

Other Matching Techniques & Baluns for Driving Yagi-Uda Antennas

[Section 9.8 of *Antenna Theory, Analysis and Design* (4e) by Balanis]

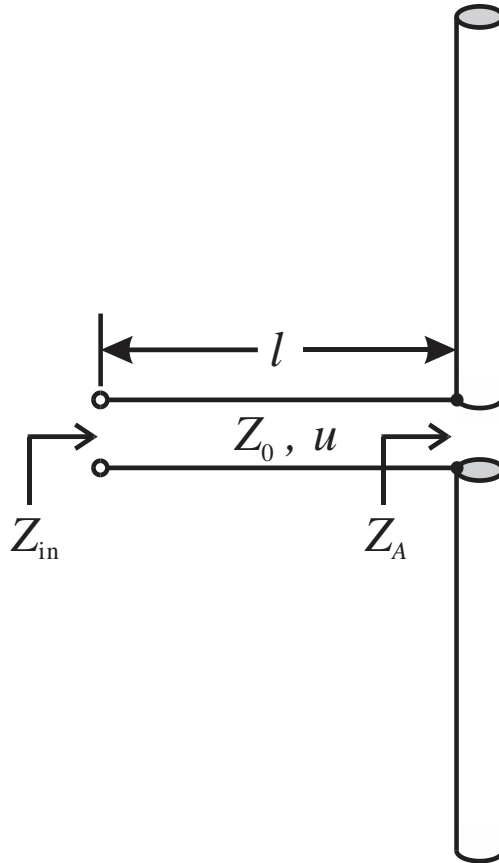


Figure 1 Antenna connected to a feeding transmission line.

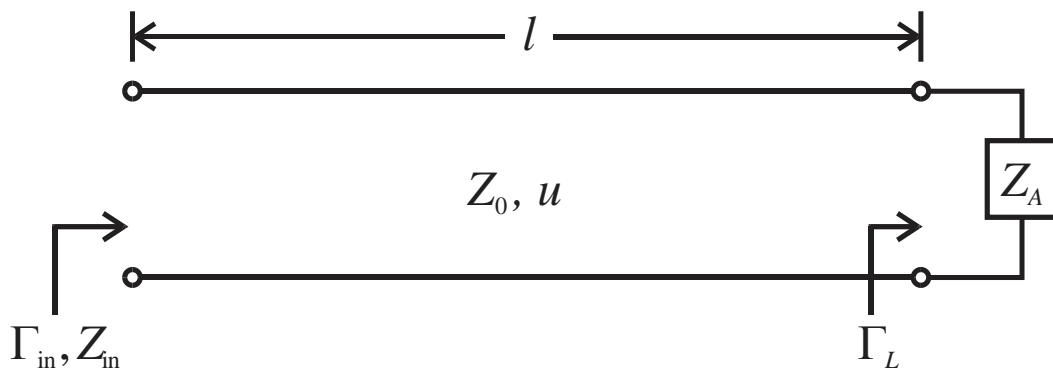


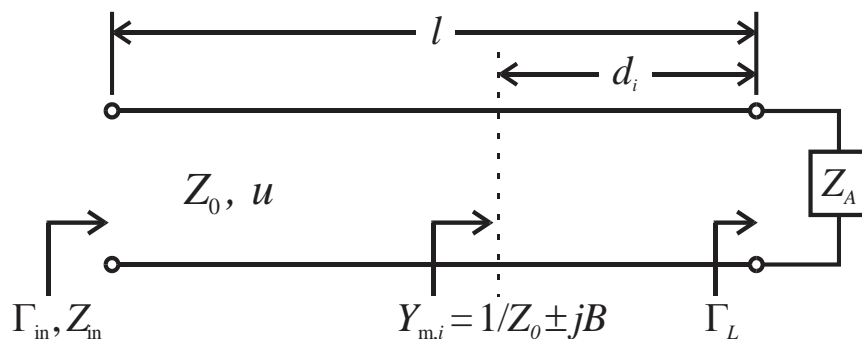
Figure 2 Antenna impedance connected to a feeding transmission line.

Matching an antenna using a discrete parallel component

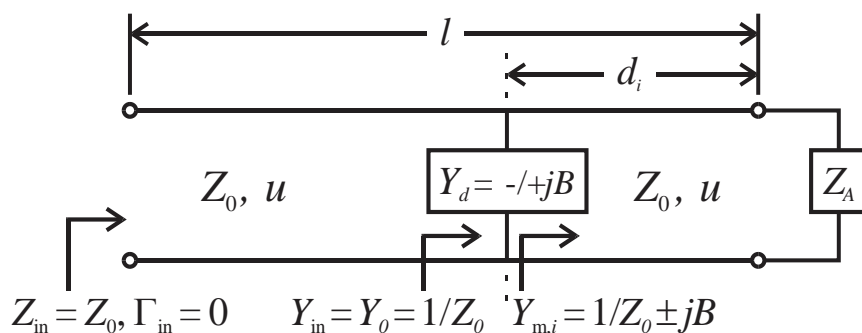
- As shown in Figures 1 and 2, we are seeking to match our antenna with input impedance Z_A to the characteristic impedance Z_0 of a feeding transmission line of length l and phase velocity u , i.e., we want $Z_{in} = Z_0$.
- Here, we will be using a discrete component connected in parallel. To avoid power losses, we will only use purely reactive components (e.g., capacitors or inductors) for matching.

Steps

- 1) Calculate normalized impedance $z_A = Z_A/Z_0$ and plot on **Smith chart** (see Figure 3).
- 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 point.
- 4) There are two normalized admittance points (i.e., match points) on the circle where the normalized conductance $g = 1$, i.e., $y_{m,i} = 1 \pm jb$. In terms of input admittance, this is where $Y_{m,i} = y_{m,i}/Z_0 = 1/Z_0 \pm jB$.
- 5) Find the distance d_i from y_L to the match points using the “WAVELENGTHS TOWARD GENERATOR” scale on the Smith chart.



- 6) Select one of the match points and add a discrete component (i.e., capacitor or inductor) in parallel with a susceptance $Y_d = \mp jB$. Remember $Y_{cap} = j\omega C$ and $Y_{ind} = -j/\omega L$.
- 7) Everywhere toward the source from the location of the discrete component will have a normalized input admittance $y_{in} = y_{m,i} + y_d = (1 \pm jb) \mp jb = 1$ or normalized input impedance $z_{in} = 1$, i.e., $Y_{in} = Y_0$ and/or $Z_{in} = Z_0$.



(Cancel w/ parallel inductor)

Capacitive susceptances

Simple Smith Chart

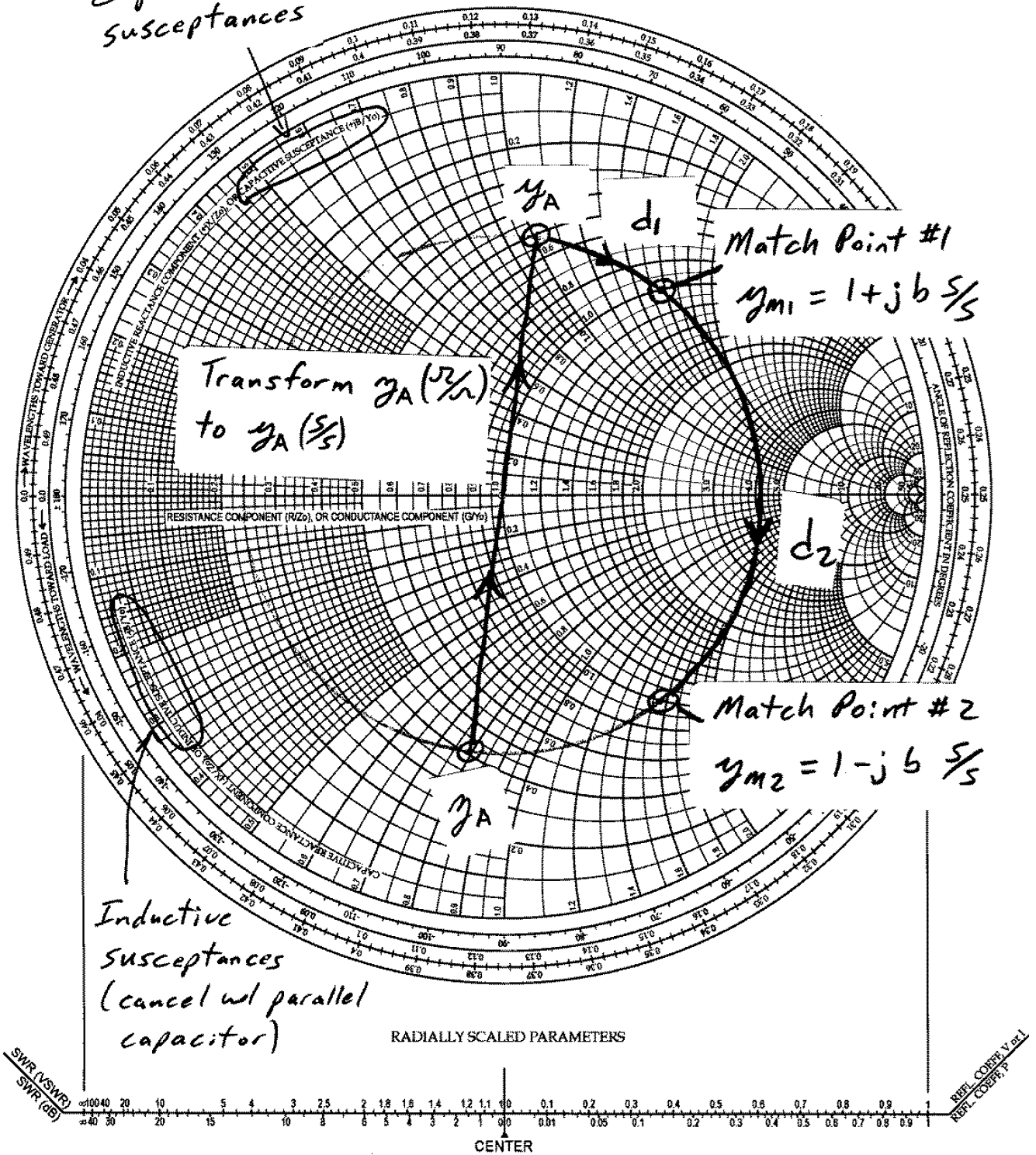


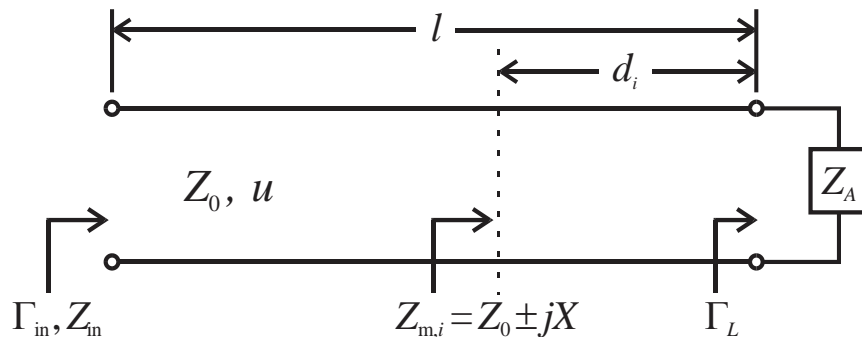
Figure 3 Smith chart for matching an antenna using discrete parallel components.

Matching an antenna using a discrete series component

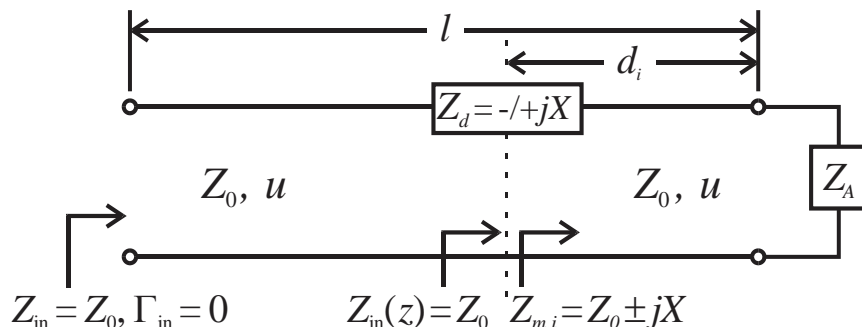
- As shown in Figs. 1 & 2, we are seeking to match our antenna with input impedance Z_A to the characteristic impedance Z_0 of a feeding transmission line, i.e., $Z_{in} = Z_0$.
- Here, we will be using a discrete component connected in series. To avoid power losses, we will only use purely reactive components (e.g., capacitors or inductors) for matching.

Steps

- 1) Calculate $z_A = Z_A / Z_0$ 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} (and y_{in}) along the transmission line with this load.
- 3) There are two points normalized impedance (i.e., match points) on the circle of constant $|\Gamma|$ that intersect the circle where the normalized resistance $r = 1$, i.e., $z_{m,i} = 1 \pm jx$. In terms of input impedance, this is where $Z_{m,i} = Z_0 \pm jX$.
- 4) Find the distance d_i from z_A to the match points using the “WAVELENGTHS TOWARD GENERATOR” scale.



- 5) Select one of the match points and add a discrete component (i.e., capacitor or inductor) in series with a reactance $Z_d = \mp jX$. Remember $Z_{cap} = -j/\omega C$ and $Z_{ind} = j\omega L$.
- 6) Everywhere toward the source from the match point will see a normalized input impedance $z_{in} = (1 \pm jx_m) \mp jx_m = 1$, i.e., $Z_{in} = Z_0$.



Simple Smith Chart

Inductive Reactance
(Cancel w/ series capacitor)

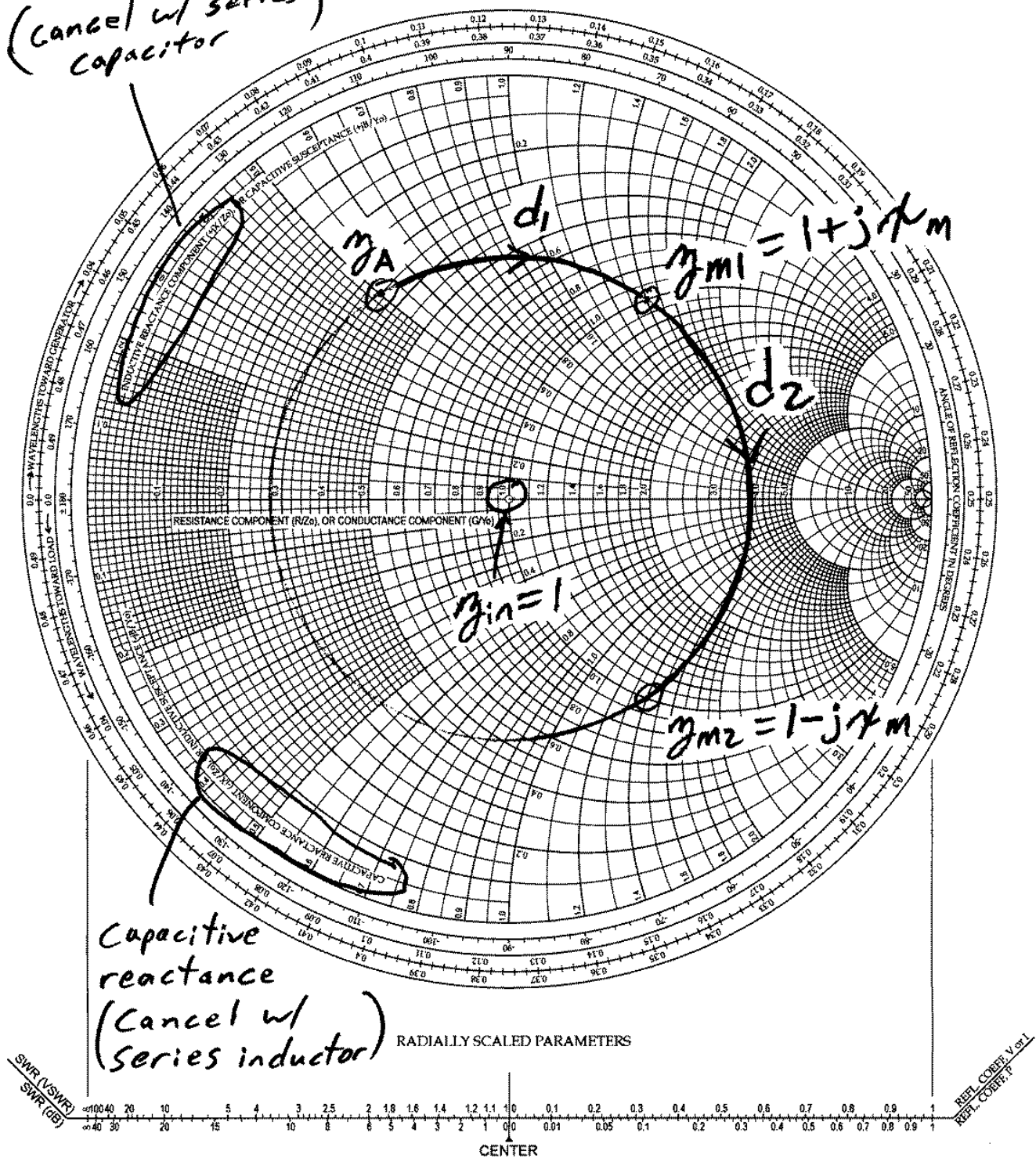


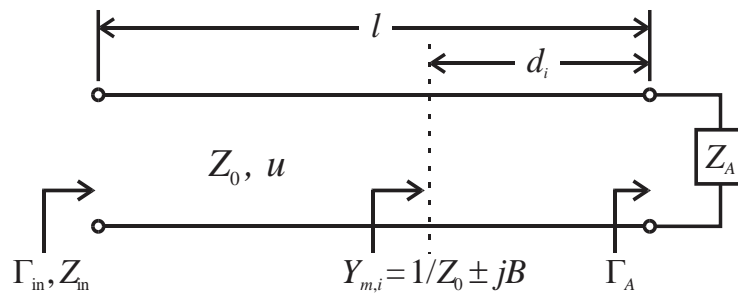
Figure 4 Smith chart for matching an antenna using discrete series components.

Matching an antenna using a shunt single-stub tuner

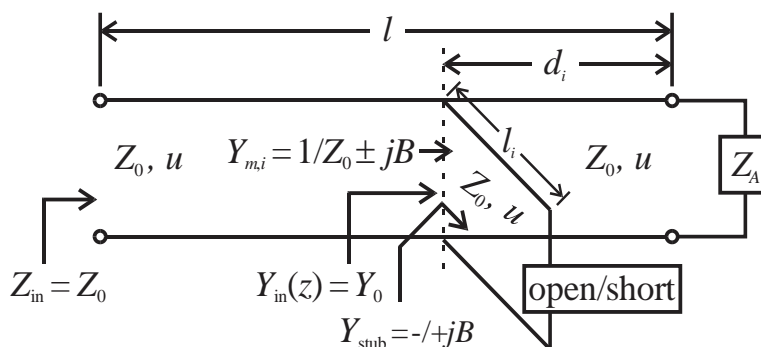
- As shown in Figs. 1 & 2, we are seeking to match our antenna with input impedance Z_A to the characteristic impedance Z_0 of a feeding transmission line, i.e., $Z_{in} = Z_0$.
- Here, we will be using a single stub connected in parallel (shunt). To avoid power losses, we will only use lossless stubs with open or short circuit terminations for matching.

Steps

- 1) Calculate $z_A = Z_A/Z_0$ and plot on Smith chart (see Figure 5).
- 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 point.
- 4) There are two points (i.e., match points) on the circle of constant $|\Gamma|$ that intersect the circle where the normalized conductance $g = 1$, i.e., $y_{m,i} = 1 \pm jb$. In terms of input admittance, this is where $Y_{m,i} = y_{m,i}/Z_0 = 1/Z_0 \pm jB = Y_0 \pm jB$.
- 5) Find the distance d_i from y_A to the match points moving in/ using the “WAVELENGTHS TOWARD GENERATOR” direction/scale.



- 6) Select a match point and design a short or open circuit terminated shunt single stub with normalized susceptance $y_{stubb} = \mp jb$, i.e., start at either the short circuit point ($y_{SC} = \infty$) or open circuit point ($y_{OC} = 0$) and move length l_i in the “WAVELENGTHS TOWARD GENERATOR” direction to $\mp jb$ point on outer edge of the Smith chart.
- 7) Everywhere toward the source from the match point will see a normalized input admittance of $y_{in} = y_{m,i} + y_{stubb} = (1 \pm jb) \mp jb = 1$ or normalized input impedance $z_{in} = 1$, i.e., $Y_{in} = Y_0$ and/or $Z_{in} = Z_0$.



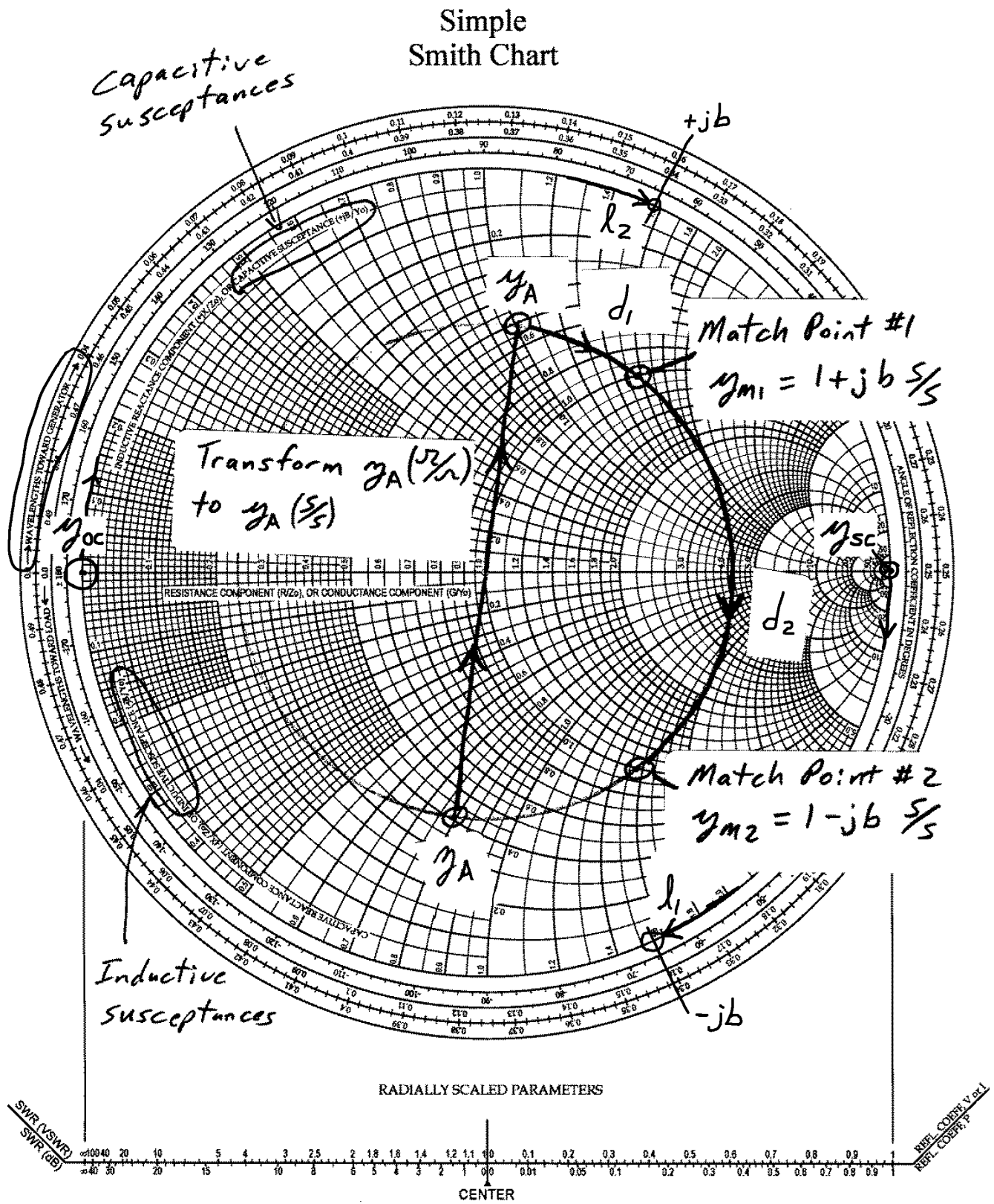
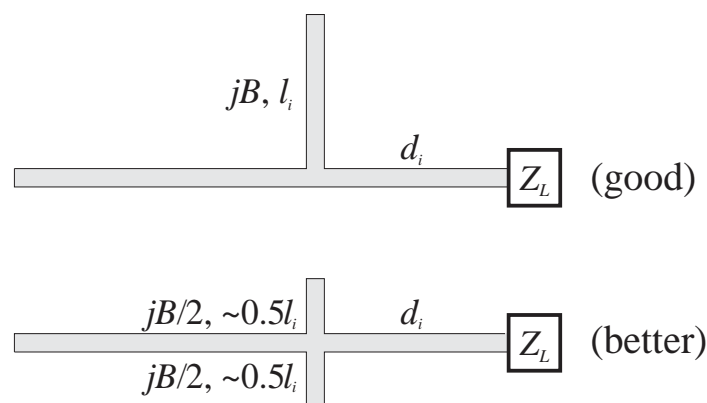


Figure 5 Smith chart for matching an antenna using a shunt single stub.

Shunt Single-stub Tuner Notes/Comments:

- Generally, stubs are terminated with either open ($Y_{OC} = 0$) or short ($Y_{SC} = \infty$) circuits for economic as well as practical reasons, i.e., can fabricate good opens and shorts.
- In theory, any purely reactive load (e.g., capacitor or inductor) could be used to terminate a stub. This is seldom done as stubs are usually used to avoid the cost and difficulty of placing discrete components.
- Single-stub tuners are inherently narrow-band matching solutions as both the location and length of the shunt single-stub tuner are in terms of wavelength λ . Picking stubs as short as possible helps increase usable bandwidth (stay on relatively flat portions of $\tan()$ or $\cot()$ functions).
- Often, particularly when using microstrip, instead of using a single shunt stub with susceptance $Y_{\text{stub}} = jB$, a pair of shorter shunt stubs, each with a susceptance $Y_{\text{stub}} = jB/2$, are placed on either side of the main microstrip (see below).

Top view



Shunt Double-stub Tuner Notes/Comments:

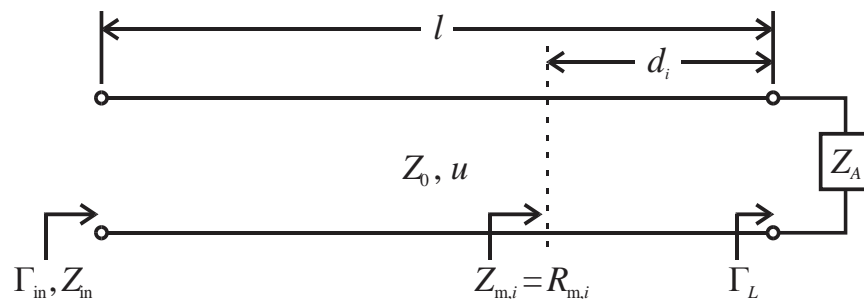
- Will not cover in this course.
- Again, stubs are terminated with either open or short circuits for economic as well as practical reasons, i.e., can fabricate good opens and shorts.
- In theory, any purely reactive load could be used to terminate a stub. This is seldom done as stubs are usually used to avoid the cost and difficulty of placing discrete components.
- While better in terms of bandwidth than shunt single-stub tuners, double-stub tuners are inherently narrow-band matching solutions as both the location and length of the shunt stubs are in terms of wavelength λ . Picking stubs as short as possible helps increase usable bandwidth (stay on relatively flat portions of $\tan()$ or $\cot()$ functions).
- Again, particularly when using microstrip, instead of using a single shunt stub with susceptance $Y_{\text{stub}} = jB$, a pair of shorter shunt stubs, each with a susceptance $Y_{\text{stub}} = jB/2$, are placed on either side of the main microstrip.

Matching an antenna using a quarter-wavelength transformer (QWT)

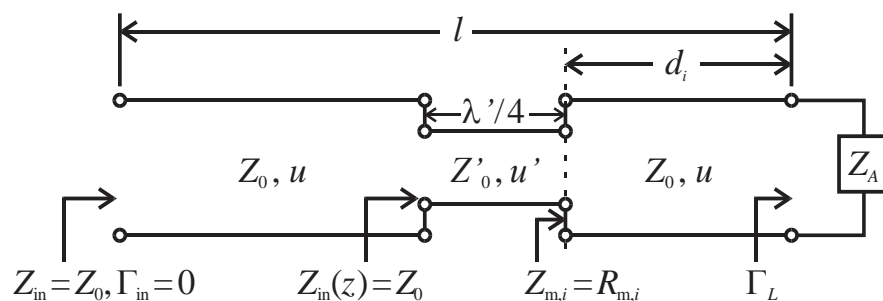
- As shown in Figs. 1 & 2, we are seeking to match our antenna with input impedance Z_A to the characteristic impedance Z_0 of a feeding transmission line, i.e., $Z_{in} = Z_0$.
- In theory, QWTs will work with any transmission lines. However, they are most common with PCB transmission lines where Z_0 is easily changed by adjusting the width of the traces.
- QWTs are inherently narrow-band matching solutions as both their location and length are in terms of wavelengths λ and λ' . Multiple section QWTs (broader bandwidth) are possible, but will not be covered in this course.
- Usually, the wavelengths λ and λ' are NOT equal as Z_0 and Z_0' involve microstrips and/or striplines of different widths. This changes the per-unit-length inductance and capacitance resulting in $u \neq u'$ and $\lambda \neq \lambda'$.

Steps

- 1) Calculate $z_L = Z_L/Z_0$ and plot on Smith chart (see Figure 6).
- 2) Draw circle, centered on Smith chart, through z_L 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 points (i.e., match points) on the circle of constant $|\Gamma|$ where it intersects the real axis. There the normalized input impedance is real, i.e., $z_{m,i} = r_{m,i} = r_{max}$ (right of center) or r_{min} (left of center).
- 4) Find the distance d_i from z_L to the match points using the “WAVELENGTHS TOWARD GENERATOR” scale.



- 5) Starting at the selected match point location d_i , insert a $\lambda'/4$ -long section of transmission line (i.e., QWT) with a characteristic impedance $Z'_0 = \sqrt{Z_0 Z_{m,i}} = \sqrt{Z_0 R_{m,i}}$.
- 6) Everywhere toward the source from the QWT will see $Z_{in} = Z_0$.



Simple Smith Chart

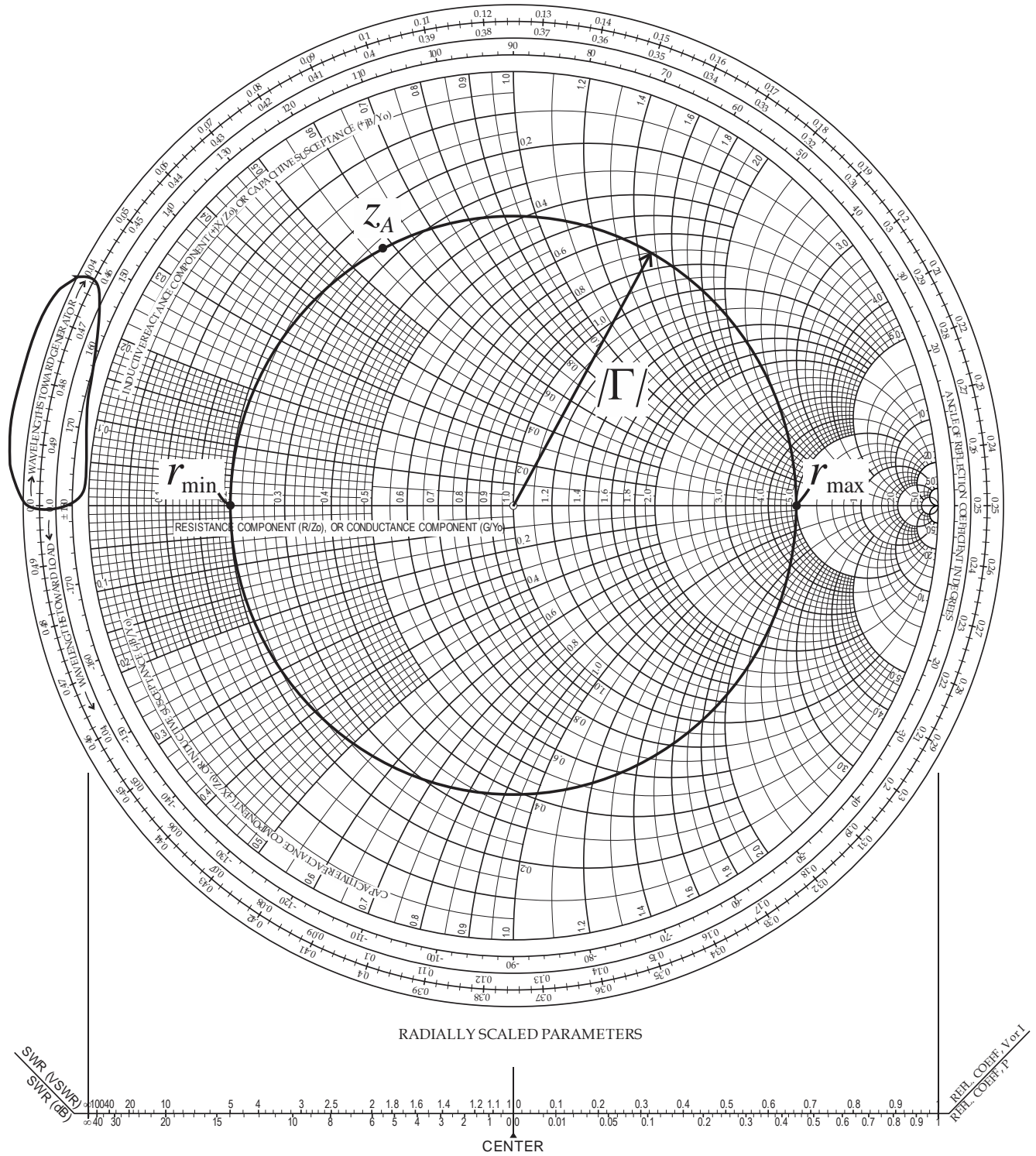
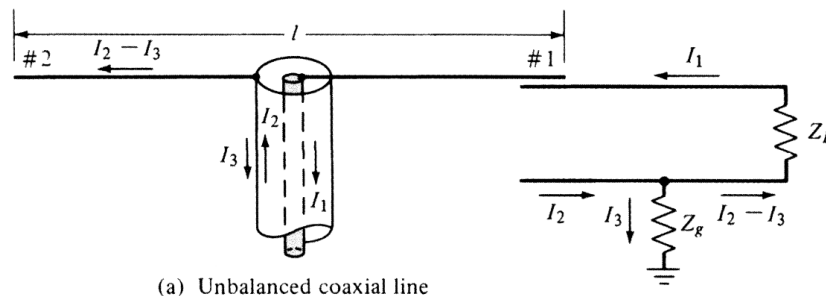


Figure 6 Smith chart for matching an antenna using a QWT.

Baluns and Transformers

- Many, if not most, antennas are balanced structures which are well suited to being driven by balanced transmission lines such as twin-lead. However, often for practical reasons, users need to use coaxial transmission lines which are unbalanced.
- Devices used to allow coaxial feeds for balanced antennas are called baluns (*balance* to *unbalance*).
- In Fig. 9.28(a), a dipole is shown with one arm connected directly to the shield of a coaxial transmission line (carrying current $I_2 - I_3$) while the other arm is connected to the center conductor (current I_1) results in unbalanced currents on the two arms due to the impedance Z_g of the shield with respect to ground allowing current I_3 to be diverted.
- To eliminate or minimize the current imbalance, there are a couple approaches which seek to increase Z_g , thus eliminating/minimizing I_3 and resulting in $I_2 - I_3 \approx I_2 \approx I_1$.



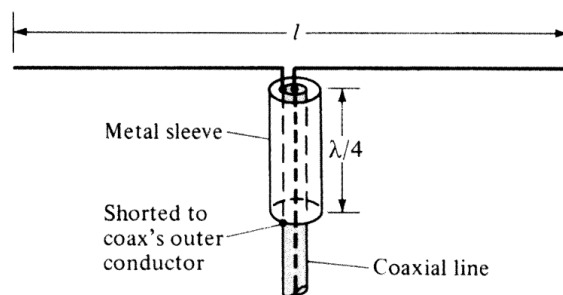
(a) Unbalanced coaxial line

Figure 9.28 Balun configurations.

[Antenna Theory, Analysis and Design (4e) by Balanis.]

Bazooka Balun

- As shown in Fig. 9.28(b), a bazooka balun uses a $\lambda/4$ -long metal sleeve around the coaxial line starting at the end of the coaxial line (does not touch dipole) that is connected/shorted to the shield at the far end.
- By transmission line theory (or as seen on a Smith chart), a short circuit becomes an open circuit after traversing $\lambda/4$ -long transmission line. Therefore, the impedance at the open end of the sleeve, $\sim Z_g$, will be very large (in theory infinity) which will minimize I_3 and balance the currents on the arms of the dipole.



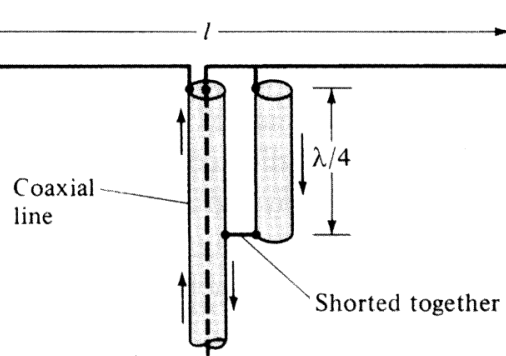
(b) Bazooka balun (1 : 1)

Figure 9.28 Balun configurations.

[Antenna Theory, Analysis and Design (4e) by Balanis.]

$\lambda/4$ Coaxial Balun

- As shown in Fig. 9.28(c), a $\lambda/4$ coaxial balun uses a $\lambda/4$ -long section of transmission line connected to the arm of the dipole fed by the center conductor on one end and connected/shorted to the shield of the feeding coaxial transmission line at the far end.

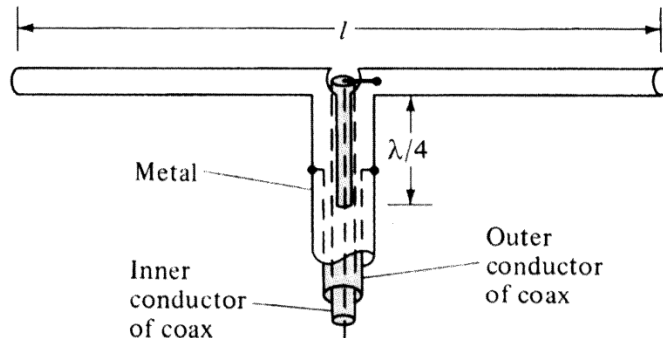


(c) $\lambda/4$ coaxial balun (1 : 1)

Figure 9.28 Balun configurations.

[Antenna Theory, Analysis and Design (4e) by Balanis.]

- Briefly, it works to minimize I_3 by providing a current that is approximately equal in magnitude, but opposite in phase to the current flowing on the shield (I_3).
- A compact configuration for achieving this $\lambda/4$ coaxial balun is shown in Fig. 9.28(d). Here, a portion of the shield of the feeding coaxial transmission is split on opposing sides a $\lambda/4$ from the feed. The part on the left is connected to the left arm of the dipole while the part on the right goes to the right arm. Mechanically, this is more difficult to construct.



(d) Coaxial balun (1 : 1)

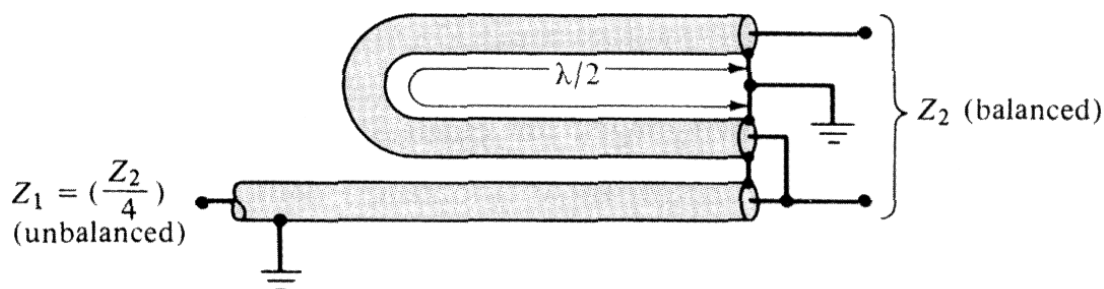
Figure 9.28 Balun configurations.

[Antenna Theory, Analysis and Design (4e) by Balanis.]

- These preceding two baluns do NOT change the input impedance of the dipole, are inherently narrowband (rely on $\lambda/4$ structures), and are relatively lossless.

$\lambda/2$ Coaxial Balun

- As shown in Fig. 9.29(a), a $\lambda/2$ coaxial balun uses a $\lambda/2$ -long section of coaxial transmission line connected as shown to create a balanced feed on the right with impedance Z_2 .
- Note, the unbalanced coaxial feed on the left has an impedance $Z_1 = Z_2/4$.
- This balun does change the impedance by a factor of 4, is inherently narrowband (rely on $\lambda/2$ -long coaxial transmission line structure), and is relatively lossless.

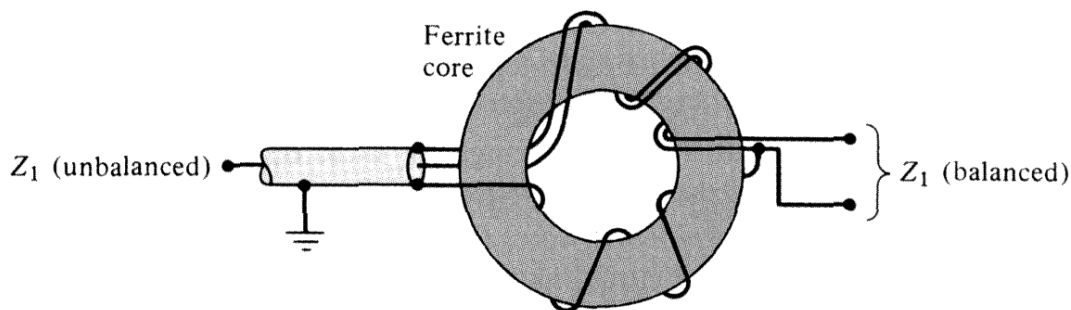


(a) $\lambda/2$ coaxial balun (4 : 1 or 1 : 4)

Figure 9.29 Balun and ferrite core transformers.
[Antenna Theory, Analysis and Design (4e) by Balanis.]

Ferrite Core Balun

- As shown in Fig. 9.29(c), a ferrite core balun uses ‘pigtailed’ from the feeding coaxial transmission line as well as the center conductor wound around a ferrite core as shown to create a balanced feed on the right.
- This balun does NOT change the input impedance between the balanced side (right) and unbalanced side (left), and can be broadband (up to 8:1 or 10:1 bandwidths possible).
- Note, the ferrite core can be lossy and introduce distortion, depending on the material and frequency.

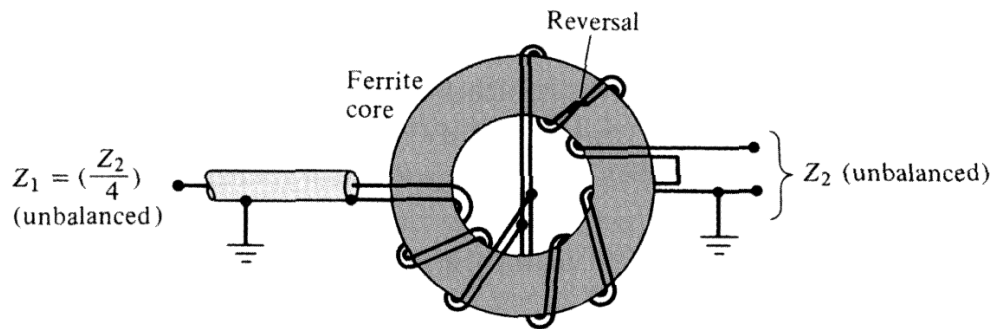


(c) Ferrite core balun (1 : 1)

Figure 9.29 Balun and ferrite core transformers.
[Antenna Theory, Analysis and Design (4e) by Balanis.]

Ferrite Core Transformer (NOT a balun)

- As shown in Fig. 9.29(b), a ferrite core transformer uses a ‘pigtail’ from the feeding coaxial transmission line as well as the center conductor wound around a ferrite core as shown to create an unbalanced feed on the right with impedance Z_2 .
- Note, the unbalanced coaxial feed on the left has an impedance $Z_1 = Z_2 / 4$.
- Note, the ferrite core can be lossy and introduce distortion, depending on the material and frequency.



(b) Ferrite core transformer (4 : 1 or 1 : 4)

Figure 9.29 Balun and ferrite core transformers.
[Antenna Theory, Analysis and Design (4e) by Balanis.]