Lec15 Impedance Matching and Tuning (II)
阻抗匹配和调谐

Series Stubs（串行短截线）

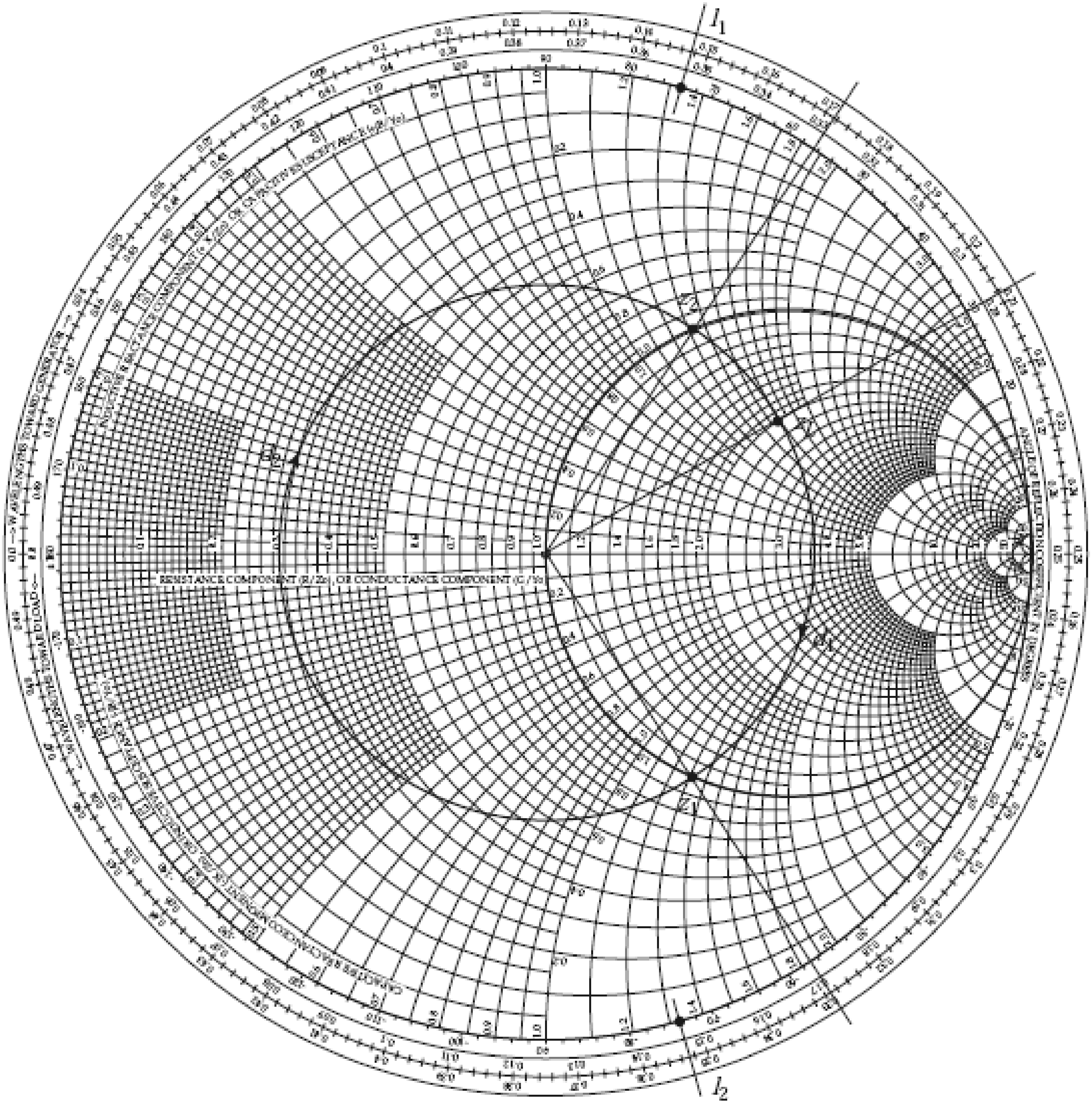
EXAMPLE 5.3 SINGLE-STUB SERIES TUNING

Match a load impedance of Z_L = 100 + j80 to a 50ohm line using a single series open-circuit stub. Assuming that the load is matched at 2 GHz and that the load consists of a resistor and inductor in series, plot the reflection coefficient magnitude from 1 to 3 GHz.

Smith chart Solution

1) First plot the normalized load impedance, zL = 2 + j1.6, and draw the SWR circle.

2) The SWR circle intersects the 1 + *j x* circle at two points, denoted as z1 and z2.


l_1
l_2
RESISTANCE COMPONENT (R/Zo), OR CONDUCTANCE COMPONENT (G/Yo)

3) The shortest distance, *d1*, from the load to the stub is, from the WTG scale,

$$d_1 = 0.328 - 0.208 = 0.120\lambda,$$

and the second distance is

$$d_2 = (0.5 - 0.208) + 0.172 = 0.463\lambda.$$

The normalized impedances at the two intersection points are

$$z_1 = 1 - j1.33,$$

$$z_2 = 1 + j1.33.$$

4) the first solution requires a stub with a reactance of *j1.33.*

The length of **an open-circuited stub** that gives this reactance can be found on the Smith chart by starting at $z = \infty$(open circuit), and moving along the outer edge of the chart (r = 0) toward the generator to the j1.33 point. This gives a stub length of $\ell_1 = 0.397\lambda.$

the required open-circuited stub length for the second solution is

$$\ell_2 = 0.103\lambda.$$

If the load is a series resistor and inductor with ZL = 100 + j80 at 2 GHz, then R = 100 and L = 6.37 nH. The two matching circuits are shown in the following figure.

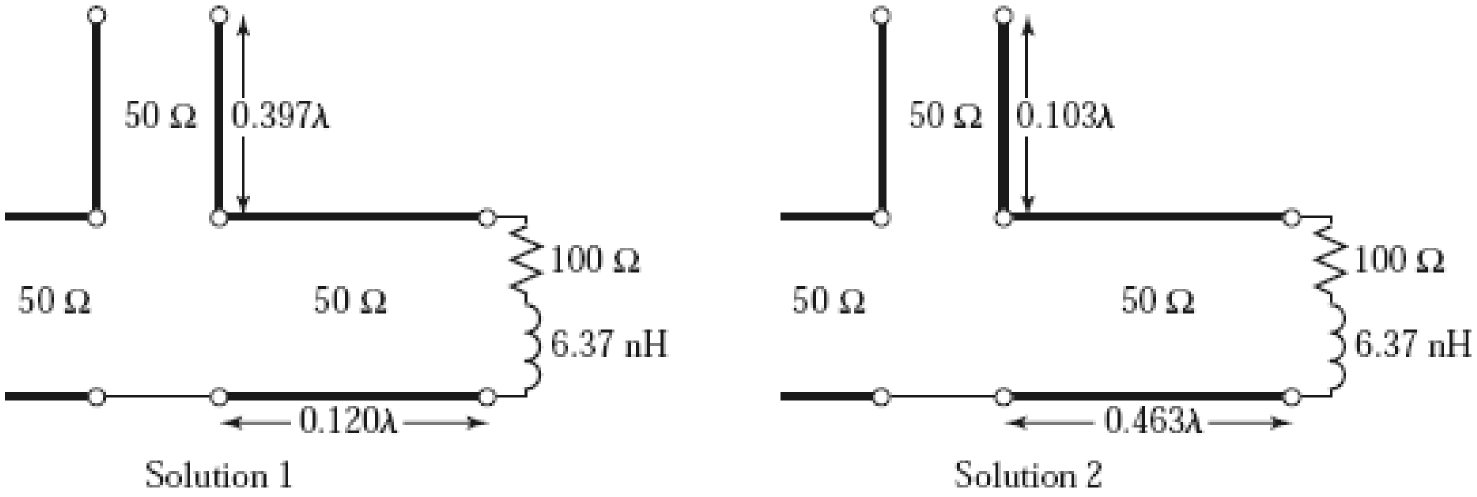
Analytical solution

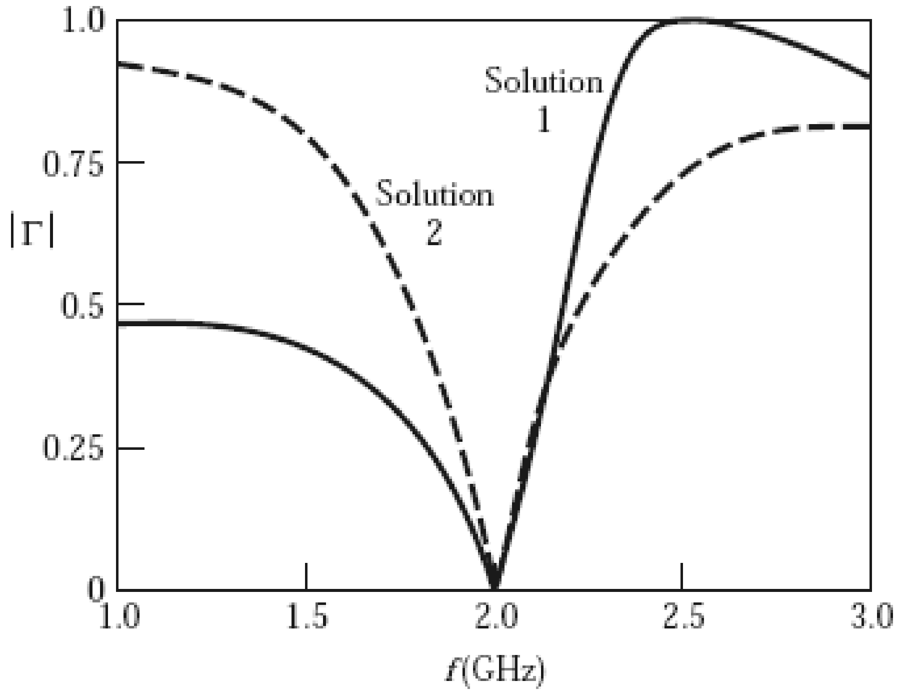
let the load admittance be written as $Y_L = 1/Z_L = G_L + jB_L.$

Then the admittance Y down a length d of line from the load is

$$Y = Y_0 \frac{(G_L + jB_L) + jtY_0}{Y_0 + jt(G_L + jB_L)},$$

where $t = \tan \beta d$ and $Y_0 = 1/Z_0$.


50 Ω
0.397λ
100 Ω
50 Ω
50 Ω
6.37 nH
0.120λ
Solution 1
50 Ω
0.103λ
100 Ω
50 Ω
50 Ω
6.37 nH
0.463λ
Solution 2


1.0
0.75
0.5
0.25
0
|Γ|
Solution 1
Solution 2
1.0
1.5
2.0
2.5
3.0
f(GHz)

(c)

The impedance at this point is

$$Z = R + jX = \frac{1}{Y},$$

where

$$R = \frac{G_L(1+t^2)}{G_L^2 + (B_L + Y_0 t)^2},$$

$$X = \frac{G_L^2 t - (Y_0 - tB_L)(B_L + tY_0)}{Y_0\left[G_L^2 + (B_L + Y_0 t)^2\right]}.$$

Now d (which implies t) is chosen so that R = Z0 = 1/Y0.

$$Y_0(G_L - Y_0)t^2 - 2B_L Y_0 t + \left(G_L Y_0 - G_L^2 - B_L^2\right) = 0.$$

Solving for t gives

$$t = \frac{B_L \pm \sqrt{G_L\left[(Y_0 - G_L)^2 + B_L^2\right]/Y_0}}{G_L - Y_0} \quad \text{for } G_L \neq Y_0.$$

If $G_L = Y_0$, then $t = -B_L/2Y_0$.

$$d/\lambda = \begin{cases} \frac{1}{2\pi}\tan^{-1} t & \text{for } t \geq 0 \\ \frac{1}{2\pi}(\pi + \tan^{-1} t) & \text{for } t < 0. \end{cases}$$

The required stub lengths are determined by first using *t* to find the reactance X. This reactance is the negative of the necessary stub reactance, Xs .

Thus, for a short circuited stub,

$$\frac{\ell_s}{\lambda} = \frac{1}{2\pi}\tan^{-1}\left(\frac{X_s}{Z_0}\right) = \frac{-1}{2\pi}\tan^{-1}\left(\frac{X}{Z_0}\right),$$

and for an open-circuited stub,

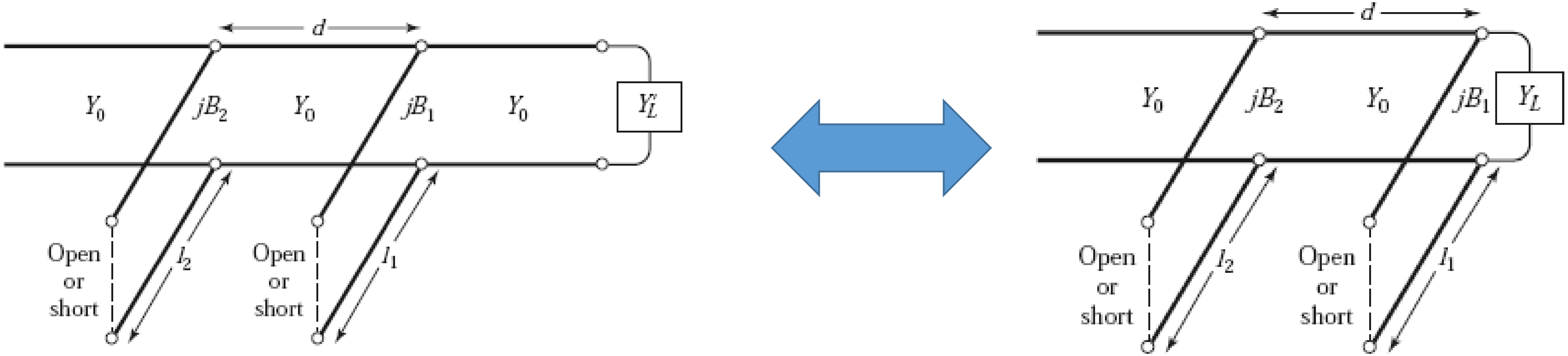
$$\frac{\ell_o}{\lambda} = \frac{-1}{2\pi}\tan^{-1}\left(\frac{Z_0}{X_s}\right) = \frac{1}{2\pi}\tan^{-1}\left(\frac{Z_0}{X}\right).$$

If the length given is negative, $\lambda/2$ can be added to give a positive result.

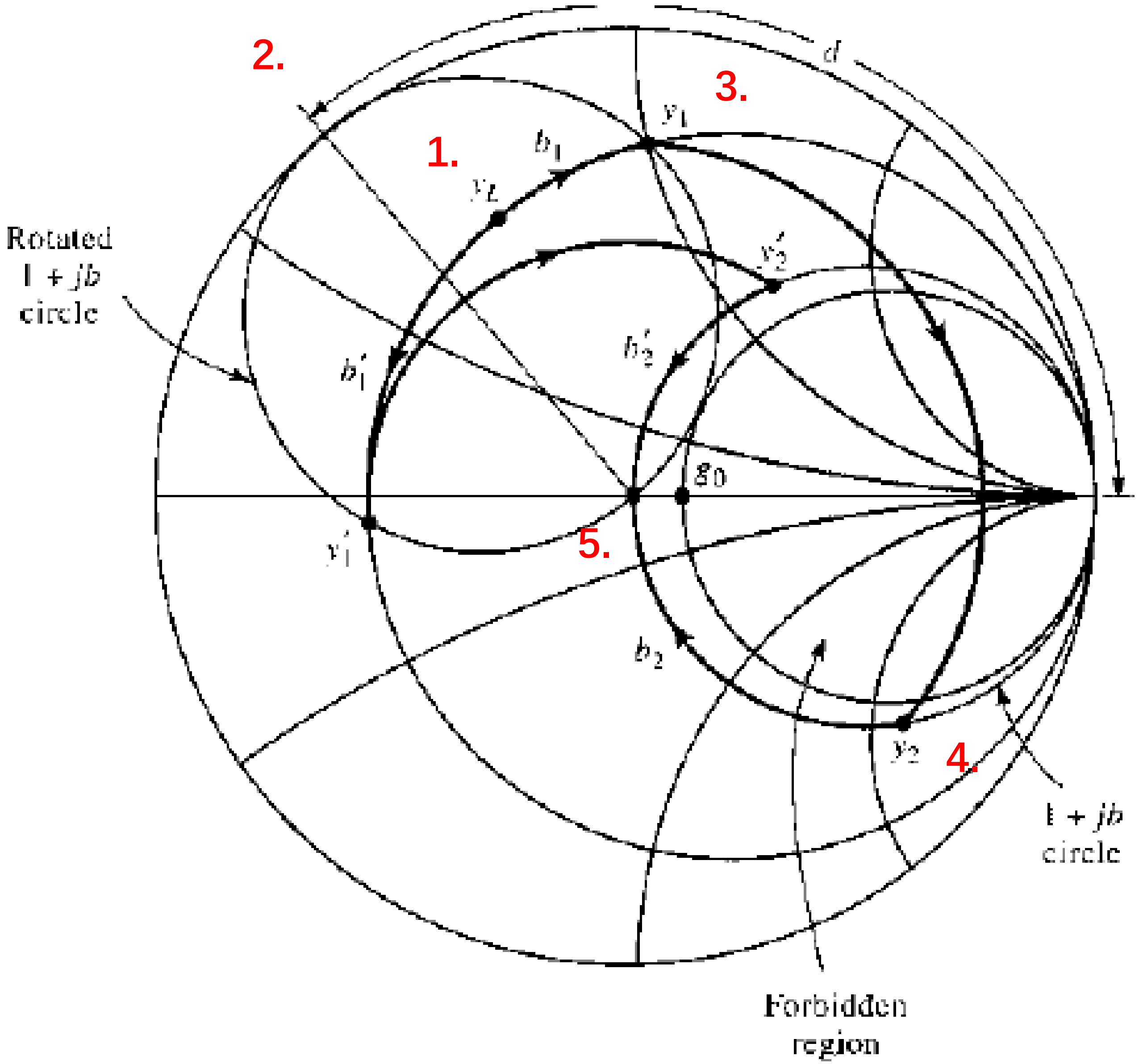
5.3 DOUBLE-STUB TUNING (双短截线调谐)

The single-stub tuner is able to match any load impedance (having a positive real part) to a transmission line, but suffers from the disadvantage of requiring **a variable length of line** between the load and the stub.

The double-stub tuner uses two tuning stubs in fixed positions.



Smith Chart Solution



1) Find y_L

2) Rotate 1+jb circle, the amount of rotation is d wavelengths toward the load.

3) move the load admittance to y1 and y1'.

4) Move y1 to y2; move y1' to y2'.

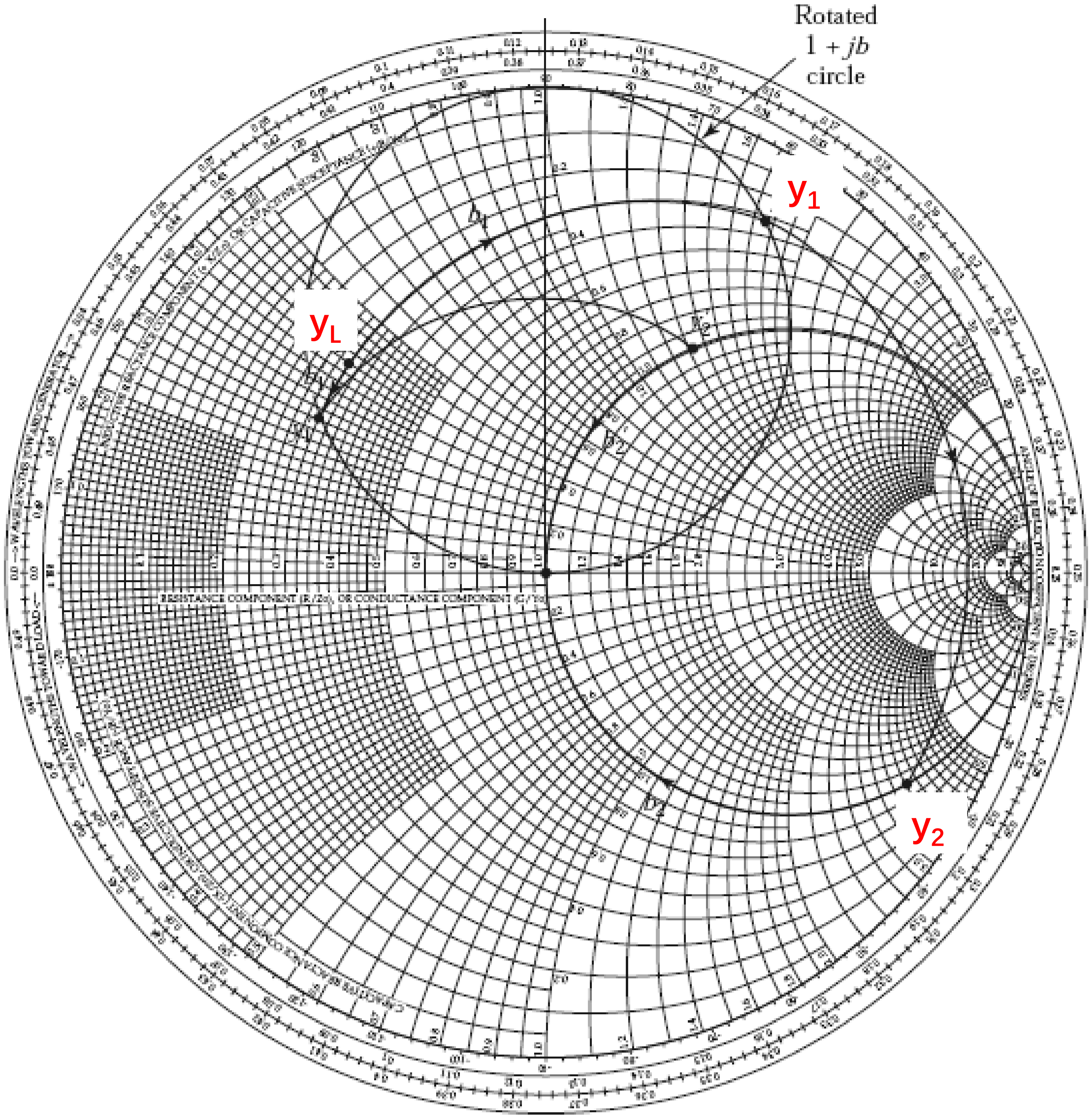
5) Move y2 and y2' to the center of smith chart.

The forbidden area is inside the shaded region of the g0 + jb circle, no value of stub susceptance b1 could ever bring the load point to intersect the rotated 1 + jb circle.

A simple way of **reducing the forbidden range** is to **reduce the distance d** between the stubs. This has the effect of swinging the rotated 1 + jb circle back toward the y =∞point, but d must be kept large enough for the practical purpose of fabricating the two separate stubs. In addition, **stub spacings near 0 or λ/2 lead to matching networks that are very frequency sensitive**. In practice, stub spacings are usually chosen **as λ/8 or 3λ/8**.

EXAMPLE 5.4 DOUBLE-STUB TUNING

Design a double-stub shunt tuner to match a load impedance $ZL = 60 - j80$ to a 50 *line. The stubs are to be open-circuited stubs and are spaced λ/8 apart.* Assuming that this load consists of a series resistor and capacitor and that the match frequency is 2 GHz, plot the reflection coefficient magnitude versus frequency from 1 to 3 GHz.



1) $y_L = 0.3 + j0.4$.

2) move yL to y1 and y1'and then

$$b_1 = 1.314 \quad \text{or} \quad b_1' = -0.114.$$

3) transform through the $\lambda/8$ section of line by rotating along a constant radius (SWR) circle λ/8 toward the generator.

$$y_2 = 1 - j3.38 \quad \text{or} \quad y_2' = 1 + j1.38.$$

4)Then the susceptance of the second stub should be

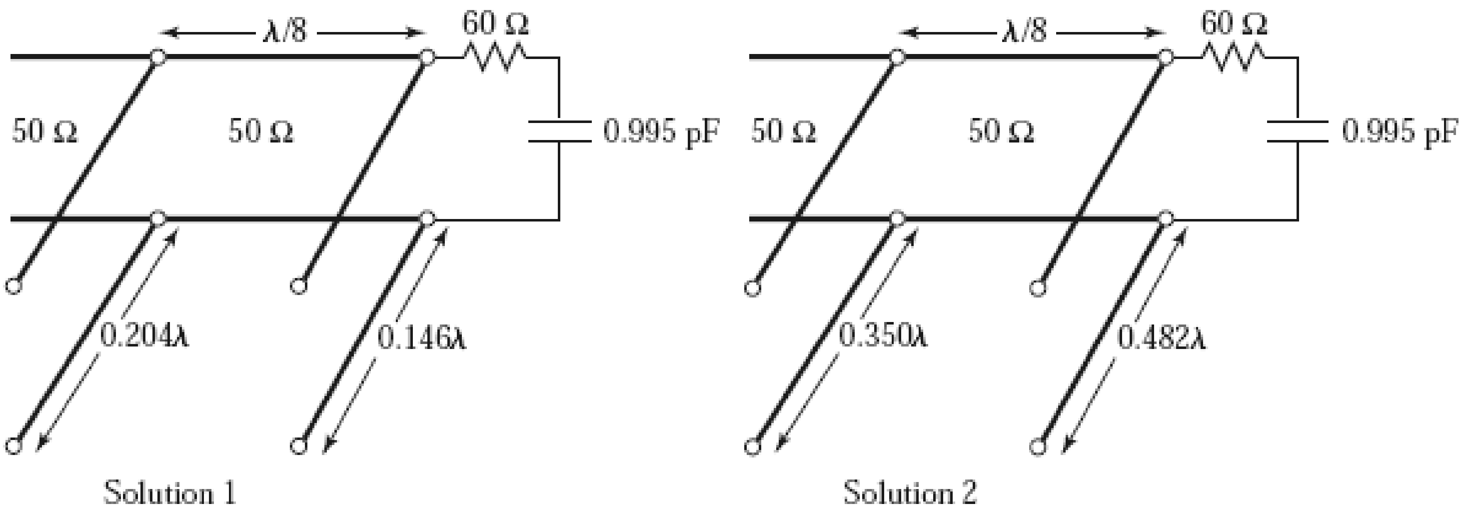
$$b_2 = 3.38 \quad \text{or} \quad b_2' = -1.38.$$

The lengths of the open-circuited stubs are then found as

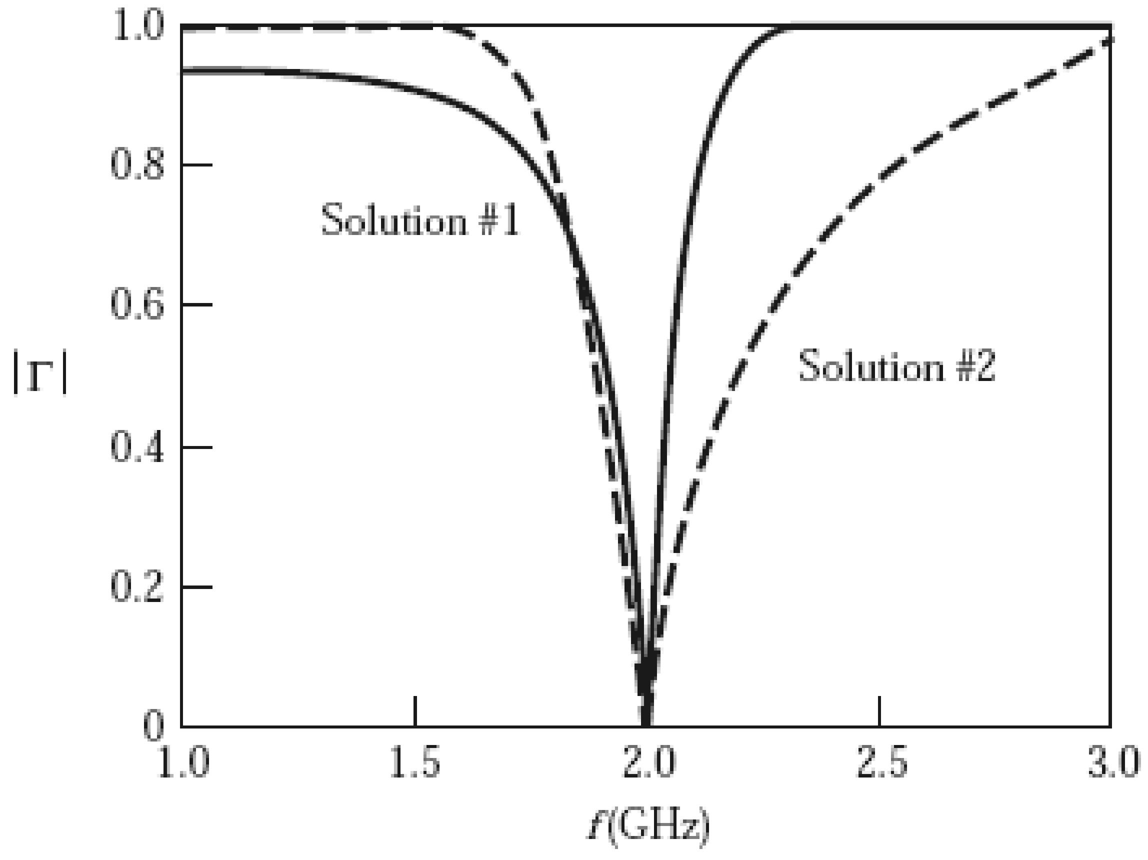
$$\ell_1 = 0.146\lambda, \ell_2 = 0.204\lambda \quad \text{or} \quad \ell_1' = 0.482\lambda, \ell_2' = 0.350\lambda.$$

This completes both solutions for the double-stub tuner design.

At f = 2 GHz the resistor-capacitor load of ZL = 60 − j80 implies that R = 60 and C = 0.995 pF.



(b)



(c)

Note that the first solution has a much narrower bandwidth than
the second (primed) solution due to the fact that both stubs for the first solution are somewhat longer (and **closer to *λ/2)*** than the stubs of the second solution.

Analytic Solution

The admittance just to the left of the first stub is

$$Y_1 = G_L + j(B_L + B_1),$$

where YL = GL + j BL is the load admittance, and B1 is the susceptance of the first stub.

After transforming through a length d of transmission line, we find that the admittance just to the right of the second stub is

$$Y_2 = Y_0 \frac{G_L + j(B_L + B_1 + Y_0 t)}{Y_0 + jt(G_L + jB_L + jB_1)},$$

where $t = \tan \beta d$ and $Y_0 = 1/Z_0$.

At this point the real part of Y2 must equal Y0,

$$G_L^2 - G_L Y_0 \frac{1 + t^2}{t^2} + \frac{(Y_0 - B_L t - B_1 t)^2}{t^2} = 0.$$

Solving for *GL* gives

$$G_L = Y_0 \frac{1+t^2}{2t^2}\left[1 \pm \sqrt{1 - \frac{4t^2(Y_0 - B_L t - B_1 t)^2}{Y_0^2(1+t^2)^2}}\right].$$

Because GL is real, the quantity within the square root must be nonnegative, and so

$$0 \leq \frac{4t^2(Y_0 - B_L t - B_1 t)^2}{Y_0^2(1+t^2)^2} \leq 1.$$

This implies that

$$0 \leq G_L \leq Y_0 \frac{1+t^2}{t^2} = \frac{Y_0}{\sin^2 \beta d},$$

which gives **the range on GL** that can be matched for a given stub spacing d.

After *d has* been set, the first stub susceptance can be determined as

$$B_1 = -B_L + \frac{Y_0 \pm \sqrt{(1+t^2)G_L Y_0 - G_L^2 t^2}}{t}.$$

Then the second stub susceptance can be found from the negative of the imaginary part of Y2

$$B_2 = \frac{\pm Y_0 \sqrt{Y_0 G_L (1 + t^2) - G_L^2 t^2} + G_L Y_0}{G_L t}.$$

The open-circuited stub length is found as

$$\frac{\ell_o}{\lambda} = \frac{1}{2\pi} \tan^{-1}\left(\frac{B}{Y_0}\right),$$

and the short-circuited stub length is found as

$$\frac{\ell_s}{\lambda} = \frac{-1}{2\pi} \tan^{-1}\left(\frac{Y_0}{B}\right),$$

where B = B1 or B2.

Homework

5.9 Design a double-stub tuner using open-circuited stubs with a $\lambda/8$ spacing to match a load admittance $Y_L = (0.4 + j1.2)Y_0$.