01 – THE MATCHING NETWORKS

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1. Two Element Networks (L)

The objective of the design is to connect, for the maximum power transfer, a load ZL=50Ω to a power transistor with an output resistance of Ro=2Ω at the frequency of 100MHz by using a 2 elements network (L type).

a) Compute the values of the elements L, C, the quality factor Q of the circuit and the bandwidth of the system.

$$R_g=\frac{R_l}{1+Q^2} \quad \rightarrow \quad Q=\sqrt{\frac{R_l}{R_g}-1}=\sqrt{\frac{50\,\Omega}{2\,\Omega}+1}\simeq 4{,}899$$

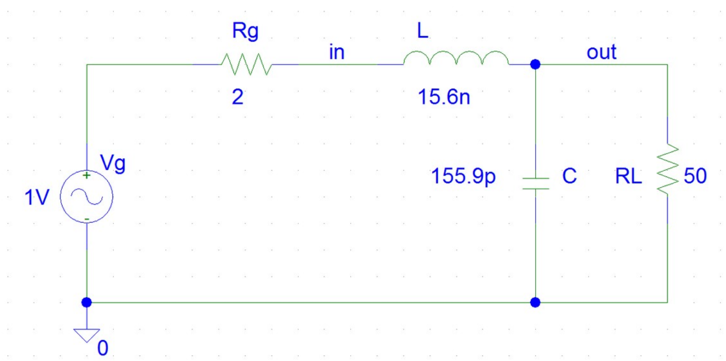
$$Q=\omega\cdot C\cdot R_l \quad \rightarrow \quad C=\frac{Q}{\omega R_l}=\frac{4{,}899}{2\,\pi\cdot 10^8\,Hz\cdot 50\,\Omega}=155{,}9\,pF$$

$$C_s=\frac{C\left(1+Q^2\right)}{Q^2}=\frac{155{,}9\cdot 10^{-12}\,pF\cdot\left(1+4{,}899^2\right)}{4{,}899^2}=162{,}39\,pF$$

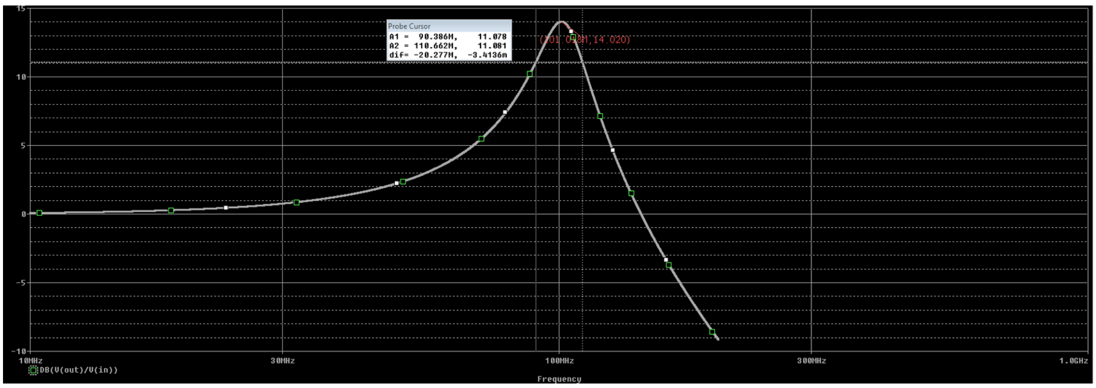
$$f_0=\frac{1}{2\,\pi\sqrt{LC_s}} \quad \rightarrow \quad L=\left(\frac{1}{2\,\pi f_0}\right)^2\cdot\frac{1}{C_s}=15{,}6\,nH$$

$$BW=\frac{f_0}{Q}=20{,}4\,MHz$$

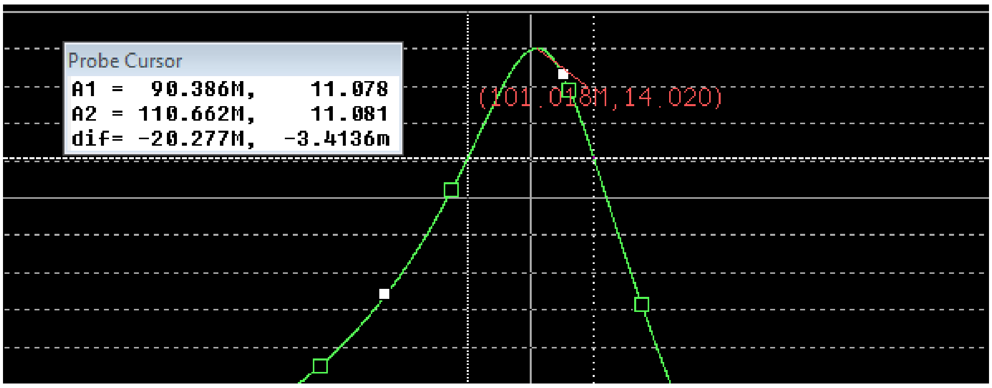
b) With the help of the PSpice simulator, draw the matching network connecting it to the load and to the transistor, as shown in Fig. 1 of annex. In particular the transistor has been modelled through an equivalent generator Vg and its output resistance, Rg. Simulate the frequency response of the circuit plotting the ratio Vout/Vin in decibels. From the graph, evaluate the 3dB bandwidth and the Q of the circuit. Compare the obtained values with those the point a).



Pspice circuit (Fig.1)



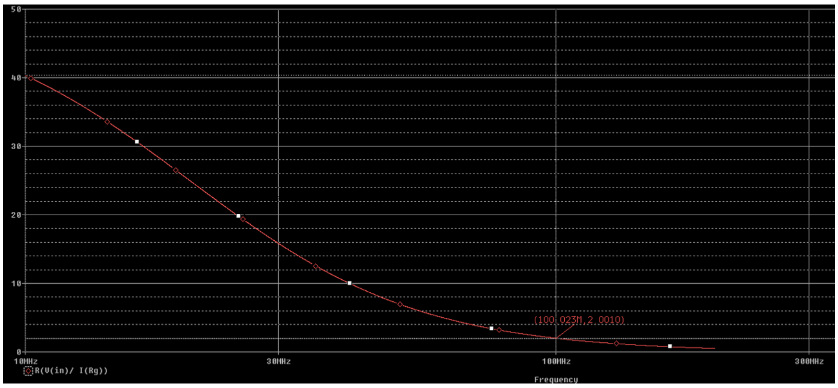
DB(V(out)/ V(in) – Frequency response of the circuit



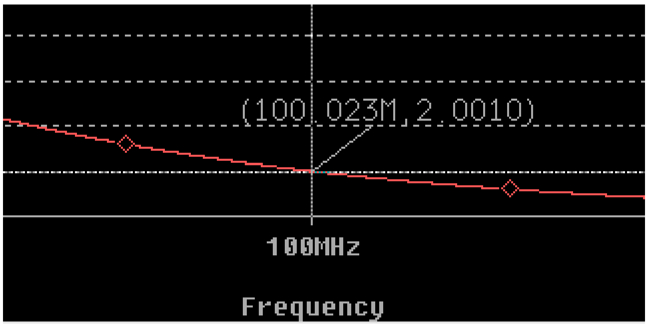
$$BW = 20{,}3\ MHz \qquad Q = \frac{f_0}{BW} = \frac{10^8\ Hz}{20{,}3 \cdot 10^6\ Hz} \simeq 4{,}926$$

Experimental values are very similar to theoretical values.

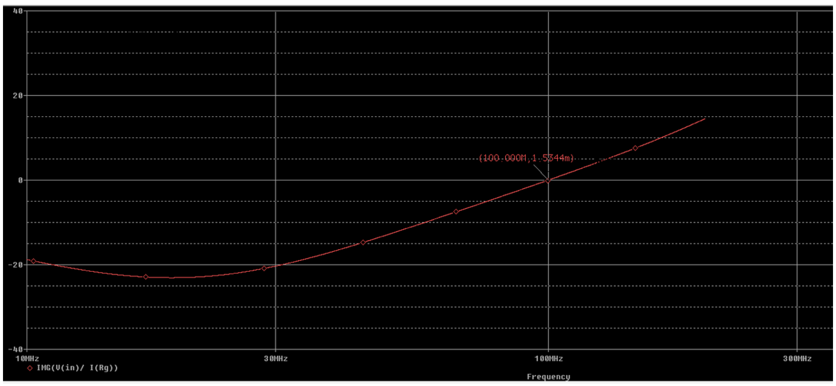
c) Evaluate through an AC analysis the real and imaginary part at the input of the matching network. Please comment on the results. Suggestion: in order to evaluate the impedance, plot the ratio V/I at the point of interest.

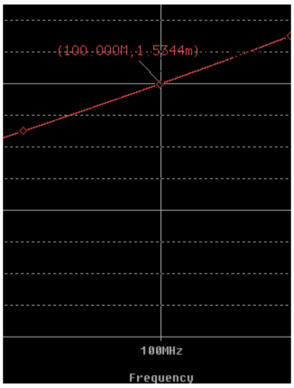


R(V(in)/ I(Rg)) – Real part of the impedance at the input if the matching network

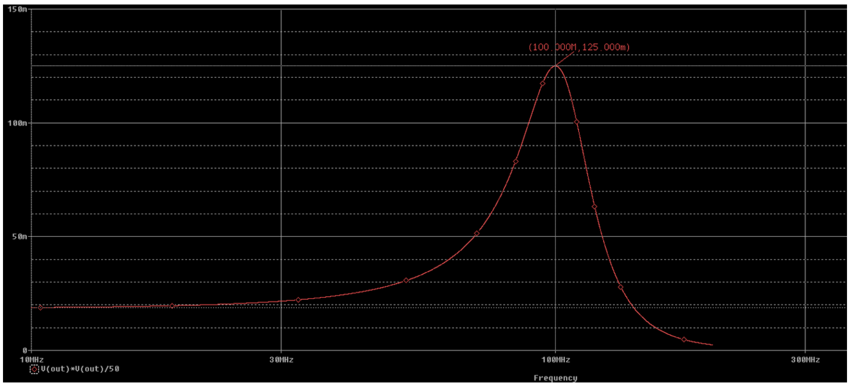


Real part of the impedance at the input if the matching network is equal to 2Ω at 100 MHz



IMG(V(in)/ I(Rg)) – Imaginary part of the impedance at the input if the matching network
 Imaginary part of the impedance at the input if the matching network is near to zero at 100 MHz

d) With the help of PSpice simulator, compute the "insertion loss", IL, introduced by the network. Recall that the IL of a network is equal to the ratio between the active power delivered to the load in the presence of the matching network, and the active power delivered to the load when the latter is connected directly to the generator. Use a reference generator with Vg=1V.



The power delivered to the load in the presence of the matching network is 125mW
Power delivered to the load without the matching newtwor is 18,5mW

$$IL_{dB}=10\log_{10}\left(\frac{P_{delWithMN}}{P_{delWithoutMN}}\right)=10\log_{10}\left(\frac{125\,mW}{18{,}5\,mW}\right)=8{,}3\,dB$$

2. Three Element Matching Network (π network)

In order to decouple the transformation ratio from the quality factor Q, realize the power match condition of point 1) by using the π network of Fig. 2. Set a quality factor Q=10.

a) Compute the value of the elements L, C1, C2, using the procedure presented during the lecture.

$$R_V = \frac{R_{max}}{1+Q^2} = \frac{50\Omega}{101} = 0{,}495\Omega$$

$$L_2 = \frac{R_V}{\omega}\sqrt{\frac{R_L}{R_V}-1} = \frac{0{,}495\,\Omega}{2\pi 100\cdot 10^6\,Hz}\sqrt{\frac{50\Omega}{0{,}495\,\Omega}-1} = 7{,}88\,nH$$

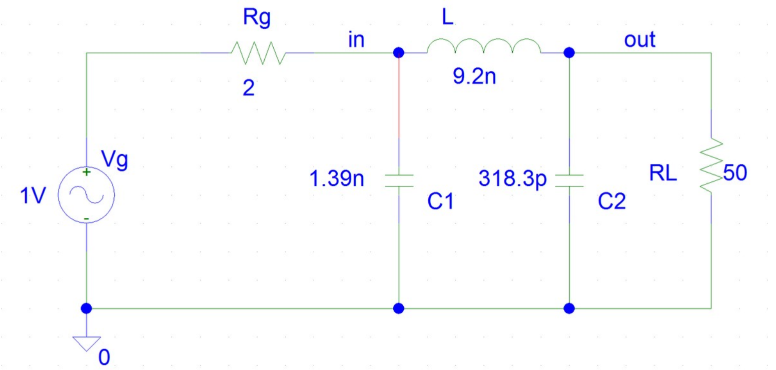
$$L_1 = \frac{R_V}{\omega}\sqrt{\frac{R_L}{R_V}-1} = \frac{0{,}495\,\Omega}{2\pi 100\cdot 10^6\,Hz}\sqrt{\frac{2\Omega}{0{,}495\Omega}-1} = 1{,}37\,nH$$

$$L = L_1 + L_2 = 9{,}2\,nH$$

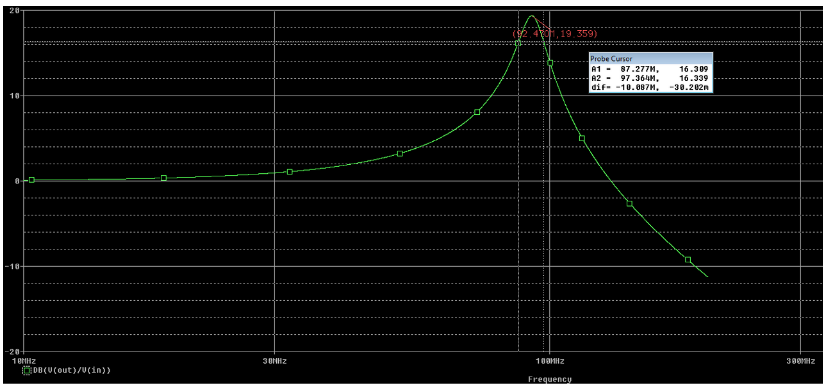
$$C_2 = \frac{1}{\omega}\sqrt{\frac{R_L}{R_V}-1} = \frac{1}{2\pi 100\cdot 10^6\,Hz}\sqrt{\frac{50\,\Omega}{0{,}495\Omega}-1} = 318{,}3\,pF$$

$$C_1 = \frac{1}{\omega}\sqrt{\frac{R_L}{R_V}-1} = \frac{1}{2\pi 100\cdot 10^6\,Hz}\sqrt{\frac{2\,\Omega}{0{,}495\,\Omega}-1} = 1{,}39\,nF$$

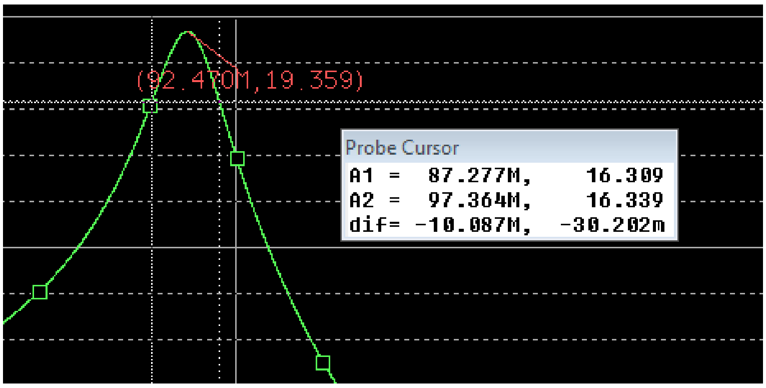
b) Simulate the frequency response of the circuit plotting the ratio Vout/Vin in decibels. From this response evaluate the factor Q of the circuit and compare it with the imposed value. Comment on the results.



Pspice circuit (Fig.2)



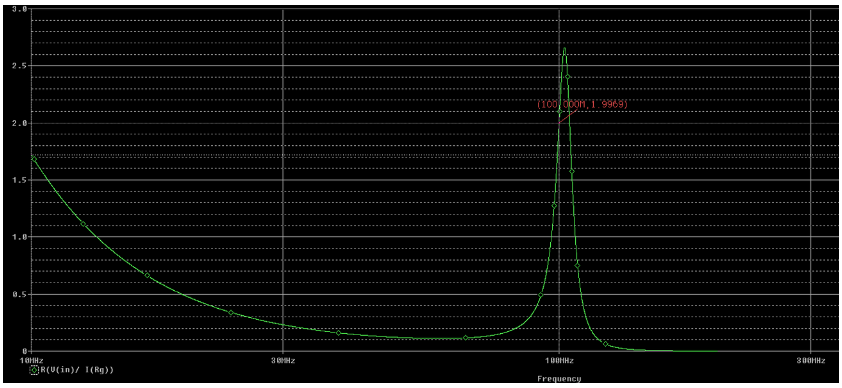
DB(V(out)/ V(in)) – Frequency response of the circuit



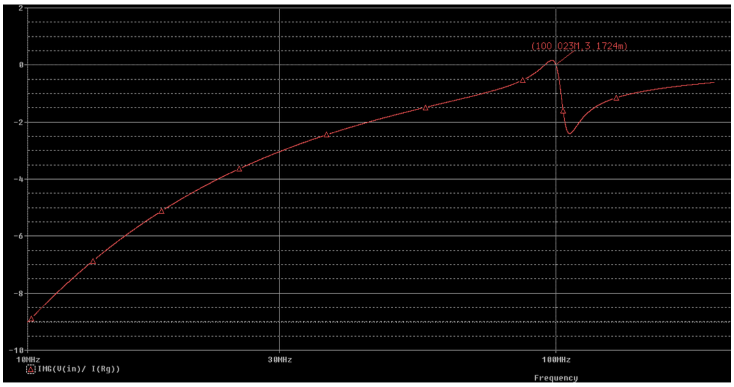
$$BW \simeq 10\,MHz \qquad Q = \frac{f_0}{BW} = \frac{92{,}5 \cdot 10^6\,Hz}{10^7\,Hz} \simeq 9{,}25$$

The experimental value of Q is similar to theoretical one.
Note that resonant frequency is 92,5MHz and the desired frequency 100MHz is out of -3dB bandwith.

c) Evaluate through an AC analysis the real and imaginary part at the input of the matching network. Please comment the results.



R(V(in)/ I(Rg)) – Real part of the impedance at the input if the matching network
Real part of the impedance at the input if the matching network is equal to 2Ω at 100 MHz



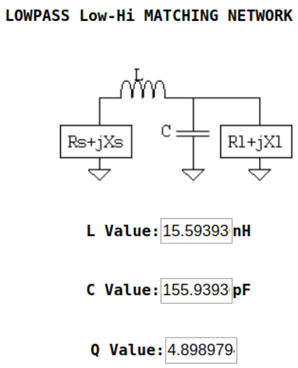
IMG(V(in)/ I(Rg)) – Imaginary part of the impedance at the input if the matching network
Imaginary part of the impedance at the input if the matching network is near to zero at 100 MHz

3. Dedicated tools for designing the Matching Networks

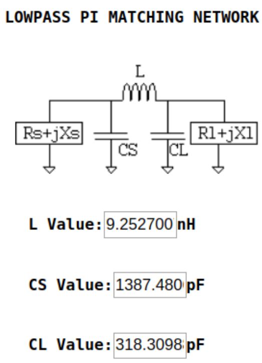
In the practice cases, due to the complexity of calculation for a matching networks of order higher than 6, we can use dedicated software in order to quickly obtain the values. An example of spreadsheet is available online at:

http://home.sandiego.edu/~ekim/e194rfs01/jwmatcher/matcher2.html

a) Use the software in order to check the value at point 1.



b) Compute the component values for the network at point 2. See the differences.



There are no differences between values obtained by calculation in point 2 and values obtained by designing tool. It is highly probable that online calculator uses same approximated formulas.

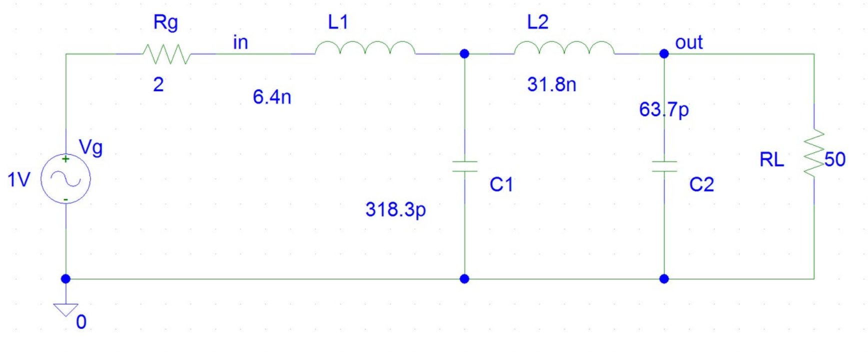
c) Evaluate the quality factor Q of the network using PSpice simulator. **Same as point 2.**

d) In order to verify the design, evaluate by the AC analysis the real and imaginary part of input impedance. **Same as point 2.**

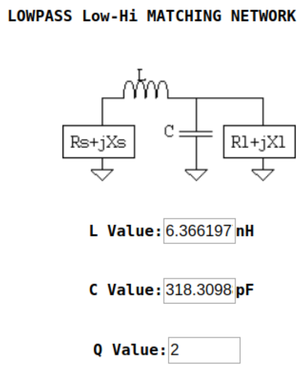
4. Wideband matching networks

In order to obtain larger band matching networks, two or more L networks can be cascaded. Referring to Fig. 3, calculate the value of L1, L2, C1 and C2, using the presented theory in order to maximize the transfer power with the highest bandwidth, (minimum Q). Suggestion: design the circuit using the dummy resistance Rv=(RG RL) 1⁄2.

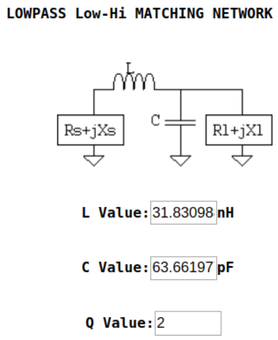
a) Simulate the frequency response of the circuit plotting the modulus of the ratio Vout/Vin in decibels. Compute the quality factor of the circuit and compare it with the Q at point 1. Please comment on the results.



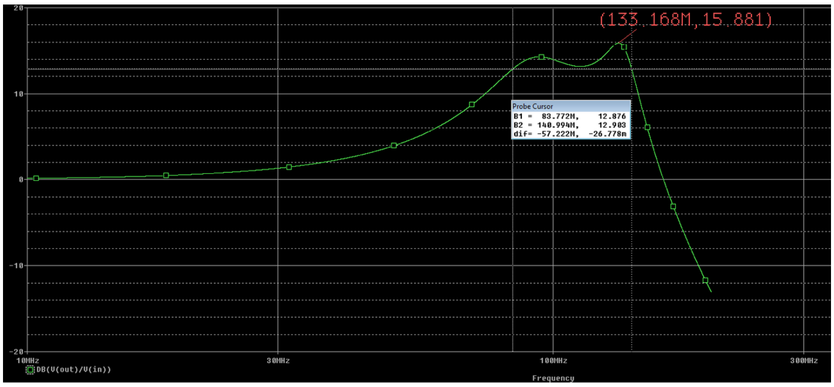
Pspice circuit (Fig.3)



Splitted virtual circuit A
Q=2



Splitted virtual circuit B
Q=2

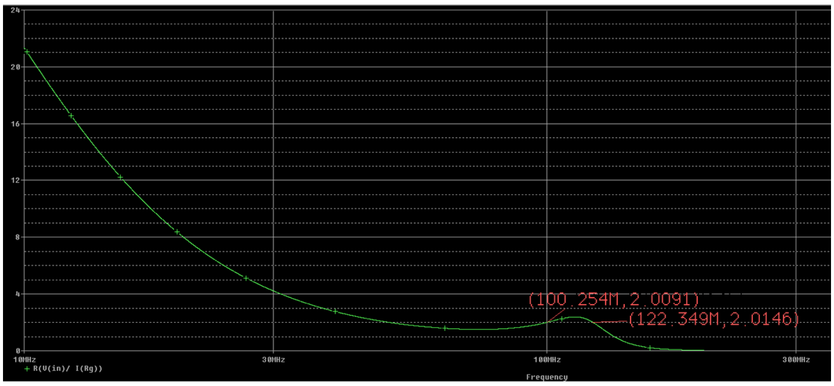


DB(V(out)/ V(in)) – Frequency response of the circuit

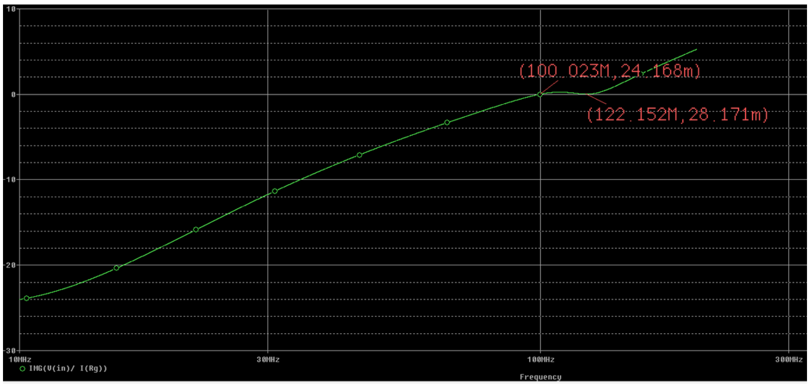
$$BW \simeq 57\ MHz \qquad Q = \frac{f_0}{BW} = \frac{120 \cdot 10^6\ Hz}{57 \cdot 10^6\ Hz} \simeq 2{,}1$$

Cascading two Matching Networks bandwidth increased.

b) Calculate the real and imaginary part of input impedance using the AC analysis.



R(V(in)/ I(Rg)) – Real part of the impedance at the input if the matching network
Real part of the impedance at the input if the matching network is equal to 2Ω at 100 MHz and at 122MHz



IMG(V(in)/ I(Rg)) – Real part of the impedance at the input if the matching network
Real part of the impedance at the input if the matching network is equal to 2Ω at 100 MHz and at 122MHz