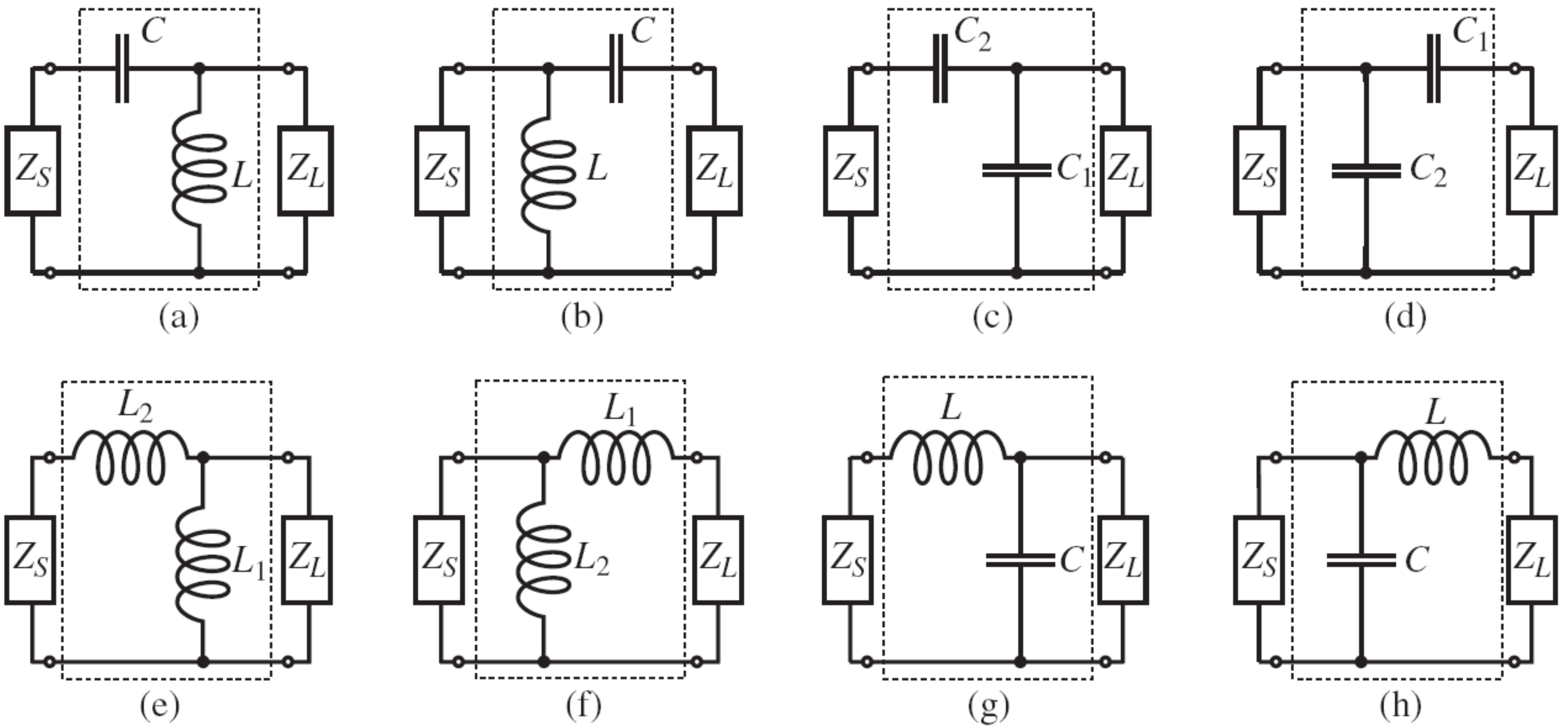
Lecture – 14 Date: 18.09.2014

- L – Type Matching Network
- Examples
- Nodal Quality Factor
- T- and Pi- Matching Networks
- Microstrip Matching Networks
- Series- and Shunt-stub Matching

L – Type Matching Network (contd.)

Various configurations



Their usefulness is regulated by the specified source and load impedances and the associated matching requirements

L – Type Matching Network (contd.)

Design procedure for two element L – Type matching Network

1. Find the normalized source and load impedances.
2. In the Smith chart, plot circles of constant resistance and conductance that pass through the point denoting the source impedance.
3. Plot circles of constant resistance and conductance that pass through the point of the complex conjugate of the load impedance ($z_M = z_L^*$).
4. Identify the intersection points between the circles in steps 2 and 3. The number of intersection points determine the number of possible L-type matching networks.
5. Find the values of normalized reactances and susceptances of the inductors and capacitors by tracing a path along the circles from the source impedance to the intersection point and then to the complex conjugate of the load impedance.
6. Determine the actual values of inductors and capacitors for a given frequency.

Example – 1

Using the Smith chart, design all possible configurations of discrete two-element matching networks that match the source impedance Z_S = (50+j25)Ω to the load Z_L = (25-j50)Ω. Assume a characteristic impedance of Z_0 = 50Ω and an operating frequency of f = 2 GHz

Solution

1. The normalized source and load impedances are:

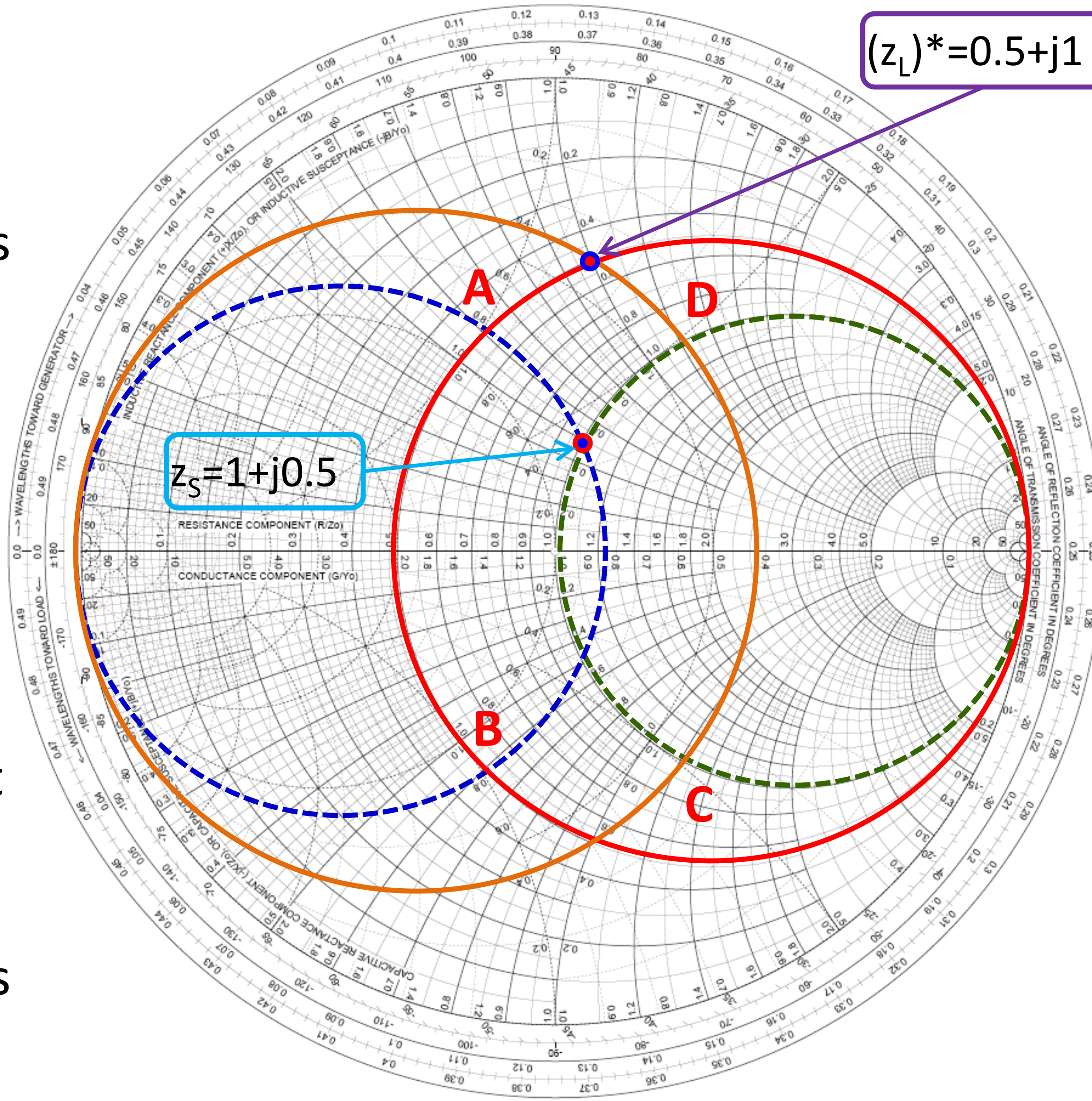
$$z_S = Z_S / Z_0 = 1 + j0.5 \qquad y_S = 0.8 - j0.4$$

$$z_S = Z_L / Z_0 = 0.5 - j1 \qquad y_S = 3 + j0.8$$

Example – 1 (contd.)

2. Mark z_S and then plot circles of constant resistance and conductance that passes through z_S.

3. Mark $(z_L)^*$ and then plot circles of constant resistance and conductance that passes through $(z_L)^*$.



Example – 1 (contd.)

4. The intersection points of these circles are A, B, C and D with the normalized impedances and inductances as:

$$z_A = 0.5 + j0.6 \qquad y_A = 0.8 - j1$$

$$z_B = 0.5 - j0.6 \qquad y_B = 0.8 + j1$$

$$z_C = 1 - j1.2 \qquad y_C = 3 + j0.5$$

$$z_D = 1 + j1.2 \qquad y_D = 3 - j0.5$$

5. There are four intersection points and therefore four L-type matching circuit configurations are possible.

$z_S \rightarrow z_A \rightarrow (z_L)^*$ ⇨ **Shunt L, Series L**

$z_S \rightarrow z_B \rightarrow (z_L)^*$ ⇨ **Shunt C, Series L**

$z_S \rightarrow z_C \rightarrow (z_L)^*$ ⇨ **Series C, Shunt L**

$z_S \rightarrow z_D \rightarrow (z_L)^*$ ⇨ **Series L, Shunt L**

Example – 1 (contd.)

6. Find the actual values of the components

In the first case:

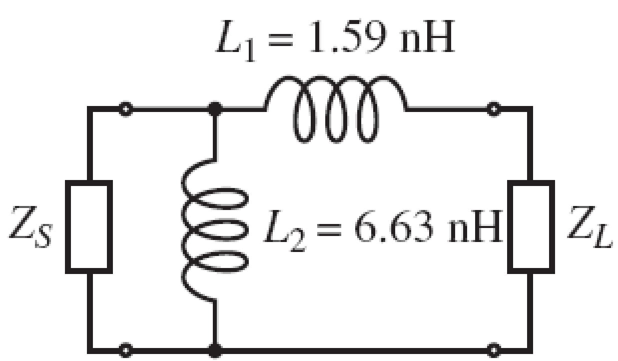
$z_S \rightarrow z_A$: the normalized admittance is changed by

$$jb_{L_2} = y_A - y_S = -j0.6 \qquad \Rightarrow L_2 = -\frac{Z_0}{b_{L_2}\omega} = 6.63nH$$

$z_A \rightarrow z_L$: the normalized impedance is changed by

$$jx_{L_1} = (z_L)^* - z_A = j0.4 \qquad \Rightarrow L_1 = \frac{x_{L_1} Z_0}{\omega} = 1.59nH$$

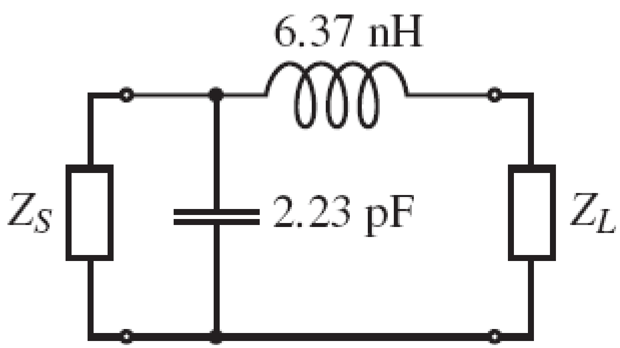
Therefore the circuit is:



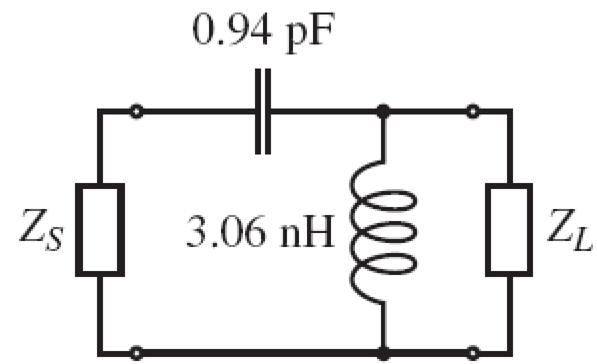
$z_S \rightarrow z_A \rightarrow (z_L)^*$

Example – 1 (contd.)

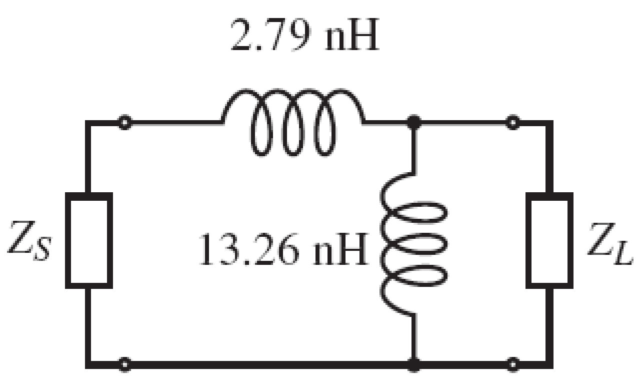
Similarly:



$z_S \rightarrow z_B \rightarrow (z_L)^*$



$z_S \rightarrow z_C \rightarrow (z_L)^*$



$z_S \rightarrow z_D \rightarrow (z_L)^*$

Forbidden Region, Frequency Response, and Quality Factor

Self Study - Section 8.1.2 in the Text Book

- The L-type matching networks can be considered as resonance circuits with f_0 being the resonance frequency.
- These networks can be described by a loaded quality factor, Q_L, given by:

$$Q_L = \frac{f_0}{BW}$$

Similarity to bandpass filter

- However, analysis of matching circuit based on bandpass filter concept is complex $\rightarrow$ In addition, it only allows approximate estimation of the bandwidth.
- More simpler and accurate method is design and analysis through the use of nodal quality factor, Q_n.

Nodal Quality Factor

- During L-type matching network analysis it was apparent that at each node the impedance can be expressed in terms of equivalent series impedance $Z_s = R_s + jX_s$ or admittance $Y_P = G_P + jB_P$.

- Therefore, at each node we can define Q_n as the ratio of the absolute value of reactance X_s to the corresponding resistance R_s.

$$Q_n = \frac{|X_S|}{R_S}$$

- Similarly,

$$Q_n = \frac{|B_P|}{G_P}$$

- The "nodal quality factor" and loaded quality factor are related as:

$$Q_L = \frac{Q_n}{2}$$

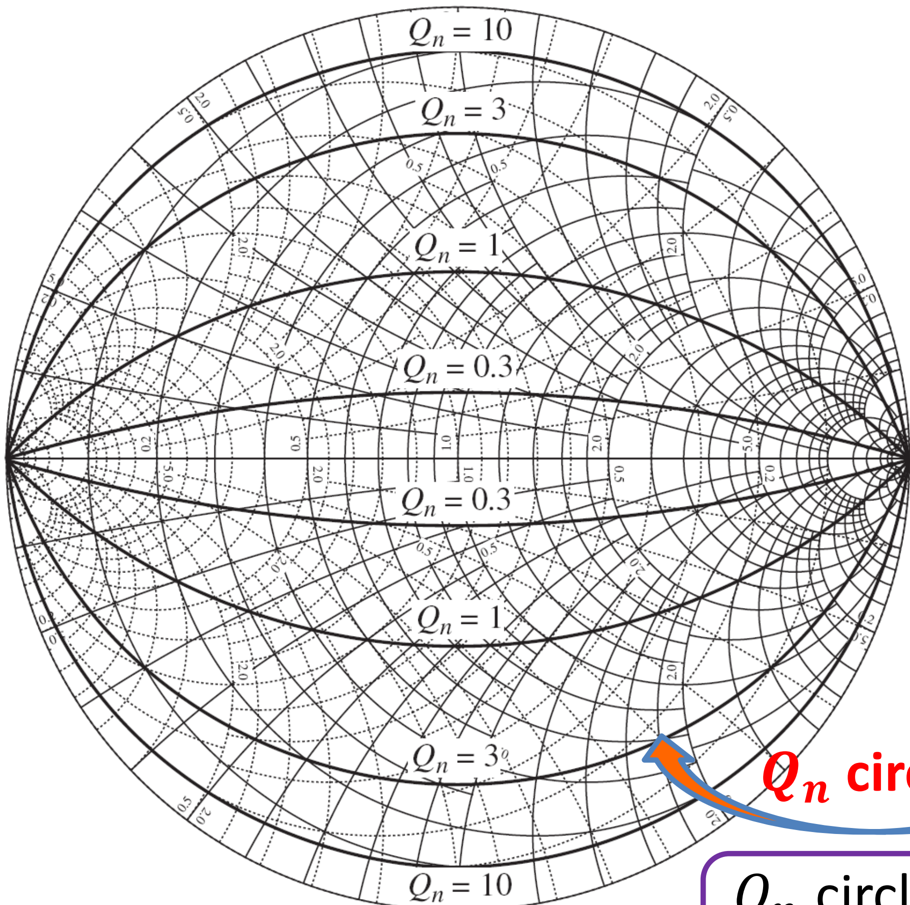
True for any L-type matching network

For more complicated networks, $Q_L = Q_n$

- BW of the matching network can be easily estimated once the "nodal quality factor" is known.

Nodal Quality Factor (contd.)

- To simplify the matching network design process even further, we can draw constant Q_n contours in the Smith chart.



We know the Smith chart expression:

$$z = r + jx = \frac{1-\Gamma_r^2-\Gamma_i^2}{(1-\Gamma_r)^2+\Gamma_i^2} + j\frac{2\Gamma_i}{(1-\Gamma_r)^2+\Gamma_i^2}$$

- The expression for Q_n:

$$Q_n = \frac{|x|}{r}z = \frac{2|\Gamma_i|}{1-\Gamma_r^2-\Gamma_i^2}$$

$$\Gamma_i^2 + \left(\Gamma_r \pm \frac{1}{Q_n}\right)^2 = 1 + \frac{1}{Q_n^2}$$

Q_n **circles!**

Q_n circles in the Smith chart help in direct determination of Q_L.

Nodal Quality Factor (contd.)

- Once you go through section 8.1.2, it will be apparent that quality factor of matching network is extremely important.
- For example, broadband amplifier requires matching circuit with low-Q. Whereas oscillators require high-Q networks to eliminate undesired harmonics in the output signal.
- It will also be apparent that L-type matching networks have no control over the values of Q_n → **Limitation!!!**
- To gain more **freedom in choosing the values of Q or Q_n**, another element in the matching network is incorporated → results in T- or Pi-network

T- and Pi- Matching Networks

- The knowledge of nodal quality factor (Q_n) of a network enables estimation of loaded quality factor → hence the Band Width (BW).
- The addition of third element into the matching network allows control of Q_L by choosing an appropriate intermediate impedance.

Example – 2

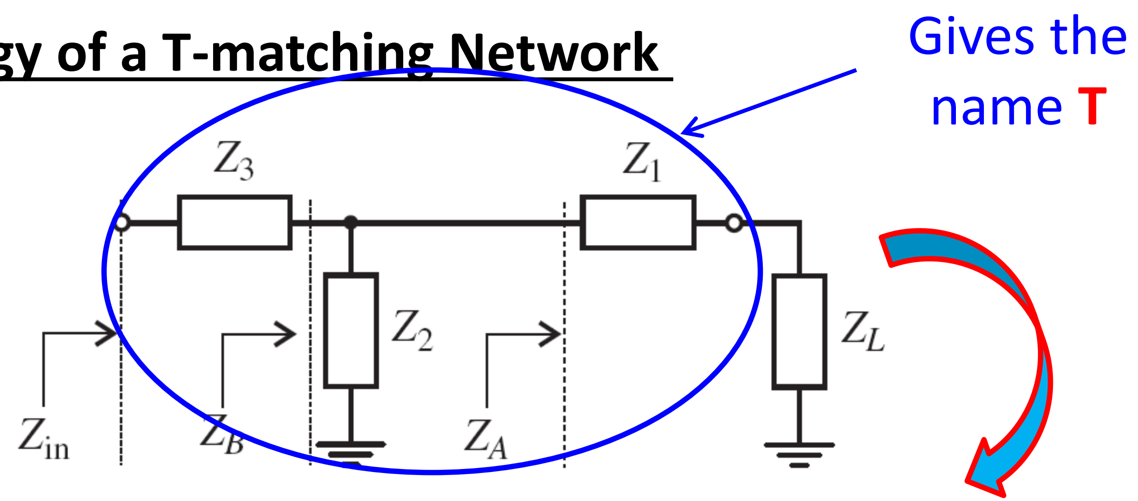
- Design a T-type matching network that transforms a load impedance $Z_L = (60 - j30)\Omega$ into a $Z_{in} = (10 + j20)\Omega$ input impedance and that has a maximum **Q_n of 3**. Compute the values for the matching network components, assuming that matching is required at $f = 1\text{GHz}$.

Solution

- Several possible configurations! Let us focus on just one!

Example – 2 (contd.)

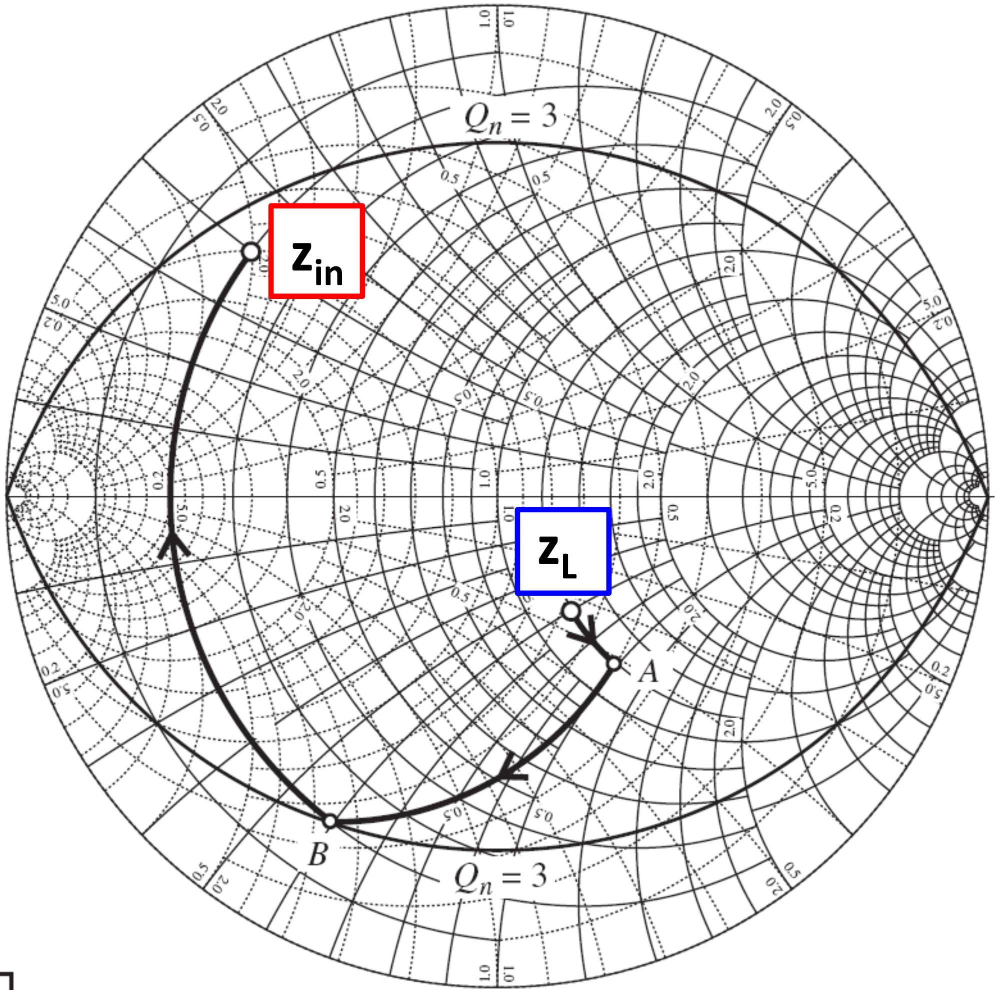
General Topology of a T-matching Network



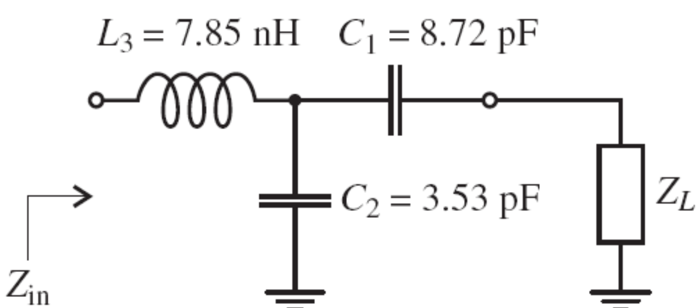
- First element in series (Z_1) is purely reactive, therefore the **combined impedance of (Z_L and Z_1)** will reside on the constant resistance circle of **$r = r_L$**
- Similarly, **Z_3** (that is purely reactive!) **is connected in series** with the input, therefore **the combined impedance Z_B** (consisting of Z_L, Z_1, and Z_2) lies on the constant resistance circle **$r = r_{in}$**
- Network needs to have a Q_n of 3 → we should choose impedance in such a way that **Z_B** is located on the **intersection** of constant resistance circle **$r = r_{in}$** and **Q_n = 3** circle → helps in the determination of **Z_3**

Example – 2 (contd.)

- The constant resistance circle of $\mathbf{z}_{\mathbf{in}}$ intersects the $Q_n = 3$ circle at point **B**. This gives value of Z_3.
- The constant resistance circle $r = r_L$ and a constant conductance circle that passes through B helps in the determination of and allows determination Z_2 and Z_1.



Final solution at 1 GHz

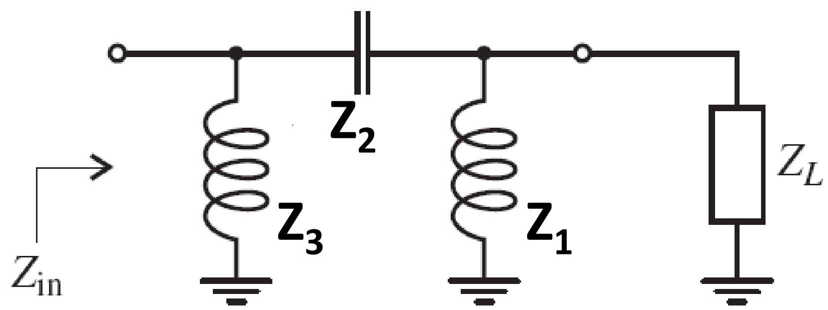


Example – 3

- For a broadband amplifier, it is required to develop a Pi-type matching network that transforms a load impedance $Z_L = (10 - j10)\Omega$ into an input impedance of $Z_{in} = (20 + j40)\Omega$. The design should involve the lowest possible $\mathbf{Q_n}$. Compute the values for the matching network components, assuming that matching is required at $f = 2.4\text{GHz}$.

Solution

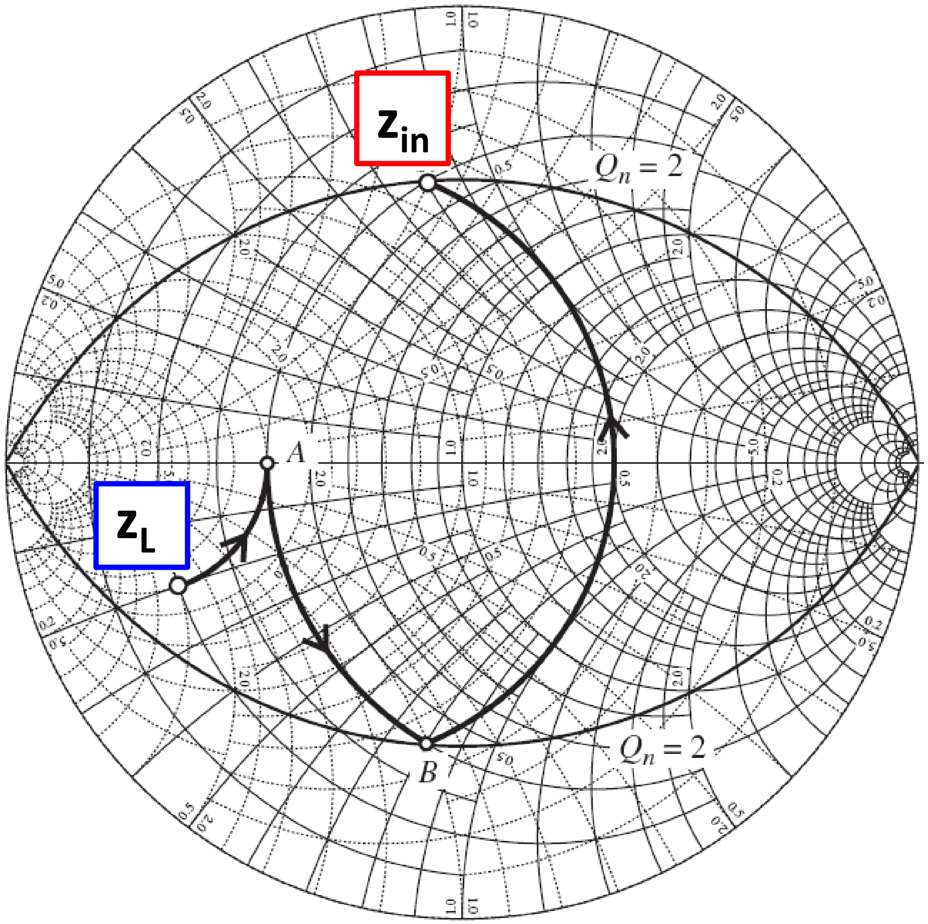
- Several Configurations possible (including the forbidden!). One such is below:



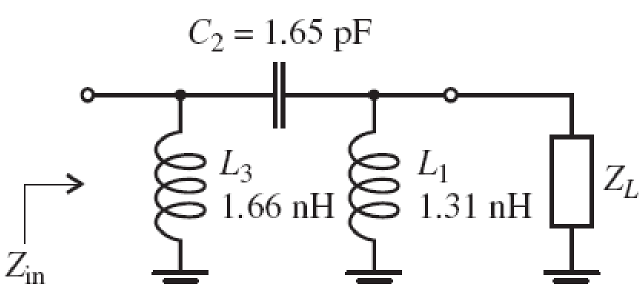
- Since the load and source impedances are fixed, we can't develop a matching network that has Q_n lower than the values at locations Z_L and Z_{in}
- Therefore in this example, the minimum value of Q_n is determined at the input impedance location as $Q_n = |X_{in}|/R_{in} = 40/20 = 2$

Example – 3 (contd.)

- In the design, we first plot constant conductance circle $g = g_{in}$ and find its intersection with Q_n=2 circle (point B) → determines the value of Z_3
- Next find the intersection point (labeled as A) of the $g=g_L$ circle and constant-resistance circle that passes through B → determines value of Z_2 and Z_1



Final solution at 2.4 GHz



Example – 3 (contd.)

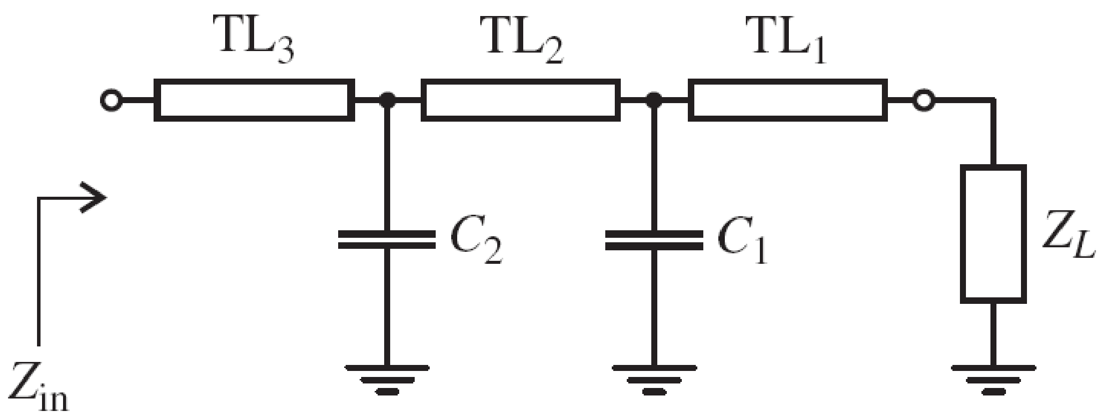
- It is important to note that the relative positions of Z_{in} and Z_L **allows only one** optimal Pi-type network for a given specification.
- All other realizations will result in higher Q_n → **essentially smaller BW!**
- Furthermore, **for smaller Z_L** the Pi-matching isn't possible!

It is thus apparent that BW can't be enhanced arbitrarily by reducing the Q_n. The limits are set by the desired complex Z_{in} and Z_L.

With increasing frequency and correspondingly reduced wavelength the influence of parasitics in the discrete elements are noticeable → distributed matching networks overcome most of the limitations (of discrete components) at high frequency

Microstrip Line Matching Networks

- In the lower RF region, its often a standard practice to use a hybrid approach that combines lumped and distributed elements.
- These types of matching circuits usually contain TL segments in series and capacitors in shunt.



- Inductors are avoided in these designs as they tend to have higher resistive losses as compared to capacitors.
- In principle, only one shunt capacitor with two TL segments connected in series on both sides is sufficient to transform any given load impedance to any input impedance.

Microstrip Line Matching Networks (contd.)

- Similar to the L-type matching network, these configurations may also involve the additional requirement of a fixed Q_n, necessitating additional components to control the bandwidth of the circuit.
- In practice, these configurations are extremely useful as they permit tuning of the circuits even after manufacturing → changing the values of capacitors as well as placing them at different locations along the TL offers a wide range of flexibility → In general, all the TL segments have the same width to simplify the actual tuning →the tuning ability makes these circuits very appropriate for prototyping.

Example – 4

Design a hybrid matching network that transforms the load $Z_L = (30 + j10)\ \Omega$ to an input impedance $Z_{in} = (60 + j80)\ \Omega$. The matching network should contain only two series TL segments and one shunt capacitor. Both TLs have a 50Ω characteristic impedance, and the frequency at which the matching is required is f = 1.5 GHz

Solution

- Mark the normalized load impedance (0.6 + j0.2) on the Smith chart.
- Draw the corresponding SWR circle.
- Mark the normalized input impedance (1.2 + j1.6) on the Smith chart.
- Draw the corresponding SWR circle.
- The choice of the point from which we transition from the load SWR circle to the input SWR circle can be made arbitrarily.

Example – 4 (contd.)