Other Matching Techniques Examples

Example of matching an antenna using a discrete parallel component

We have a Yagi-Uda antenna where the input impedance of the driven element is found to be $Z_A = 40 + j\,80\ \Omega$. We wish to match it to a feeding transmission line ($Z_0 = 50\ \Omega$ & $u = 2.5 \times 10^8$ m/s) at 500 MHz using a discrete capacitor connected in parallel.

- The wavelength is $\lambda = u/f = 2.5 \times 10^8/500 \times 10^6 = 0.5$ m.

Steps

1) Calculate normalized impedance $z_A = Z_A/Z_0 = (40 + j\,80)/50 \Rightarrow$ **$z_A = 0.8 + j\,1.6\ \Omega/\Omega$** and plot on **Smith chart** (see Figure 2).
2) Draw circle, centered on Smith chart, through z_A point. This circle of constant $|\Gamma|$ includes the locus of all possible z_{in} (and y_{in}) along the transmission line with this load.
3) Go $\lambda/4$ (180°) around the circle of constant $|\Gamma|$ from z_A point to **$y_A = 0.25 - j\,0.5$ S/S** point and plot.
4) Note, the two match points are $y_{m,i} = 1 \pm j1.8$ S/S. In order to use a discrete capacitor for matching, **select $y_{m,2} = 1 - j1.8$ S/S** as it has an inductive susceptance. Note, $Y_{m,2} = y_{m,2}/Z_0 = (1 - j1.8)/50 = 0.02 - j0.036$ S.
5) Find distance d_2 from y_A to $y_{m,2}$ using scales on Smith chart, $d_2 = 0.077\lambda + 0.317\lambda \Rightarrow$ **$d_2 = 0.394\lambda$** or, in meters, $d_2 = 0.394(0.5) \Rightarrow$ **$d_2 = 0.197$ m**.
6) At d_2, add a discrete capacitor in parallel with susceptance $Y_{cap} = j\omega C = +j0.036$ S. Solving for C yields $C = 0.036/(2\pi\, 500 \times 10^6) = 1.1459 \times 10^{-11}$ F $\Rightarrow$ **$C = 11.459$ pF**.
7) As shown on Figure 1, everywhere toward the source from the location of C will be matched, i.e., $Z_{in} = 50\ \Omega$.

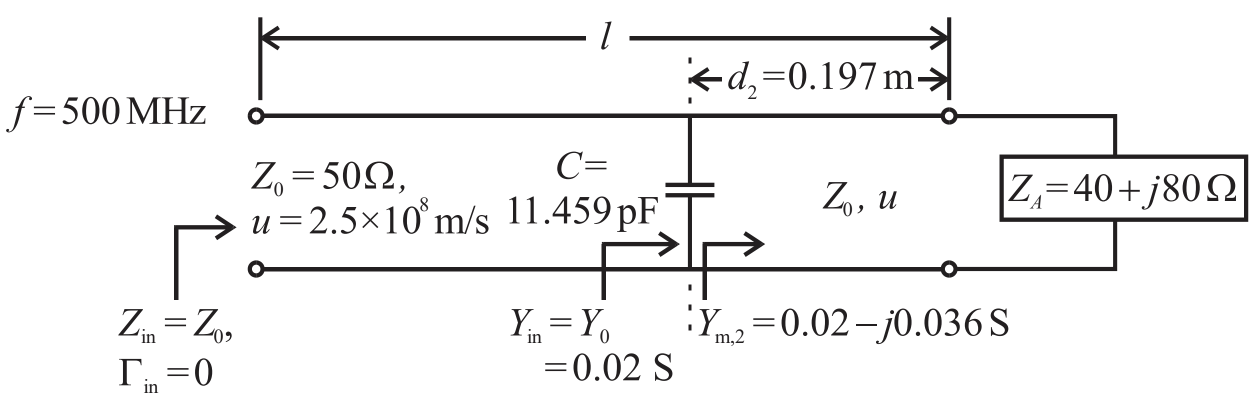

Figure 1 Matching antenna using discrete parallel capacitor.

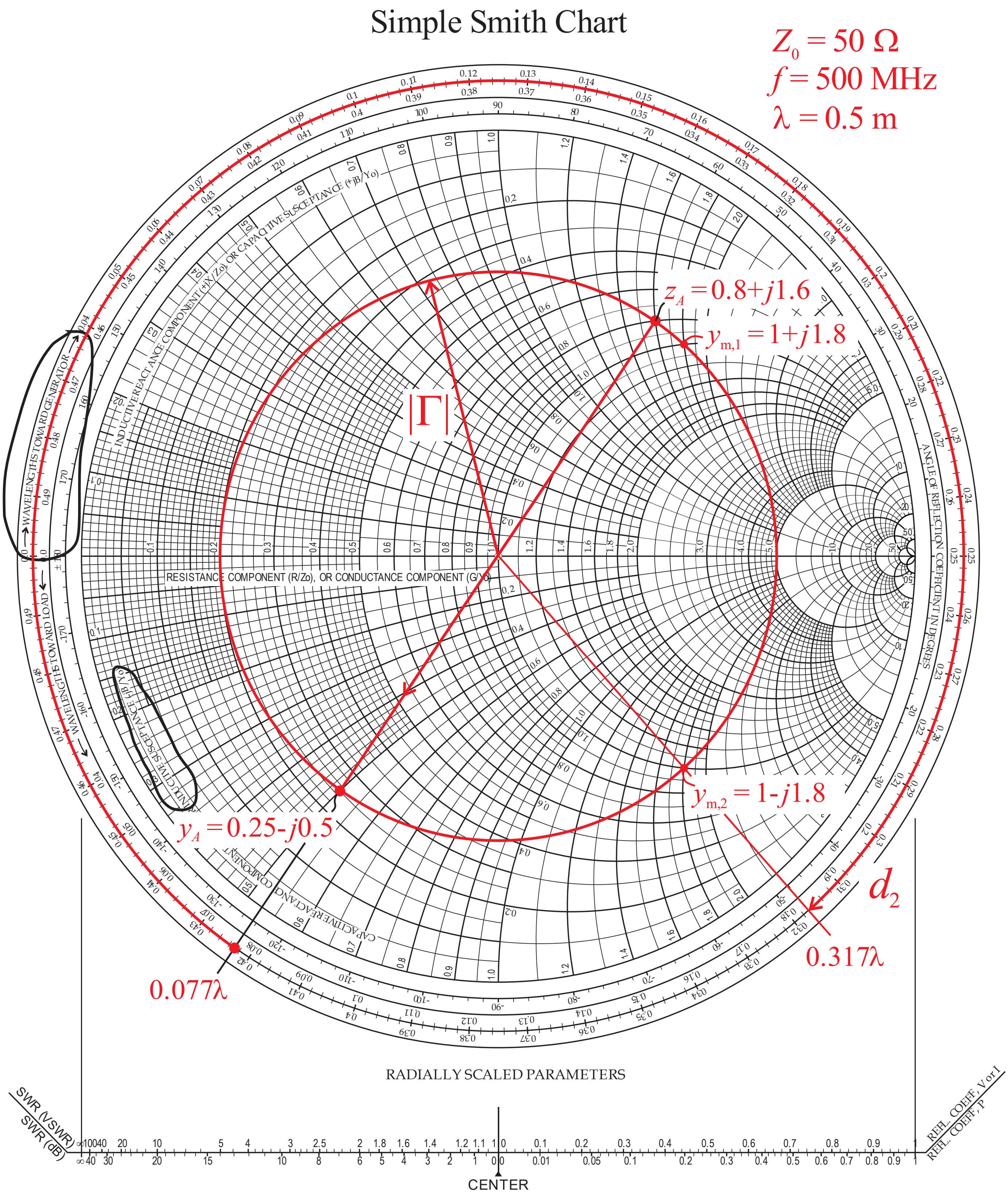

Figure 2 Smith chart for matching antenna using discrete parallel capacitor.

Example of matching an antenna using a discrete series component

We have a Yagi-Uda antenna where the input impedance of the driven element is found to be $Z_A = 17.5 + j\,30\ \Omega$. We wish to match it to a feeding transmission line ($Z_0 = 50\ \Omega$ & $u = 2.4 \times 10^8$ m/s) at 120 MHz using a discrete inductor connected in series.

- The wavelength is $\lambda = u/f = 2.4 \times 10^8 / 120 \times 10^6 = 2$ m.

Steps

1) Calculate normalized impedance $z_A = Z_A / Z_0 = (17.5 + j\,30)/50 \Rightarrow$ **$z_A = 0.35 + j\,0.6\ \Omega/\Omega$** and plot on **Smith chart** (see Figure 4).
2) Draw circle, centered on Smith chart, through z_A point. This circle of constant $|\Gamma|$ includes the locus of all possible z_{in} along the transmission line with this load.
3) The two match points are $z_{m,i} = 1 \pm j1.5\ \Omega/\Omega$. To use a discrete series inductor for matching, **select $z_{m,2} = 1 - j1.5\ \Omega/\Omega$** as it has a capacitive reactance. Note, $Z_{m,2} = z_{m,2}\, Z_0 = (1 - j1.5)\,50 = 50 - j75\ \Omega$.
4) Find distance d_2 from z_A to $z_{m,2}$ using scales on Smith chart, $d_2 = 0.3241\lambda - 0.0921\lambda \Rightarrow$ **$d_2 = 0.232\lambda$** or, in meters, $d_2 = 0.232(2) \Rightarrow$ **$d_2 = 0.464$ m**.
5) At d_2, add a discrete inductor in series with reactance $Z_{ind} = j\omega L = j75\ \Omega$. Solving for L yields $L = 75/(2\pi\, 120\times10^6) = 9.947\times10^{-8}$ H $\Rightarrow$ **$L = 99.47$ nH**.
6) As shown on Figure 3, everywhere toward the source from the inductor will see an input impedance of $Z_{in} = Z_0 = 50\ \Omega$.

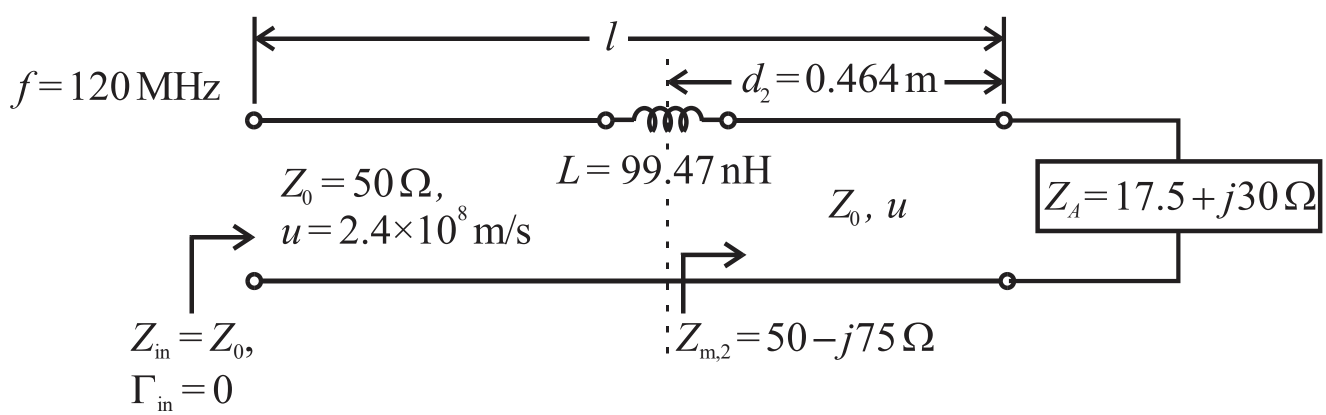

Figure 3 Matching antenna using discrete series inductor.

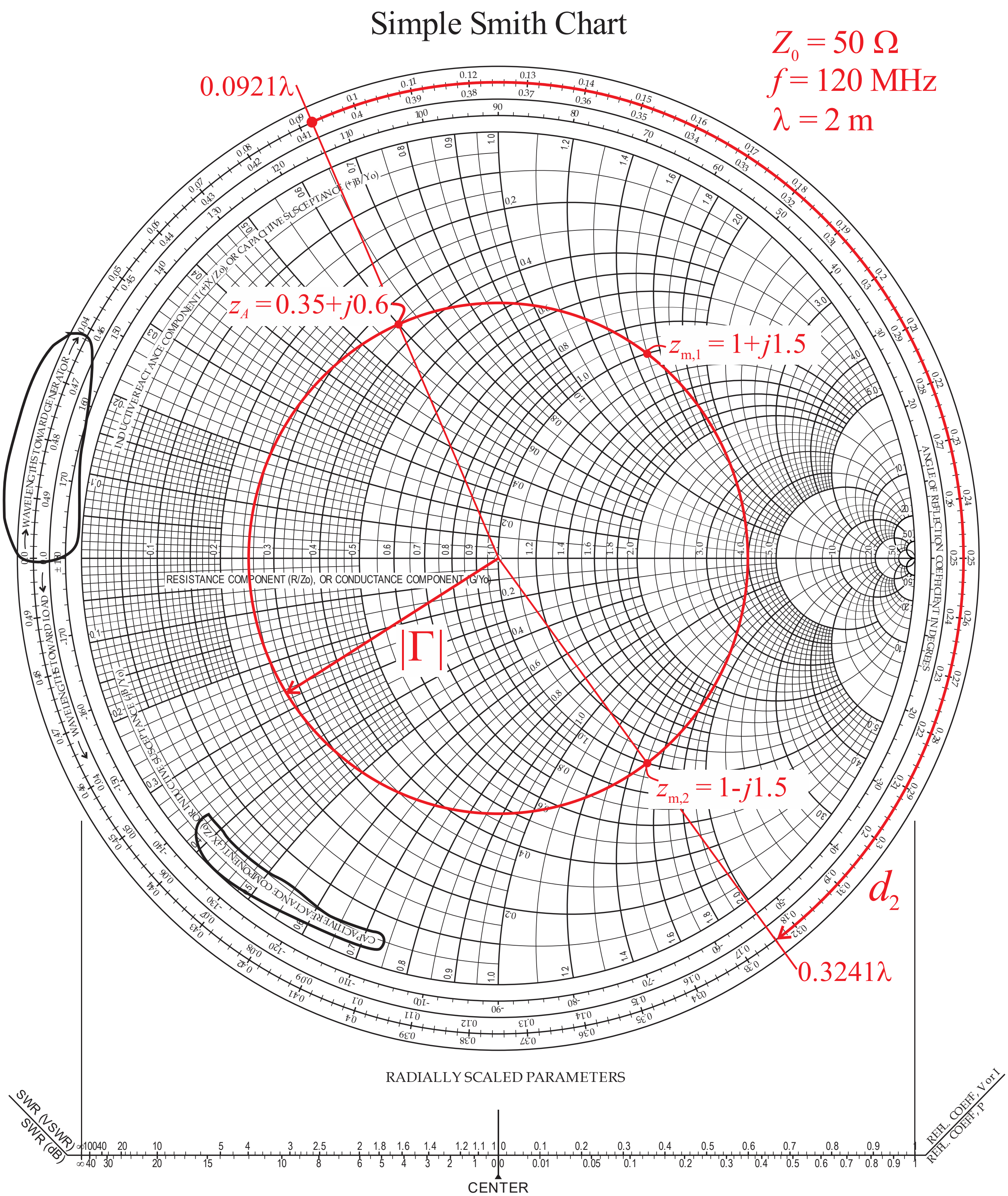

Figure 4 Smith chart for matching an antenna using discrete <u>series</u> inductor.

Example of matching an antenna using a shunt single-stub tuner

We have a horn antenna with an input impedance of $Z_A = 154.8 - j402\ \Omega$. We wish to match it to a feeding transmission line ($Z_0 = 300\ \Omega$ & $u = 2.8 \times 10^8$ m/s) at 800 MHz using a short circuit stub made from the same transmission line connected in parallel as close to the antenna as possible.

- The wavelength is $\lambda = u/f = 2.8 \times 10^8/800 \times 10^6 = 0.35$ m = 35 cm.

Steps

1) Calculate the normalized impedance for the horn $z_A = Z_A/Z_0 = (154.8 - j\,402)/300 \Rightarrow$ **$z_A = 0.516 - j\,1.34\ \Omega/\Omega$** and plot on **Smith chart** (see Figure 6).
2) Draw circle, centered on Smith chart, through z_A point. This circle of constant $|\Gamma|$ includes the locus of all possible z_{in} (and y_{in}) along the transmission line with this load.
3) Go $\lambda/4$ (180°) around the circle of constant $|\Gamma|$ from z_A point to normalized admittance **$y_A = 0.25 + j\,0.65$ S/S** point and plot.
4) Note, the two match points are $y_{m,i} = 1 \pm j2$ S/S. Select match point **$y_{m,1} = 1 + j2$ S/S** as being closest to y_A.
5) Find distance d_1 from y_A to $y_{m,1}$ using scales on Smith chart, $d_1 = 0.1875\lambda - 0.0946\lambda \Rightarrow$ **$d_1 = 0.0929\lambda$** or, in centimeters, $d_1 = 0.0929(35) \Rightarrow$ **$d_1 = 3.2515$ cm**.
6) For match point $y_{m,1}$, design a short circuit terminated shunt single stub with normalized susceptance $y_{stub} = -j2$ S/S, i.e., start at the short circuit point ($y_{SC} = \infty$) move length l_1 in the "WAVELENGTHS TOWARD GENERATOR" direction to the $-j2$ point on outer edge of the Smith chart. Here, $l_1 = 0.3238\lambda - 0.25\lambda \Rightarrow$ **$l_1 = 0.0738\lambda$** or, in centimeters, $l_1 = 0.0738(35) \Rightarrow$ **$l_1 = 2.583$ cm**.
7) As shown on Figure 5, everywhere toward the source from the stub will be matched, i.e., $Y_{in} = Y_0 = 1/300$ S or $Z_{in} = Z_0 = 300\ \Omega$.

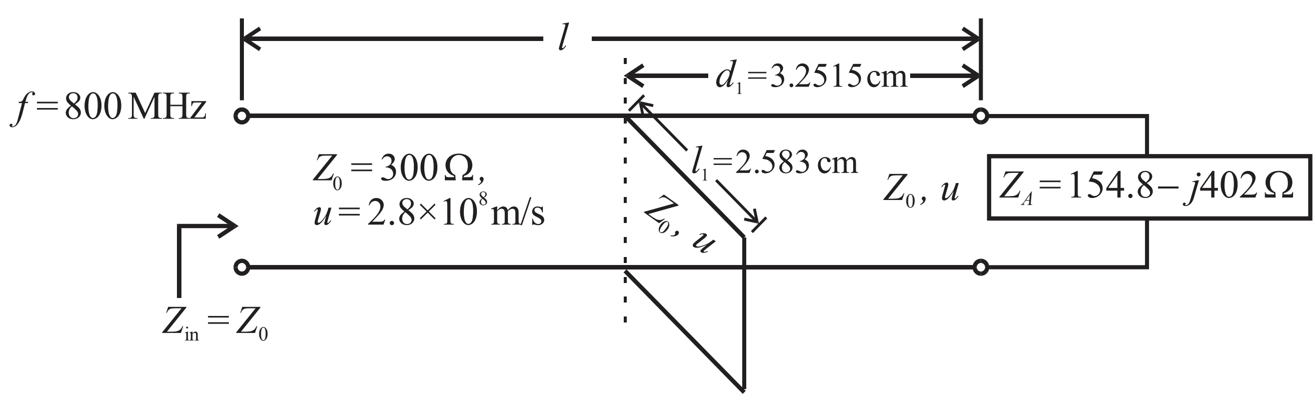

Figure 5 Matching a horn antenna using a short-circuit shunt single stub.

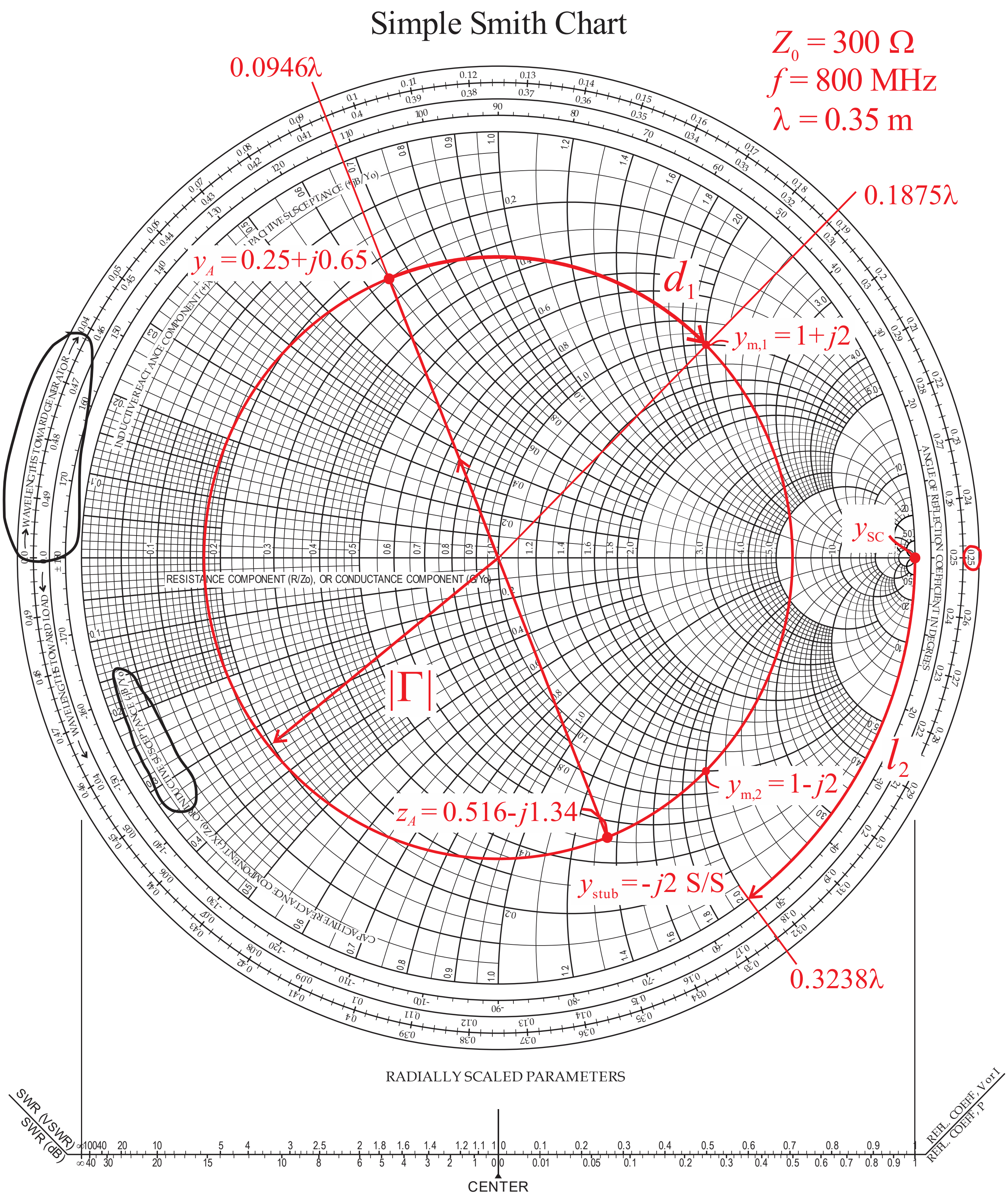

Figure 6 Smith chart for matching a horn antenna using a shunt single stub.

Example of matching an antenna using a quarter-wavelength transformer (QWT)

At 1.2 GHz, a dipole antenna has an input impedance $Z_A = 75 + j\,52.5\,\Omega$. We wish to match it to a 50 Ω planar transmission line (TL), fabricated on a printed circuit board (PCB) with a dielectric of 0.031" thickness and relative permittivity 2.2, using a planar TL QWT on the same PCB. To be able to assume that the planar TL is essentially lossless, all traces must be greater 3 mm in width. Connect the QWT as close to the dipole as possible.

- Using Table 11.1 and equations (11.21b) & (11.21c) from *Elements of Electromagnetics* (7e) by Sadiku, a lossless planar TL has a phase velocity $u = 1/(\mu\varepsilon)^{0.5}$ and characteristic impedance $Z_0 = \eta\, d/w$ where η is the intrinsic impedance of the dielectric, d is the dielectric thickness, and w is the trace width.
- For a 50 Ω planar TL on this PCB, the planar trace width is $w_{50} = \eta\, d/Z_0 = (376.7303/(2.2)^{0.5})\,0.031(25.4)/50 \Rightarrow \underline{w_{50} = 4.000\text{ mm}}$, the phase velocity is $u = 1/(\mu_0\, 2.2\varepsilon_0)^{0.5} = c\,/(2.2)^{0.5} \Rightarrow \underline{u = 2.0212\times10^8\text{ m/s}}$, and the wavelength is $\lambda = u/f = 2.0212\times10^8/1.2\times10^9 \Rightarrow \underline{\lambda = 0.16843\text{ m} = 168.433\text{ mm}}$.
- Note, u and λ do NOT depend on planar TL dimensions. Therefore, $u = u'$ and $\lambda = \lambda'$.

Steps

1) Calculate the normalized impedance for the dipole $z_A = Z_A/Z_0 = (75 + j\,52.5)/50 \Rightarrow$ $\underline{\mathbf{z_A = 1.5 + j\,1.05\ \Omega/\Omega}}$ and plot on **Smith chart** (see Figure 8).
2) Draw circle, centered on Smith chart, through z_A point. This circle of constant $|\Gamma|$ includes the locus of all possible z_{in} (and y_{in}) along the transmission line with this load.
3) There are two match points on the circle where it intersects the real axis; $r_{m,1} = r_{max} = 2.5$ ($R_{max} = 2.5(50) = 125\,\Omega$) and $r_{m,2} = r_{min} = 0.4$ ($R_{min} = 0.4(50) = 20\,\Omega$). In order to select a match point, skip ahead to use the equation from step 5) and the above information-
   - For R_{max} = 125 Ω, $Z'_{0,max} = \sqrt{Z_0 R_{max}} = \sqrt{50(125)} \Rightarrow Z'_{0,max} = 79.057\Omega$ and $w_{max} = (376.73/(2.2)^{0.5})\,0.031(25.4)/79.1 \Rightarrow \underline{w_{max} = 2.530\text{ mm}}$ (too narrow).
   - For R_{min} = 20 Ω, $Z'_{0,min} = \sqrt{Z_0 R_{max}} = \sqrt{50(20)} \Rightarrow Z'_{0,min} = 31.623\Omega$ and $w_{min} = (376.73/(2.2)^{0.5})\,0.031(25.4)/31.6 \Rightarrow \underline{w_{min} = 6.324\text{ mm}}$ (OK). **Use R_{min} match point**.
4) Find the distance d_2 using scales on Smith chart, $d_2 = 0.5\lambda - 0.192\lambda \Rightarrow \underline{\mathbf{d_2 = 0.308\lambda}}$ or, in millimeters, $d_2 = 0.308(168.433) \Rightarrow \underline{\mathbf{d_2 = 51.877\text{ mm}}}$.
5) Starting at d_2, insert a QWT with a characteristic impedance $Z'_{0,min} = \sqrt{Z_0 R_{max}} = \sqrt{50(20)} \Rightarrow \underline{Z'_{0,min} = 31.623\Omega}$, width $\underline{w_{min} = 6.324\text{ mm}}$, and length $\lambda'/4 = 168.433/4 \Rightarrow \underline{\mathbf{\lambda'/4 = 42.108\text{ mm}}}$.
6) As shown on Fig. 7, everywhere toward the source from the QWT sees $Z_{in} = Z_0 = 50\,\Omega$.

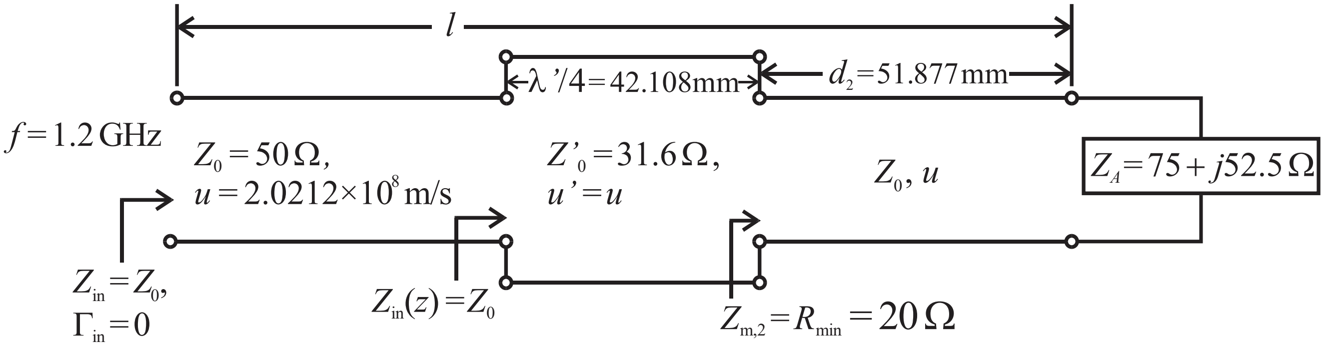

Figure 7 Matching a dipole using a QWT.

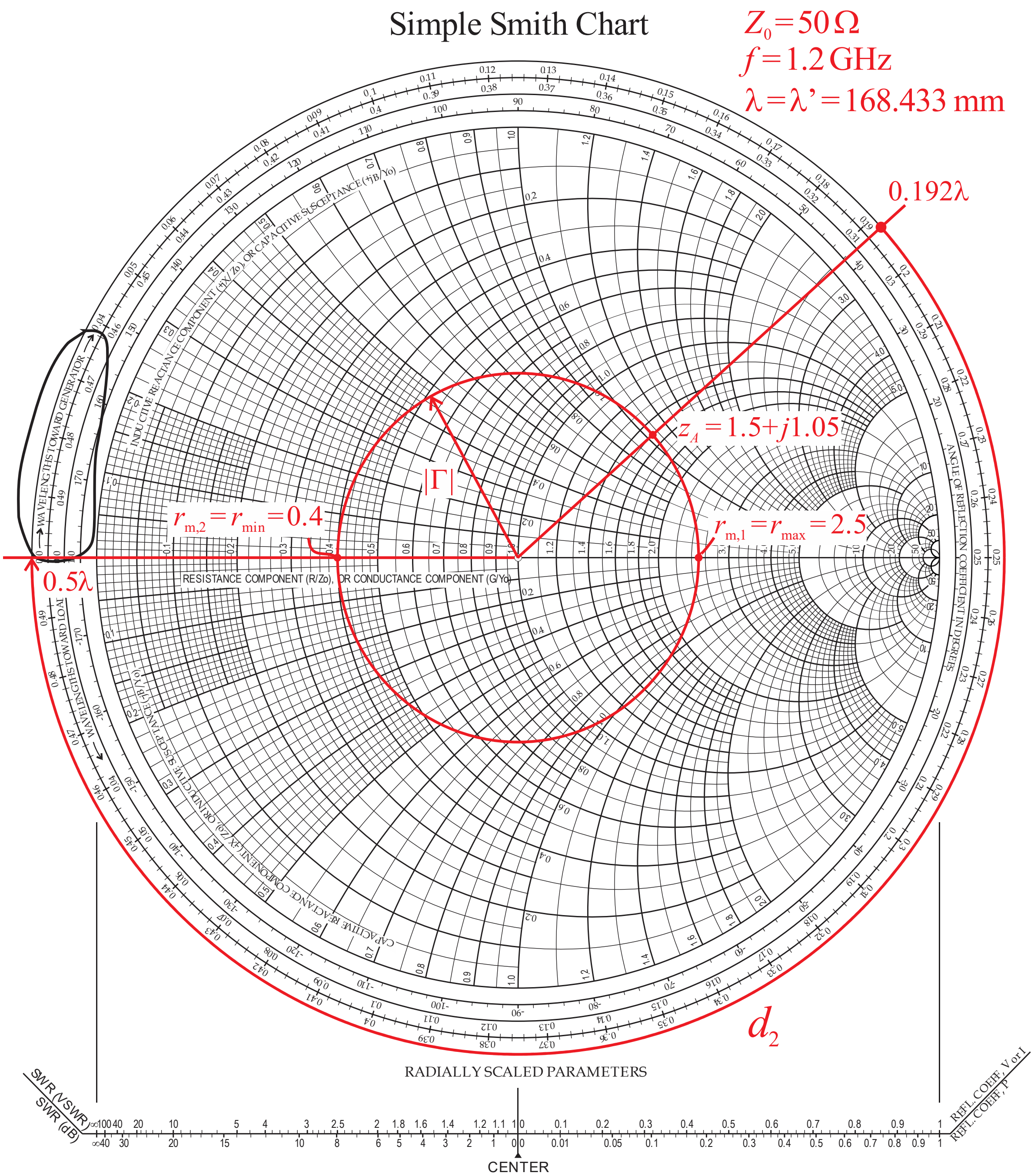

Figure 8 Smith chart for matching dipole using a QWT.