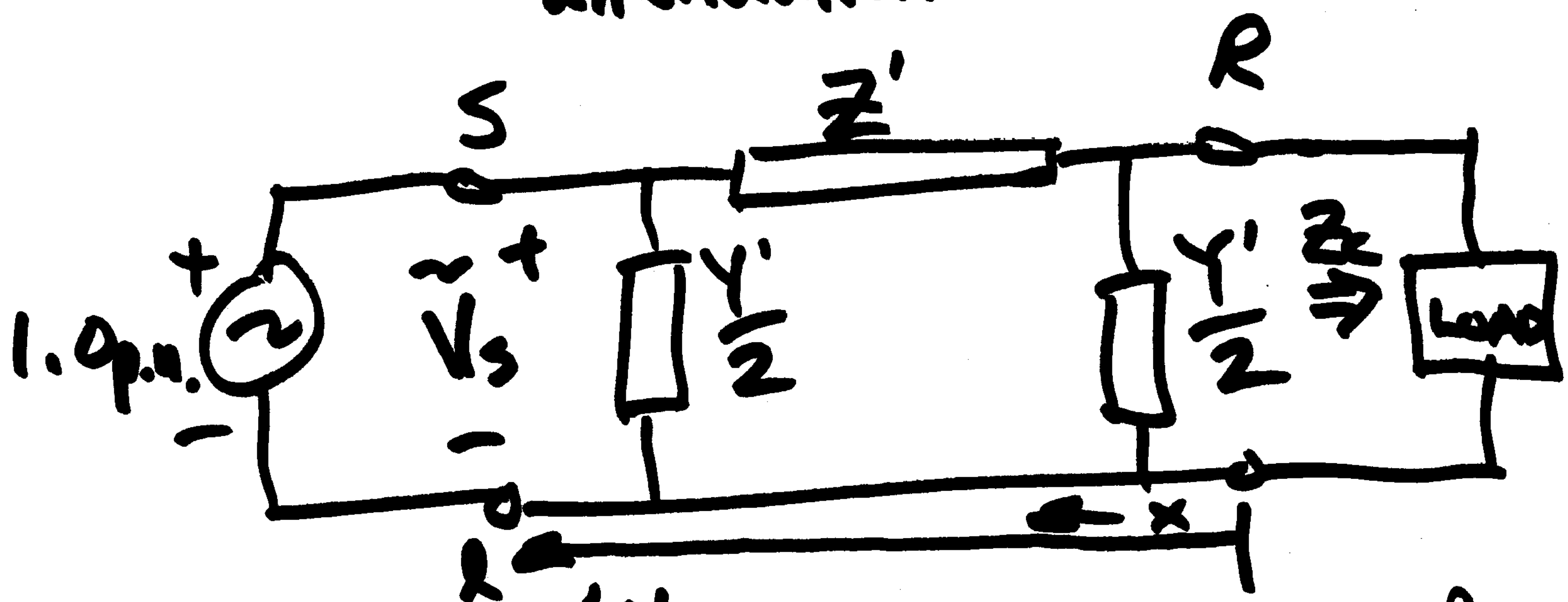
$$Z_c = \sqrt{\frac{z}{y}}$$

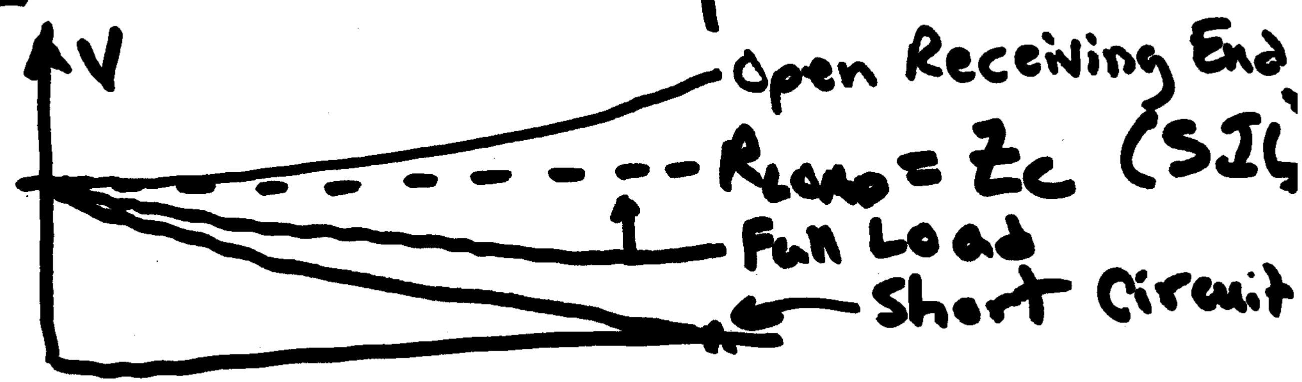
$$\gamma = \sqrt{z\,y} = \alpha + j\beta$$

attenuation ($\alpha$)

phase angle rotation ($\beta$)

How a wave travels down line.



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 $\lambda$



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

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

$e^{j\beta x}$: 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, $\lambda = \dfrac{v}{f} = \dfrac{3\times10^8 \text{ m/s}}{60}$

$\cong$ 5000 Km

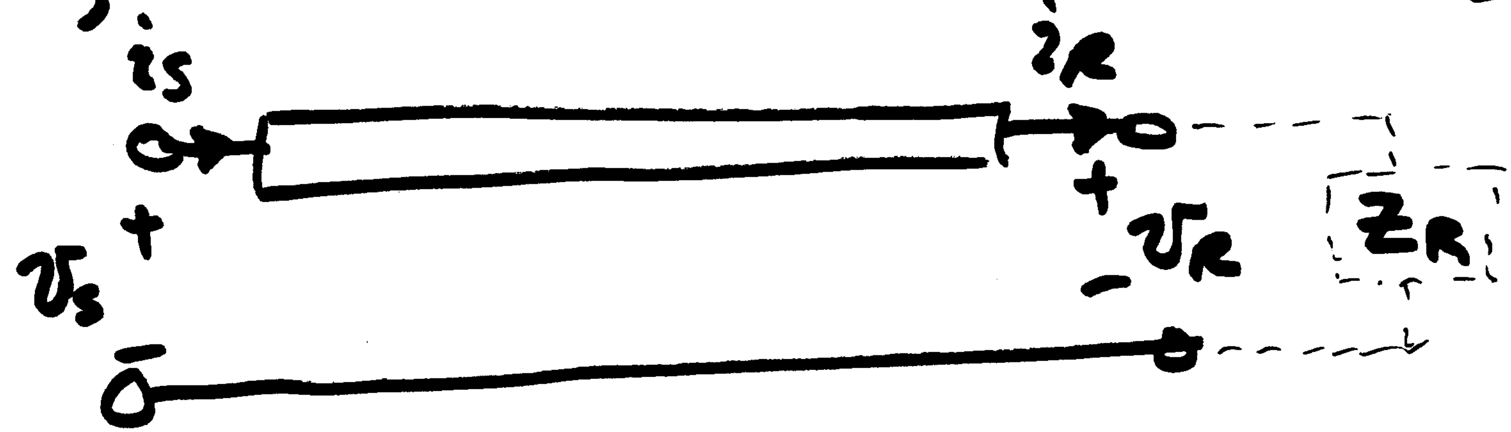
$\cong$ 3100 miles

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

- Side Comments (later) on
  T-Line loading limits
  - Thermal
  - Voltage Limits, $V_S$ & $V_R \Rightarrow VR$
    $.95 < V < 1.05$
  - Stability Limits

# Travelling Waves

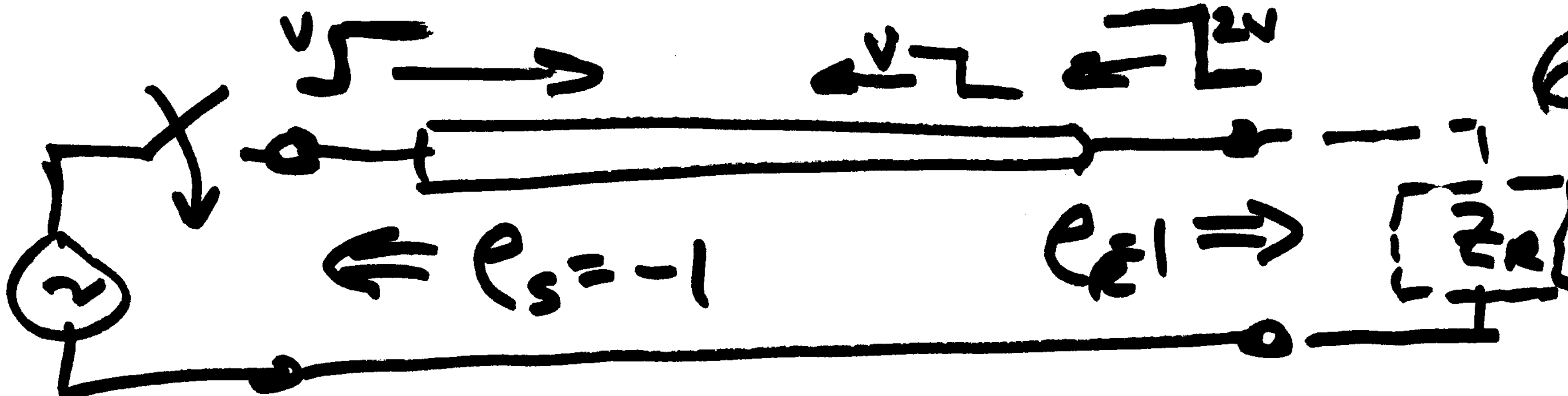





Impedance at receiving end:

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

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




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. $Z_R = 0$)

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

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

(From Lecture 13)

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

best for Trav. Waves.

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

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

$\alpha$ = attenuation constant

$\beta$ = angular propagation constant.

# Traveling Wave Example (ATPDraw) 7

~~See page 14, Lecture 13~~

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

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

250-miles long

$z = 0.2 + j0.6\ \Omega/mi$
$y = j7.3\ \mu S/mi$

$\Rightarrow$ $L = 0.398\ H$, $C = 484\ \mu F$, $R = 50\ \Omega$ } Total

If losses are ignored,

$Z_c = 286.69\ \Omega$
$\gamma = j0.00209$ rad/mi $\leftarrow \beta$
$(\alpha = 0)$

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

$= 3006$ mi

7a

250-mi Line

$z = 0.2_R + j0.6_X$ Ω/mi

$y = j7.3\,\mu S$/mi

a) $Z_c = \sqrt{\frac{z}{y}} = 294.3\angle{-9.22^\circ}\,\Omega$

0° for lossless

**Note:** Very typical for H.V. ohd line to have $300 < Z_c < 350$

b) $\gamma = \sqrt{zy}$

$= .00215\angle 80.8^\circ$

$= \underset{\alpha}{.00034} + j\underset{\beta}{.00212}$

90° for lossless.

Typical: $\frac{X}{R}$ ratio $\cong$ 20 for E.H.V. Line

Before creating ATP example, let's predict behavior: 8

<u>**Lossless:**</u> $\lambda = \frac{2\pi}{\beta} = \frac{2\pi}{.00209} = 3006\text{ mi}$

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

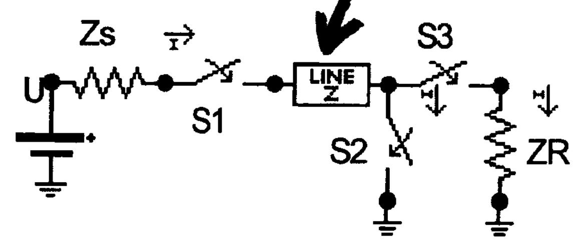
(should be $3\times10^{8}$... rounding.)

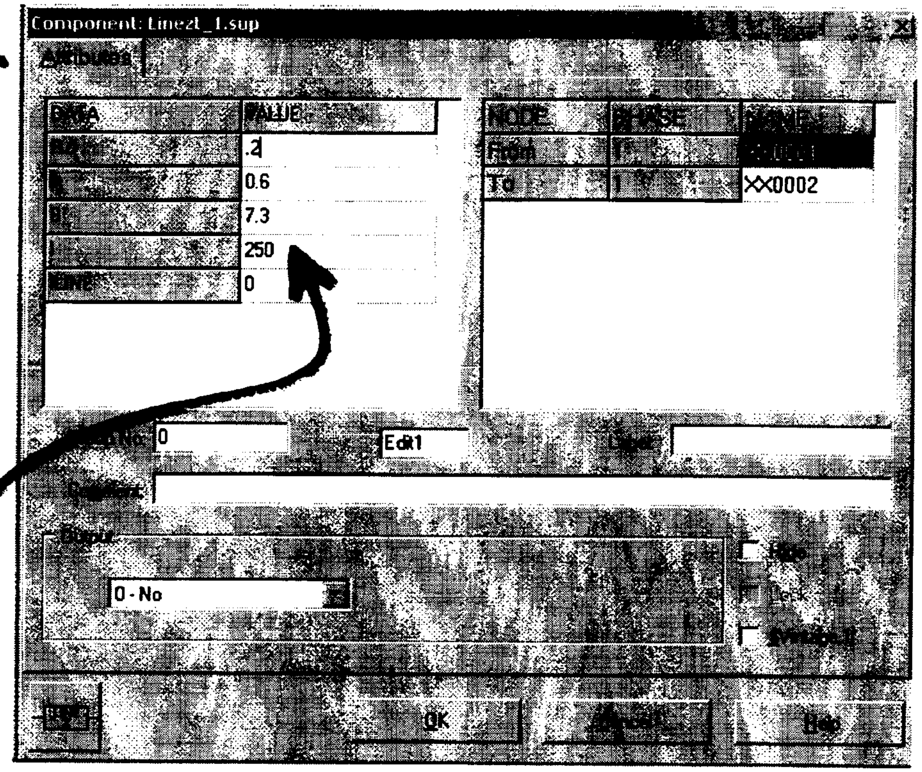
Propagation Time: Approx:

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

## 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
$B = 7.3\ \mu S/mi$
$\ell$ (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

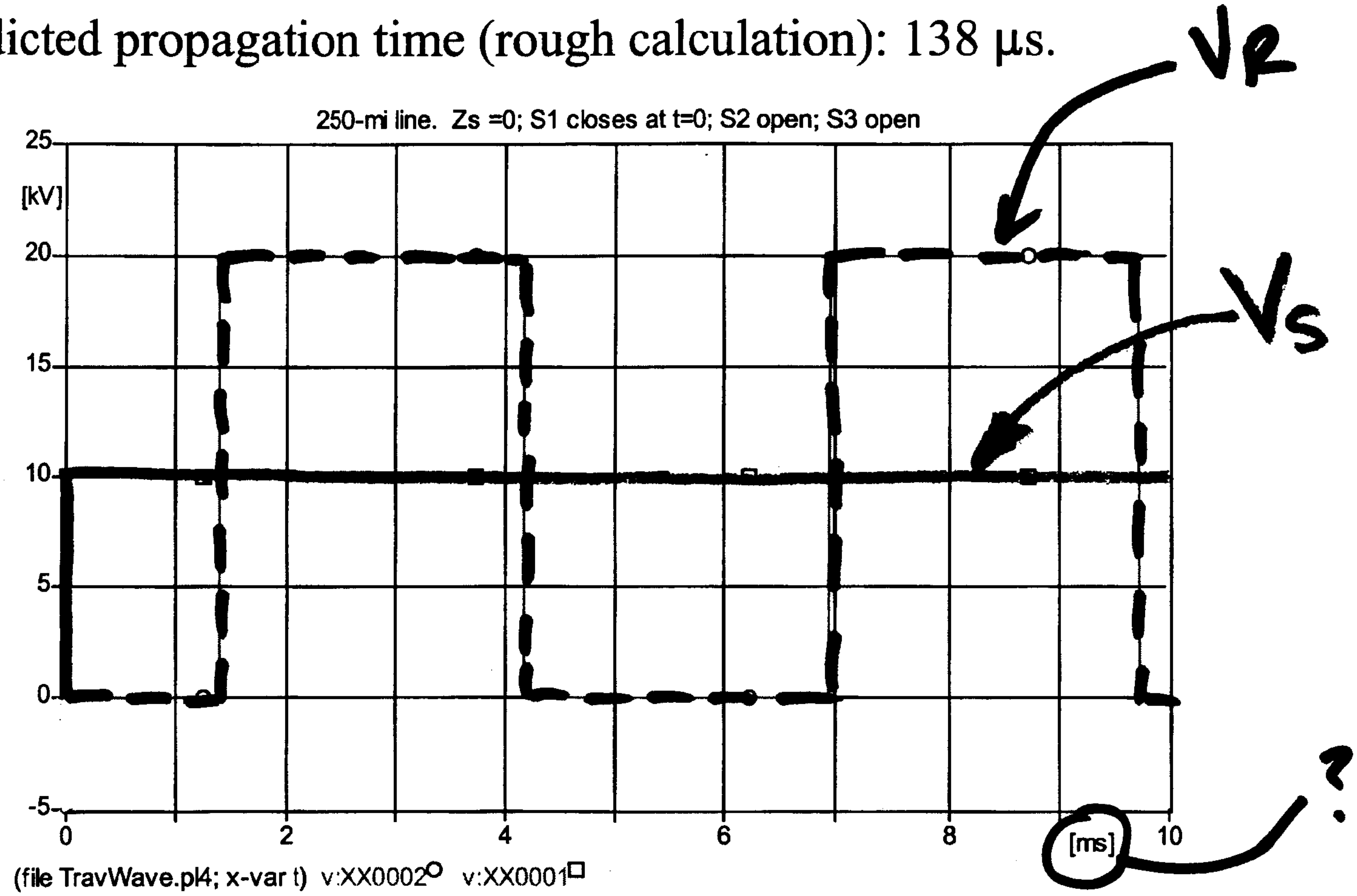
Ref: EE5200 notes, Lectures 13 and 14.

$\boxed{\text{HELP}}$

Name : LINEZT_1 - Distributed parameters, single phase
Card : BRANCH
Data : R/l= Resistance pr. length in [Ohm/m]
The lossless part can be described in three ways
0. Inductance L' in [mH/m] if Xopt=0 or in [ohm/m] if Xopt=power frequency
Capacitance C' in [uF/m] if Copt=0 or in [uMho/m] if Copt=power frequency
1. Modal surge impedance in [ohms]; Z=sqrt(L'/C')
Modal propagation velocity in [m/s]; v=1/sqrt(L'*C')
2. Modal surge impedance in [ohms]
Modal propagation time in [s]; T=sqrt(L'*C')*length
Xopt. and Copt. are set in menu: ATP|Settings/Simulation.
The user can choose conductance modeling G=0 (the usual case) and G=R*C/L (distortionless)
length= length of line in [m]
Node : From= Start node of line — SENDING
To= End node of line — REC.
Only branch voltage output is reliable.
RuleBook: IV.D.1

# 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 $\alpha \times l$

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

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

Close look at $\gamma = \alpha + j\beta$

$$\gamma = \sqrt{zy} = \sqrt{(.2+j.6)\,\Omega/\text{mi} * j7.3\,\mu S/\text{mi}}$$

$$= .00034/\text{mi} + j\,0.00212\ \text{rad/mi}$$

$$= \underbrace{.00034\ \frac{\text{neper}}{\text{mi}}} + j.00212\ \text{rad/mi}$$

Tells us how much attenuation/mi the wave will experience.

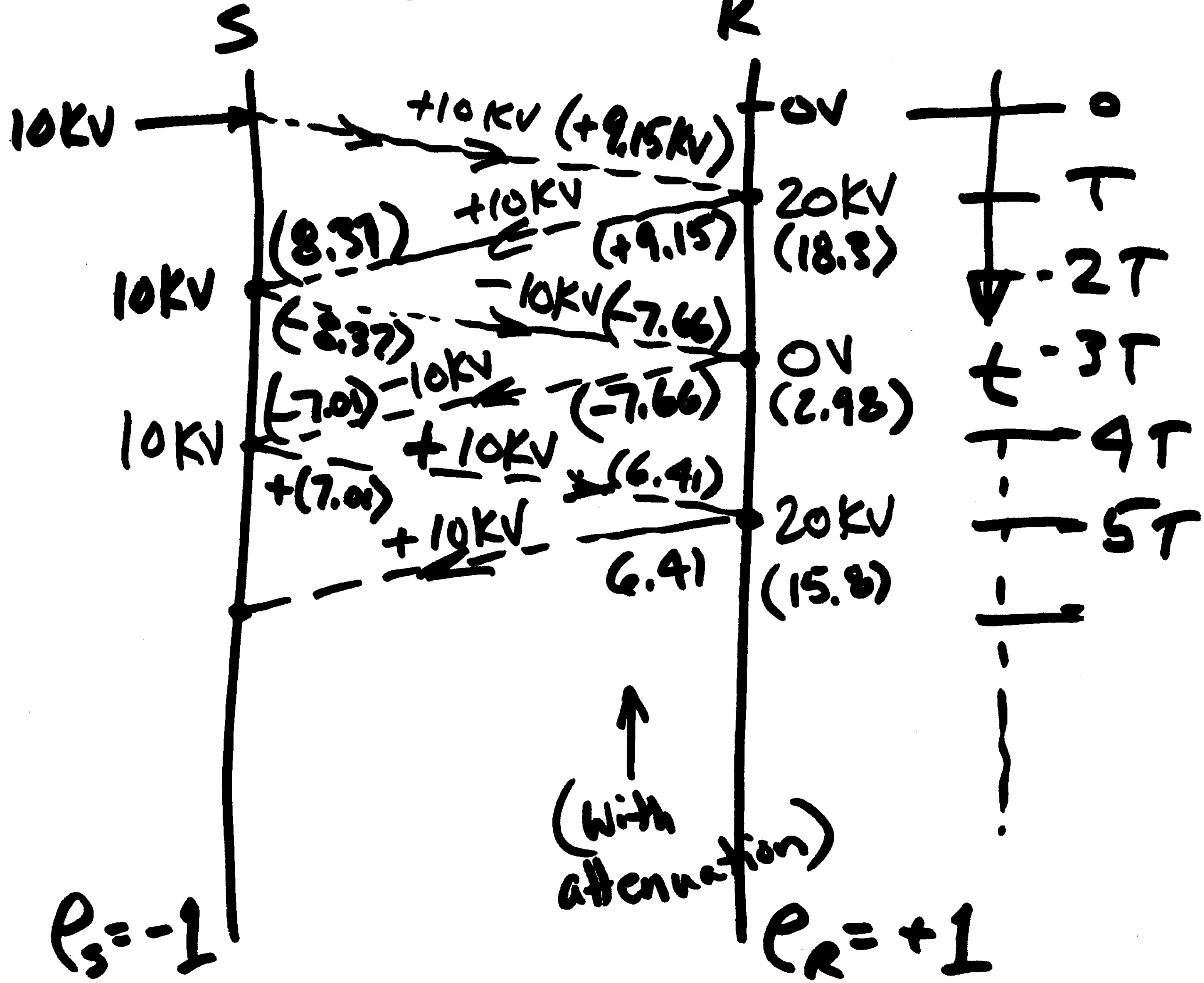
For 250 mi : Atten = $(.00034\ \frac{\text{neper}}{\text{mi}})(250\ \text{mi})$

$= 0.085$ or $8.5\%$.

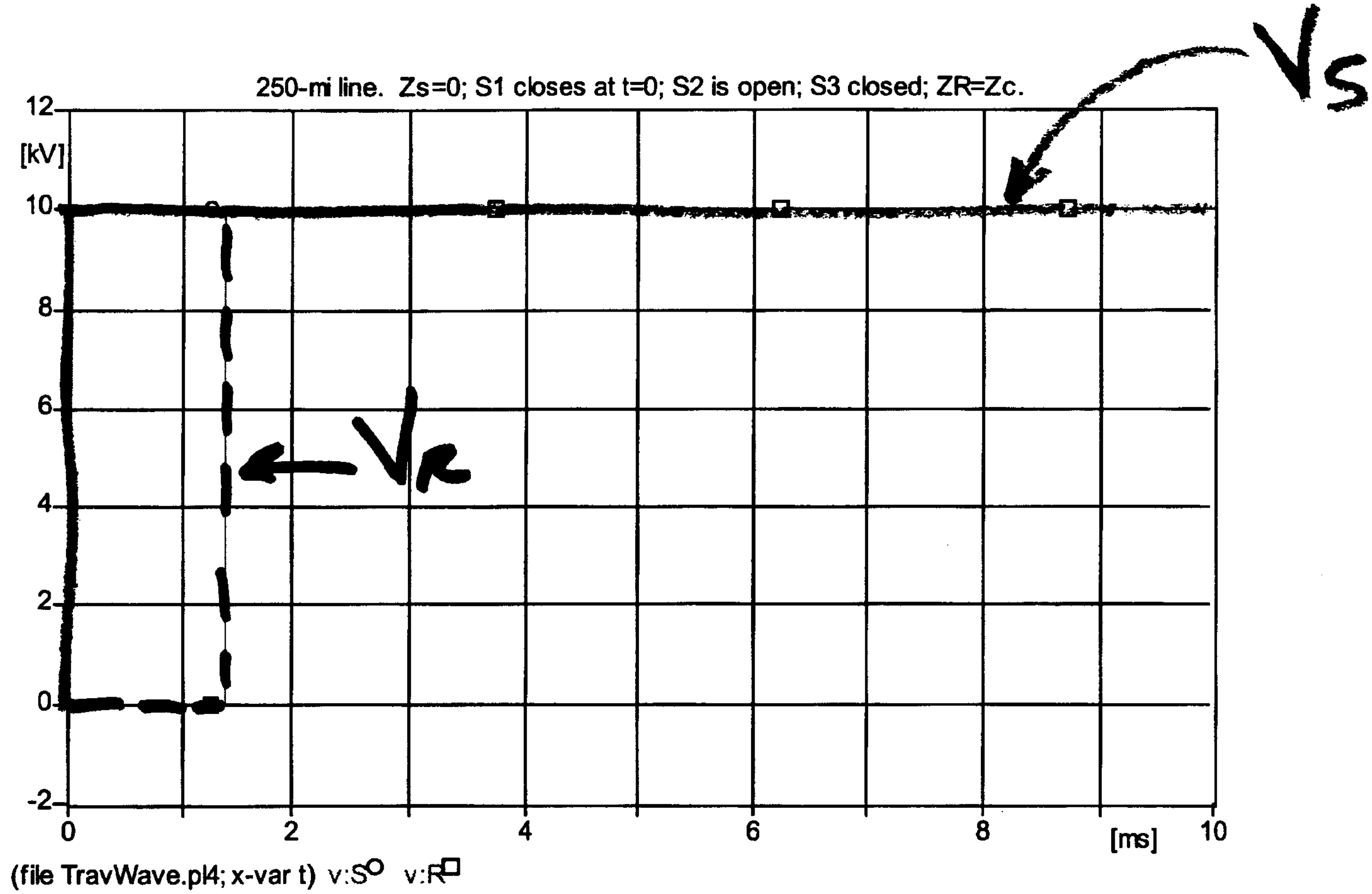
# "Bounce Diagrams"

Refer to end of Lecture 14 notes...

11b



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




Note: no reflection or voltage overshoot at receiving end !