ECE 344

Microwave Fundamentals

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lect4
Ideal transmission line component in ADS

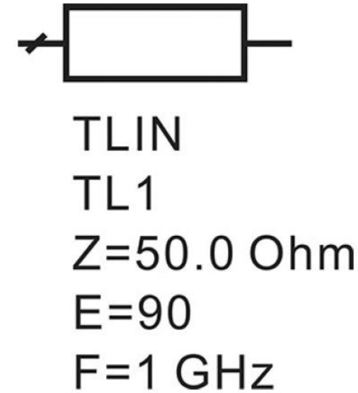


Figure An ideal transmission line component in ADS

Example 1

Figure shows an ideal transmission line in the ADS schematic window. The **E** in the figure represents the electrical length

(1) If the wavelength at 1 GHz is denoted as λ_o, what is the length of the transmission line?

(2) What is the electrical length **E** at a frequency of 3 GHz?

Solutions

(1) Since

$$\theta = \beta l = \frac{2\pi l}{\lambda_o} = \frac{\pi}{2}$$

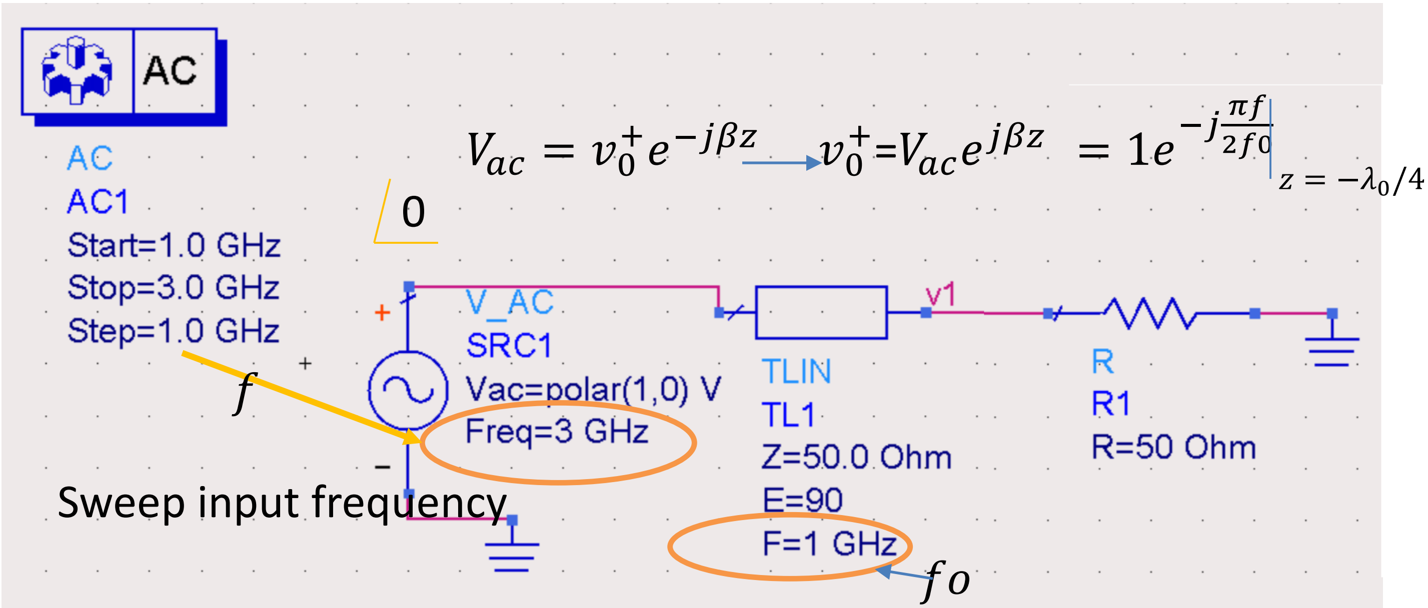
then the length is found to be $l = 0.25\,\lambda_o$. physical length if fabricated=7.5 cm

(2) The electrical length is

$$\theta = \beta l = \frac{\omega l}{v_p} = \frac{2\pi l}{\lambda}$$

Now, keeping the phase velocity and length fixed, the electrical length is proportional to the frequency. Thus, at 3 GHz, $|E|$ 270°.

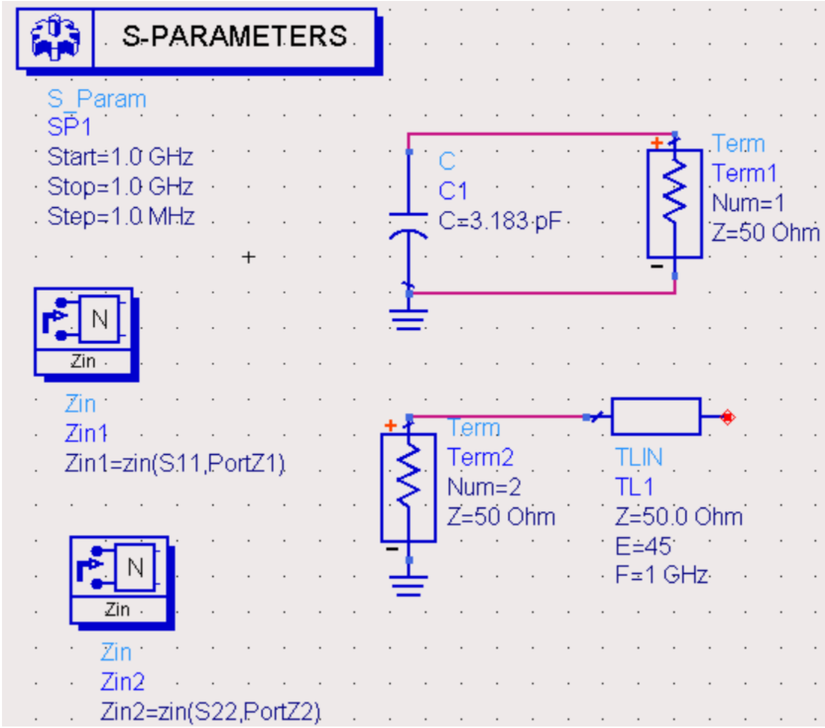
Verify by ADS



freq	v1
1.000 GHz	1.000 / -90.000
2.000 GHz	1.000 / -179.999
3.000 GHz	1.000 / 90.000

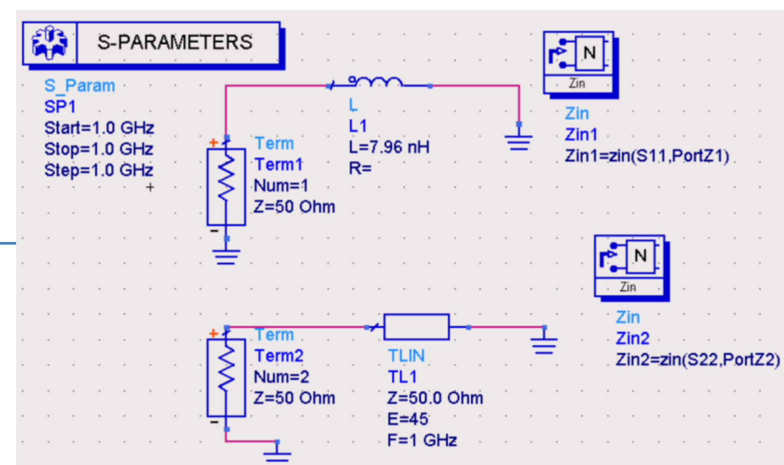
openTLequivC **Example 2**

Open end and short end TL equivalent elements



freq	Zin1	Zin2
1.000 GHz	50.002 / -90.000	50.000 / -90.000

openTLequivC

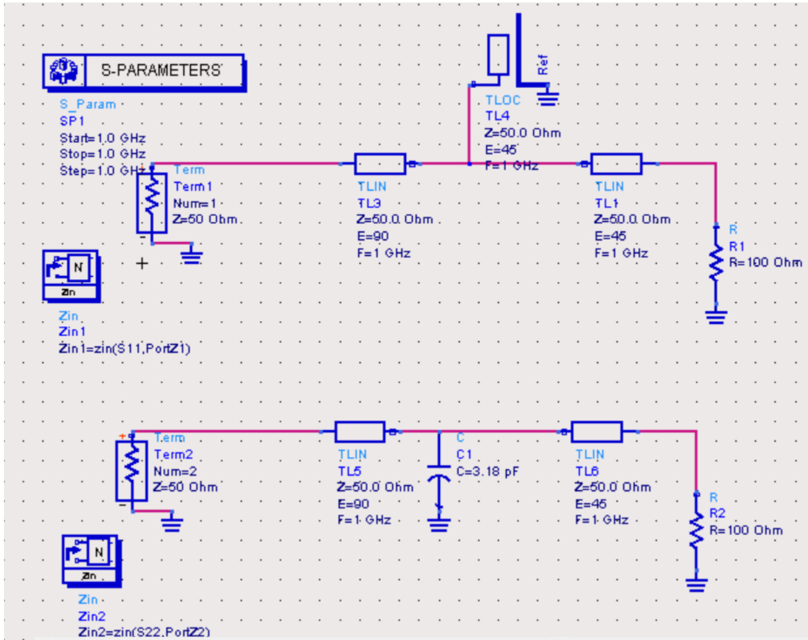


shortTLequivL

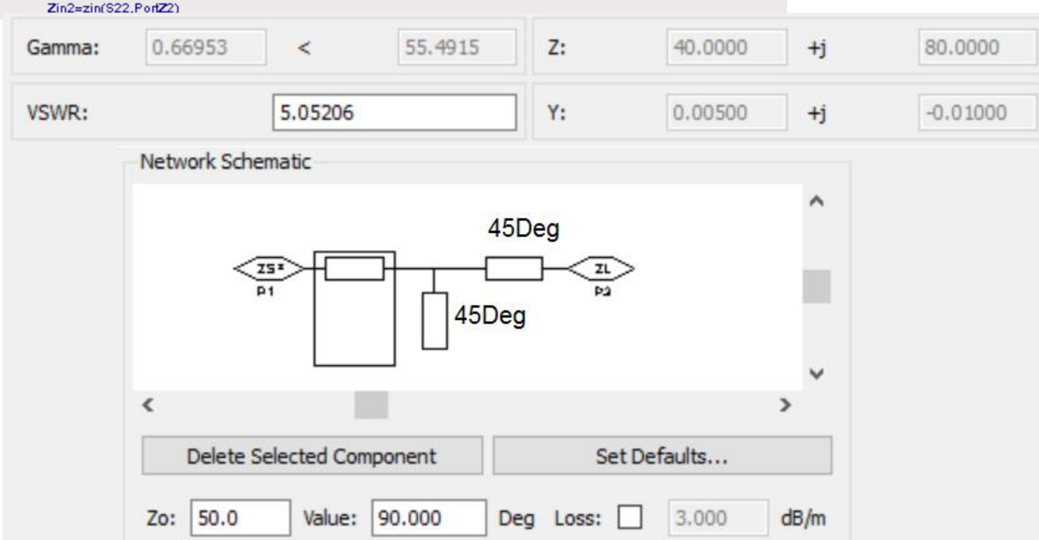
freq	Zin1	Zin2
1.000 GHz	50.014 / 90.000	50.000 / 90.000

Example 3

Zin for microwave circuit contain $\lambda/8$ open end TL and its equivalent capacitor (OC TL is shunt connection as its equivalent capacitor),using schematic and smith-chart utility



freq	Zin1	S(1,1)	Zin2	S(2,2)
1.000 GHz	40.000 + j80.000	0.670 / 55.491	40.000 + j79.951	0.669 / 55.513



Example 4

A 50Ω line of length λ/2 is connected at one end to a reflectionless 50Ω generator. The other end is terminated alternatively with load Z = Z1,or Z = Z2.

Determine for the two terminations Z = Z1, Z = Z2.

a) The reflection coefficient of the load Γ

b) The input impedance on the generator side Z'

Where Z1 = 50Ω ,and Z2 = 30 – j 40 Ω

Solution:

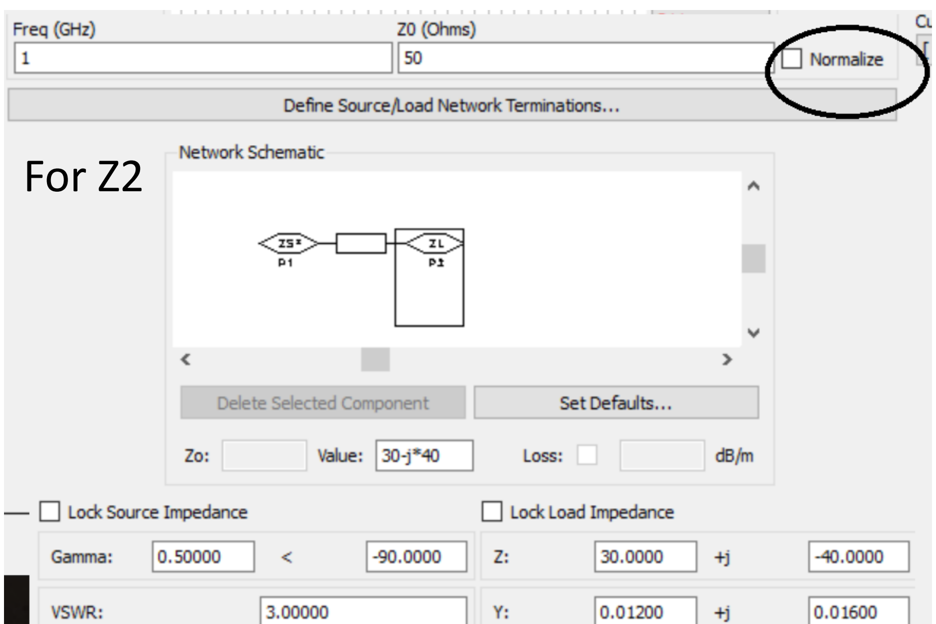
At length λ/2 tan**β**l=0 and Zin=ZL

AT Z1 Γ=0, Zin=Z1

At Z2 Γ= - j0.5 zin=Z2

Use smithchart utility to check your answer:

For Z2



Example 5

Given a 50 Ω transmission line that is 0.25 λ long excited by a 1 V voltage source at 300 MHz frequency with an internal impedance of 100 Ω, and the line is terminated by a load $Z_L = 100 - j40\,\Omega$, determine $\Gamma_L, Z_{in}, V_{in}, V_o^+$

$$\Gamma_L = \frac{Z_L - Z_o}{Z_L + Z_o} = 0.378 - j0.166$$

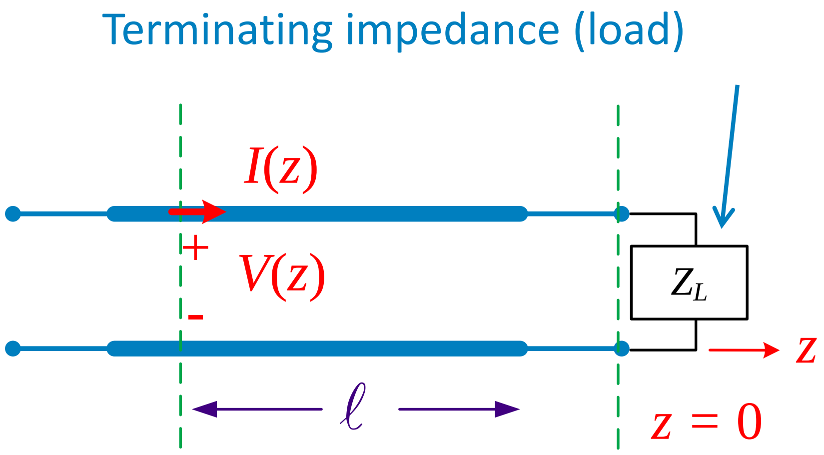
$$Z_{in} = Z_o * Z_o / Z_L = 21.55 + j8.62$$

$$V_{in} = V_{TH}\frac{Z_{in}}{Z_{in} + Z_{TH}} = 0.1814 + j0.058$$

$$V_o^+ = \frac{V_{in}}{e^{j\beta l}(1 + \Gamma_L e^{-2j\beta l})} = 0.0144 - j0.295$$

Terminated Transmission Line (cont.)

$$V(z) = V_0^+ e^{-\gamma z} + V_0^- e^{+\gamma z}$$



What if we know

V^+ and V^- @ $z = -\ell$

Can we use $z = -\ell$ as a reference plane?

$$V_0^+ = V^+(0) = V^+(-\ell)e^{-\gamma\ell}$$

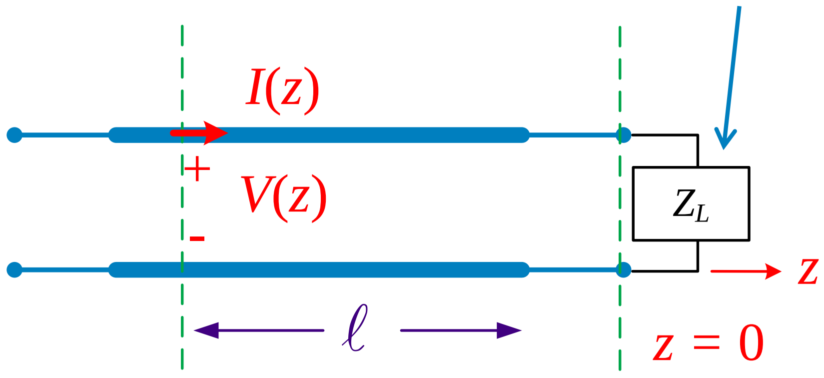
$$V^-(-\ell) = V^-(0)e^{-\gamma\ell}$$

$$\Rightarrow V_0^- = V^-(0) = V^-(-\ell)e^{\gamma\ell}$$

Hence

$$V(z) = V^+(-\ell)e^{-\gamma(z+\ell)} + V^-(-\ell)e^{\gamma(z+\ell)}$$

Terminated Transmission Line (cont.)



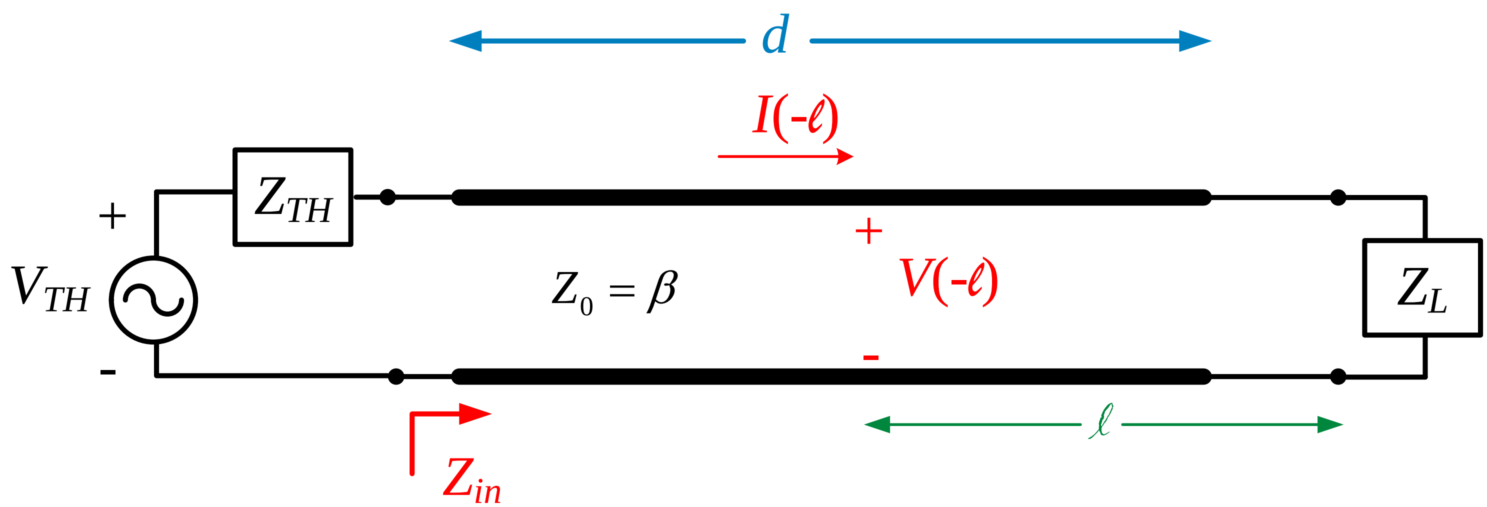
Compare:

$$V(z) = V^{+}(0)e^{-\gamma z} + V^{-}(0)e^{+\gamma z}$$

$$V(z) = V^{+}(-\ell)e^{-\gamma(z-(-\ell))} + V^{-}(-\ell)e^{\gamma(z-(-\ell))}$$

Note: This is simply a change of reference plane, from $z = 0$ to $z = -\ell$.

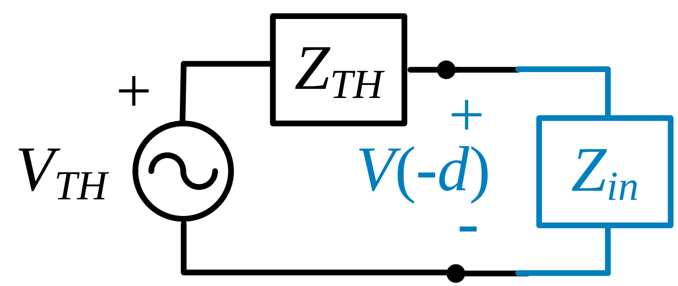
Example



Find the voltage at any point on the line.

$$Z_{in} = Z(-d) = Z_0\left(\frac{Z_L + jZ_0 \tan(\beta d)}{Z_0 + jZ_L \tan(\beta d)}\right)$$

$$\Rightarrow \quad V(-d) = V_{TH}\left(\frac{Z_{in}}{Z_{in} + Z_{TH}}\right)$$



Example (cont.)

Note: $$V(-\ell) = V_0^+ e^{j\beta\ell}\left(1+\Gamma_L e^{-2j\beta\ell}\right)$$

$$\Gamma_L = \frac{Z_L - Z_0}{Z_L + Z_0}$$

At $\ell = d$:

$$V(-d) = V_0^+ e^{j\beta d}\left(1+\Gamma_L e^{-j2\beta d}\right) = V_{TH}\left(\frac{Z_{in}}{Z_{in}+Z_{TH}}\right)$$

$$\Rightarrow V_0^+ = V_{TH}\left(\frac{Z_{in}}{Z_{in}+Z_{TH}}\right) e^{-j\beta d}\left(\frac{1}{1+\Gamma_L e^{-j2\beta d}}\right)$$

Hence

$$V(-\ell) = V_{TH}\left(\frac{Z_{in}}{Z_m+Z_{TH}}\right) e^{-j\beta(d-\ell)}\left(\frac{1+\Gamma_L e^{-j2\beta\ell}}{1+\Gamma_L e^{-j2\beta d}}\right)$$

Example (cont.)

Some algebra:

$$Z_{in} = Z(-d) = Z_0 \left(\frac{1+\Gamma_L e^{-j2\beta d}}{1-\Gamma_L e^{-j2\beta d}} \right)$$

$$\Rightarrow \frac{Z_{in}}{Z_{in} + Z_{TH}} = \frac{Z_0 \left(\frac{1+\Gamma_L e^{-j2\beta d}}{1-\Gamma_L e^{-j2\beta d}} \right)}{Z_0 \left(\frac{1+\Gamma_L e^{-j2\beta d}}{1-\Gamma_L e^{-j2\beta d}} \right) + Z_{TH}} = \frac{Z_0 \left(1+\Gamma_L e^{-j2\beta d}\right)}{Z_0 \left(1+\Gamma_L e^{-j2\beta d}\right) + Z_{TH} \left(1-\Gamma_L e^{-j2\beta d}\right)}$$

$$= \frac{Z_0 \left(1+\Gamma_L e^{-j2\beta d}\right)}{\left(Z_{TH} + Z_0\right) + \Gamma_L e^{-j2\beta d} \left(Z_0 - Z_{TH}\right)}$$

$$= \left(\frac{Z_0}{Z_{TH} + Z_0} \right) \frac{\left(1+\Gamma_L e^{-j2\beta d}\right)}{1+\Gamma_L e^{-j2\beta d} \left(\frac{Z_0 - Z_{TH}}{Z_{TH} + Z_0} \right)}$$

$$= \left(\frac{Z_0}{Z_{TH} + Z_0} \right) \frac{\left(1+\Gamma_L e^{-j2\beta d}\right)}{1-\Gamma_L e^{-j2\beta d} \left(\frac{Z_{TH} - Z_0}{Z_{TH} + Z_0} \right)}$$

Example (cont.)

Hence, we have

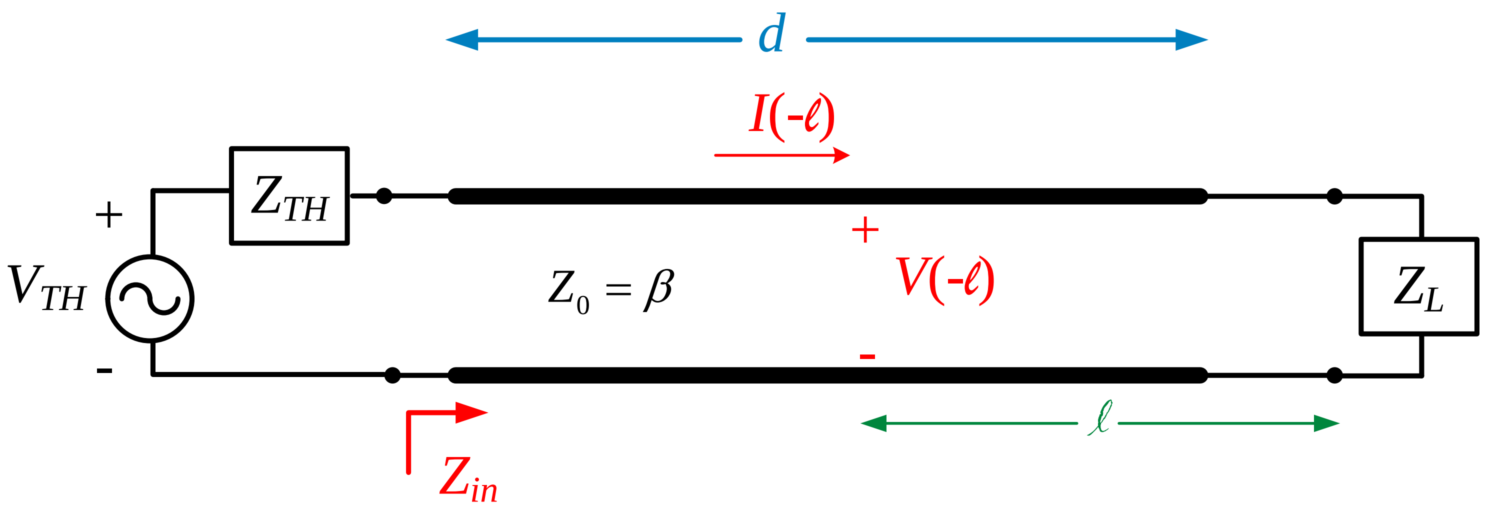
$$\frac{Z_{in}}{Z_{in}+Z_{TH}}=\left(\frac{Z_0}{Z_0+Z_{TH}}\right)\left(\frac{1+\Gamma_L e^{-j2\beta d}}{1-\Gamma_S\Gamma_L e^{-j2\beta d}}\right)$$

where $\Gamma_S=\dfrac{Z_{TH}-Z_0}{Z_{TH}+Z_0}$

Therefore, we have the following alternative form for the result:

$$V(-\ell)=V_{TH}\left(\frac{Z_0}{Z_0+Z_{TH}}\right)e^{-j\beta(d-\ell)}\left(\frac{1+\Gamma_L e^{-j2\beta\ell}}{1-\Gamma_S\Gamma_L e^{-j2\beta d}}\right)$$

Example (cont.)



$$V(-\ell) = V_{TH}\left(\frac{Z_0}{Z_0 + Z_{TH}}\right)e^{-j\beta(d-\ell)}\left(\frac{1+\Gamma_L e^{-j2\beta\ell}}{1-\Gamma_S\Gamma_L e^{-j2\beta d}}\right)$$

Voltage wave that would exist if there were no reflections ($\Gamma_L = 0$)from the load (a semi-infinite transmission line or a matched load).

Example 6

Given a 50 Ω transmission line that is 0.25λ long excited by a 1Voltage source at 300MHz Frequency with an internal impedance of 100 Ω, and the line is terminated by a load Zl=100-j40 Ω determine v(l=-λ/8)

$$V(z = -\ell) = V_{TH}\left(\frac{Z_0}{Z_0 + Z_{TH}}\right)e^{-j\beta(d-\ell)}\left(\frac{1+\Gamma_L e^{-j2\beta\ell}}{1-\Gamma_S\Gamma_L e^{-j2\beta d}}\right)$$

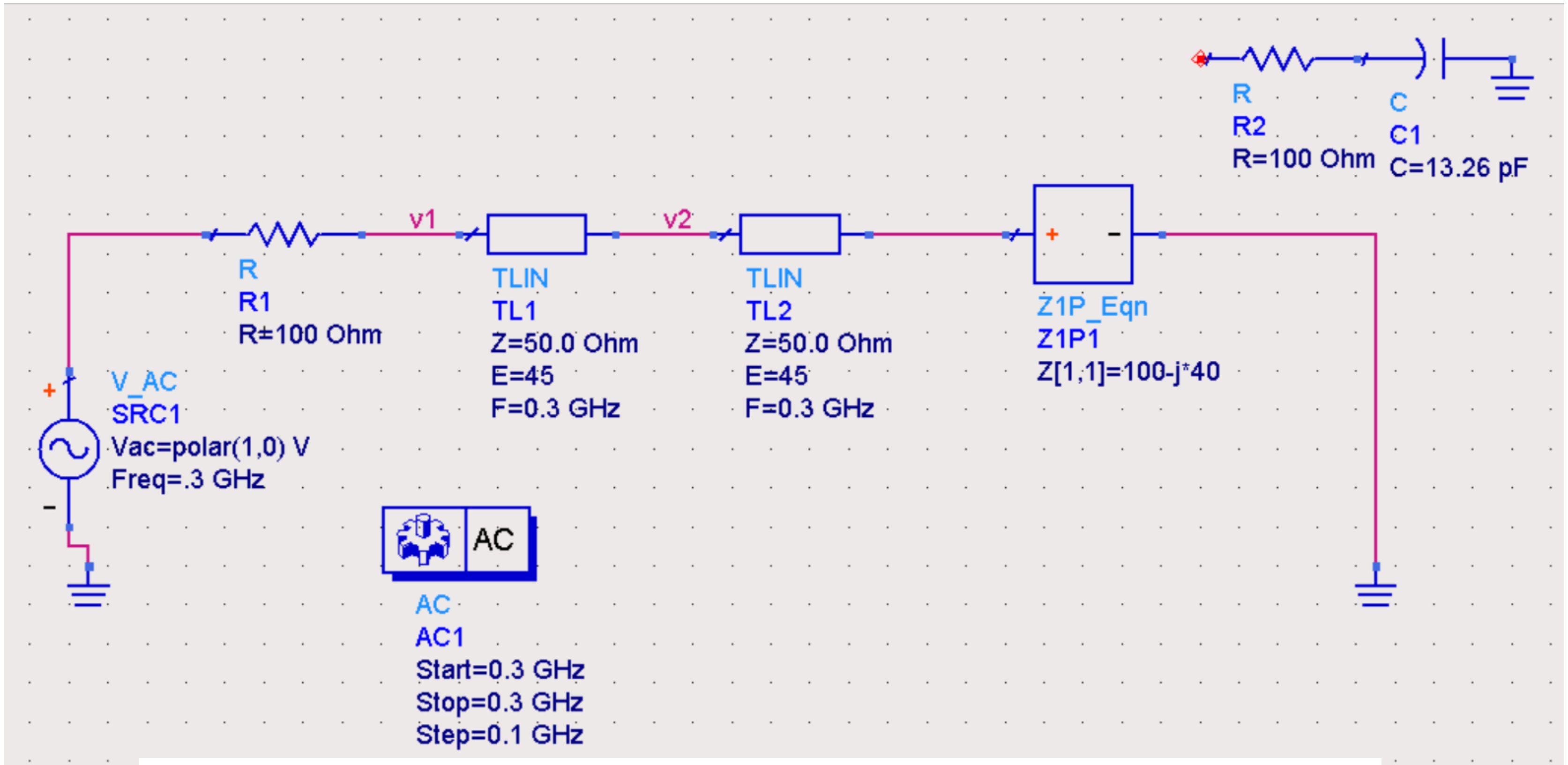
$$\Gamma_L = \frac{Z_L - Z_o}{Z_L + Z_o} = 0.378 - j0.166$$

$$\Gamma_s = \frac{100-50}{100+50}$$

$$V\left(l = \frac{\lambda}{8}\right) = 1 * \left(\frac{50}{150}\right) * \left(e^{-j45}\right)\left(\frac{1 + (0.378 - j0.166)e^{-\frac{j\pi}{2}}}{1 - \frac{1}{3}(0.378 - j0.166)e^{-j\pi}}\right)$$

= 0.108 – j 0.248

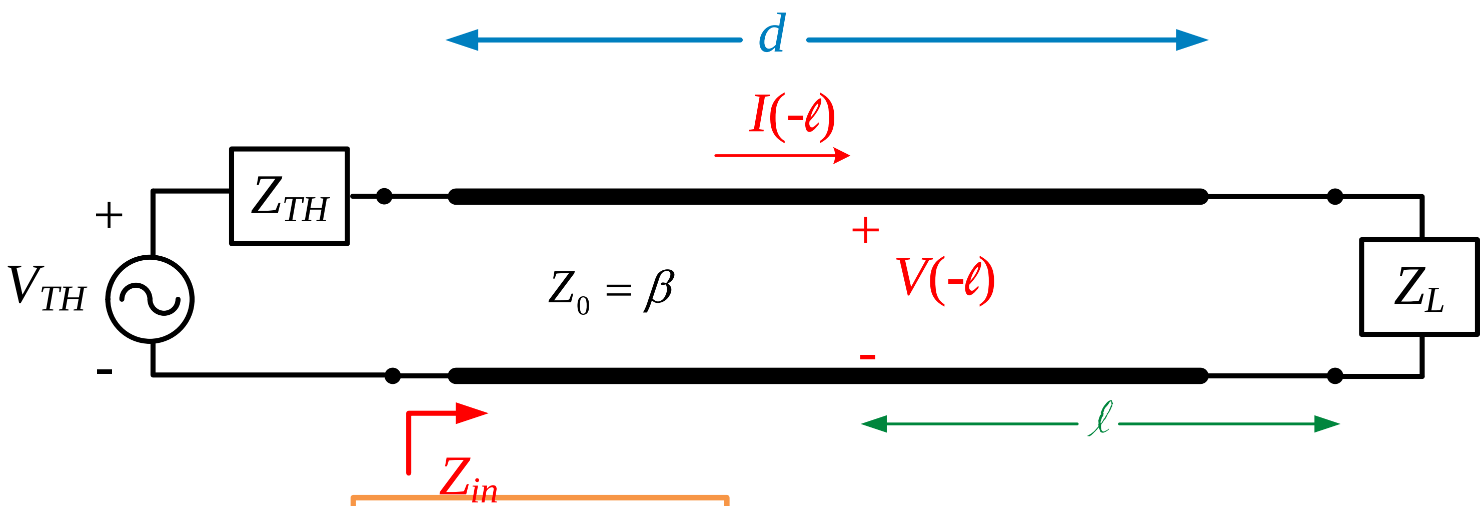
Simulate Example 6 by ADS



inputvoltage

freq	v1	v2
300.0 MHz	0.181 + j0.058	0.108 - j0.248

Special case for incident voltage when Z_{TH}=Zo



$$V(-\ell) = V_{TH}\left(\frac{Z_0}{Z_0 + Z_{TH}}\right)e^{-j\beta(d-\ell)}\left(\frac{1+\Gamma_L e^{-j2\beta\ell}}{1-\Gamma_S\Gamma_L e^{-j2\beta d}}\right)$$

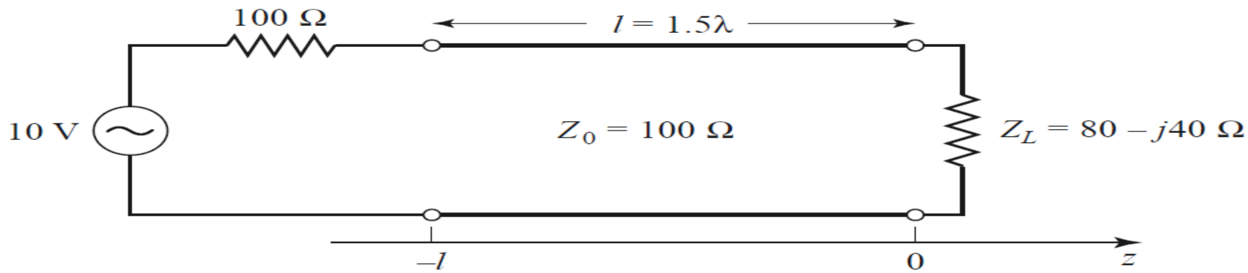
$$\Gamma_S = 0 \qquad \left|V_0^+\right| = Vg/2$$

$$\Gamma_S = \frac{Z_{TH} - Z_0}{Z_{TH} + Z_0}$$

$Z_{TH}=V_g$

Example 7

A generator is connected to a transmission line as shown in the accompanying figure. Find the voltage as a function of z along the transmission line. Plot the magnitude of this voltage for $-\ell \leq z \leq 0$.



$V_o^+ = 5\,V \;, \Gamma_s = 0$

$V(-\ell) = 5\, e^{-j\beta(d-\ell)}\left(1+\Gamma_L e^{-j2\beta\ell}\right)$, $\Gamma_L = \dfrac{-20-j40}{180-j40} = 0.24\ \lfloor -104^o$

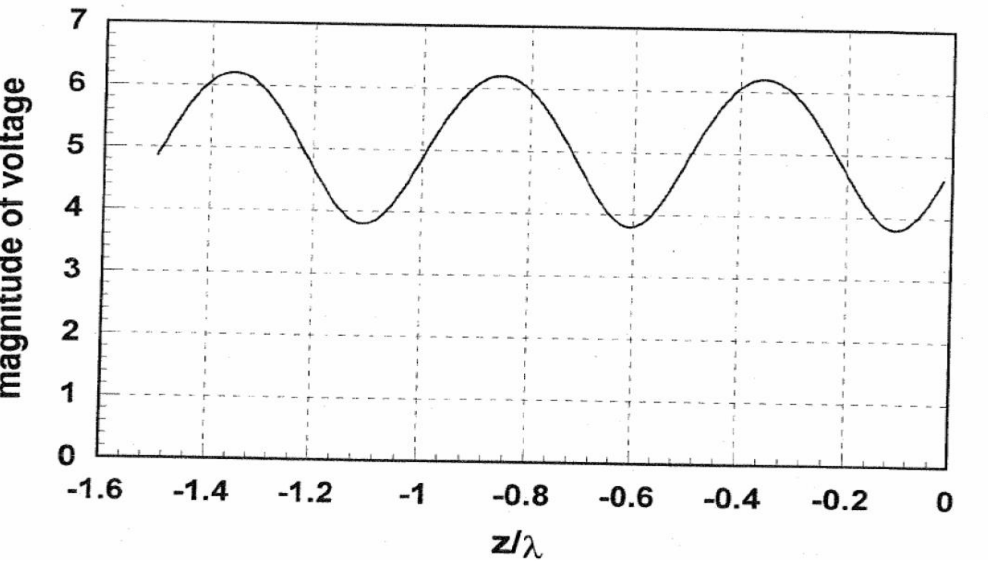
l_{max} $at\ \ -104 - 2\beta l_{max}=0$

$l_{max}=0.355\lambda$ and $V_{max} = 5(1.24) = 6.2\,V$

l_{min} $at\ \ -104 - 2\beta l_{min}=\pi$

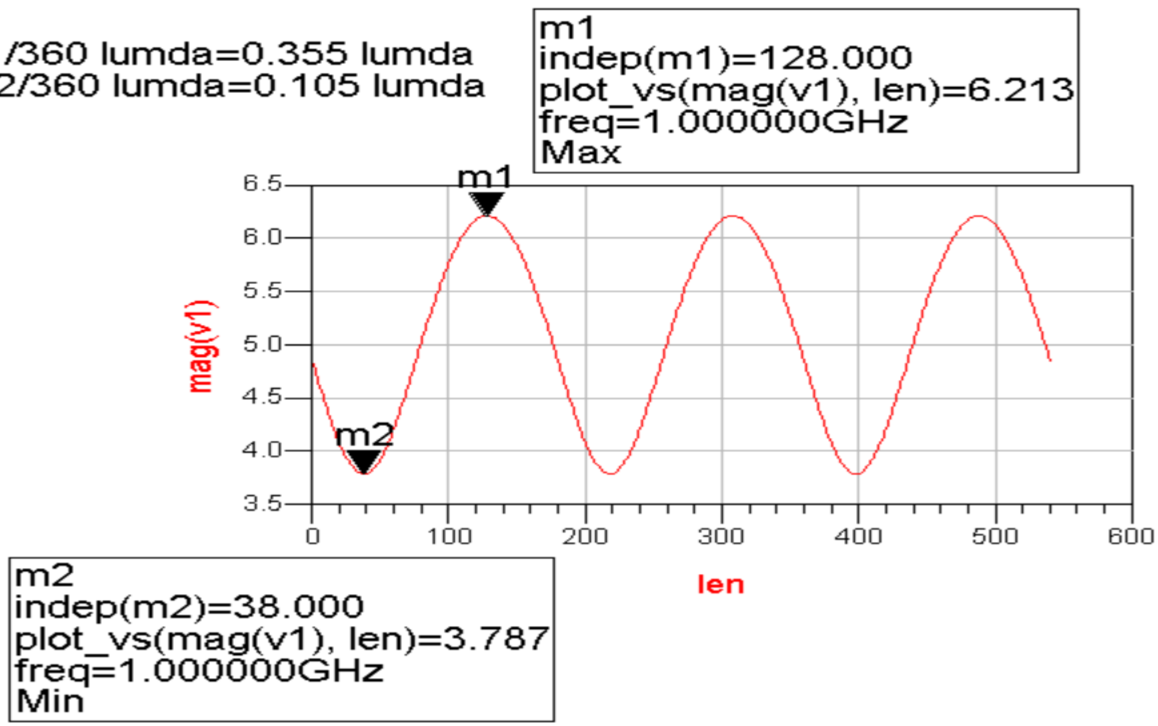
$l_{min}=0.1055\lambda$ and $V_{min} = 5(1-0.24)=3.8$ V $\qquad l_{max}-l_{min}= \lambda/4$

$$V_L = 10 * \frac{Z_L}{Z_{L+}Z_S} = 4.86\lfloor -13.5^o$$



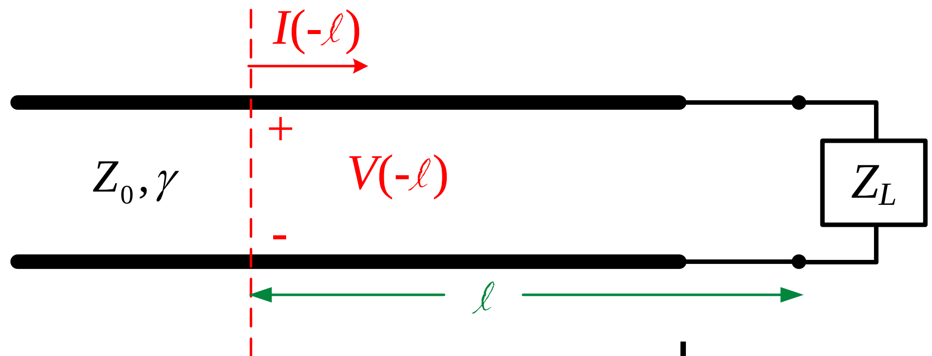
ADS Simulation

lmin=m1/360 lumda=0.355 lumda
lmax=m2/360 lumda=0.105 lumda



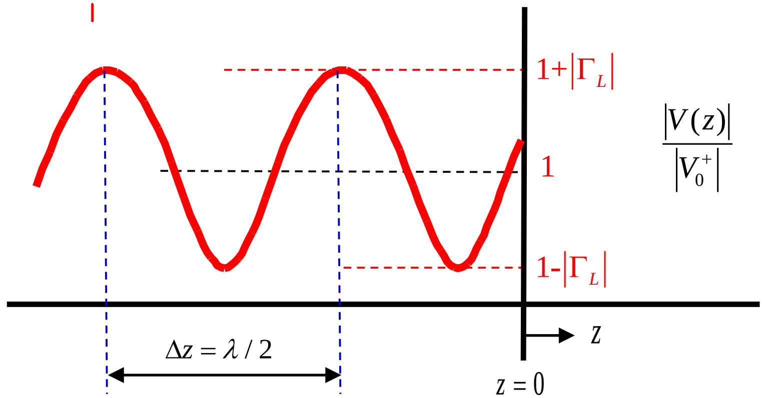
Voltage Standing Wave Ratio

$$V(-\ell) = V_0^+ e^{j\beta\ell}\left(1+\Gamma_L e^{-2j\beta\ell}\right)$$
$$= V_0^+ e^{j\beta\ell}\left(1+|\Gamma_L| e^{j\phi_L} e^{-2j\beta\ell}\right)$$



$$|V(-\ell)| = |V_0^+|\left|1+|\Gamma_L| e^{j\phi_L} e^{-j2\beta\ell}\right|$$

$$V_{\max} = |V_0^+|\left(1+|\Gamma_L|\right)$$
$$V_{\min} = |V_0^+|\left(1-|\Gamma_L|\right)$$



$$\text{Voltage Standing Wave Ratio (VSWR)} = \frac{V_{\max}}{V_{\min}}$$

$$\text{VSWR} = \frac{1+|\Gamma_L|}{1-|\Gamma_L|}$$