Lecture - 4

Matching Networks

A smith chart is the representation in the reflection coefficient plane, called the Γ plane, of the relation

$$\Gamma = \frac{Z - Z_0}{Z + Z_0} \qquad -(1)$$

Defining the normalized impedance

$$z = \frac{Z}{Z_0} = \frac{R + jX}{Z_0} = r + jx \qquad -(2)$$

We can then rewrite equation 1 as

$$\Gamma = \frac{z-1}{z+1}$$

example 1:-

Find y for $z = 1+j1$ using the Smith Chart (See smith chart)

If the impedance has negative real part we will get a reflection coefficient which will be greater than 1.

If you look at the reflection coefficient line on the Smith chart example 1

$z = 1 + j1$

-Point A on smith chart

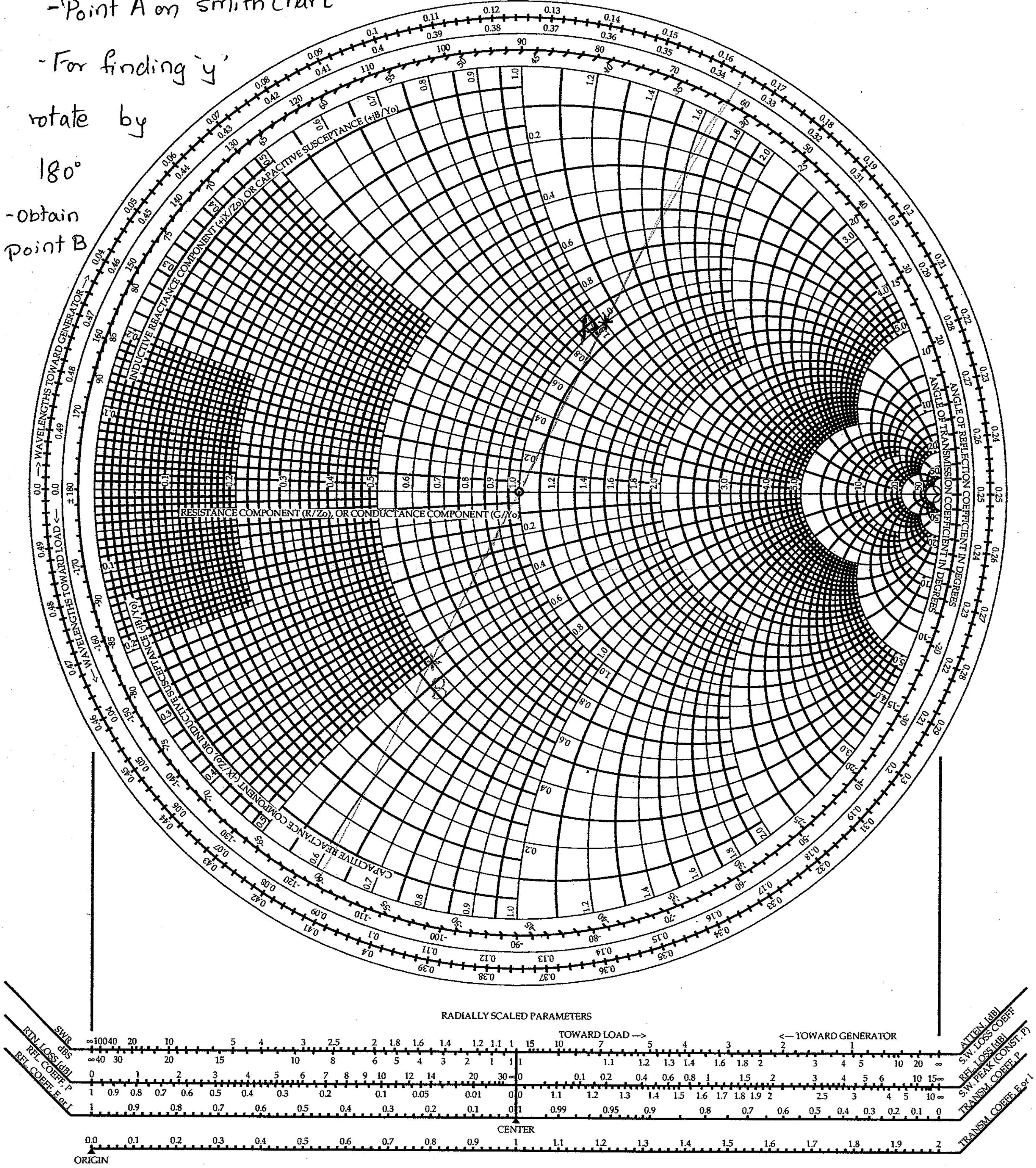
-For finding 'y' rotate by 180°

-obtain point B

The Complete Smith Chart

Black Magic Design

$y = 0.5 - j0.5$



you will observe that $|\Gamma|$ is $\ll$ 1. For these cases the ~~i~~mpedance would map outside the Smith chart. For solving these problems we have to use Compressed Smith chart which looks like the one in Figure 2.2.5.

- An alternate way to approach this problem is to plot on the smith chart $\frac{1}{\Gamma^*}$ and take the values of resistance circles as being negative and the reactance circle as the same as the normal smith chart.

- Lets do an example

example 2:

Find the impedance whose reflection coefficient is $2.236\angle 26.56°$

<u>Soln</u> (See smith chart)

<u>Normalized impedance and admittance Smith Chart</u> (ZY smith chart)

The impedance-to-admittance conversion can also be obtained by superimposing two Smith charts and rotating one of the charts by 180°. The rotated chart represents admittances and the other chart represents impedances. The superposition of the original and example 2:

$\Gamma = 2.236 \angle 26.56^\circ$

$\frac{1}{\Gamma^*} = 0.447 \angle 26.56^\circ$

- Plot this point

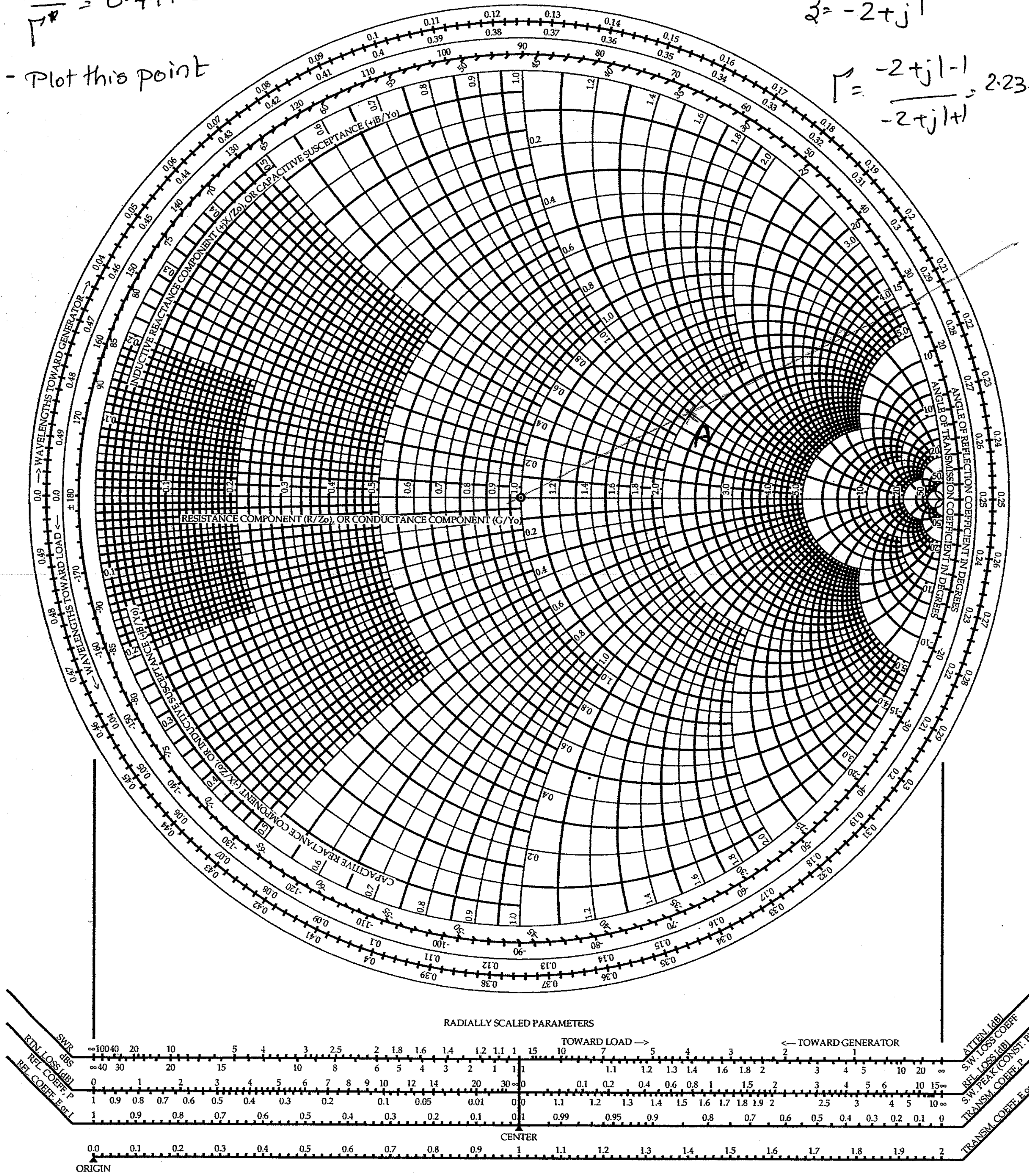
The Complete Smith Chart

Black Magic Design

- The 'z' is then written as

$z = -2 + j1$

$\Gamma = \frac{-2+j1-1}{-2+j1+1} = 2.236 \angle 26.56^\circ$



the rotated chart is known as the normalized impedance and admittance coordinates Smith chart. The chart is also referred to as the ZY smith chart.

- The various Smith charts can be used to represent the frequency response of circuits, or from the frequency response of a circuit in the Smith Chart an equivalent circuit model can be developed.

- The simplest frequency responses that can be represented in the Smith chart are those of a series RL circuit, a series RC circuit, a parallel RL circuit, and a parallel RC circuit

Example 3:-

The input equivalent circuit for a transistor on chip is shown in figure below. Determine value of R, L, and C.

The S_{11} for this transistor is plotted in figure 1.10.2

Soln

From the figure we observe that

$f_a = 1GHz$

i/p impedance associated with S_{11} is $Z_{IN} = 50(0.2 - j0.2)$

$= 10 - j10\ \Omega$

$z = \frac{Z}{Z_0} = \frac{R + j\omega L}{Z_0} = r + jx$

Lets assume $r = 0{\cdot}2\Omega$

and reactance varies from $j0{\cdot}24$ at f_a to $j0{\cdot}5$ at f_b

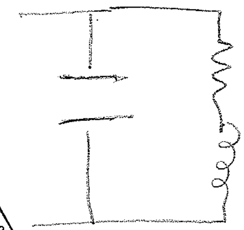
The Complete Smith Chart (ZY)

If we add capacitor in parallel

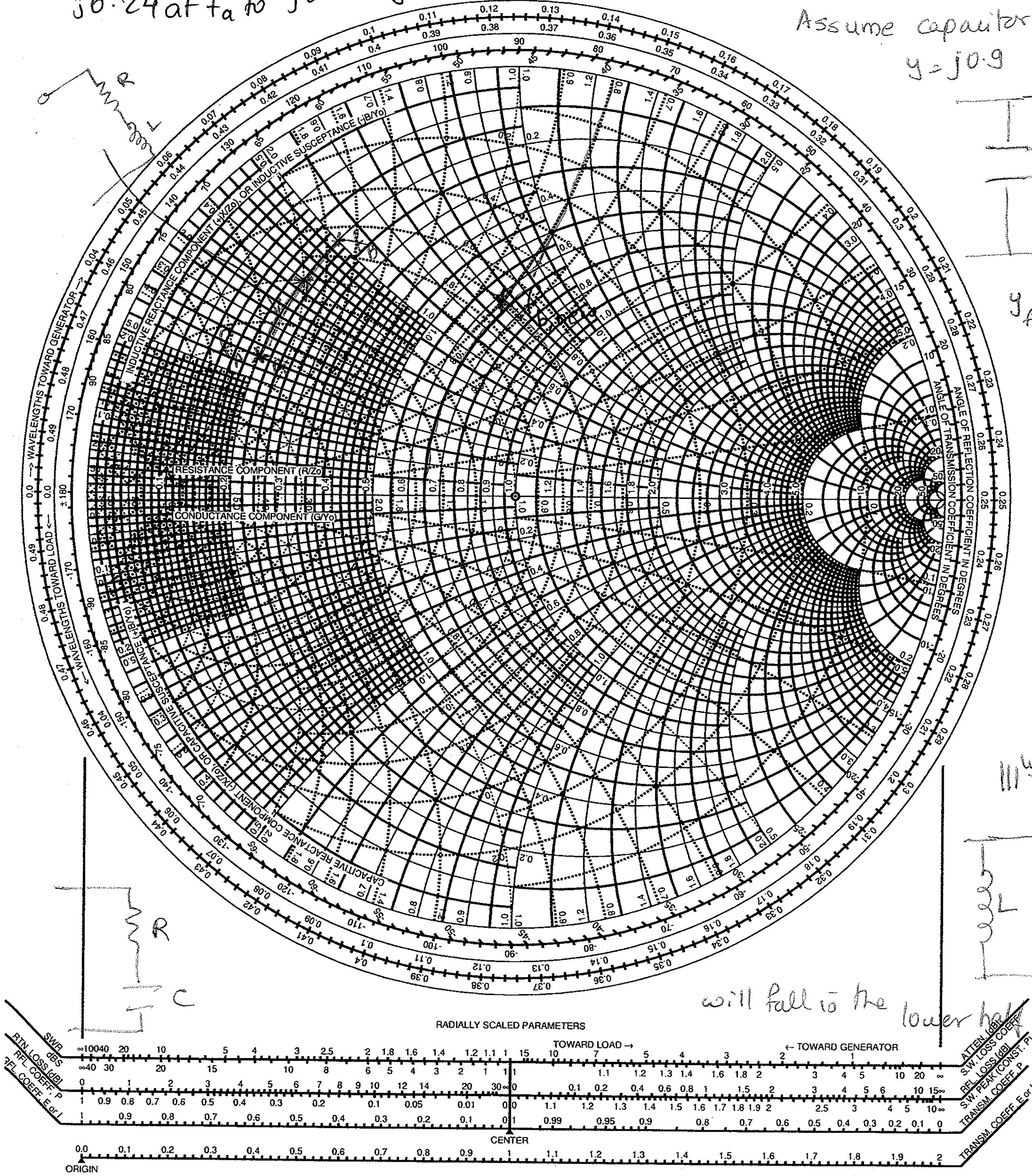
$z = 0{\cdot}2 + j0{\cdot}5$

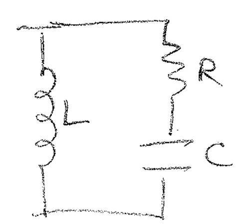
$y = 0{\cdot}7 - j1{\cdot}7$

Assume capacitor has $y = j0{\cdot}9$



$y_{f_a\,new} = 0{\cdot}7 - j0{\cdot}8$





will fall to the lower half of the Smith Chart

$f_b = 10\,GHz \quad Z_{IN} = 50\,(0.2 + j0.15) = 10 + j\,7.5$

From the equivalent circuit we have

At $f_a = 1\,GHz$

$$10 - j10 = R + j\left[\omega_a L - \frac{1}{\omega_a C}\right] \qquad -(1)$$

At $f_b = 10\,GHz$

$$10 + j7.5 = R + j\left[\omega_b L - \frac{1}{\omega_b C}\right] \qquad -(2)$$

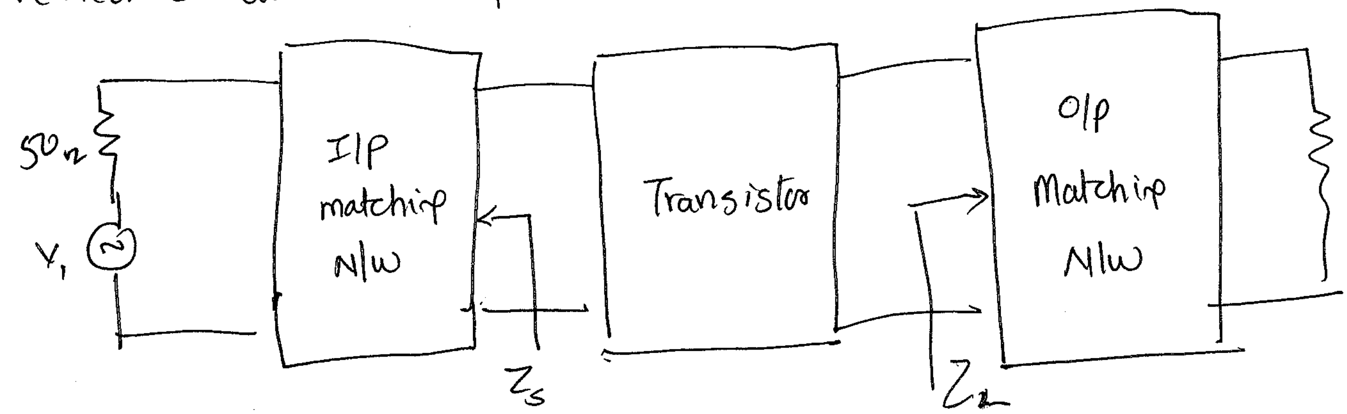
Solving these equations we get

$R = 10\,\Omega$

$L = 0.1024\,nH \qquad C = 14.95\,pF$

IMPEDANCE MATCHING NETWORKS

When we study amplifiers matching N/ws play an important role for delivering maximum power to the output and preventing reflections at the input



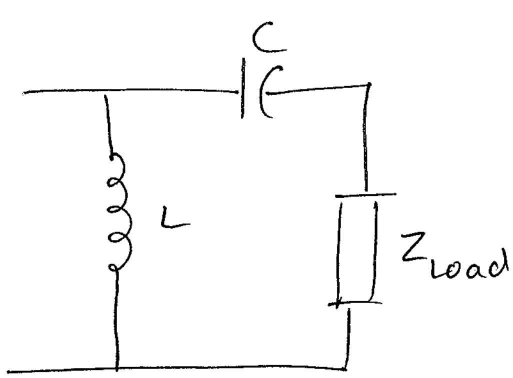
I/P matching N/w is used to transform the generator impedance to source impedance. Z_S

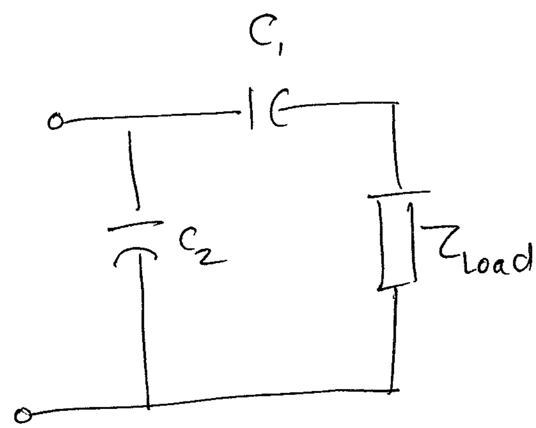
- O/P matching N/w is used to transform 50Ω to load impedance Z_L

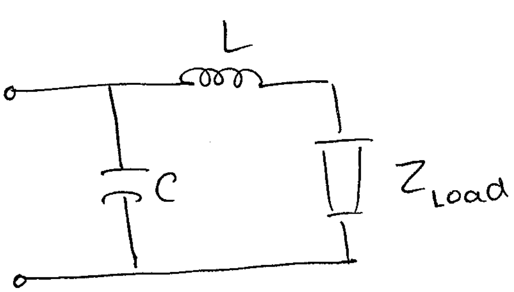
- Although many different matching N/ws can be designed, the eight Ell section (also denoted as L sections) are used more often. The matching N/ws are lossless in order not to dissipate any of the signal power.

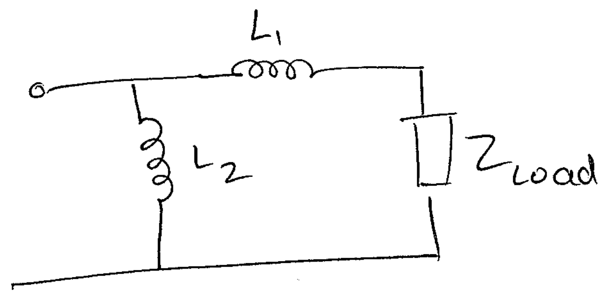
The ZY smith chart can be used for designing the matching N/w.

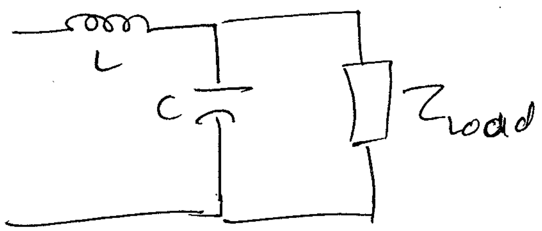
Here are the 8 configurations

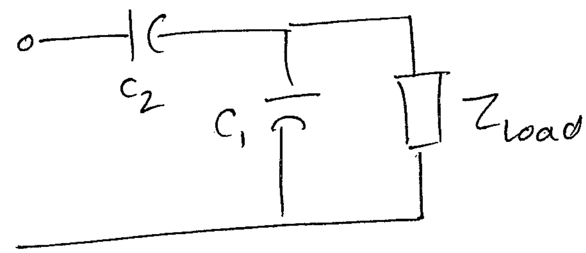


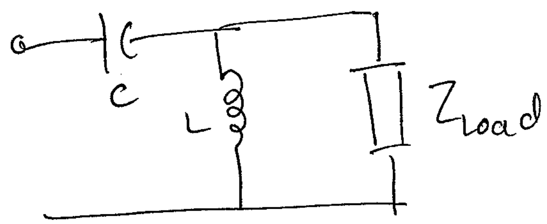


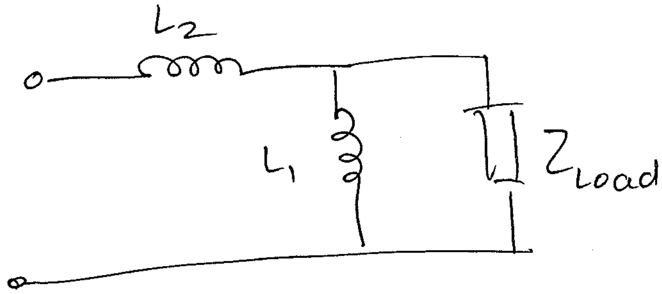












Now lets see what happens when we add a series reactance element to an impedance or a parallel susceptance element to an admittance in the ZY Smith chart.

① Lets see the effect of adding a series inductance L ($z_L = j0.8$) to an impedance $z = (0.3 - j0.3)$ (See smith chart)

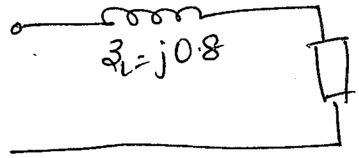
② Lets see the effect of adding a shunt inductor L ($y_L = -j2.4$) to an admittance y ($y = 1.6 + j1.6$) on the ZY Smith chart (See Smith chart)

$z = 0.3 - j0.3$

-Mark point A

Adding $j = 0.8$

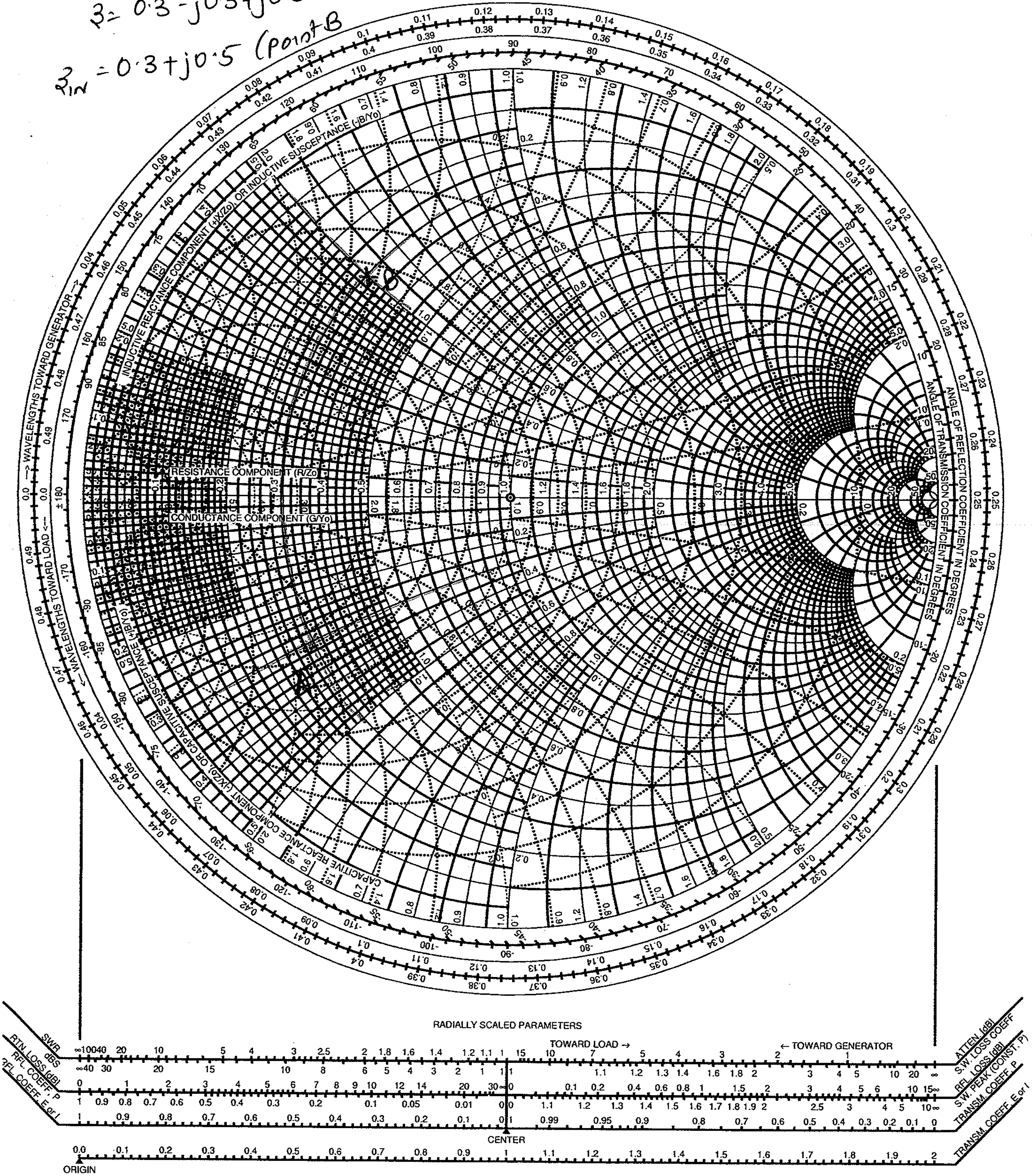
this becomes



The Complete Smith Chart (ZY)

$z = 0.3 - j0.3 + j0.8$

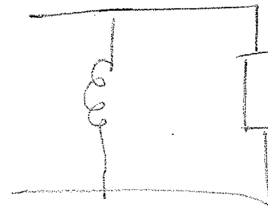
$z_{in} = 0.3 + j0.5$ (point B



$y = 1.6 + j1.6$

mark point A

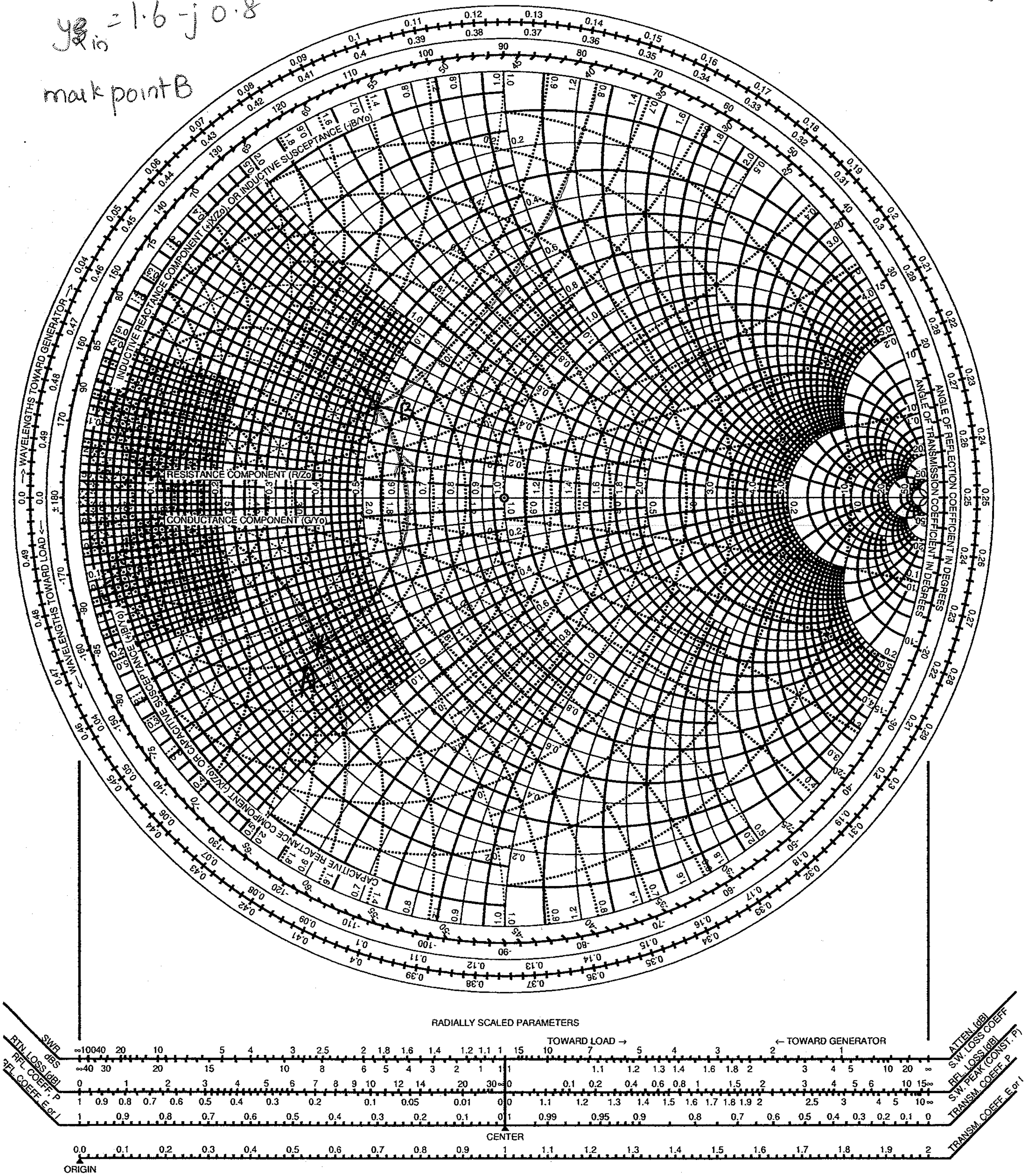
The Complete Smith Chart (ZY)



$y = 1.6 + j1.6 - j2.4$

$y_{in} = 1.6 - j0.8$

mark point B



-Adding a series inductance (reactance) produces a motion along a constant resistance circle in the ZY Smith chart, and adding shunt susceptance produces a motion along a constant conductance circle in the ZY Smith chart.

These are shown in figure 2.4.7

eg. $Z_{Load} = 10 + j10$ is to be matched to 50 Ω load. (See smith chart)

$z_{load} = 0.2 + j0.2$

Sometimes a specific matching N/w cannot be used to accomplish a given match.

- For example any load impedance falling in the marked region cannot be matched to 50 Ω with a network shown in the figure (see smith chart) — II

- Second observation is that for the ELL matching Network only those with inductor and a capacitor can be used to provide a match between a resistive load and an input resistance.

$z = 0.2 + j0.2$

Plot point A

Series L - shunt C

$z_L = j0.4 - j0.2$

$= j0.2$

See that B is along constant conductance

the admittance at B is

$y_B = 1 - j2$

- moving from B to C

$y_C = 0 - (-j2)$

$= j2$

$z_C = \frac{1}{j2} = -j0.5$

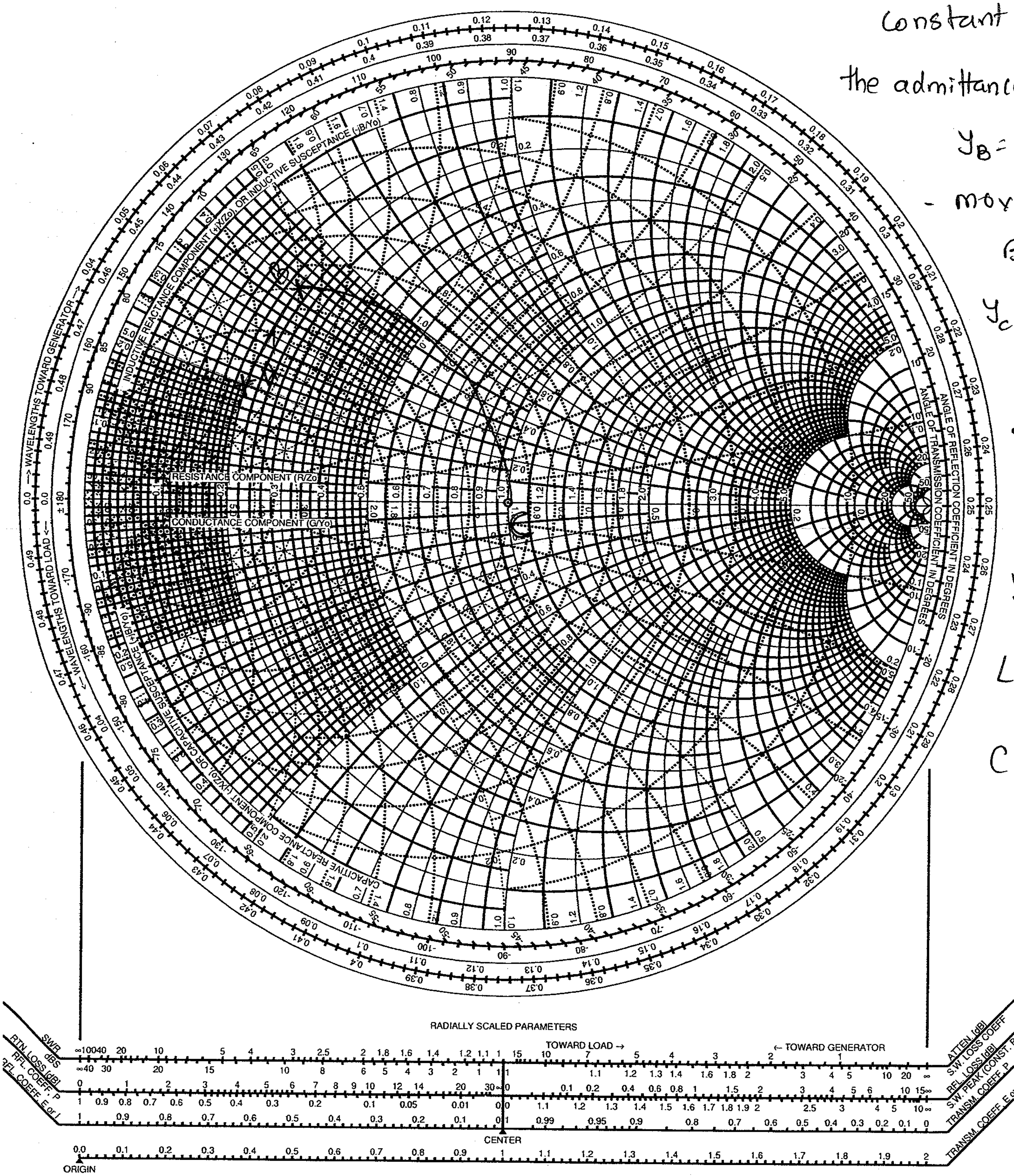
At point C

$y_{IN} = z_{IN} = 1$

$L = \frac{10}{2\pi f}$

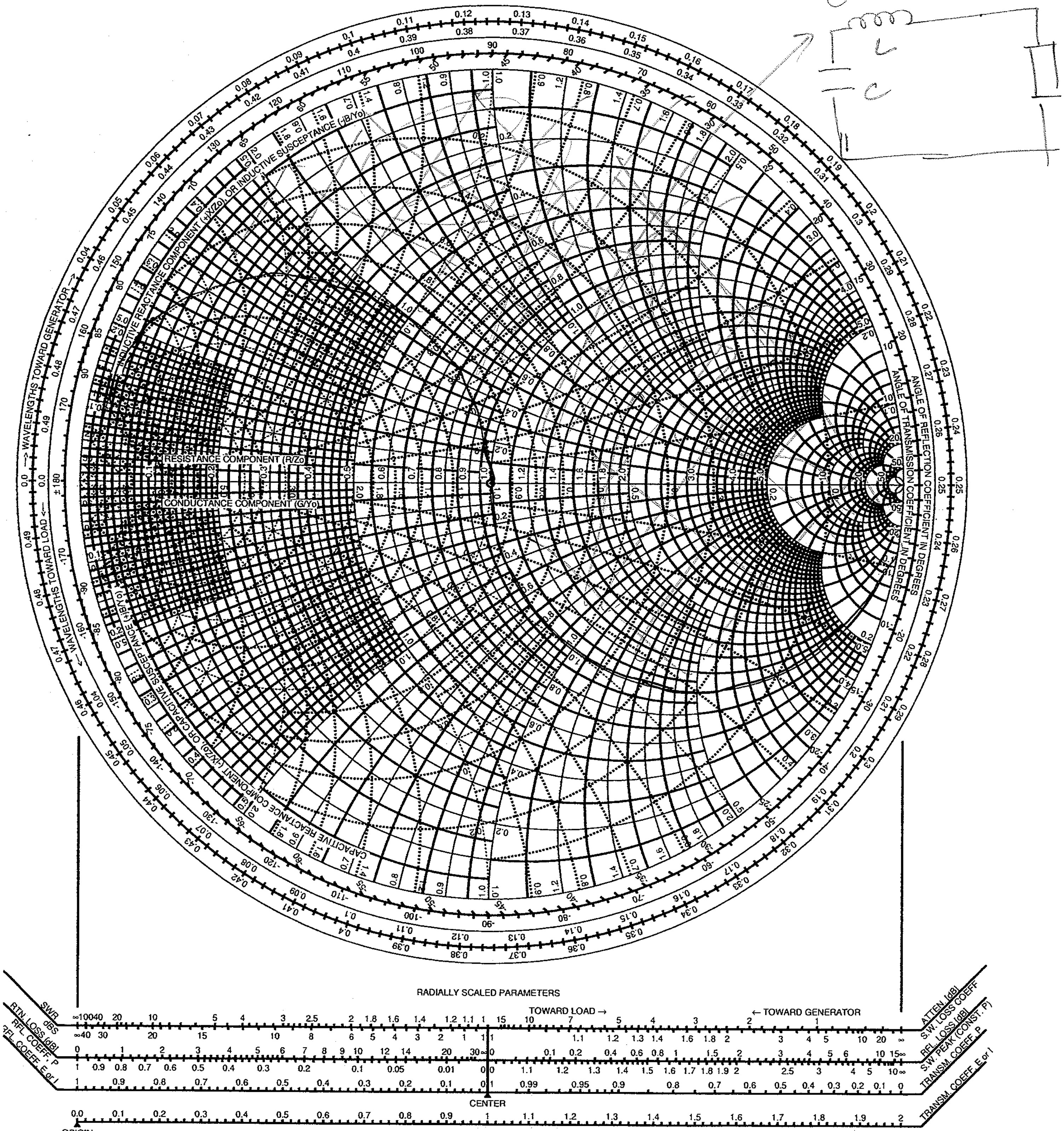
$C = \frac{1}{2\pi f \times 25 \times f}$

The Complete Smith Chart (ZY)



The Complete Smith Chart (ZY)

cannot be used



In a resonant circuit, the ratio of its resonant frequency f_o to its bandwidth is known as the loaded Q of the circuit.

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

If BW is expressed in Hz

$$Q_L = \frac{f_o}{BW}.$$

The Ell matching N/w is used for matching at a certain frequency. The frequency response of an Ell network can be classified as either a low pass filter or a high pass filter.

At each node of the Ell matching network, there is an equivalent series input impedance, denoted as $R_s + jX_s$.

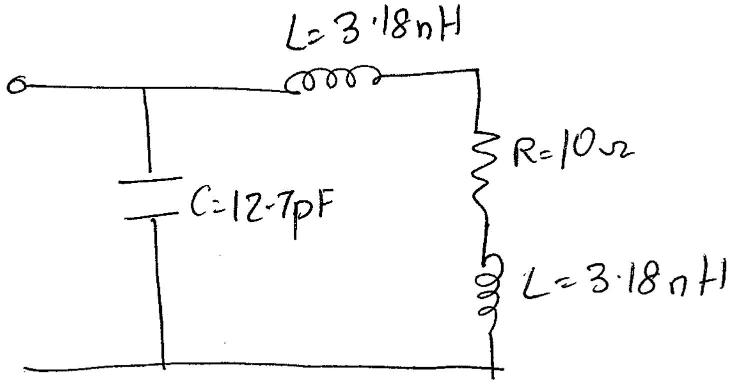
Hence, a circuit node Q, denoted by Q_n can be defined at each node as

$$Q_n = \frac{|X_s|}{R_s} \quad - (1)$$

If the equivalent parallel input admittance at the node is $G_p + jB_p$, the circuit node Q can be expressed as

$$Q_n = \frac{|B_p|}{G_p} \qquad -(2)$$

For eg:- For the ckt shown below

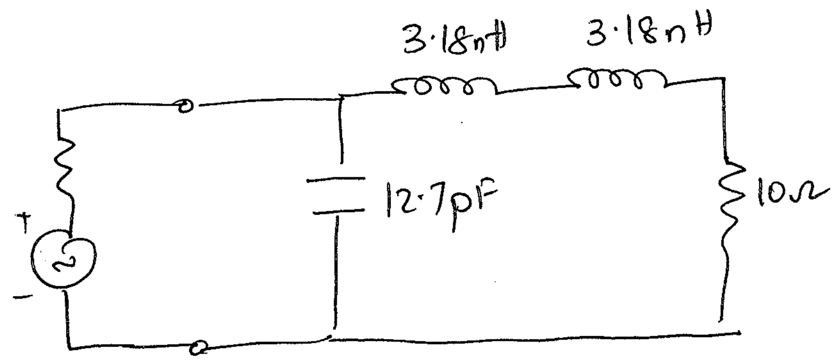


i/p impedance of the circuit at point B is $0.2+j0.4$.

∴ The ckt node Q is $Q_n = \frac{0.4}{0.2} = 2$

The equivalent parallel admittance is readily found to be $1-j2$ producing ckt node Q. according to (2) can be written as. $Q_n = \frac{2}{1} = 2$

The ckt can be written as.

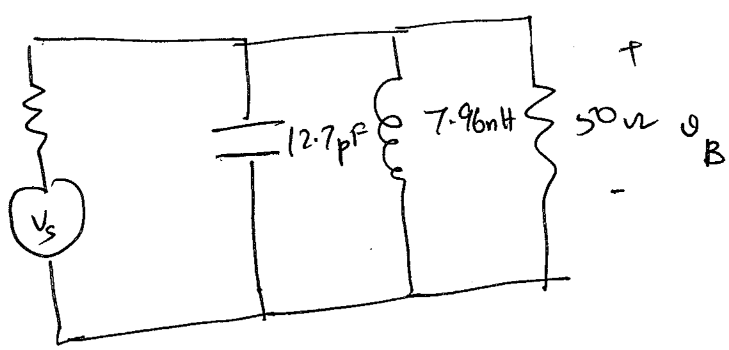


For a narrowband range of frequencies around f_o, the filter can be viewed as Bandpass filter with a loaded Q which can be calculated as

$$Q = \frac{f_o}{BW}$$

The equivalent bandpass filter is shown in figure below which is obtained by changing $Z_B = 10 + j20\Omega$ to an equivalent admittance (ie $50\Omega \parallel$ with $j25$)

The Q loaded can be given as



$$Q_L = \frac{\omega_o}{BW} = \omega_o R_T C = 1$$

The relation between Q_L and Q_n is that

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