

Empirical Rules for Using Transmission Line Theory

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1

The Need of Transmission Line Theory

- For analog circuits:

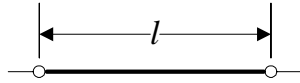
If the physical length of the transmission media is larger
10% of the wavelength of the highest frequency of interest

- For digital circuits:

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

2

Calculating L and C in a Lossless TL



Example

$$Z_o, \epsilon_r$$

$$Z_o = 50\Omega, \epsilon_r = 4 \text{ (FR4)}$$



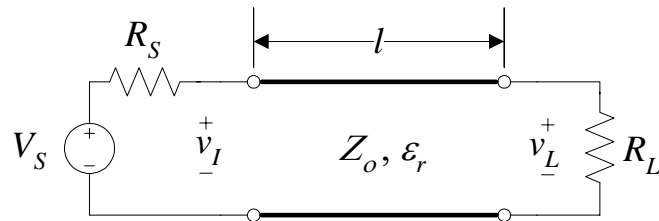
$$v_p = \frac{c}{\sqrt{\epsilon_r}} = \frac{30\text{cm/ns}}{\sqrt{\epsilon_r}} = 15\text{cm/ns}$$

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

then $L = 333.325\text{nH/m}$ and $C = 133.33\text{pF/m}$

3

Lossless Transmission Line – Resistive Load



$$Z_o = 50\Omega$$

$$\epsilon_r = 4 \text{ (FR4)}$$

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

$$f = 1\text{GHz}$$

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

4

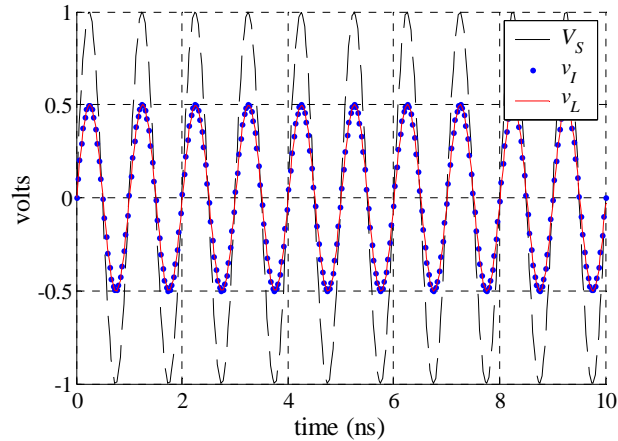
Lossless Transmission Line – Resistive Load

Case 1: Very short line; source and load matched

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

$$R_S = 50\Omega$$

$$R_L = 50\Omega$$



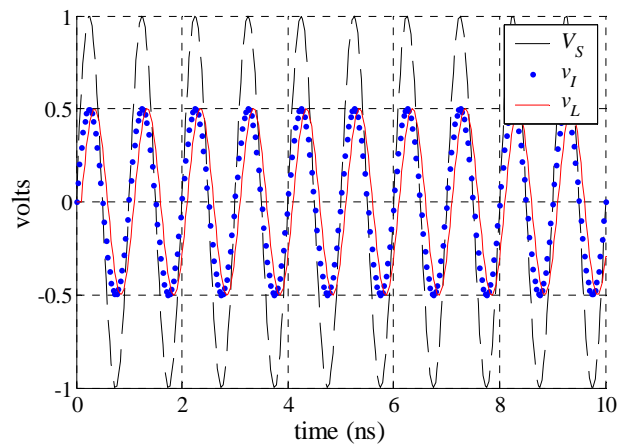
Lossless Transmission Line – Resistive Load

Case 2: Short line; source and load matched

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

$$R_S = 50\Omega$$

$$R_L = 50\Omega$$



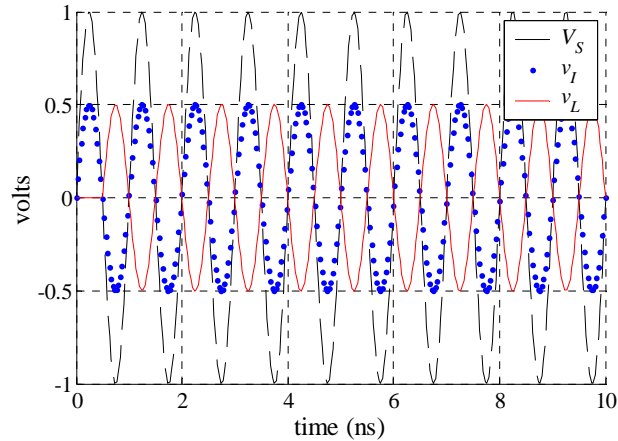
Lossless Transmission Line – Resistive Load

Case 3: Long line; source and load matched

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

$$R_S = 50\Omega$$

$$R_L = 50\Omega$$



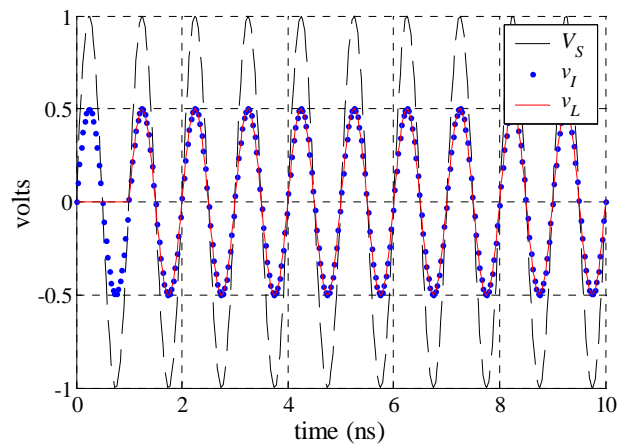
Lossless Transmission Line – Resistive Load

Case 4: Very long line; source and load matched

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

$$R_S = 50\Omega$$

$$R_L = 50\Omega$$



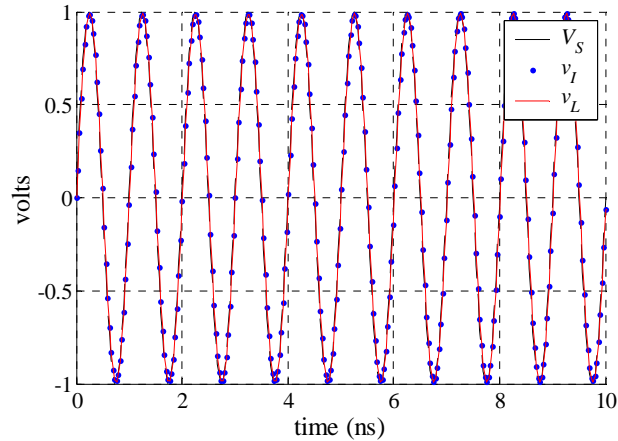
Lossless Transmission Line – Resistive Load

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

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

$$R_S = 50\Omega$$

$$R_L = 5000\Omega$$



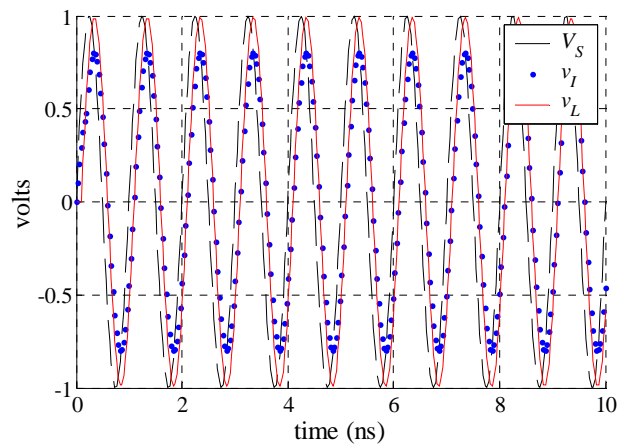
Lossless Transmission Line – Resistive Load

Case 6: Short line; source matched and load mismatched

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

$$R_S = 50\Omega$$

$$R_L = 5000\Omega$$

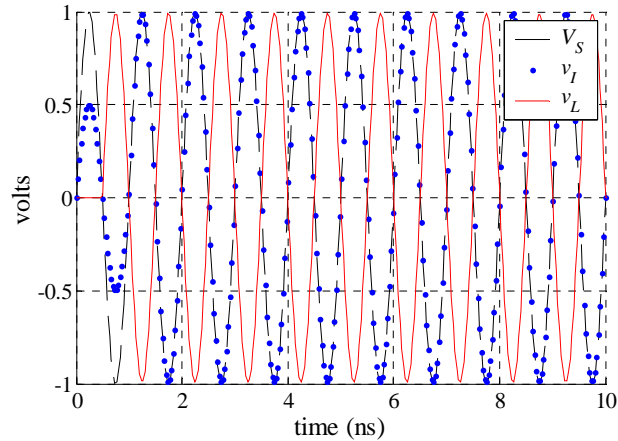


Lossless Transmission Line – Resistive Load

Case 7: Long line; source matched and load mismatched

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

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

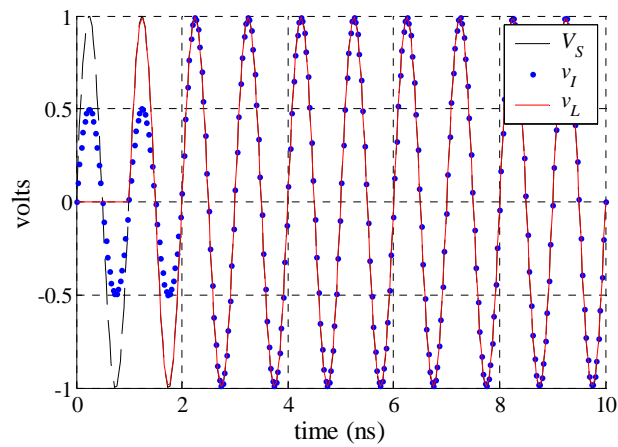


Lossless Transmission Line – Resistive Load

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

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

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

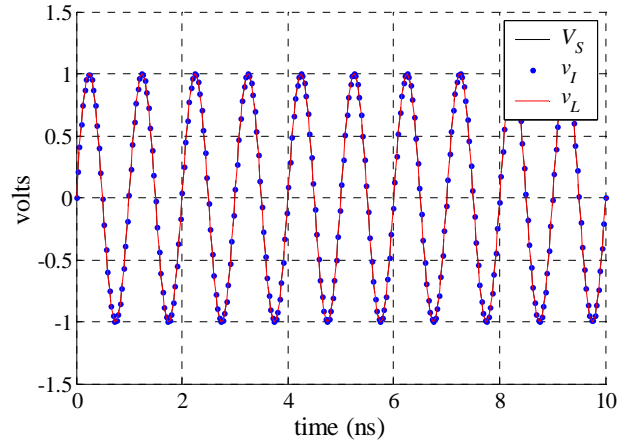


Lossless Transmission Line – Resistive Load

Case 9: Very short line; source and load mismatched

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

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

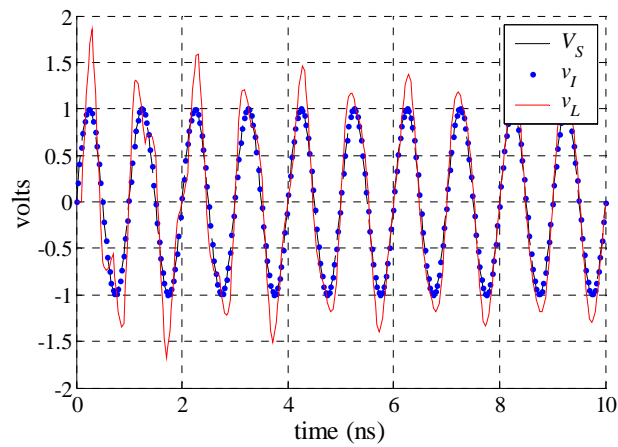


Lossless Transmission Line – Resistive Load

Case 10: Short line; source and load mismatched

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

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

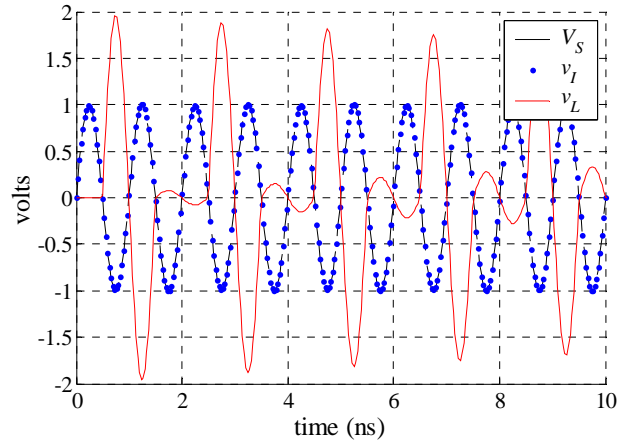


Lossless Transmission Line – Resistive Load

Case 11: Long line; source and load mismatched

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

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

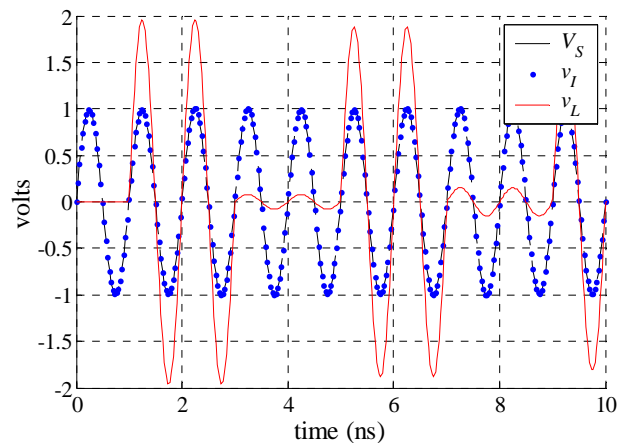


Lossless Transmission Line – Resistive Load

Case 12: Very long line; source and load mismatched

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

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



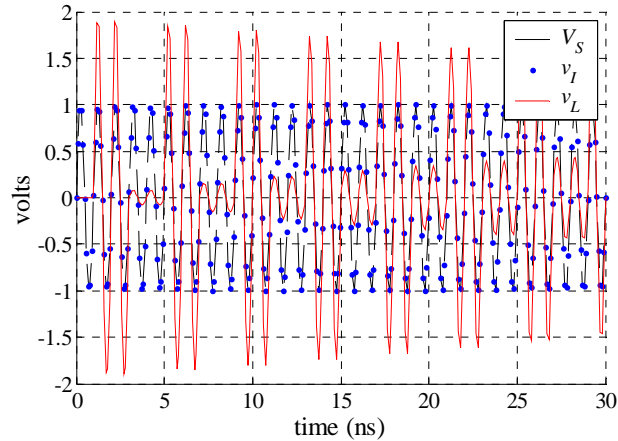
Lossless Transmission Line – Resistive Load

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

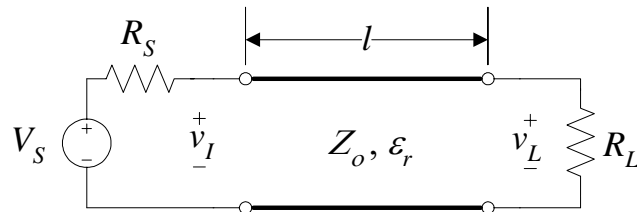
$$l = \lambda = 15\text{cm}$$

$$R_S = 0.5\Omega$$

$$R_L = 5000\Omega$$



Lossless Transmission Line – Resistive Load

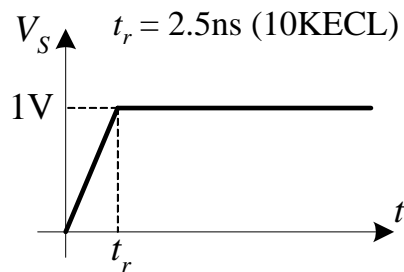


$$Z_o = 50\Omega$$

$$\epsilon_r = 4 \text{ (FR4)}$$

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

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



Lossless Transmission Line – Resistive Load

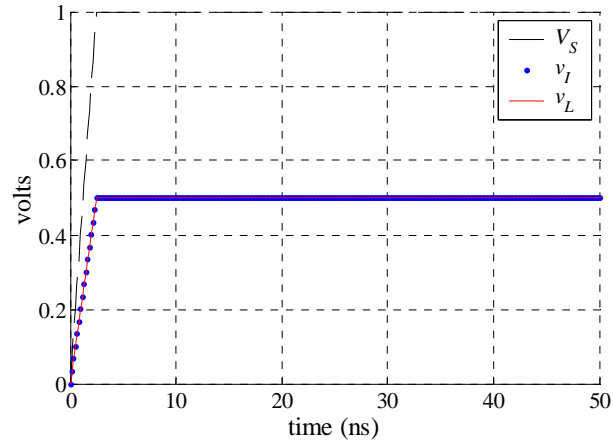
Case 1: Very short line; source and load matched

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

$$l = 0.375 \text{ cm}$$

$$R_S = 50 \Omega$$

$$R_L = 50 \Omega$$



Lossless Transmission Line – Resistive Load

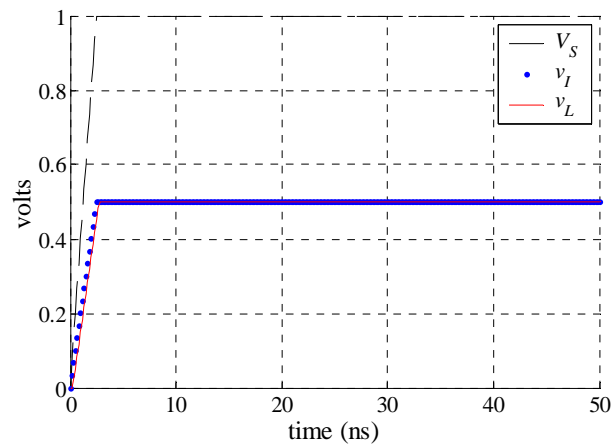
Case 2: Short line; source and load matched

$$t_d = t_r / 10 = 0.25 \text{ ns}$$

$$l = 3.75 \text{ cm}$$

$$R_S = 50 \Omega$$

$$R_L = 50 \Omega$$



Lossless Transmission Line – Resistive Load

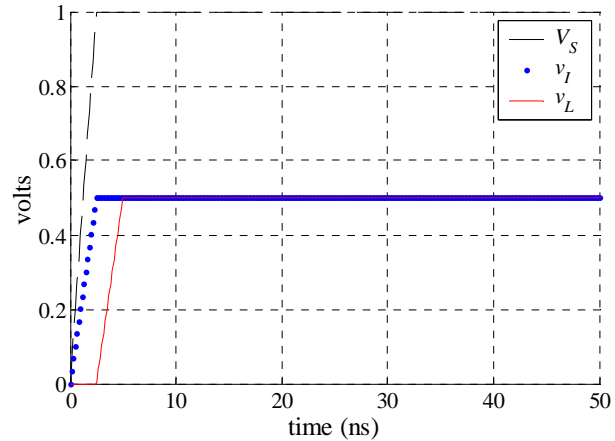
Case 3: Long line; source and load matched

$$t_d = t_r = 2.5\text{ns}$$

$$l = 37.5\text{cm}$$

$$R_S = 50\Omega$$

$$R_L = 50\Omega$$



Lossless Transmission Line – Resistive Load

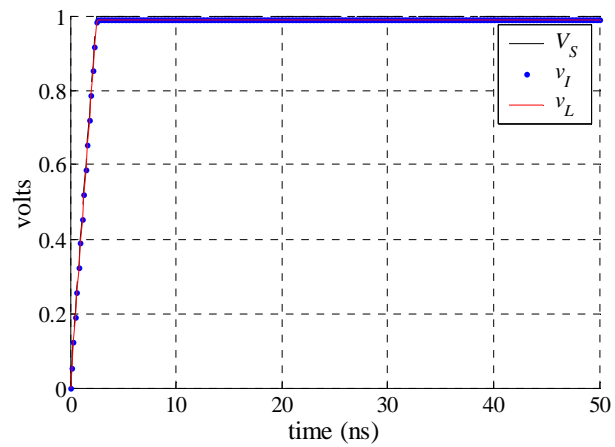
Case 5: Very short line; source matched and load mismatched

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

$$l = 0.375\text{cm}$$

$$R_S = 50\Omega$$

$$R_L = 5000\Omega$$



Lossless Transmission Line – Resistive Load

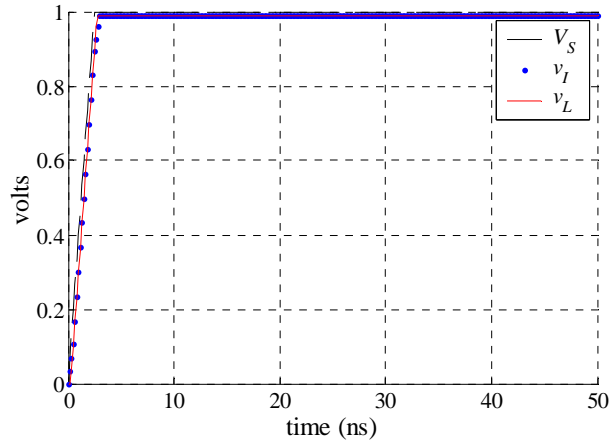
Case 6: Short line; source matched and load mismatched

$$t_d = t_r/10 = 0.25\text{ns}$$

$$l = 3.75\text{cm}$$

$$R_S = 50\Omega$$

$$R_L = 5000\Omega$$



Lossless Transmission Line – Resistive Load

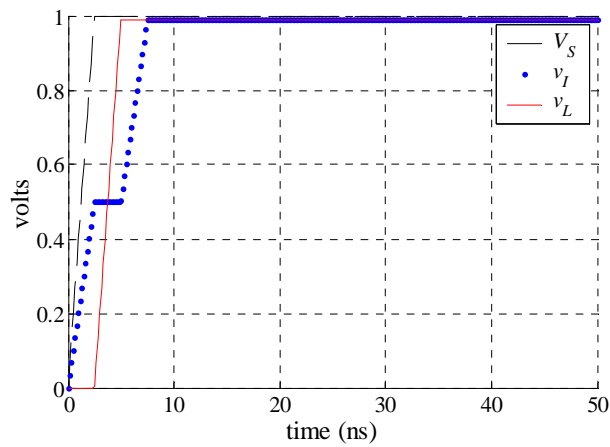
Case 7: Long line; source matched and load mismatched

$$t_d = t_r = 2.5\text{ns}$$

$$l = 37.5\text{cm}$$

$$R_S = 50\Omega$$

$$R_L = 5000\Omega$$



Lossless Transmission Line – Resistive Load

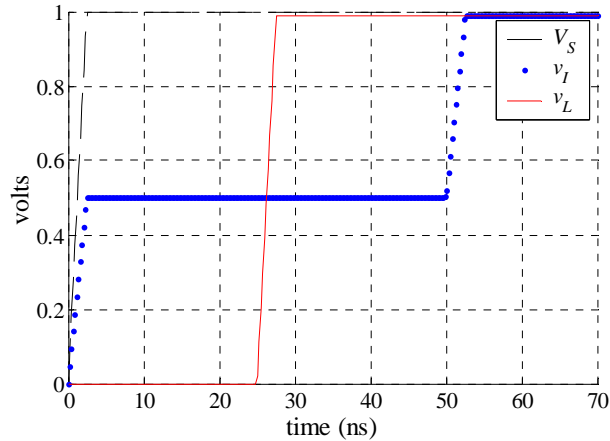
Case 8: Very long line; source matched and load mismatched

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

$$l = 375\text{cm}$$

$$R_S = 50\Omega$$

$$R_L = 5000\Omega$$



Lossless Transmission Line – Resistive Load

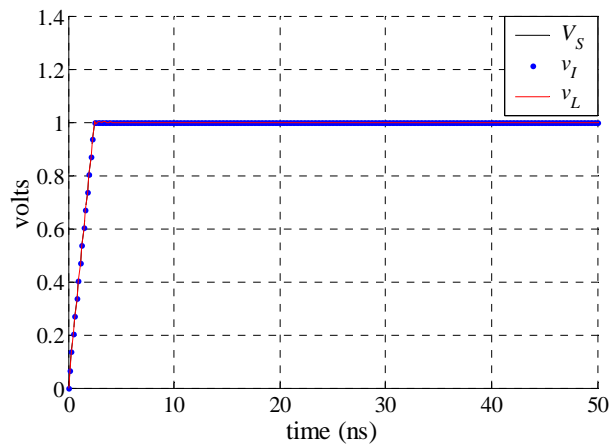
Case 9: Very short line; source and load mismatched

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

$$l = 0.375\text{cm}$$

$$R_S = 0.5\Omega$$

$$R_L = 5000\Omega$$



Lossless Transmission Line – Resistive Load

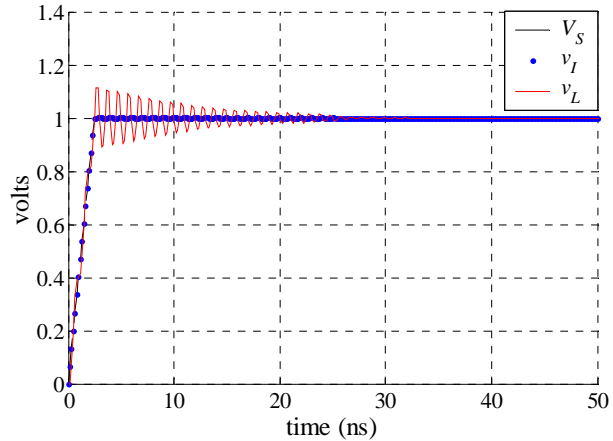
Case 10: Short line; source and load mismatched

$$t_d = t_r/10 = 0.25\text{ns}$$

$$l = 3.75\text{cm}$$

$$R_S = 0.5\Omega$$

$$R_L = 5000\Omega$$



Lossless Transmission Line – Resistive Load

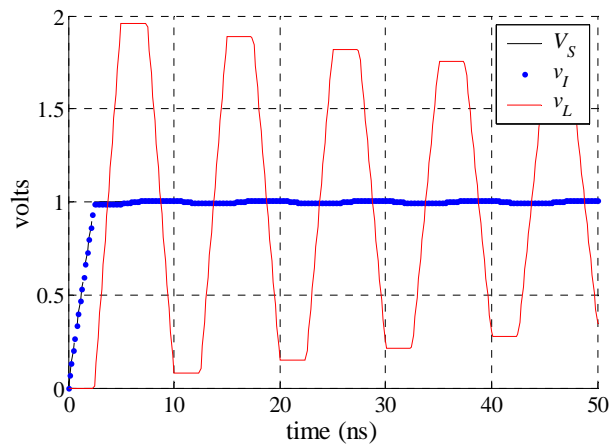
Case 11: Long line; source and load mismatched

$$t_d = t_r = 2.5\text{ns}$$

$$l = 37.5\text{cm}$$

$$R_S = 0.5\Omega$$

$$R_L = 5000\Omega$$



Lossless Transmission Line – Resistive Load

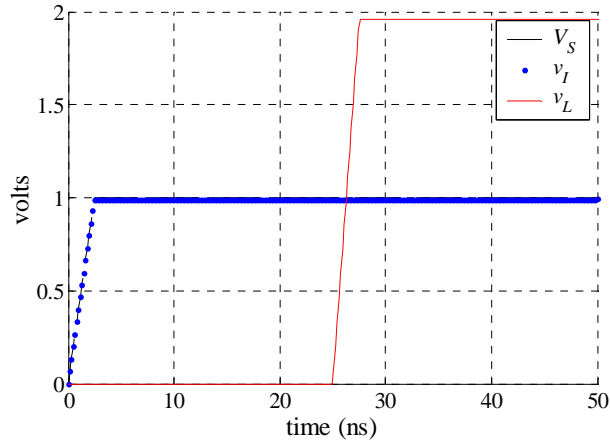
Case 12: Very long line; source and load mismatched

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

$$l = 375\text{cm}$$

$$R_S = 0.5\Omega$$

$$R_L = 5000\Omega$$



Lossless Transmission Line – Resistive Load

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

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

$$l = 375\text{cm}$$

$$R_S = 0.5\Omega$$

$$R_L = 5000\Omega$$

