Test 2.1 Transmission Line Effects

Solution: (b) $l/\lambda < 0.01$

As a rule of thumb, phase shift and reflection effects can be ignored if l is shorter than about 1% of λ.

Test 2.2 Dispersion

Solution: (c) The shape of a rectangular pulse traveling in a dispersive transmission line **becomes distorted**, with the degree of distortion being proportional to the length of the line. This is because the pulse is composed of many **frequency components** (Fourier analysis) and on a dispersive line they **travel at different velocities**.

Test 2.3 TEM

Solution: (d) TEM stands for **T**ransverse **E**lectro**m**agnetic.

Test 2.4 TEM

Solution: (d) In TEM, the **E** field, **H** field, and direction of propagation **are all orthogonal** to each other.

Test 2.5 Coaxial Line

Solution: (a)

$$L' = \frac{\mu}{2\pi} \ln\left(\frac{a}{b}\right).$$

Since $\ln(b/a) = \ln 2 \neq 0$ and μ cannot be zero, L' **can never be zero**.

Test 2.6 Coaxial Line

Solution: (d) $\sigma = 0$, because

$$G' = \frac{2\pi\sigma}{\ln(b/a)}$$

and for a perfect dielectric insulator, $\sigma = 0$.

Test 2.7 TEM Line

Solution: (b)

$$L'C' = \mu\varepsilon = \mu_0\varepsilon_0 = \frac{1}{c^2}\,,$$
$$C' = \frac{1}{L'c^2} = \frac{1}{(1/27)\times 10^{-6}\times(3\times 10^8)^2} = 0.3 \text{ nF/m}.$$

Test 2.8 Lossless Line

Solution: (a) Nondispersive and $\alpha = 0$.

A lossless line has $R' = G' = 0$, which makes $\alpha = 0$ and u_p independent of frequency.

Test 2.9 Microstrip Line

Solution: (d) Since $Z_0 = 50\ \Omega > 44 - 2\varepsilon_\mathrm{r} = 44 - 4 = 40$,

$$p = \sqrt{\frac{\varepsilon_\mathrm{r}+1}{2}\,\frac{Z_0}{60}} + \left(\frac{\varepsilon_\mathrm{r}-1}{\varepsilon_\mathrm{r}+1}\right)\left(0.23 + \frac{0.12}{\varepsilon_\mathrm{r}}\right) = 1.117,$$
$$s = \frac{8e^p}{e^{2p}-2} = 3.33.$$

Test 2.10 Reflection Coefficient

Solution: (c) $\Gamma = 1e^{j\theta}$, with $\theta = -90^\circ \pm 180^\circ$.

$$Z_\mathrm{L} = j\omega L = j50\times 10^3\times 10^{-3} = j50\ \Omega,$$
$$\begin{aligned}\Gamma &= \frac{Z_\mathrm{L}-Z_0}{Z_\mathrm{L}+Z_0}\\ &= \frac{j50-50}{j50+50}\\ &= \frac{-(50-j50)}{50+j50} = -\frac{50\sqrt{2}\tan^{-1}(-1)}{50\sqrt{2}\tan^{-1}(1)} = 1e^{-j2\times 45^\circ} \pm 180^\circ,\end{aligned}$$

or

$$(\Gamma) = 1 \quad \text{and} \quad \theta_\mathrm{r} = -90^\circ \pm 180^\circ.$$

Test 2.11 SWR

Solution: (c)

$$S = \frac{1+|\Gamma|}{1-|\Gamma|} = \frac{1+0.5}{1-0.5} = 3.$$

Test 2.12 Voltage Max

Solution: (a) $|\widetilde{V}_{\text{max}}| = (1+|\Gamma|)(V_0^+) = (1+0.5)\times 2 = 3$ V.

Test 2.13 Voltage Min

Solution: (d) $|\widetilde{V}_{\text{min}}| = (1-|\Gamma|)(V_0^+) = (1-0.5)\times 2 = 1$ V.

Test 2.14 First Voltage Max

Solution: (b)

$$\begin{aligned} d_{\text{max}} &= \frac{\theta_{\text{r}}\lambda}{4\pi} \qquad \left(\text{since } \theta_{\text{r}} = 30^\circ = \frac{\pi}{6} \text{ is positive}\right) \\ &= \frac{(\pi/6)\times 60 \text{ cm}}{4\pi} = 2.5 \text{ cm}. \end{aligned}$$

Test 2.15 First Voltage Max

Solution: (b) Since $\theta_{\text{r}} = -30^\circ = -\pi/6$ is negative,

$$\begin{aligned} d_{\text{max}} &= \frac{\theta_{\text{r}}\lambda}{4\pi} + \frac{\lambda}{2} \\ &= \frac{-(\pi/6)\times 60 \text{ cm}}{4\pi} + \frac{60 \text{ cm}}{2} = 27.5 \text{ cm}. \end{aligned}$$

Test 2.16 Reflection Coefficient

Solution: (c)

$$\begin{aligned} \lambda &= 2\times 40 \text{ cm} = 80 \text{ cm}. \\ d_{\text{max}} &= \frac{\theta_{\text{r}}\lambda}{4\pi}, \\ 5 \text{ cm} &= \frac{\theta_{\text{r}}\times 80 \text{ cm}}{4\pi} \quad \Rightarrow \quad \theta_{\text{r}} = 0.25\pi = 45^\circ. \end{aligned}$$

$$|\Gamma| = \frac{S-1}{S+1} = \frac{3-1}{3+1} = 0.5.$$

$$\Gamma = 0.5e^{j45^\circ} = (0.35 + j0.35).$$

Test 2.17 Equivalent Inductor

Solution: (a)

$$L_{\text{eq}} = \frac{Z_0 \tan \beta\ell}{\omega}.$$

$$\left(\frac{25}{\pi}\right) \times 10^{-9} = \frac{100 \tan \beta\ell}{2\pi \times 2 \times 10^9} \quad \Rightarrow \quad \beta\ell = \frac{\pi}{4}.$$

$$\ell = \frac{\pi}{4\beta} = \frac{\pi}{4 \times (2\pi/\lambda)} = \frac{\lambda}{8} = \frac{8 \text{ cm}}{8} = 1 \text{ cm}.$$

Test 2.18 Input Impedance

Solution: (d) Since $\frac{\lambda}{2} = \frac{6}{2} = 3$ cm, the line length of 9 cm is a multiple of $\lambda/2$, in which case

$$Z_{\text{in}} = Z_{\text{L}} = 150\ \Omega.$$

Test 2.19 Input Impedance

Solution: (b) $\frac{\lambda}{2} = \frac{6}{2} = 3$ cm.

Subtracting multiples of $\lambda/2$ leaves 1.5 cm, which is $\lambda/4$. The input impedance for such a quarter-wave transformer is

$$Z_{\text{in}} = \frac{Z_0^2}{Z_{\text{L}}} = \frac{75^2}{150} = 37.5\ \Omega.$$

Test 2.20 Transmitted Power

Solution: (d)

$$\Gamma = \frac{Z_{\text{L}} - Z_0}{Z_{\text{L}} + Z_0} = \frac{150 - 100}{150 + 100} = 0.2.$$

$$\text{Transmitted Power Fraction} = 1 - |\Gamma|^2 = 1 - (0.2)^2 = 0.96.$$

Test 2.21 Input Impedance

Solution: **(a)** Since each antenna is connected to a line of length $\lambda/2$, the input impedance of each of the two lines at the connection junction is 75 Ω, and their parallel combination is $75/2 = 37.5$ Ω. Line 1 also is $\lambda/2$, so

$$Z_{\text{in}} = 37.5\ \Omega.$$

Test 2.22 Input Impedance

Solution: **(c)** Both line segments are $\lambda/4$ transformers. At input to line 2,

$$Z_{\text{in}_2} = \frac{Z_{02}^2}{Z_{\text{L}}} = \frac{50^2}{100} = 25\ \Omega.$$

At input to line 1,

$$Z_{\text{in}} = \frac{Z_{01}^2}{Z_{\text{in}_2}} = \frac{100^2}{25} = 400\ \Omega.$$

Test 2.23 Impedance

Solution: **(b)**

$$|\Gamma| = \frac{S-1}{S+1} = \frac{2-1}{2+1} = \frac{1}{3}\,.$$

Since Z_0 and Z_{L} are both purely real, Γ can be either $1/3$ or $-1/3$.

$$Z_0 = \left(\frac{1-\Gamma}{1+\Gamma}\right) Z_{\text{L}}.$$

For $\Gamma = 1/3$,

$$Z_0 = \left(\frac{1-1/3}{1+1/3}\right) 200 = 100\ \Omega.$$

For $\Gamma = -1/3$,

$$Z_0 = \left(\frac{1+1/3}{1-1/3}\right) 200 = 400\ \Omega.$$

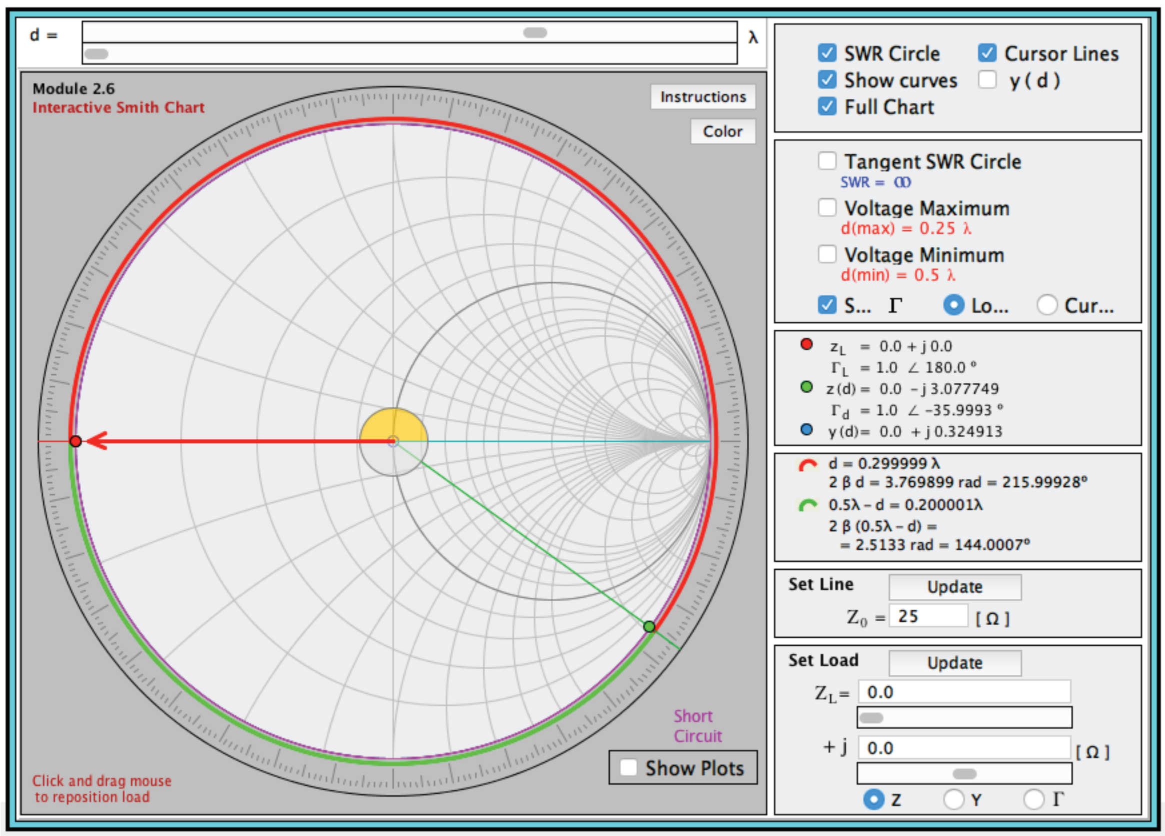
Test 2.24 Input Impedance

Solution: (c) On the Smith chart, the impedance of a short circuit is located along the perimeter on the left-hand side of the horizontal axis. Moving clockwise by $d = (0.8 - 0.5)\lambda = 0.3\lambda$ leads to

$$z_{\text{in}} = z(d) = 0 - j3.078,$$

or

$$Z_{\text{in}} = z_{\text{in}} \times 25 = -j77\ \Omega.$$



Test 2.25 Load Impedance

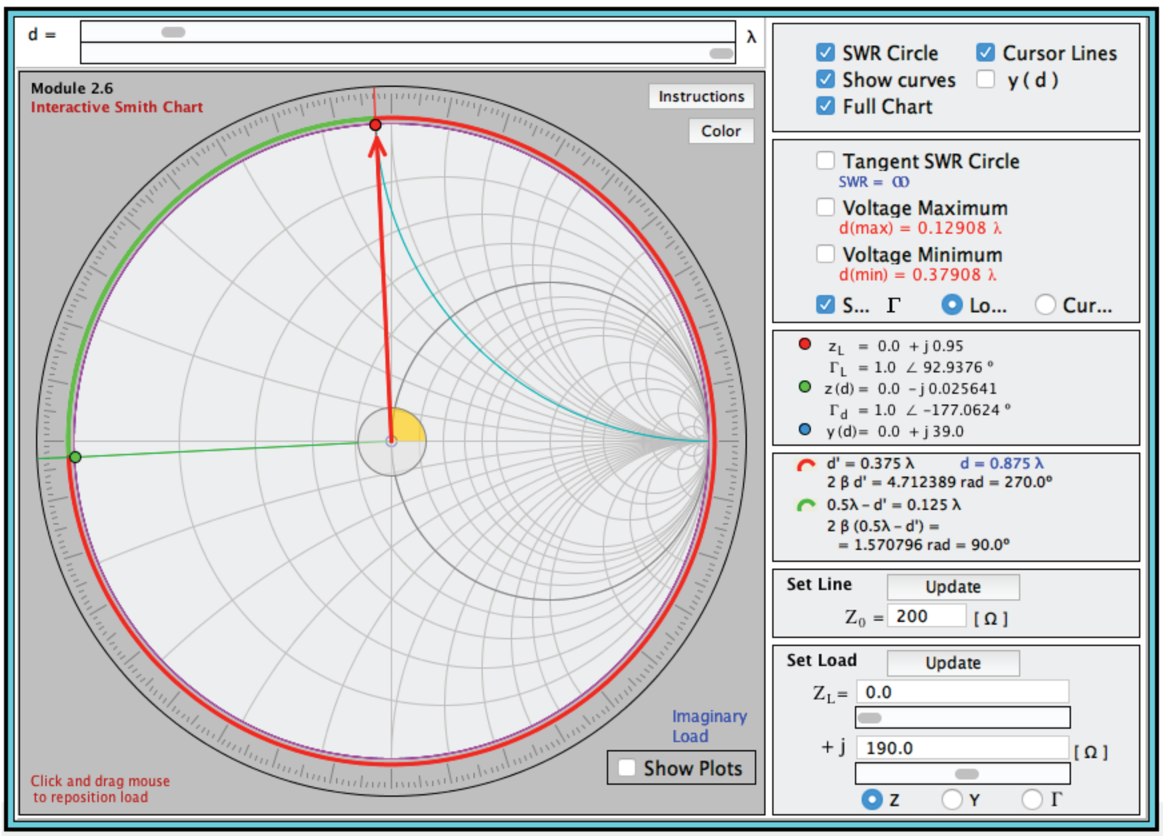
Solution: (a)

$$z_{\text{in}} = \frac{Z_{\text{in}}}{Z_0} = \frac{-j5}{200} = -j0.025.$$

Moving on the Smith chart CCW by $3\lambda/8 = 0.375\lambda$ leads to

$$z_L = 0 + j0.95.$$

Hence, $Z_L = z_L Z_0 = j0.95 \times 200 = j190\ \Omega$.



Test 2.26 Input Impedance

Solution: (c)

$$\lambda = \frac{c}{\sqrt{\varepsilon_r}\, f} = \frac{3 \times 10^8}{\sqrt{2.25} \times 5 \times 10^9} = 4 \text{ cm},$$

$$l = \frac{31 \text{ cm}}{4 \text{ cm}} = 7.75\lambda.$$

Subtracting 7.5λ leaves behind 0.25λ = quarter-wave transformer. Hence,

$$Z_{\text{in}} = \frac{Z_0^2}{Z_{\text{L}}} = \frac{50^2}{100} = 25\ \Omega.$$

Test 2.27 Quarter-Wave Transformer

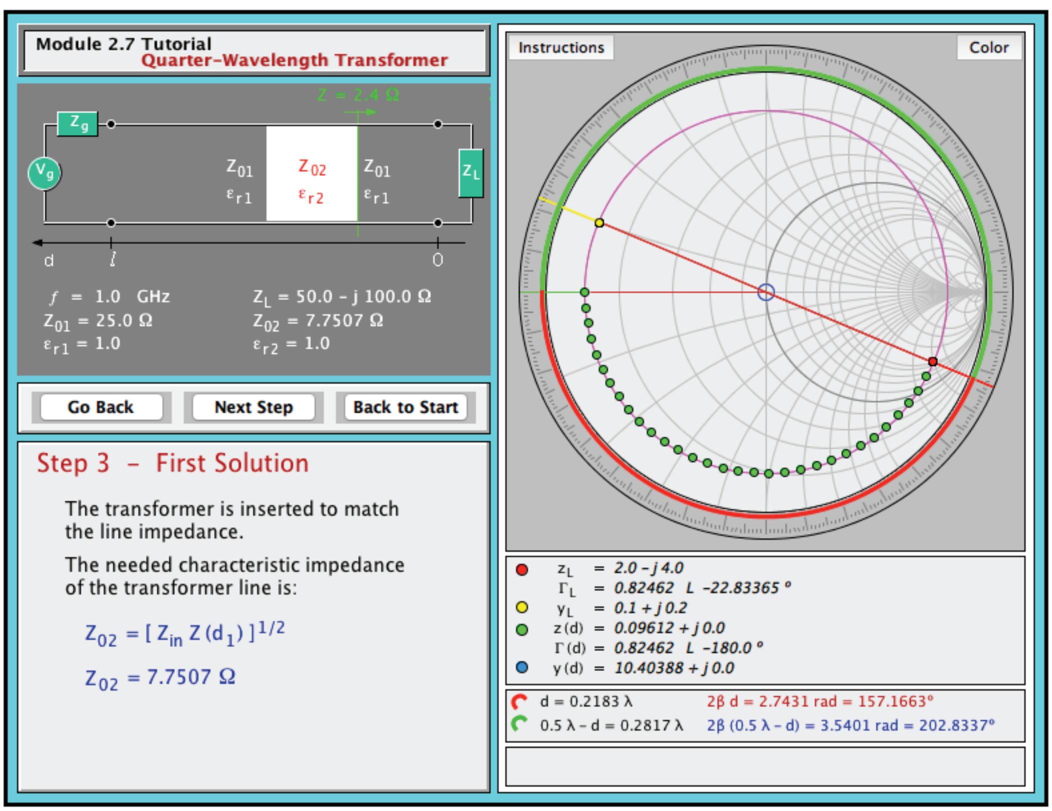
Solution: (b)

$$z_{\text{L}} = \frac{Z_{\text{L}}}{Z_0} = \frac{50 - j100}{25} = 2 - j4.$$

First solution:

$$d_1 = 0.218\lambda = 0.218 \times 30\ \text{cm} = 6.5\ \text{cm},$$
$$Z_{02} = 7.75\ \Omega.$$

Hence, $d_1 = 6.5$ cm.



Test 2.28 Quarter-Wave Transformer

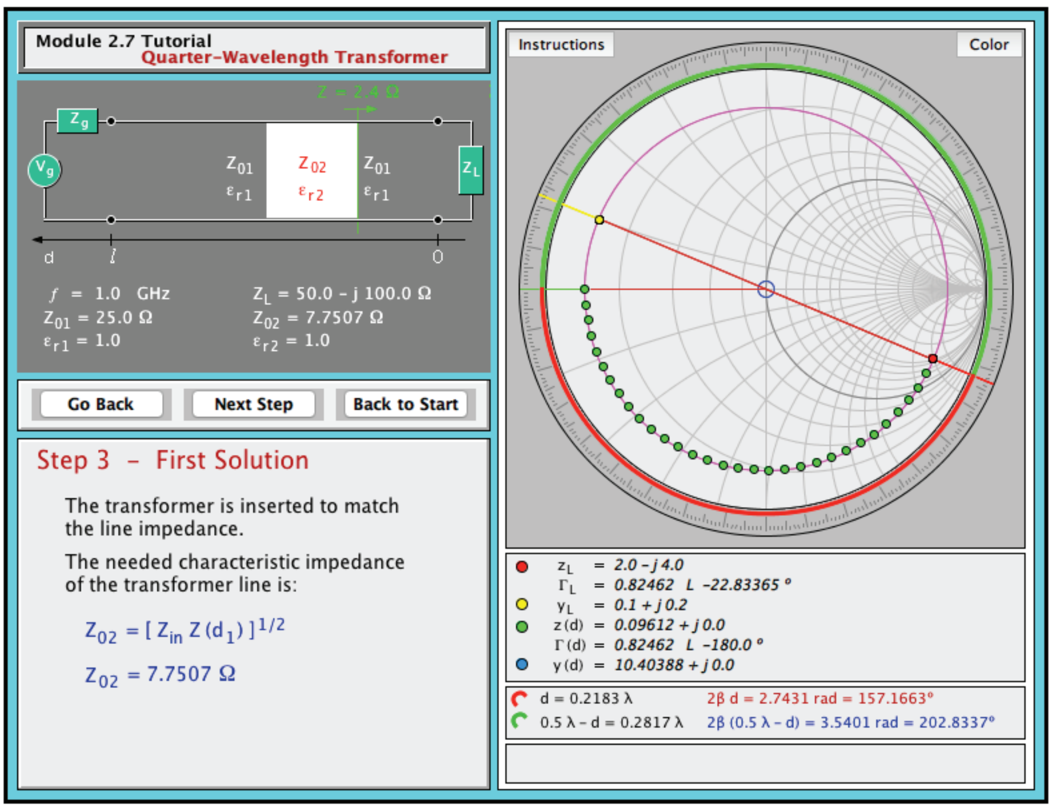
Solution: (a)

$$z_L = \frac{Z_L}{Z_0} = \frac{50 - j100}{25} = 2 - j4.$$

First solution:

$$d_1 = 0.218\lambda = 0.218 \times 30 \text{ cm} = 6.5 \text{ cm},$$
$$Z_{02} = 7.75\ \Omega.$$

Hence, $Z_{02} = 7.75\ \Omega$.



Test 2.29 Matching

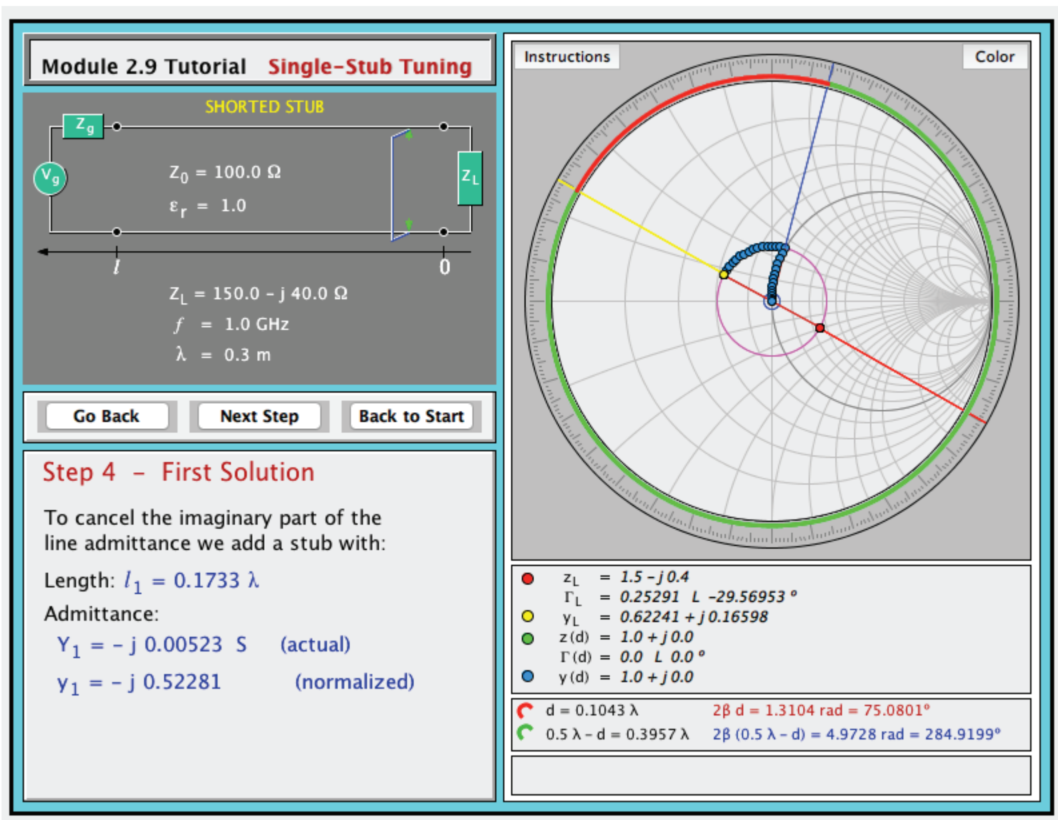
Solution: (d)

$$z_L = \frac{Z_L}{Z_0} = \frac{150 - j40}{100} = 1.5 - j0.4.$$

Solution 1:

$$d_1 = 0.104\lambda,$$
$$l_1 = 0.173\lambda.$$

Hence, $l_1 = 0.173\lambda$.



Test 2.30 Matching

Solution: (c)

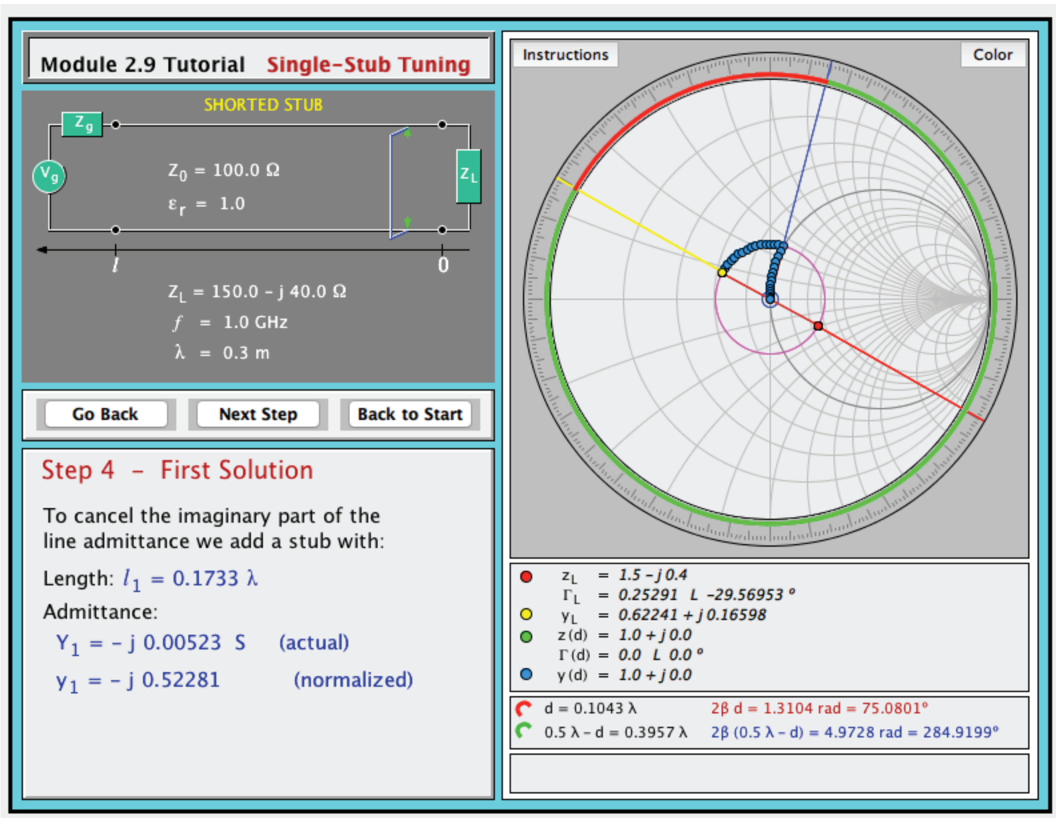
$$z_L = \frac{Z_L}{Z_0} = \frac{150 - j40}{100} = 1.5 - j0.4.$$

Solution 1:

$$d_1 = 0.104\lambda,$$

$$l_1 = 0.173\lambda.$$

Hence, $d_1 \approx 0.1\lambda$.



Test 2.31 Impedance Matching

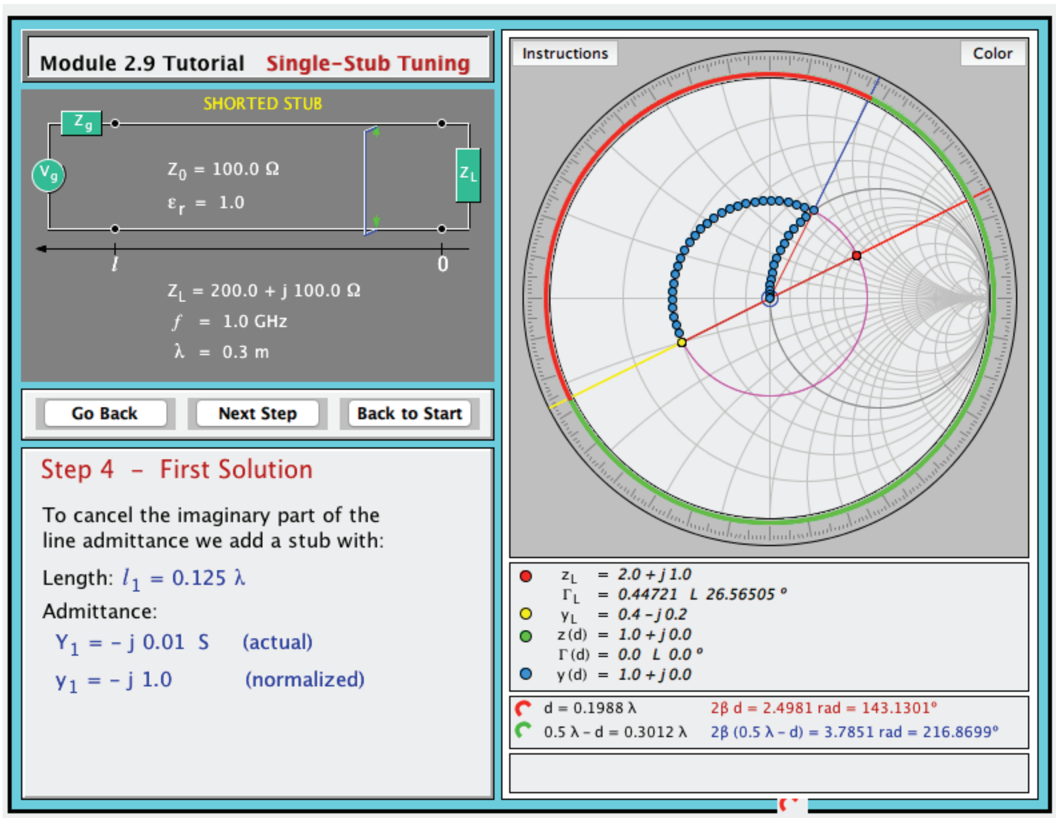
Solution: (a)

$$z_L = \frac{Z_L}{Z_0} = \frac{200 - j100}{100} = 2 + j1.$$

Solution 1:

$$d_1 = 0.2\lambda,$$
$$l_1 = 0.125\lambda.$$

Hence, $l_1 = 0.125\lambda$.



Test 2.32 Impedance Matching

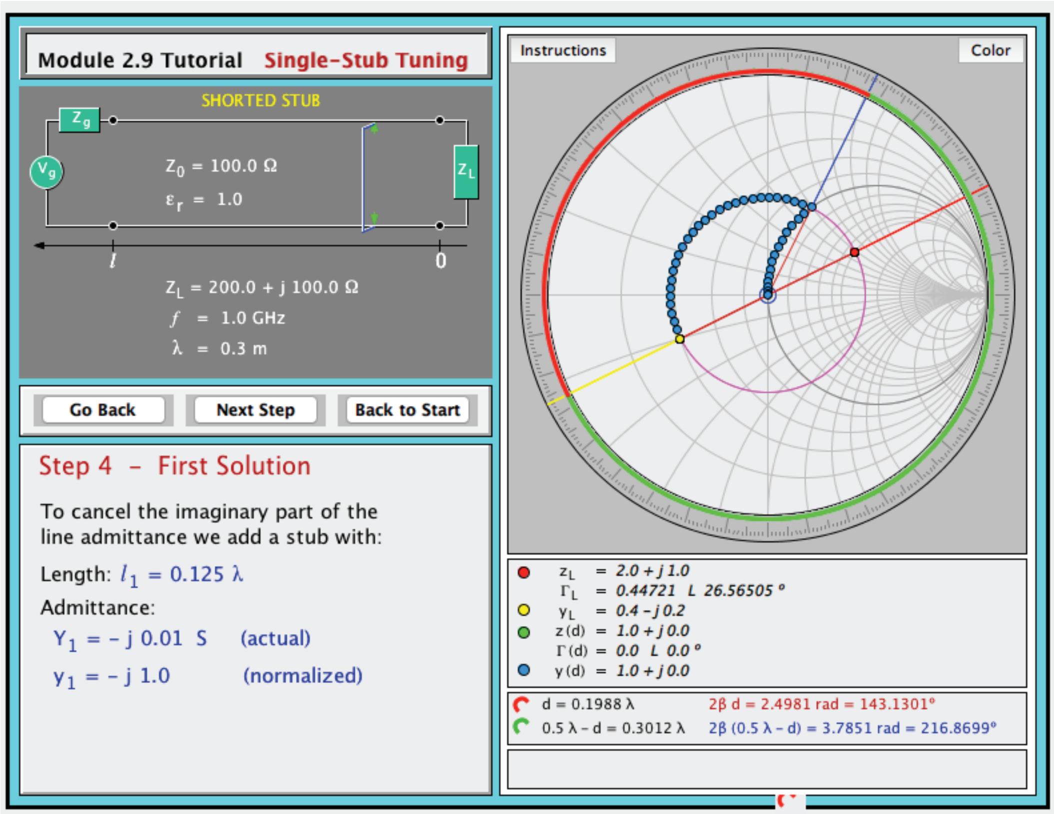
Solution: (b)

$$z_L = \frac{Z_L}{Z_0} = \frac{200 - j100}{100} = 2 + j1.$$

Solution 1:

$$\begin{aligned} d_1 &= 0.2\lambda, \\ l_1 &= 0.125\lambda. \end{aligned}$$

Hence, $d_1 = 0.2\lambda$.



Test 2.33 Transient Response

Solution: (b)

$$u_{\mathrm{p}} = \frac{c}{\sqrt{\varepsilon_{\mathrm{r}}}} = \frac{3\times10^8}{\sqrt{9}} = 1\times10^8 \text{ m/s},$$

$$\frac{2\ell}{u_{\mathrm{p}}} = 6\ \mu\text{s},$$

$$\ell = \frac{6\times10^{-6}\times1\times10^8}{2} = 300 \text{ m}.$$

Test 2.34 Transient Response

Solution: (d) Since $V(0,t)$ dropped from 5 V to 2.5 V at 6 μs,

$$\Gamma = \frac{2.5}{5} = 0.5.$$

$$V(0, 6\ \mu\text{s}) = V_1^+ + \Gamma_\text{L} V_1^+ = V_1^+(1 + \Gamma_\text{L}).$$

Hence,

$$2.5 = 5(1 + \Gamma_\text{L}),$$

which leads to

$$\Gamma_\text{L} = -0.5.$$

$$Z_\text{L} = \left(\frac{1 + \Gamma_\text{L}}{1 - \Gamma_\text{L}}\right) Z_0 = \left(\frac{1 - 0.5}{1 + 0.5}\right) \times 150 = 50\ \Omega.$$