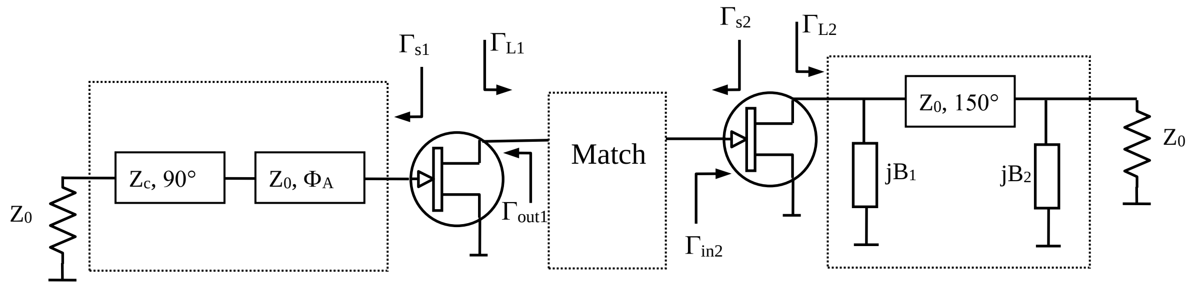
Exercise 1 (010217)

The following scheme shows a 2 stage low noise amplifier operating at 12 GHz



The transistors are equal and are characterized by the following parameters (Z_0=50 Ω):

$S_{11}=0.569\angle 78.2°$, $S_{12}=0.1\angle -58.5°$ $S_{21}=3.226\angle -52.1°$ $S_{22}=0.132\angle 120.7°$

NF_{min}=0.51 dB $\Gamma_{min}=0.358\angle -137.2$ r_n=0.12

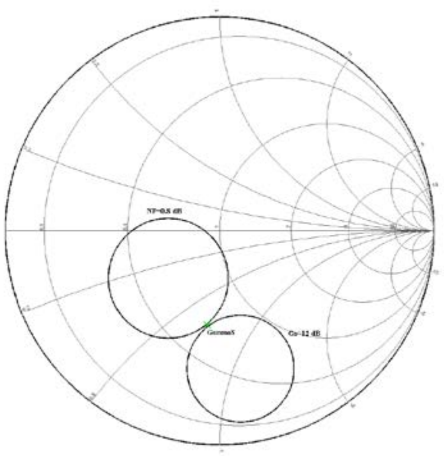
The first stage must be designed for NF=0.8 dB while the second stage must be designed for the maximum transducer gain (compatibly with stability). It is also requested that the inter-stage network ("Match") operates in conjugate matching both at input and output ($\Gamma_{L1}=\Gamma^*_{out1}$, $\Gamma_{s2}=\Gamma^*_{in2}$).

1) Evaluate Γ_{s1}, Γ_{L1}, Γ_{s2}, Γ_{L2} in order to fit the requirements
2) Compute the available gain of the two stages and the noise figure of the second stage
3) Compute the overall transducer gain and the overall noise figure of the amplifier (Hint: the overall available gain is the sum (in dB) of the available gain of the stages, then being the output matched…)
4) Design the input and output transforming networks. The parameters of the first are Z_c and Φ_A; the unknowns of the second are B_1 and B_2.

Solution

Inserting the S parameters in the e-Smith Chart we discover that the transistors are unconditionally stable with G_{Tmax}=12.788, $\Gamma_{S,opt}=0.74\angle -81.4$, $\Gamma_{L,opt}=0.51\angle -155.2$.

1) The first stage must be however designed for NF_1=0.8, so we draw the circle with this NF value on the S. C. Then, in order to find the value of Γ_{s1} determining the maximum available gain compatible with the assigned NF, we draw some circles with Ga=cost (< G_{Tmax}) and look for the one about tangent to the NF circle:



We found Ga1=11.96 dB. The tangent point gives $\Gamma_{s1}=0.44\angle -97.9°$. In order to get Ga=GT we impose conjugate matching at the output of transistor 1 and we get (from the S.C.):

$\Gamma_{L1}=(\Gamma_{out1})^{*}=0.311\angle{-135°}$. The second stage operates for the maximum transducer gain so it has $\Gamma_{s2}=\Gamma_{S,opt}$, $\Gamma_{L2}=\Gamma_{L,opt}$.
2) The overall Ga is the sum (in dB) of the Ga of the two stages (the second is equal to G_{Tmax}), so $Ga=Ga1+G_{Tmax}=24.74$ dB. The noise figure of the second stage is obtained by assigning the current point on the S.C. equal to $\Gamma_{s2}=\Gamma_{S,opt}$ and asking for the optimum gamma load. We get $NF_2=2.53$ dB.
3) The overall transducer gain coincides with the overall Ga because the output of the second transistor is matched: GT=Ga=24.74 dB. The overall noise figure is given by the following formula:

$$\left(NF\right)_{TOT}=NF_1+\frac{NF_2-1}{G_{a1}}=10^{0.08}+\frac{10^{0.253}-1}{10^{1.2}}=1.252\rightarrow 0.98\text{ dB}$$

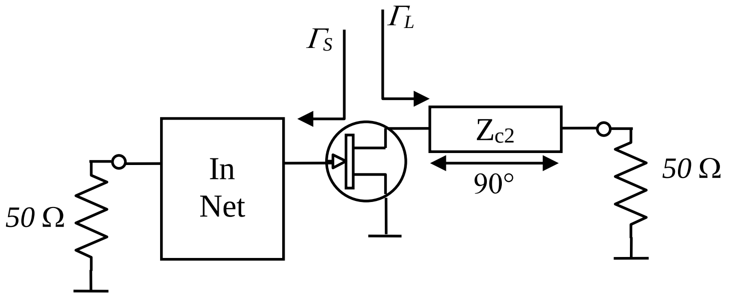
4) First network: we move on the circle with $|\Gamma|=|\Gamma_{s1}|$ toward the load up to the intersection with the real axis → $\Phi_A=48.9°$.The impedance seen in this point is $Z=2.571\cdot 50=128.55\ \Omega$. The characteristic impedance Zc of the landa/4 transformer is the given by Zc=sqrt(128.55*50)=80.17 Ω.

Second network: draw the circle g=1 rotated by 300° toward the source. Set the current point to Γ_{L2} and store in memory. Draw the circle g=cost passing for Γ_{L2} and select one intersection between the two circles ($\Gamma=0.385\angle 172.69°$). The value of imaginary part of DeltaY with the sign reversed gives b1=1.537. Give an increment to the current point Γ by 300°; the new current point has y=1+jb2 → b2=-0.834.

Exercise 260916

We want to design an amplifier operating at 1 GHz according to the scheme in the following figure. Note that Γ_L must be chosen in order to be realizable with the considered output network
a) Compute Γ_S and Γ_L for the maximum transducer gain (compatibly with the previous condition on Γ_L)
b) Evaluate the value of Z_{c2} of the output matching network

Hint: in order the output network is realizable Γ_L must be real (why?)



Scattering parameters of the transistor:
$S_{11}=0.839\angle{-66.7°}$ $S_{12}=0.039\angle 53.5°$ $S_{21}=11.76\angle 128.7°$ $S_{22}=0.642\angle{-36.3°}$

Solution:
The transistor is potentially instable with Gmax=24.79 dB. Selecting the power gain $G_P=24$ dB, we draw the power gain constant circle on the Smith Chart. We note that this circle intersect the horizontal axis in two point; one of them is the right selection because we have a real Γ_L and then a real Z_L, that can be obtained with the λ/4 transformer:

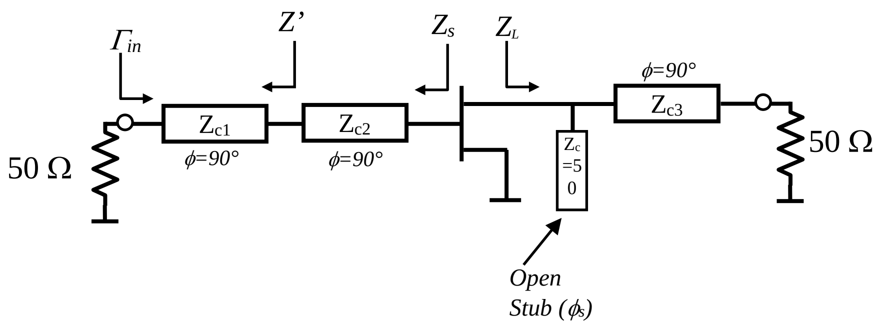
Γ_L=-0.632 → Z_L=0.226·50=11.3 Ω
Z_{c2}=sqrt(50·11.3)=23.77 Ω

In order to have G_T=G_P we must impose the matching condition at the transistor input. From the Smith chart we get immediately the optimum Γ_S:

Γ_S=0.9∠53.2

<u>Exercise 030216</u>

The low noise amplifier at 2 GHz with the scheme in the figure must be designed.



S_{11}=0.519∠-133.27°
S_{12}=0.095∠17.7°
S_{21}=4.071∠41.2°
S_{22}=0.392∠-90.39°

NF_{min}=0.35 dB
$\Gamma_{s,opt}$=0.52∠94.6
r_n=0.081

The goal of the design is to obtain the transducer gain G_T>14 dB and the noise figure NF=1 dB.

A) Evaluate Z_S and Z_L in order to fit this requirements.
B) Evaluate Z_{c1}, Z_{c2}, Z_{c3} and ϕ_s.
C) Evaluate the input reflection coefficient Γ_{in}

The input network is constituted by two sections of transmission lines λ/4 long. The chosen value of Zs must be compatible with this network topology (for computing Z_{c1} and Z_{c2} select a suitable value for Z').

The stub length ϕ_s and the characteristic impedance Z_{c3} of the line must be evaluated for the output network (note that the line reports a real admittance in parallel to the stub).

Solution:

The value of Zs must be on the circle with NF=1 dB and inner to the circle Gav=14 dB. Moreover, due to the topology of the input network Zs must be real. Using the electronic Smith chart we find that there is only one point on the Γs plane satisfying the above conditions:

$$\Gamma_s = 0.501\angle 180° \Rightarrow \quad z_s = 0.332 \Rightarrow \quad Z_s = 50 \cdot z_s = 16.6\ \Omega$$

The two λ/4 transformers operate as impedance inverters with K=Zc. Imposing Z'=30 Ω (about in the middle of the range Zs→50) we get:

$$Z_{c1} = \sqrt{50 \cdot Z'} = 38.73\ \Omega, \qquad Z_{c2} = \sqrt{Z_s \cdot Z'} = 22.32\ \Omega$$

Using the Smith chart, selecting "optimum gamma, load" we get:

$$\Gamma_L = 0.615\angle 96.92°, \qquad G_T = 14.482\ \text{dB}, \qquad NF = 1\ \text{dB}$$

For designing the output network, we observe that the impedance presented by this network at the transistor output is constituted by the parallel of the susceptance of the open circuited stub with the resistance obtained from the λ/4 transformer. The obtaining YL from the Smith chart:

$$y_L = 0.506 - j0.993 \Rightarrow \quad Y_L = \frac{y_L}{50} = 0.01012 - j0.01986$$

Then:

$$b_s = \tan\left(\phi_s\right) = -0.993 \Rightarrow \phi_s = 135.2°$$

$$\frac{Z_{c3}^2}{50} = \frac{1}{0.01012} \Rightarrow Z_{c3} = 70.29\ \Omega$$

For computing Gin we must evaluate first gamma at the input of the transistor ($\Gamma_{in,t}$) from the smit chart (“S Param., Gamma IN”):

$$\Gamma_{in,t} = 0.696\angle -158.035° \quad \left(Z_{in,t} = 9.3 - j9.4\right)$$

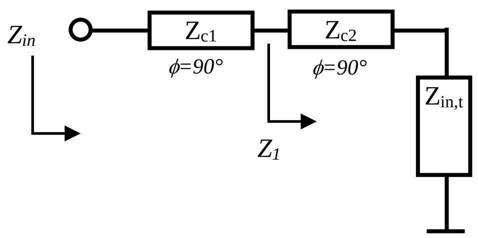
Then we evaluate the impedance Z_1 at the input of the second λ/4 transformer (see the figure):

$$Z_1 = \frac{Z_{c2}^2}{Z_{in,t}} = 26.5 + j26.8$$

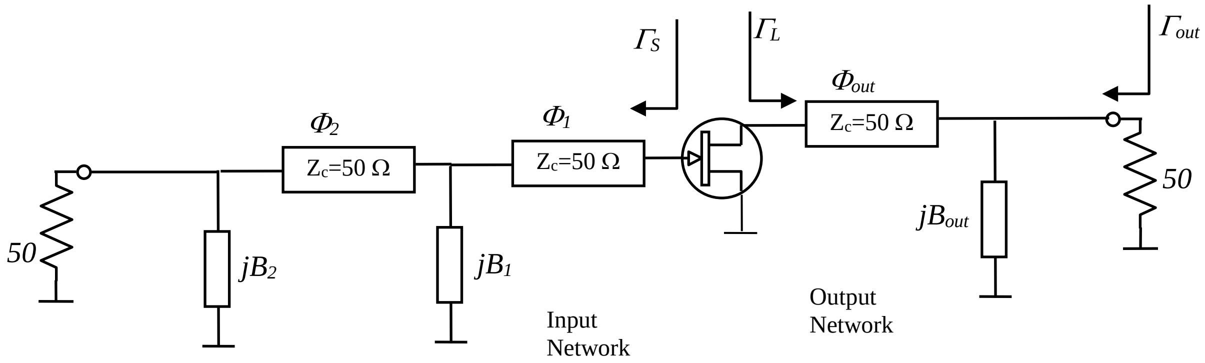
The input impedance is obtained from the first λ/4 transformer:

$$Z_{in} = \frac{Z_{c1}^2}{Z_1} = 28 - j28.3 \quad \left(z_{in} = 0.56 - j0.57\right)$$

$$\Gamma_{in} = 0.432\angle -107.91° \text{ (from the Smith chart)}$$



Exercise (140717)



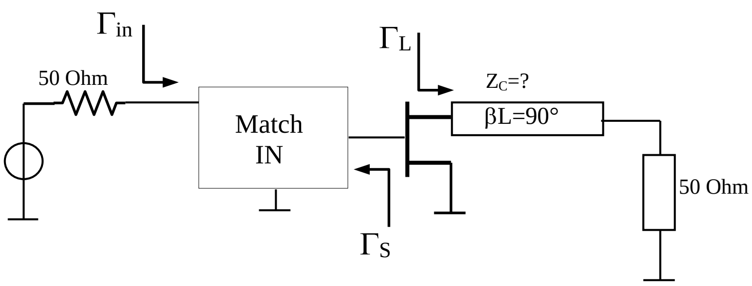
The scheme in the figure represents an amplifier operating at 5 GHz.
The amplifier circuit parameters are given in the following:

S Partameters: S_{11}=0.6∠179° S_{21}=2.64∠ -7° S_{12}=0.137∠-39 S_{22}=0.4∠ -139°
Noise Paramters: Γ_{opt}=0.44, 157° F_{min}=1 dB R_n=0.12
Input network: B_2=-0.0571 S, B_1=-0.0204 S, Φ_2=135°, Φ_1=45°
Output network: B_{out}=0.0272 S, , Φ_{out}=30.58°

Note that the susceptances (B_1, B_2, B_{out}) are **NOT** normalized!

1. Determine the reflection coefficients Γ_S e Γ_L
2. Evaluate the transducer gain G_T and the noise figure *NF* of the amplifier
3. Compute the reflection coefficient Γ_{out} observed by the load

Exercise 220217
We want to design the amplifier in the figure operating at 2 GHz, with matching at input (Γ_{in}=0).
It is known that the Match IN network is lossless.
The S parameters of the active device at 2 GHz are given in the following table.



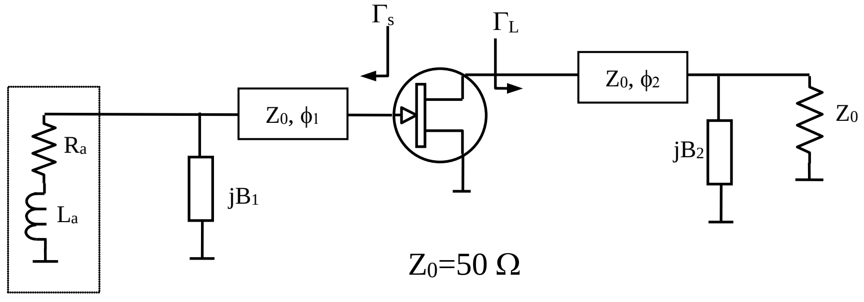
S_{11}=0.828∠ -81.1°
S_{12}=0.076∠33.4°
S_{21}=4.390∠ 99.8°
S_{22}=0.539∠ -60.1°

1) Evaluate Γ_S and Γ_L in order to get the highest transducer gain compatibly with stability and the matching requirement (note that the Γ_L selected must be realizable with the output network assigned)
2) Evaluate the characteristic impedance Z_c of the output transmission line.

Solution:

We draw the circle Gp=17 dB (<MSG=17.62 dB). Then select one of the points on this circle crossing the horizontal axis: $\Gamma_L=0.195$, to which corresponds $\Gamma_S=(\Gamma_{in})^*=0.77\angle 83.56°$. Being the output matched: $G_T=G_P=17$ dB.
The impedance Z_L corresponding to Γ_L is $Zs=50\cdot 1.485=72.25\ \Omega$. Then $Z_c=\text{sqrt}(50\cdot 72.25)=60.93\ \Omega$.

<u>Exercise 280617</u>



The scheme in the figure represents a low noise amplifier operating at 10 GHz, directly connected to an antenna whose radiation impedance is modeled by the resistance R=35 Ω in series with the inductance L=0.4 nH.
The active device is characterized by the following parameters:
Scattering: $S_{11}=0.36\angle -171°$, $S_{12}=0.044\angle 67°$ $S_{21}=7.28\angle 80°$ $S_{22}=0.45\angle -26°$
Noise: $r_n=0.17$, $NF_{min}=1.3$ dB, $\Gamma_{min}=0.05\angle 28°$

The design goal is to obtain NF=1.5 dB with the corresponding maximum transducer gain G_T.

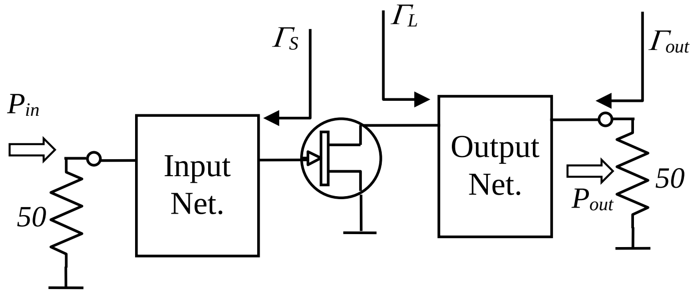
1) Evaluate the reflection coefficients Γ_S and Γ_L that allow the requested design goal. Specify the value of G_T obtained.
2) Compute the parameters of the transforming networks B_1, ϕ_1, B_2, ϕ_2. (the computing procedure must be reported)

Solution:
The antenna impedance is given by: $Za=Ra+j2\pi f_0 L_a=35+j25.13\ \Omega$.
The assigned transistor is unconditionally instable with $G_{Tmax}=20.4$ dB. To satisfy the goal we must find Γ_S which determines the imposed NF=1.5 dB; then imposing the conjugate matching at output we get Γ_L. We start drawing on the electronic Smith Chart the circle with NF=1.5. Then we draw some circles with Available Gain constant until we find the one tangent to the NF circle. The tangent point gives the optimum $\Gamma_S=0.264\angle 171.3$ Selecting “Optimum Gamma Load” on the S.C. we get $\Gamma_L=0.541\angle -28.67°$ and $G_T=19.3$ dB.
The input network transforms Za into Γ_S. We start the design entering $Z_{a,norm}=0.7+j0.5$ and drawing the circle g=const. passing for this point. We then enter Γ_S, store in memory and draw the circle $|\Gamma|$=const. passing for this point. We select one of the intersections of the two circles and the phase of DeltaGamma divided by 2 gives the parameter $\phi_1=44.53°$. We store the current point in memory and select the marker representing $Z_{a,norm}$. The imaginary part of DeltaY with the sign reversed gives $B_{1,norm}=1.2$ (the sign is reversed because in the last step the susceptance B_1 must be subtracted).

The output network is a standard single stub transformer. Applying the procedure in slides we obtain: ϕ_2=104.35, $B_{2,norm}$=1.28.

<u>Exercise 180913</u>

We want design a single stage amplifier at 6 GHz using the scheme in the following figure (input and output networks are lossless):



The amplifier must deal with an input signal whose maximum average power is 0 dBm (two tones separated by 10 MHz). It is requested that the carrier-to-intermodulation (C/I) ratio at output must be at least 30 dB. Moreover the noise figure of the amplifier must as small as possible .

The transistor to be used has the following parameters:

$S_{11}=0.63\angle156°$ $S_{21}=3.52\angle 59°$ $S_{12}=0.064\angle66°$ $S_{22}=0.31\angle -36°$

Γ_{opt}=0.24, -179° F_{min}=2 dB R_n=0.11 (Noise parameters)

3^{th} order Intercept point (IP3): 26 dBm

1) Evaluate the transducer gain to be assigned to the amplifier in order the C/I requirement is satisfied

2) Determine Γ_S and Γ_L for satisfying the requirements on the noise figure, having imposed the transducer gain previously computed

3) What is the value of Γ_{out}? (justify the answer!)

<u>Solution</u>

The condition on the (C/I) ratio determine the maximum average output power:

$$C/I = 2IP_3 - 2P_{out} + 6 \;\Rightarrow\; P_{out} = IP_3 + 3 - \frac{C/I}{2} = 14 \text{ dBm}$$

Then the Transducer Gain of the amplifier results: G_T =14-0=14 dB.

Now we introduce the transistor parameters into the Smith Chart. The transistor is unconditionally stable with $G_{T,max}$=15.2 dB. The circle with G_{av}=G_T=14 dB is then draw on the chart (representing the complex plane of Γ_s). On the same chart also some circles with NF=const. must be drawn, with NF>2 dB. The circle to be selected is the one tangent in a single point to the circle G_{av}=14 dB (see the following picture). The tangent point represents the value of Γ_s to be selected: Γ_s =0.49∠-160°. The NF circle correspond to NF=2.2 dB.

Now, in order to get G_T=G_{av}, we must impose the match at the output, i.e. $\Gamma_L = \Gamma_o^*$, where Γ_o is the reflection coefficient looking into the transistor output. With the S.C. we obtain:

$\Gamma_L = 0.47\angle36.2°$

Having imposed the matching condition at the transistor output and being the output network lossless, Γ_{out} result zero.

Exercise 250613

The LNA in the previous exercise adopts the balanced configuration (fig. 1). It is reminded that the overall transducer gain (G_{RF}) and the noise figure (NF) of this configuration are the same of the single amplifiers

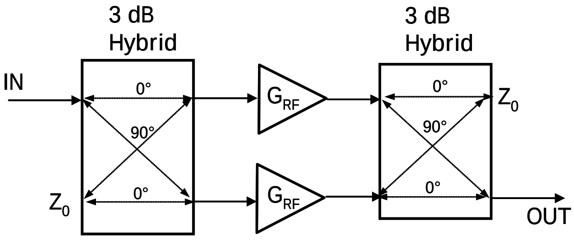
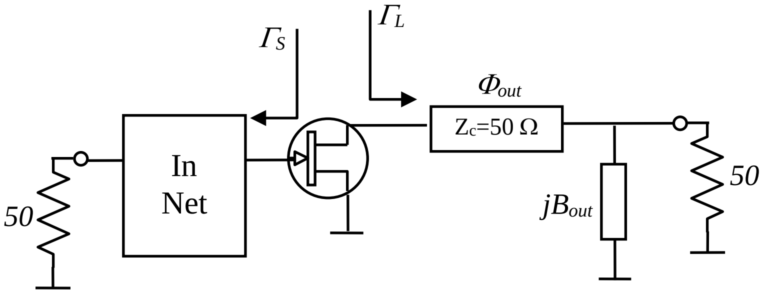


Fig. 1

Each amplifier is constituted by the single stage schematic shown in fig. 2 (also the scattering parameters and noise figure parameters of the transistors are reported).



$S_{11}=0.9\angle{-69°}$ $S_{21}=3.51\angle 111°$
$S_{12}=0.07\angle 43°$ $S_{22}=0.45\angle -53°$

$\Gamma_{opt}=0.62\angle 56°$ $F_{min}=0.5$ dB
$R_n=0.44$

Fig. 2

1) Explain why the balanced configuration is convenient in this case
2) Determine Γ_s and Γ_L in order to get G_{RF}=15 dB and NF=1.2 dB
3) Evaluate Φ_{out} and B_{out} in fig. 2

Solution:
1) The balanced configuration allows the matching at the input even if the two amplifiers are not matched (they must be designed for the requested NF)
2) With the assigned transistor parameters, the following result is obtained:

Scattering Parameters at 4 GHZ

S11 (Mag, Phase deg) 0.9 , -69

S12 (Mag, Phase deg) 0.07 , 43

S21 (dB, Phase deg) 10.9061 , 111

S22 (Mag, Phase deg) 0.45 , -53

Potentially INSTABLE

Maximum Stable Gain (dB): 17.0021

Stability Coefficient K: 0.38887

Noise Parameters at 4 ghz

Minimum Noise Figure (dB): 0.5

Optimum Gamma Source (Mag, Phase deg): 0.62 , 56

Normalized Noise Resistance: 0.44

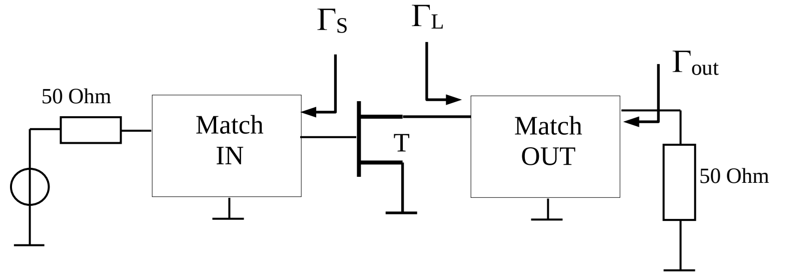
The transistor is then compatible with the requirements. It must be however necessary to verify that the values of Γ_S and Γ_L found are within the stable regions.

The circles N_F=1.2 dB and G_{AV}=15 dB are then drawn on the Smith Chart, together with the stability circle of the source. One of the two intersections is selected (both are outside the forbidden region of Γ_S); the assigned value of Γ_S results: $0.442\angle 100.1°$. The value of GL is obtained by imposing the matching condition at output. Selecting: S Param. --> Optimum Gamma --> Load in the Smith Chart the following value is obtained: $\Gamma_L = 0.585\angle 62.01°$ (note that also this point is outside the forbidden region of Γ_L).

3) The value of Γ_L is inserted in the Smith Chart as current point. We store it in memory and draw the circle with constant Γ passing through it. The circle with g=1 is then drawn and one on the intersections with the previous circle is selected. The increment of the phase of gamma divided by 2 is equal to the electrical length Φs=31.8°. The imaginary part of the admittance observed at the selected point represents the susceptance Bout (normalized): B_{out}=0.02.(-1.439)=-0.0288

Exercise 090215

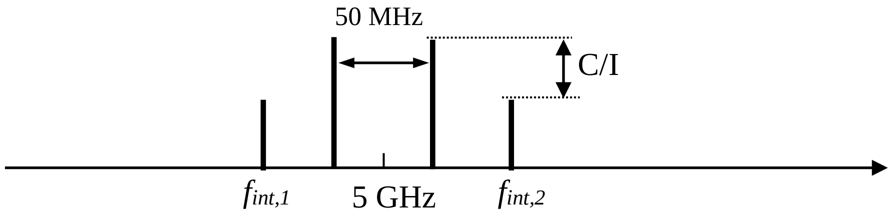
The following figure is the scheme of a single stage amplifier to be designed at 5 GHz. The design goal is to get the largest value for the transducer gain compatible with the stability condition. Moreover we also require that the output is matched (Γ_{out}=0)



$S_{11}=0.772\angle 6.17°$
$S_{12}=0.2\angle -82.08°$
$S_{21}=2.224\angle -137.15°$
$S_{22}=0.508\angle 37.07°$

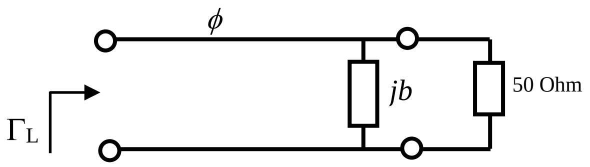
1) Choose Γ_S e Γ_L in order to meet the requirements. Specify the corresponding transducer gain

2) Design the Match OUT network (single-stub configuration)
3) Assume a 2-tone driving signal with f_0=5 GHz and Δf=50 MHz. Assuming the 3th order intercept point of the device IP_3=40 dBm, compute the output peak power for which the ratio C/I is equal to 30 dB. What is the power in each intermodulation line? What are the frequencies ($f_{int,1}$, $f_{int,2}$) of the intermodulation lines?



<u>Solution</u>
After inserting on the electronic S.C. the S parameters, we get the transistor information (potentially instable, MGS=10.46 dB). The we draw the stability circles for source and load.
Being the output matched required, we draw the circle with available power gain equal to 10.4 and select $\Gamma_S=0.3\angle -26.85°$. The conjugate match at the transistor output determine $\Gamma_L=0.584\angle -52.72$ and $G_T=G_{AV}$=10.4 dB

The OUT network is implemented as a single stub matching network:



Using the S.C. we enter Γ_L , store it, and draw the circle with const | Γ |. Then draw the circle g=1 and select one of the intersection between the two circles.

The angle of “DeltaG” tab gives $2\phi=178.37 \rightarrow \phi=89.18°$.

The imaginary part of Y (current point tabs) gives b=-1.438.

The susceptance *b* is implemented as a short-circuited stub with:

$$\phi_s = \tan^{-1}\left(\frac{1}{1.438}\right) = 34.78°$$

It has CI=2(IP3-P_0), with P_0 power per line at f0. Then P_0=IP3-CI/2=25 dBm.
Moreover PEP=P_0+6=31 dBm.
The power in each intermod. line is P_0-CI=-5 dBm.
The frequencies of intermod. line are 5±0.075=(4.925,5.075) GHz