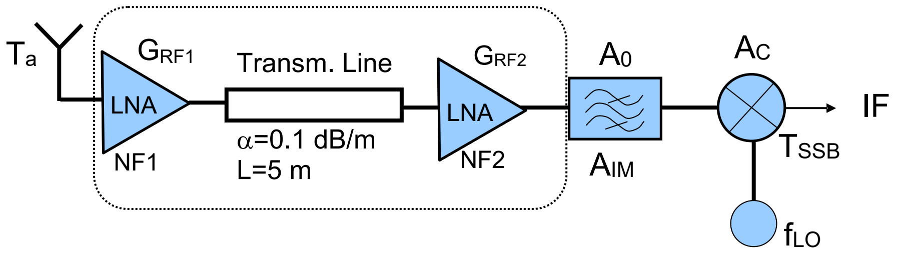
RF SYSTEMS
1th February 2017

Surname & Name
Identification Number
Signature

Exercise 1

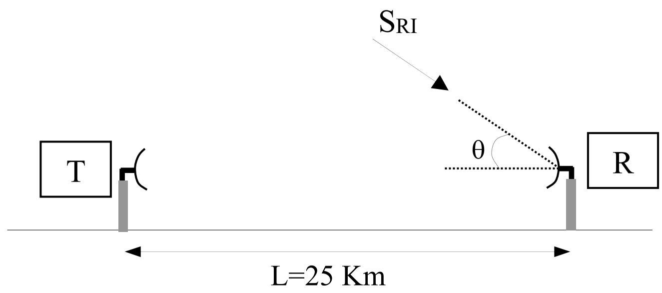
The scheme in the figure represents the RF front-end of a receiver operating at 12 GHz.
The two LNAs are separated by a transmission line 5 m long (attenuation α=0.1 dB/m).
The filter is tuned at the center frequency of the receiver (12 GHz) with 10 MHz passband and 1 dB attenuation in passband; the attenuation in the stopband at the image frequency is A_{IM}=30 dB.
The other parameters are reported below.



T_A=150°K
G_{RF1}=10 dB, NF1=1 dB
A_0=1 dB, A_{IM}=30 dB
G_{RF2}=15 dB, NF2=2 dB
A_c=6 dB, T_{SSB}=350 °K

a) Assuming the IF frequency equal to 140 MHz and the local oscillator frequency (f_{LO}) above the signal band, where is located the image band?
b) The elements inside the dashed box are connected in cascade. They can be replaced by an equivalent amplifier with $G_{RF,eq}$, NF_{eq}. Evaluate these parameters (assume G_a=G_T for all the elements. Hint: the transmission line operates as a dissipative attenuator the noise figure of which is equal to its attenuation).
c) Draw the equivalent scheme for the evaluation of the noise temperature
d) Evaluate the equivalent noise temperature T_{eq} at the input of the front-end

Exercise 2

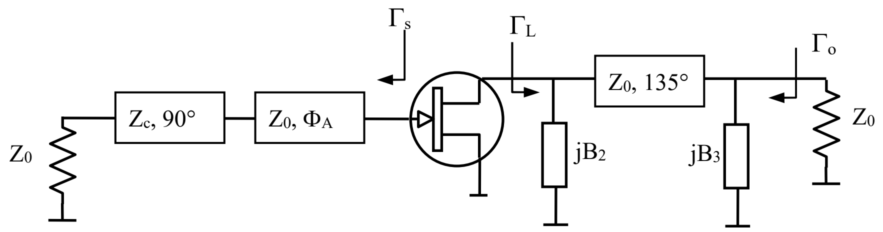


The transmitter operates at 6 GHz with a transmitted power P_T=10 dBm. The receiver is located 25 Km apart from the transmitter. The two antennas are equal, optimally pointed and exhibit G_T=G_R=25 dB with directivity function $f(\theta)=cos^4(\theta)$. A QAM signal with band B=10 MHz is employed and the receiver is characterized by E_B/N_0=15 dB and T_{sys}=500 °K (System Noise Temperature).

1) Discarding S_{RI}, evaluate the SNR_{sys} at the input of the receiver and the maximum allowed data rate R.
2) Consider now $S_{RI}=5\cdot 10^{-12}$ W/m^2. It represents the power density of a wave incident at the receiving antenna with θ=45°. Assuming this signal as an interference noise with power P_{NI}, the overall noise at the receiver input becomes $KT_{sys}B+P_{NI}$.
   a) Evaluate the power P_{NI}.
   b) Evaluate the new transmitted power from T that determines the same SNR_{sys} in absence of the interfering signal.

Exercise 3

The following scheme shows a single stage low noise amplifier operating at12 GHz



The transistor is characterized by the following parameters (Z_0=50 Ω):

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

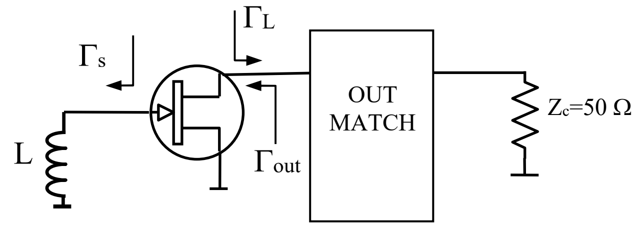
NF_{min}=0.51 dB Γ_{min}=0.358∠-137.2 r_n=0.12

The amplifier must be designed for NF=0.8 dB (the transducer gain must be maximized compatibly with the NF imposed).

1) Evaluate the values of Γ_s, Γ_L in order to fit the requirements
2) Design the two transforming networks.
3) What is the output reflection coefficient (Γ_o) of the amplifier?

Exercise 4

The following scheme refers to an oscillator working at f_{osc}=425 MHz. The S parameters of the transistor are also reported on the figure.



$S_{11}=0.69\angle -55°$
$S_{12}=0.026\angle 64.7°$
$S_{21}=27.5\angle 146.3°$
$S_{22}=0.82\angle -35.7°$

1) Imposing $|\Gamma_{out}|$=1.3 compute the values of Γ_S and Γ_L determining the start of oscillation
2) Evaluate the values of L producing the requested value of Γ_S
3) Check the conditions for the start-up of oscillation
4) Chose a suitable topology and design the output network

Solution

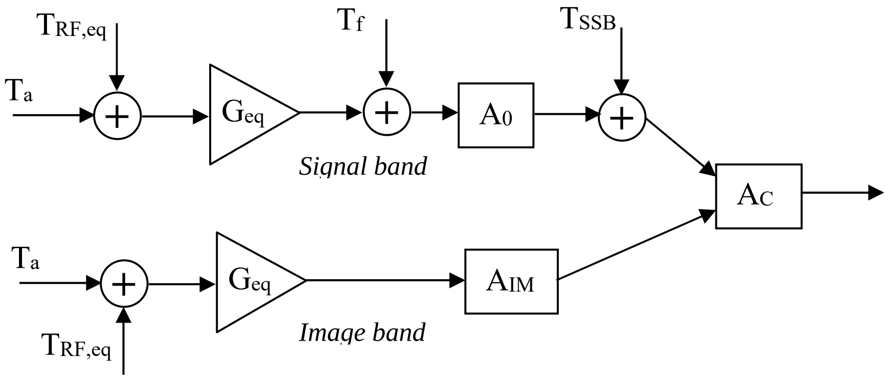
Exercise 1

a) It has f_{im}-f_{ol}=f_{IF} and f_{ol}-f_{RF}=f_{IF}. then $f_{im} = f_{RF}+2f_{IF}$ = 12.28 GHz

b) The transmission line is equivalent to an attenuator with NF_L=A=0.1·5=0.5 dB and gain G_L=-0.5 dB. The overall gain (available) is then G_a=G_{RF1}+G_L+G_{RF2}=24.5 dB. The transducer gain is equal to G_a being the output of LNA2 matched: G_{eq}=24.5 dB. For the overall noise figure:

$$NF_{eq} = NF_1 + \frac{NF_L - 1}{G_{RF1}} + \frac{NF_2 - 1}{G_{RF1} G_L} = 1.33 \text{ (1.26 dB)}$$

c) Considering both the RF and the image channels it has:



With $T_{RF,eq}$=290(10$^{NFeq/10}$-1)=95.7 °K, T_f=290(10$^{A0/10}$-1)=75.09 °K

d) T_{eq} at the input of the receiver is evaluated as:

$$T_{eq} = T_a + T_{RF,eq} + \frac{T_f}{G_{eq}} + T_{SSB}\frac{A_0}{G_{eq}} + \left(T_a + T_{RF,eq}\right)\frac{A_0}{A_{IM}} = 247.84 \text{ °K}$$

Exercise 2

The SNR_{sys} is defined as $SNR_{sys} = \frac{P_r}{KT_{sys}B} = \left(\frac{E_b}{N_0}\right)\left(\frac{R}{B}\right)$, where Pr is obtained from the Friis equation: $P_r = P_t\left(\frac{\lambda}{4\pi L}\right)^2 G_T \cdot G_R$ with $\lambda=3\cdot10^8/6\cdot10^9=0.05$m. Replacing we get Pr:

Pr=10+25+25-10log($3.95\cdot10^{13}$)=-76 dBm ($2.5119\cdot10^{-11}$ W).

SNR_{sys} is then obtained: SNR_{sys} =-76-30-10 log($1.38\cdot10^{-23}\cdot500\cdot10^7$)=25.6 dB

We can compute the data rate R from the first equation:

$$R = B\frac{SNR_{sys}}{\left(E_b/N_0\right)} = 10\cdot10^{2.56-1.5} = 114.8 \text{ Mbit/s}$$

The power received from the interference is given by

$$P_{NI} = A_e S_{RI} f\left(45°\right) = S_{RI} G_R \frac{\lambda^2}{4\pi}\cos^4\left(45°\right) = 7.86\cdot10^{-14} \text{ W}$$

The noise power from the receiver is $KT_{sys}B=6.9\cdot10^{-14}$ W. Then, in order to maintain the SNR_{sys} unchanged we must have:

$$SNR_{sys} = \frac{P_r'}{P_{NI}+KT_{sys}B} = \frac{P_r}{KT_{sys}B} \Rightarrow \frac{P_r'}{P_r} = 1+\frac{P_{NI}}{KT_{sys}B} = 2.139$$

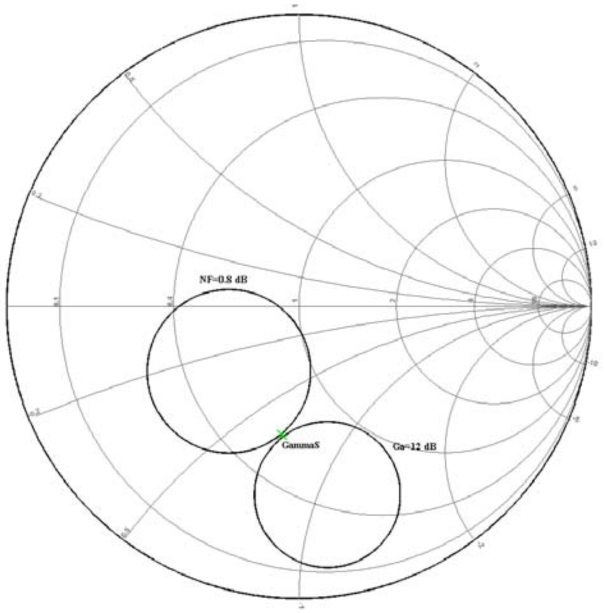
The transmitted P_t' power must increase of the same amount, then:

$$P_t' = P_r\left(1+\frac{P_{NI}}{KT_{sys}B}\right) = 10\cdot2.139 = 21.39 \text{ mW (13.3 dBm)}$$

Exercise 3

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

1) We draw the circle with NF=0.8 dB on the S. C. Then, in order to find the value of Γ_s 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 Ga=11.96 dB. The tangent point gives $\Gamma_s=0.44\angle-97.9°$. In order to get Ga=$G_T$ we impose conjugate matching at the output of the transistor getting from the S.C.: $\Gamma_L=(\Gamma_{out})^*=0.311\angle-135°$.

2) Input network: we move on the circle with $|\Gamma|=|\Gamma_s|$ toward the load up to the intersection with the real axis → Φ_A=48.9°.The impedance seen in this point is Z=2.571·50=128.55 Ω. The characteristic impedance Zc of the landa/4 transformer is the given by Zc=sqrt(128.55·50)=80.17 Ω.

Output network: draw the circle g=1 rotated by 270° toward the source. Set the current point to Γ_L and store in memory. Draw the circle g=cost passing for Γ_L and select one intersection between the two circles ($\Gamma=0.161\angle-170.76°$). The value of imaginary part of DeltaY with the sign reversed gives b2=0.594. Give an increment to the current point Γ by +270°; the new current point has y=1+jb3 → b3=-0.325.

3) Being the transistor output in conjugate matching and the output network lossless also the amplifier output is matched, i.e. $\Gamma_o=0$.

Exercise 4

Inserting the scattering parameter into the S.C. we discover the device potentially instable and the suitable for an oscillator.

1) Draw the mapping circle for $|\Gamma out|$=1.3 and select one of the intersection with the unit circle: $\Gamma s=1\angle 132.31°$. The corresponding reactance results $Xs=0.442 \cdot 50=22.1\ \Omega$. Evaluate $\Gamma out=1.3\angle -10.4$ → $Zout=-5.21-j3.53$. The assign $Z_L=1.7+j3.52$. Using the S.C. we enter this value as current point and compute $|\Gamma in|$=1.79, so the oscillation start up is guaranteed.

3) We have at f_{osc}=425 MHz: $X_s = \omega_{osc} L = 22.1$. Replacing $\omega_{osc}=2\pi \cdot 425$ MHz we get L=8.28 nH.

4) Using a single stub network: Φ=58.75°, b=-2.73.