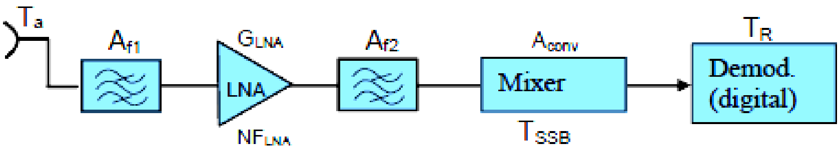
RF SYSTEMS
Written Test of 28 June 2017

Surname & Name
Identification Number
Signature

Exercise 1

Consider the following receiver operating at 15 GHz with signal bandwidth B=70 MHz and data rate R=150 Mbit/sec.



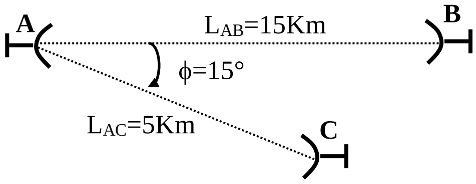
T_A=403°K
TR=400°K
NF_{LNA}=2 dB

1) Evaluate the equivalent noise temperature at the receiver input (T_{eq}) that determines the ratio E_b/N_0 =25 dB (with the received power at the antenna (P_{rec}) equal to -63.3 dBm).
2) Assuming the minimum power at the input of the demodulator P_{dem}= -49.3 dBm, the attenuation of filter 1 A_{f1}= 1 dB, the gain G_{LNA}=22 dB and the conversion loss of the mixer A_{conv}=6 dB, find the attenuation of filter 2 (A_{f2}) and T_{SSB} of the mixer in order to get the requested T_{eq},

Hint: Assume T_0=293 °K and K=$1.38 \cdot 10^{-23}$ for computations.

Exercise 2

Three antennas A, B and C are placed as shown in the figure (*x,y* plane) and operate at 12 GHz. The power transmitted from antenna A (P_T=1W) is received by antenna B and both antennas are directed along the maximum of directivity diagram.

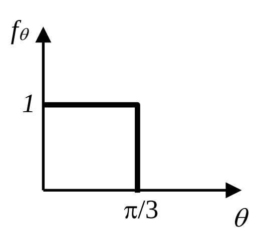


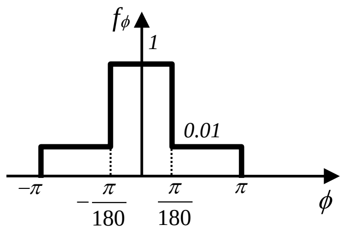
Antennas A and B have the following directivity function $f(\theta,\phi)= f_\theta(\theta)\cdot f_\phi(\phi)$, with:

$f_\theta(\theta)$= 1 for $0<\theta<60°$ (=0 elsewhere),

$f_\phi(\phi)$,=1 for $-1°<\phi<1°$

=0.01 for $1°<\phi<-1°$

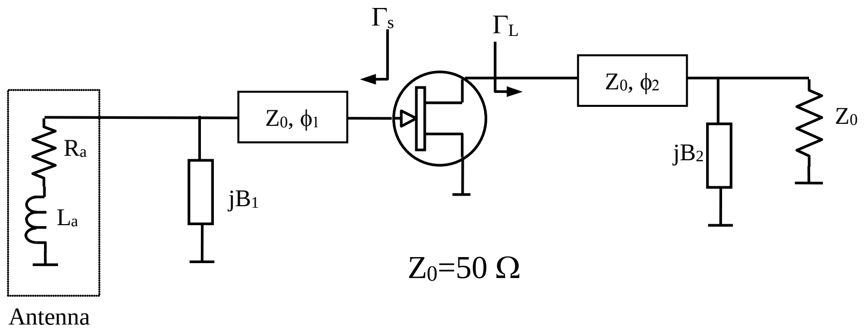




Note that θ=0 defines the (*x,y*) plane. The range of ϕ is $-\pi<\phi<\pi$

1) Compute the maximum directivity gain G of antennas A and B (assume the efficiency η=0.9). Hint: use the integral formula relating $f(\theta,\phi)$ to G.
2) Compute the power received by the antenna B
3) Antenna C is a dish with aperture efficiency e_a=0.5; it is optimally pointed toward antenna A. Evaluate its diameter in order the received power is the same received by antenna B.

Exercise 3



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

<u>Exercise 1</u>

1) Evaluation of the required T_{eq}:

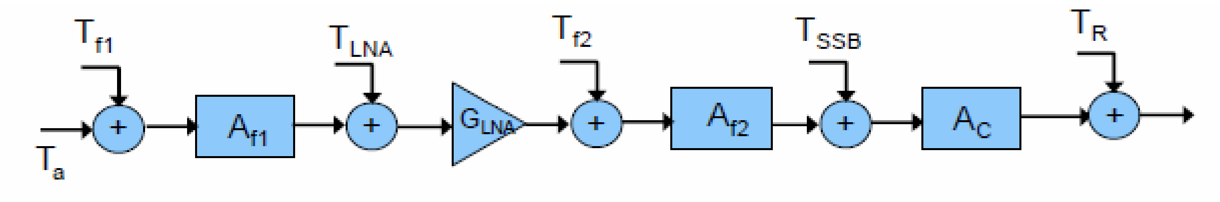
$$SNR_{dB} = P_{rec} - \left(KT_{eq}B\right)_{dBm} = \left(\frac{E_b}{N_0}\right)_{dB} + \left(\frac{R}{B}\right)_{dB} \Rightarrow \left(KT_{eq}B\right)_{dBm} = -91.61 \text{ dBm}$$

$$T_{eq} = \frac{10^{-12.161}}{70\cdot 10^{6}\cdot 1.381\cdot 10^{-23}} = 714.02\ °\text{K}$$

2) Evaluation of A_{f2}:

$$P_{rec} - A_{f1} + G_{LNA} - A_{f2} - A_{conv} = P_{dem} \Rightarrow A_{f2} = -63.3 + 49.3 - 1 + 22 - 6 = 1 \text{ dB}$$

Teq expression:



$$T_{eq} = T_a + T_{f1} + A_{f1}T_{LNA} + \frac{A_{f1}\left[\left(T_{SSB} + A_c T_R\right)A_{f2} + T_{f2}\right]}{G_{LNA}}$$

TSSB can be derived as:

$$T_{eq} = T_a + T_{f1} + A_{f1}T_{LNA} + \frac{A_{f1}\left[\left(T_{SSB} + A_c T_R\right)A_{f2} + T_{f2}\right]}{G_{LNA}}$$

$$T_{SSB} = \frac{\left(T_{eq} - T_a - T_{f1} - A_{f1}T_{LNA}\right)G_{LNA} - T_{f2}A_{f1}}{A_{f2}} - A_c T_R$$

where:

$$T_{eq} = 714.02, \quad 701T_{f1} = T_0\left(10^{0.1} - 1\right) = T_{f2} = 75.8651, \quad T_{LNA} = T_0\left(10^{0.2} - 1\right) = 171.3737$$

$$A_{f1} = 10^{0.1} = A_{f2} = 1.2589, G_{LNA} = 10^{2.2} = 158.4893, A_c = 10^{0.6} = 4$$

Replacing we get: T_{SSB}=281.62 °K

Esercizio 2

$$G = \frac{4\pi\eta}{\int_0^{\pi} f_\theta(\theta)\sin(\theta)\,d\theta \int_{-\pi}^{\pi} f_\varphi(\varphi)\,d\varphi} = \frac{4\pi\cdot 0.9}{\left[-\cos(2)\right]_0^{\pi/3}\cdot\left(\left[\varphi\right]_{-\frac{\pi}{180}}^{\frac{\pi}{180}} + 2\cdot 0.01\cdot\left[\varphi\right]_{\frac{\pi}{180}}^{\pi}\right)} = \frac{4\pi\cdot 0.9}{0.5\cdot\frac{2\pi}{180}\left(1+0.01\frac{179}{180}\right)} = 232.26 \text{ (23.66 dB)}$$

$$P_{rB,dBm} = P_{tA,dBm} - 20\cdot\log\left(\frac{4\pi L_{AB}}{\lambda}\right) + G_{t,dB} + G_{r,dB} + f_A(0,0)\big|_{dB} + f_B(0,0)\big|_{dB} = 30 - 20\cdot\log\left(\frac{4\pi L_{AB}}{\lambda}\right) + 2\cdot G =$$

$$30 - 137.5472 + 2\cdot 23.66 = -60.23 \text{ dBm}$$

$$f_C(0,15) = 0.01\big| \text{ (-20 dB)}$$

$$P_{rC,dBm} = P_{tA,dBm} - 20\cdot\log\left(\frac{4\pi L_{AC}}{\lambda}\right) + G + G_B + f_A(0,15)\big|_{dB} + f_C(0,0)\big|_{dB} = P_{rB,dBm} = -60.23$$

$$G_B = -60.23 - 30 + 128 - 23.66 + 20 = 34.11 \text{ dB}$$

$$G_B = A_e\frac{4\pi}{\lambda^2} = e_a\frac{1}{4}\pi d^2\frac{4\pi}{\lambda^2} = e_a\left(\frac{\pi d}{\lambda}\right)^2 \Rightarrow d = \frac{\lambda}{\pi}\sqrt{\frac{G_B}{e_a}} = 0.57 \text{ m}$$

Exercise 3

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: $\phi_2=104.35$, $B_{2,norm}=1.28$.