Criteria for using Transmission Line Theory: Basic Experiments

Dr. José Ernesto Rayas-Sánchez

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The Need of Transmission Line Theory

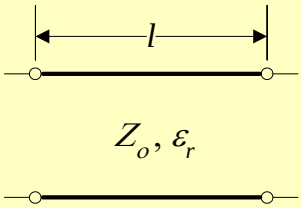
- For analog circuits:

  If the physical length of the transmission media is larger 10% of the wavelength of the highest frequency of interest

- For digital circuits:

  If the propagation time in the longest transmission path is larger than 10% of the fastest transition time

Calculating *L* and *C* in a Lossless TL



Example

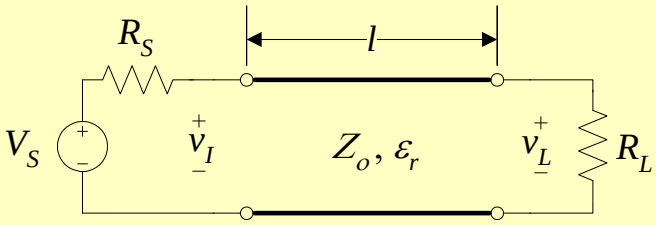
$Z_o = 50\Omega$, $\varepsilon_r = 4$ (FR4)

$$v_p = \frac{c}{\sqrt{\varepsilon_r}} = \frac{30\text{cm/ns}}{\sqrt{\varepsilon_r}} = 15\text{cm/ns}$$

$$Z_o = \sqrt{\frac{L}{C}} = 50\Omega \qquad v_p = \frac{1}{\sqrt{LC}} = 15\text{cm/ns}$$

then L = 333.325nH/m and C = 133.33pF/m

Lossless Transmission Line – Resistive Load



Z_o = 50 Ω
ε_r = 4 (FR4)

$$V_S = 1\text{V}\sin(2\pi ft)$$
$$f = 1\text{GHz}$$

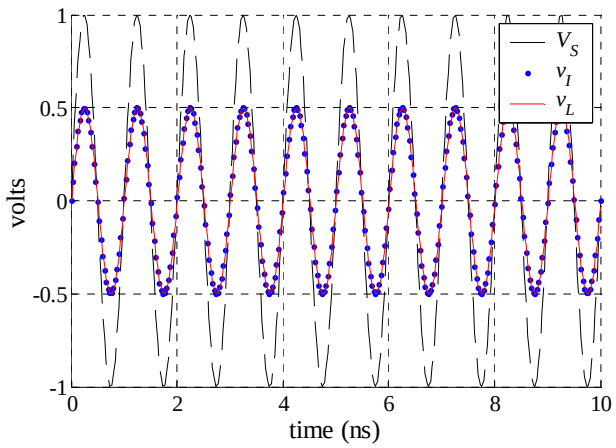
$$\lambda = \frac{v_p}{f} = \frac{15\text{cm/ns}}{1\text{GHz}} = 15\text{cm}$$

Lossless Transmission Line – Resistive Load

Case 1: Very short line; source and load matched

$l = 0.01\lambda = 0.15\text{cm}$

$R_S = 50\Omega$
$R_L = 50\Omega$

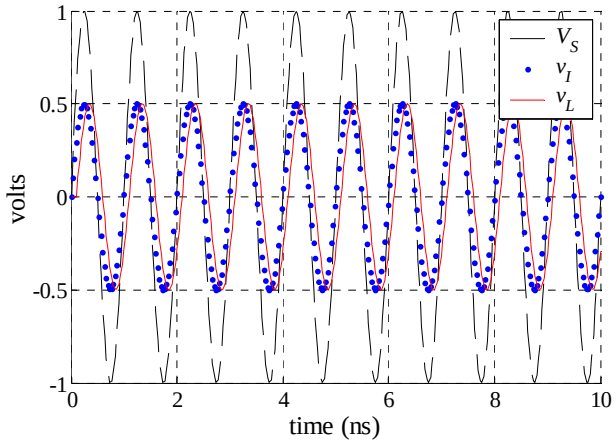


Lossless Transmission Line – Resistive Load

Case 2: Short line; source and load matched

$l = 0.1\lambda = 1.5\text{cm}$

$R_S = 50\Omega$
$R_L = 50\Omega$

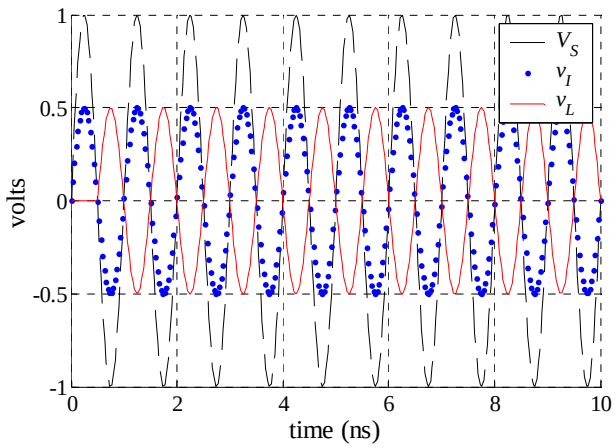


Lossless Transmission Line – Resistive Load

Case 3: Long line; source and load matched

$l = 0.5\lambda = 7.5\text{cm}$

$R_S = 50\Omega$
$R_L = 50\Omega$



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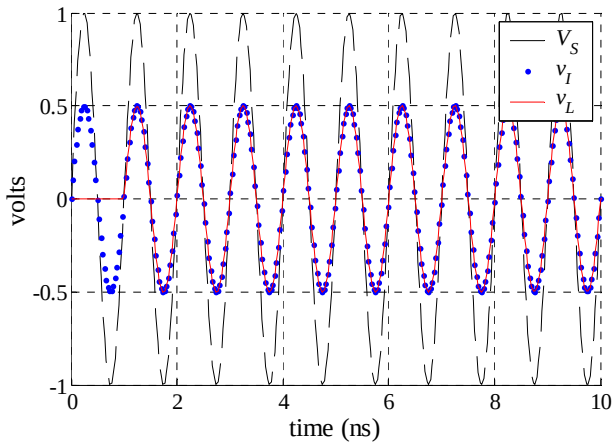
Lossless Transmission Line – Resistive Load

Case 4: Very long line; source and load matched

$l = \lambda = 15\text{cm}$

$R_S = 50\Omega$
$R_L = 50\Omega$



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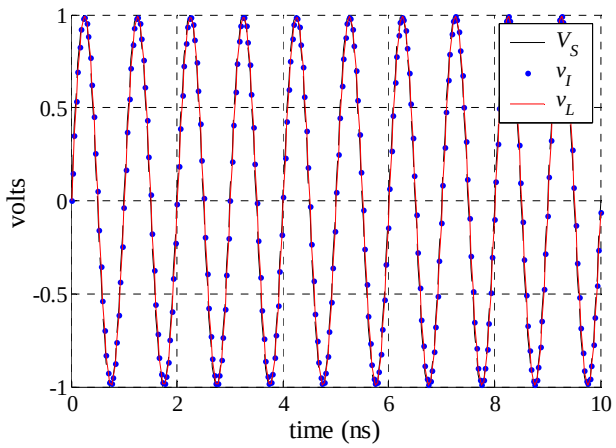
Lossless Transmission Line – Resistive Load

Case 5: Very short line; source matched and load mismatched

$l = 0.01\lambda = 0.15\text{cm}$

$R_S = 50\Omega$
$R_L = 5000\Omega$

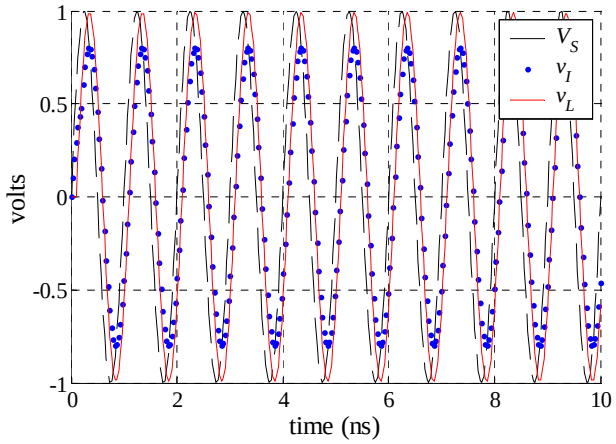


Lossless Transmission Line – Resistive Load

Case 6: Short line; source matched and load mismatched

$l = 0.1\lambda = 1.5\text{cm}$

$R_S = 50\Omega$
$R_L = 5000\Omega$

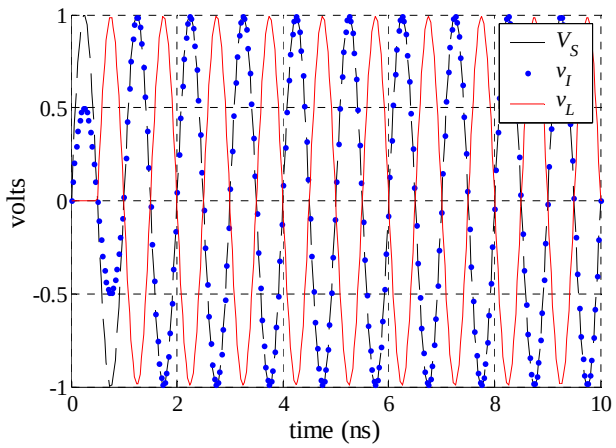


Lossless Transmission Line – Resistive Load

Case 7: Long line; source matched and load mismatched

$l = 0.5\lambda = 7.5\text{cm}$

$R_S = 50\Omega$
$R_L = 5000\Omega$

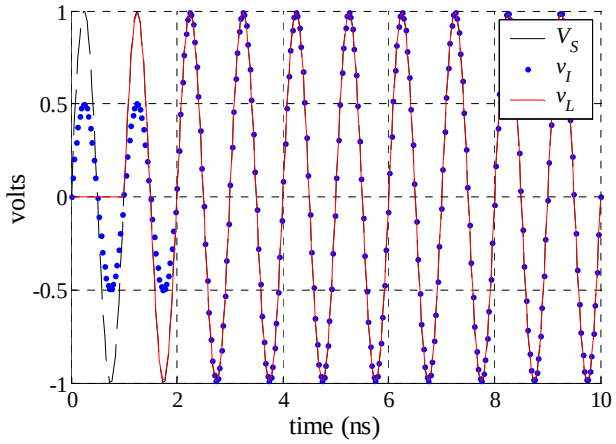


Lossless Transmission Line – Resistive Load

Case 8: Very long line; source matched and load mismatched

$l = \lambda = 15\text{cm}$

$R_S = 50\Omega$
$R_L = 5000\Omega$

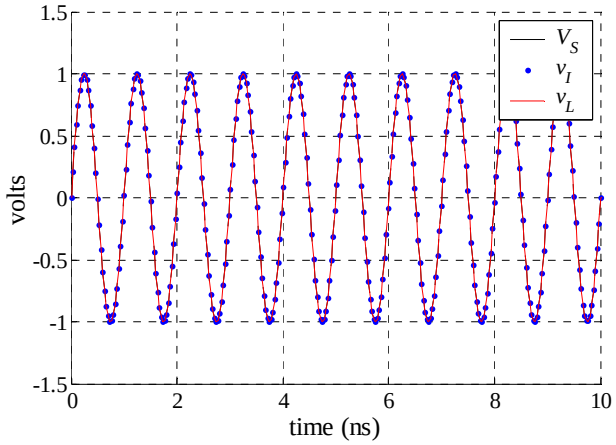


Lossless Transmission Line – Resistive Load

Case 9: Very short line; source and load mismatched

$l = 0.01\lambda = 0.15\text{cm}$

$R_S = 0.5\Omega$
$R_L = 5000\Omega$

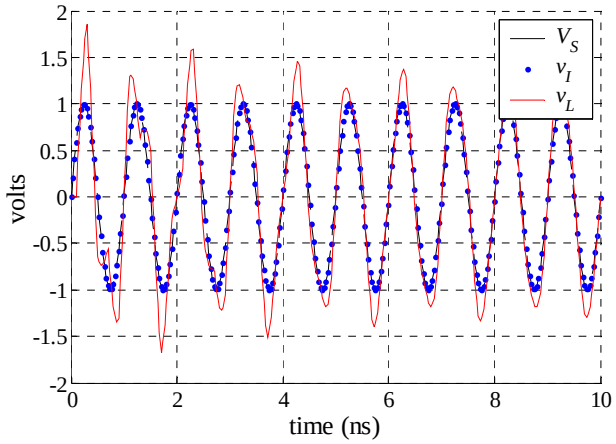


Lossless Transmission Line – Resistive Load

Case 10: Short line; source and load mismatched

$l = 0.1\lambda = 1.5\text{cm}$

$R_S = 0.5\Omega$
$R_L = 5000\Omega$

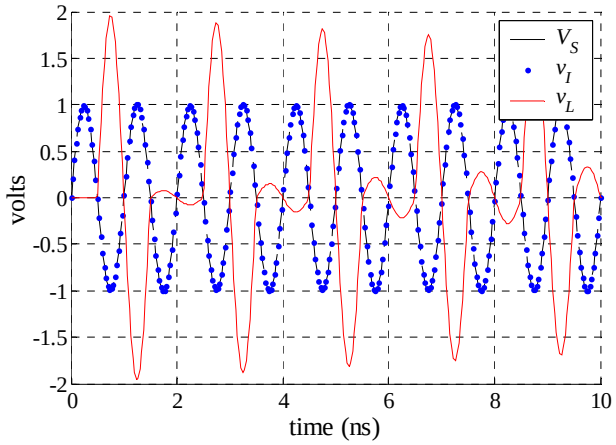


Lossless Transmission Line – Resistive Load

Case 11: Long line; source and load mismatched

$l = 0.5\lambda = 7.5\text{cm}$

$R_S = 0.5\Omega$
$R_L = 5000\Omega$

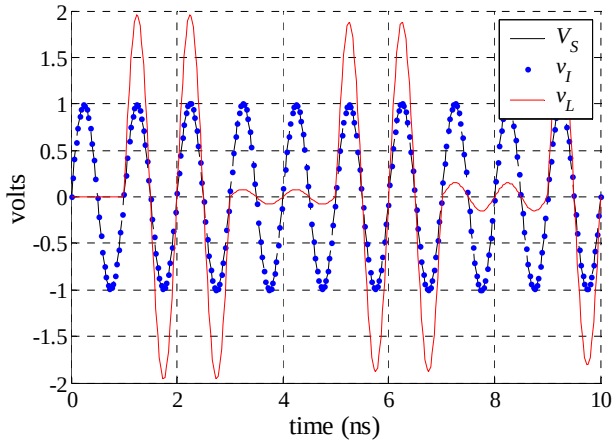


Lossless Transmission Line – Resistive Load

Case 12: Very long line; source and load mismatched

$l = \lambda = 15\text{cm}$

$R_S = 0.5\Omega$
$R_L = 5000\Omega$

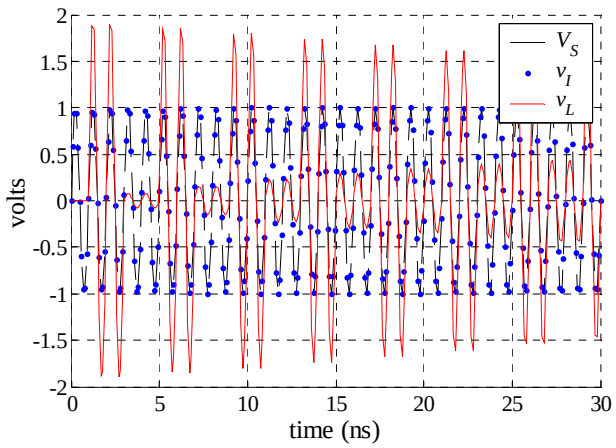


Lossless Transmission Line – Resistive Load

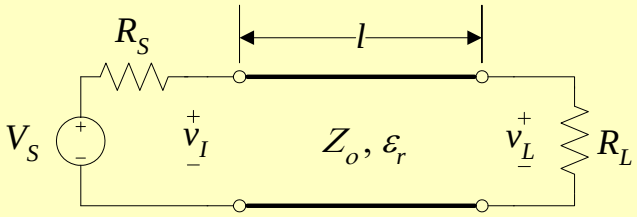
Case 12b: Very long line; source and load mismatched

$l = \lambda = 15\text{cm}$

$R_S = 0.5\Omega$
$R_L = 5000\Omega$



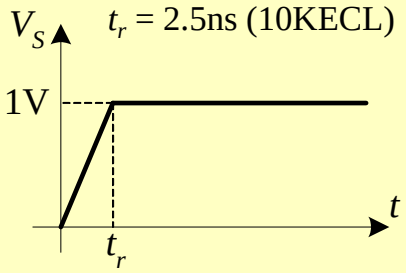
Lossless Transmission Line – Resistive Load



$Z_o = 50\ \Omega$
$\varepsilon_r = 4$ (FR4)

$$t_d = \frac{l}{v_p} = \frac{l}{15\text{cm}}\text{ns}$$

$l = (15\text{cm})\ t_{d(\text{ns})}$



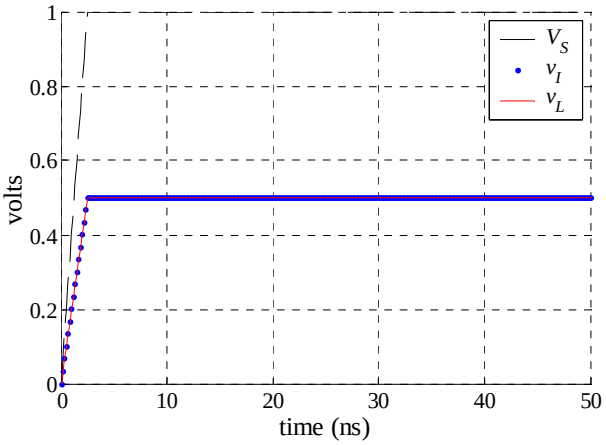
Lossless Transmission Line – Resistive Load

Case 1: Very short line; source and load matched

$t_d = t_r /100 = 0.025$ns

$l = 0.375$cm

$R_S = 50\Omega$
$R_L = 50\Omega$



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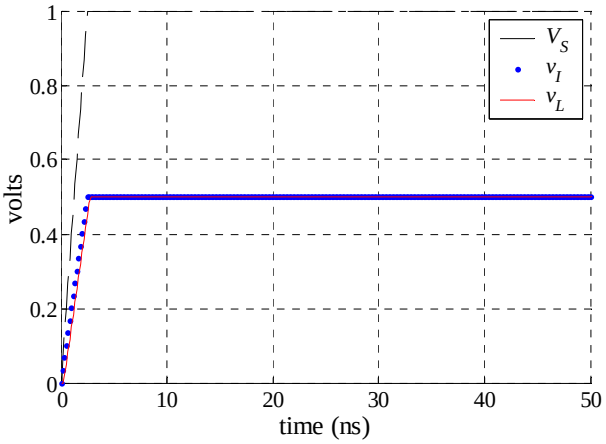
Lossless Transmission Line – Resistive Load

Case 2: Short line; source and load matched

$t_d = t_r /10 = 0.25$ns

$l = 3.75$cm

$R_S = 50\Omega$
$R_L = 50\Omega$



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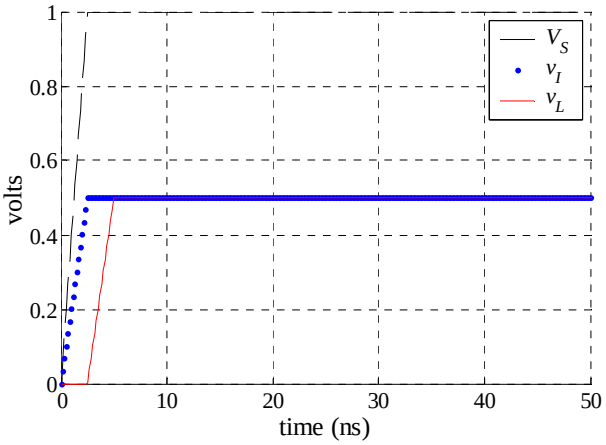
Lossless Transmission Line – Resistive Load

Case 3: Long line; source and load matched

$t_d = t_r = 2.5$ns

$l = 37.5$cm

$R_S = 50\Omega$
$R_L = 50\Omega$



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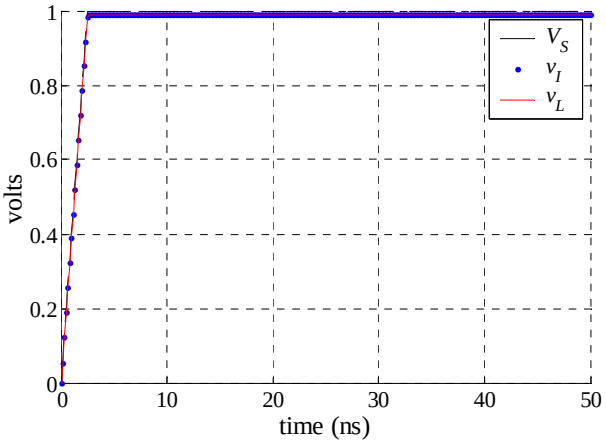
Lossless Transmission Line – Resistive Load

Case 5: Very short line; source matched and load mismatched

$t_d = t_r/100 = 0.025$ns

$l = 0.375$cm

$R_S = 50\Omega$
$R_L = 5000\Omega$



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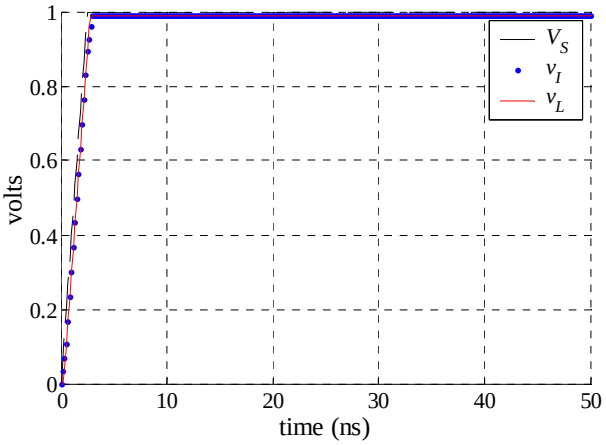
Lossless Transmission Line – Resistive Load

Case 6: Short line; source matched and load mismatched

$t_d = t_r/10 = 0.25$ns

$l = 3.75$cm

$R_S = 50\Omega$
$R_L = 5000\Omega$



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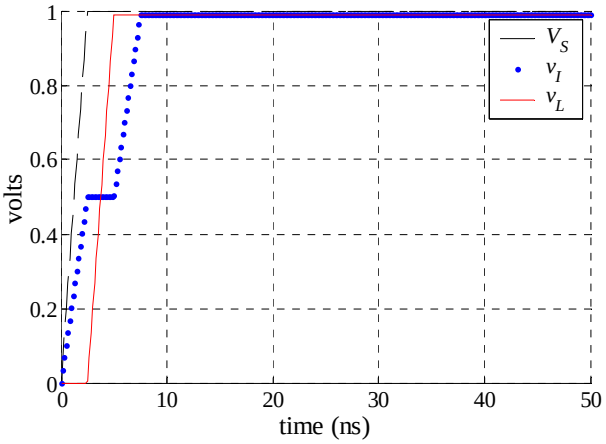
Lossless Transmission Line – Resistive Load

Case 7: Long line; source matched and load mismatched

$t_d = t_r = 2.5$ns

$l = 37.5$cm

$R_S = 50\Omega$
$R_L = 5000\Omega$



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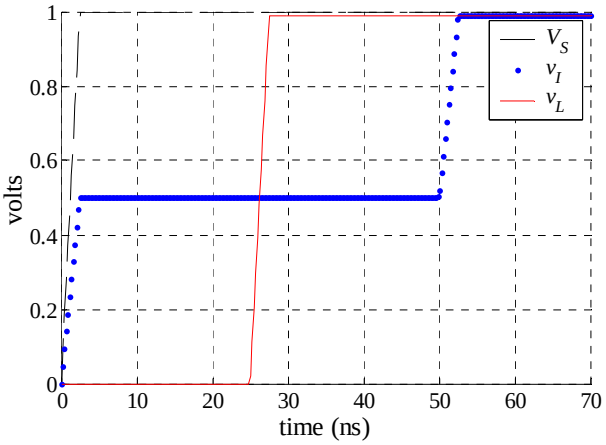
Lossless Transmission Line – Resistive Load

Case 8: Very long line; source matched and load mismatched

$t_d = 10t_r = 25\text{ns}$

$l = 375\text{cm}$

$R_S = 50\Omega$
$R_L = 5000\Omega$



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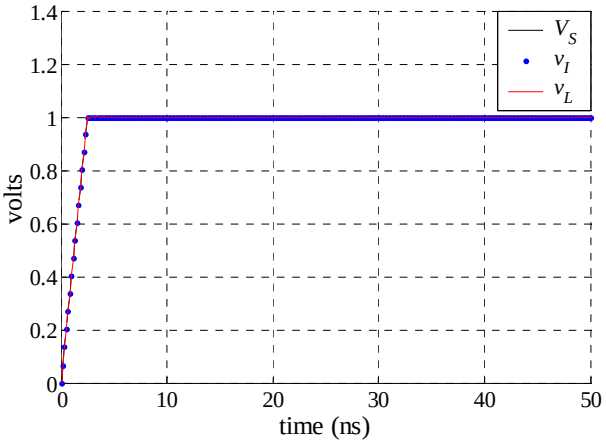
Lossless Transmission Line – Resistive Load

Case 9: Very short line; source and load mismatched

$t_d = t_r/100 = 0.025\text{ns}$

$l = 0.375\text{cm}$

$R_S = 0.5\Omega$
$R_L = 5000\Omega$



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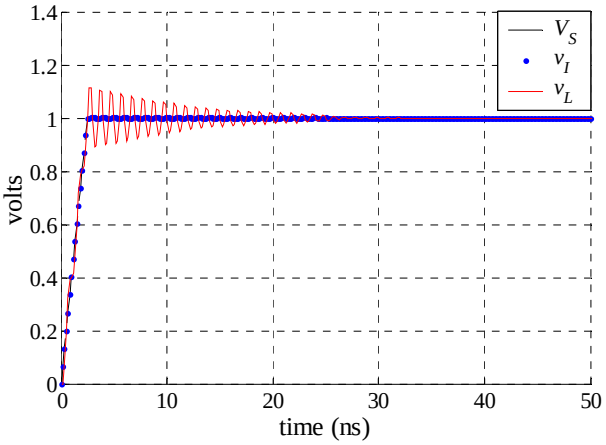
Lossless Transmission Line – Resistive Load

Case 10: Short line; source and load mismatched

$t_d = t_r/10 = 0.25$ns

$l = 3.75$cm

$R_S = 0.5\Omega$
$R_L = 5000\Omega$



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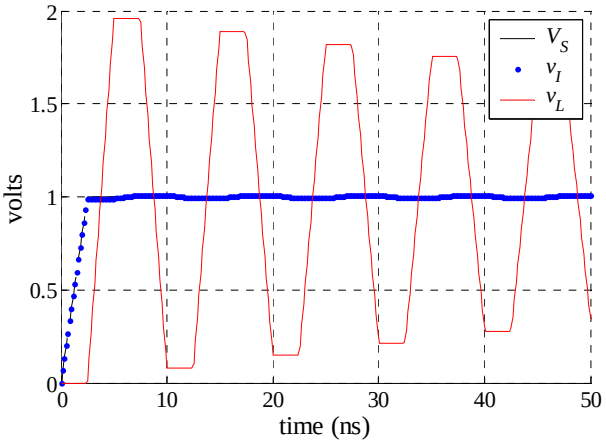
Lossless Transmission Line – Resistive Load

Case 11: Long line; source and load mismatched

$t_d = t_r = 2.5$ns

$l = 37.5$cm

$R_S = 0.5\Omega$
$R_L = 5000\Omega$



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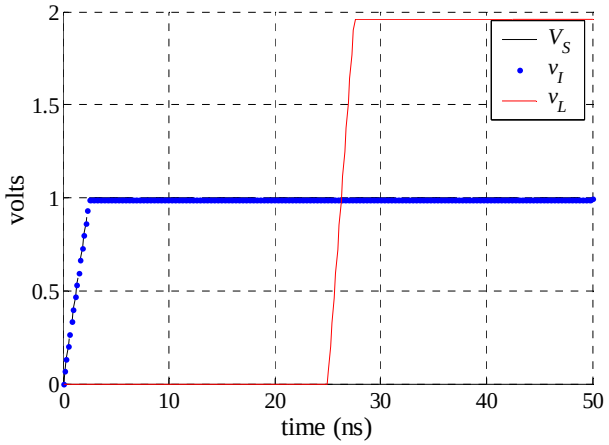
Lossless Transmission Line – Resistive Load

Case 12: Very long line; source and load mismatched

$t_d = 10t_r = 25\text{ns}$

$l = 375\text{cm}$

$R_S = 0.5\Omega$
$R_L = 5000\Omega$



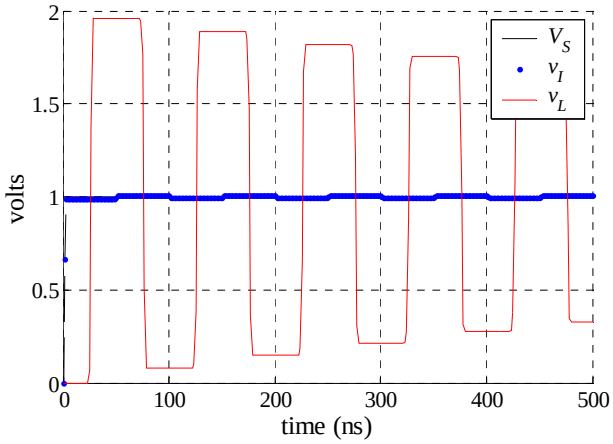
Lossless Transmission Line – Resistive Load

Case 12b: Very long line; source and load mismatched

$t_d = 10t_r = 25\text{ns}$

$l = 375\text{cm}$

$R_S = 0.5\Omega$
$R_L = 5000\Omega$



Conclusions

It is confirmed that transmission line theory is needed…

- For analog circuits:

  If the physical length of the transmission media is larger 10% of the wavelength of the highest frequency of interest

- For digital circuits:

  If the propagation time in the longest transmission path is larger than 10% of the fastest transition time