RF SYSTEMS
Written Test of July 25th, 2022

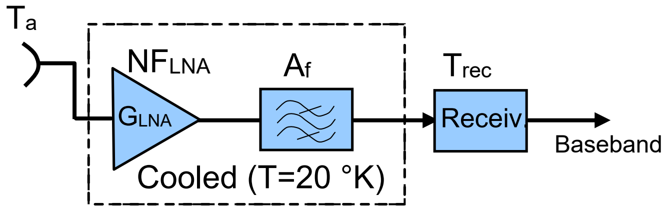
Surname & Name
Identification Number
Signature

Exercise 1

The Mars Reconnaissance Orbiter (MRO) was launched in 2005 to study the geology and climate of Mars. It is equipped with a digital transmitter operating at 8.439 GHz (transmitted power P_T=100 W). The antenna of the spacecraft is a 3m dish with aperture efficiency e_a=0.6. The receiving station on the Earth has a 70m dish antenna with e_a=0.65 and the (G/T) parameter of the receiving station is 60 dB (T represents the equivalent noise temperature of the receiver).
Assuming the required E_b/N_0 equal to 10 dB and the average distance (L) between Earth and MRO equal to $60 \cdot 10^6$ Km, answer the following questions.

1) Evaluate the gain of both antennas and the half-power beamwidth θ_{3dB} of the Earth station antenna (assume the directivity gain of the earth antenna (D) about equal to its gain G)
2) Evaluate the power received by the Earth station and the data rate R allowed by the assigned E_b/N_0, including in the link losses a supplementary attenuation A_S=10 dB to account for possible atmospheric events (rain, etc).
3) MRO is equipped with a camera which takes high resolution pictures of the Mars surface (max resolution: 800 Mpixels). Each photo (16.4 Gbit) is compressed to 5 Gbit before transmission to Earth. Considering that MRO is occulted from the Earth for about 1/3 of the orbit time around Mars, the data can be sent to Earth for 10 hours a day. How many high-resolution photos can be sent in a day?

Exercise 2



T_a=10°K
NF_{LNA}= ?
G_{LNA}=20 dB
A_f=0.5 dB
T_{rec}= 100 °K

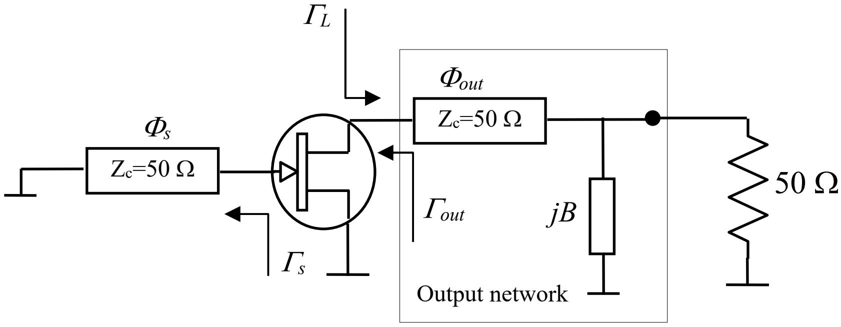
The scheme in the above figure represents the front-end of the Earth Station receiver of exercise 1 (note that the low noise amplifier and the filter are cooled at 20°K).

1) Draw the equivalent scheme including the noise sources (equivalent temperatures) and write the expression of the system temperature (Tsys)
2) Imposing the value of T_{sys} previously computed, evaluate the noise figure of the LNA
3) If the system SNR must be 13 dB, what is the system bandwidth?

Note: in case the previous exercise has not been solved assume T_{sys}=25 °K.

Exercise 3

We want design the oscillator in the following figure, operating at 5 GHz:



The scattering parameters of the transistor are given by:

S_{11}= 0.844∠-62.3°, S_{21}=5.273∠121.7°, S_{12}=0.069∠42.7°, S_{22}=0.521∠-52.6°

a) Select a value for Γ_s and evaluate the electrical length Φ_s of the first line. (Hint: set $|\Gamma_{out}|=1.2$ and select the Γ_s which determines the minimum value of Φ_s)

b) Design the output network, once the required value of Γ_L has been computed

Solutions

Exercise 1

1) The gain is computed with the following formula:

$$G = A_e \frac{4\pi}{\lambda^2} = \left(e_a \frac{1}{4}\pi d^2 \right) \frac{4\pi}{\lambda^2} = e_a \left(\frac{d\pi}{\lambda} \right)^2$$

with $\lambda = c/f_0 = 0.0355$ m. Replacing e_a and d we get G_S=46.25 dB, G_E=73.96 dB.
The half-power beamwidth can be assumed equal to the aperture of the cone with constant gain G:

$$\Delta\theta = 2\cos^{-1}\left(1 - \frac{2}{D_{MAX}}\right) \cong 2\cos^{-1}\left(1 - \frac{2}{G}\right) = 0.046°$$

2) The received power is obtained from the Friis equation:

$$P_R = P_T - 20\log 10\left(\frac{4\pi L}{\lambda}\right) + G_E + G_S - A_S \text{ (logarithmic units)}$$

with P_T=20 dBm, L=$6 \cdot 10^{10}$ m, A_S=10 dB. Replacing, we get P_R=-136.32 dBW.
The data rate (R) is related to the signal-to-noise ratio:

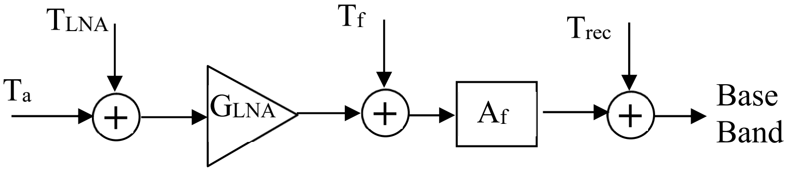
$$SNR_{sys} = \frac{P_r}{KT_{sys}B} = \left(\frac{E_b}{N_0}\right)\left(\frac{R}{B}\right) \quad \Rightarrow \quad R = \frac{P_r}{KT_{sys}\left(E_b/N_0\right)}$$

T_{sys} is obtained from (G/T)=60 dB: with G_E=73.96 it has T_{sys}=13.96 dB → 24.89 °K.
Replacing in the formula (K=$1.38 \cdot 10^{-23}$) we get R=6.79 Mbit/sec

3) Each photo requires the transmission of 5 Gbit at R bit/sec, so the transmission time results t_{ph}= $5 \cdot 10^9 / 6.79 \cdot 10^6$ = 736.38 sec. The number of transmitted photos in 10 h (=36000 sec) is then given by N_{ph}=int(36000/736.38)=48.

Exercise 2

Equivalent scheme with the noise sources:



T_{sys} is the equivalent system temperature defined at the input:

$$T_{sys} = T_a + T_{LNA} + \frac{T_f}{G_{LNA}} + T_{rec}\frac{A_f}{G_{LNA}}$$

Imposing Tsys=24.89 °K and T_f=$T_0(10^{(Af/10)}-1)$=2.44 °K (note that T0=10 °K) we get TLNA:

$$T_{LNA} = T_{sys} - T_a - \frac{T_f}{G_{LNA}} - T_{rec}\frac{A_f}{G_{LNA}} = 24.89 - 10 - 2.44/100 - 100 \cdot 1.122/100 = 13.74 \text{ °K}$$

Then NF=$10 \cdot \log 10(1+T_{LNA}/T_0)$=2.27 dB

With SNR=13 dB we have:

$$SNR_{sys} = \frac{P_r}{KT_{sys}B} = 20 \quad \Rightarrow \quad B = \frac{P_r}{KT_{sys}20} = 3.4 \text{ MHz}$$

Exercise 3

After entering the S parameters in the S.C. we discover that the transistor is potentially instable (K=0.399) so the design of the oscillator is possible.

a) The mapping circle with $|\Gamma_{out}|$=1.2 is then drawn and one of the intersections with the outer circle defines the value of Γ_s. The one to be selected is the closest to the short circuit, i.e. $\Gamma_s=1\angle 94.493°$. It has then ϕ_S=(180-94.493)/2=42.75°.
b) The value of Z_{out} is then obtained from the S.C.: Z_{out}=-0.538-j2.163. The load impedance is then given by Z_L=0.538/3+j2.163=0.179+j2.163 ($\Gamma_L=0.939\angle 49.379°$).
   To design the output network the circle with $|\Gamma_L|$=0.939 is first drawn together with the circle g=1. The current point (Γ_L) is stored and he first intersection of the two circles is selected ($\Gamma=0.939\angle 159.91°$). The phase of Delta Gamma tab determines the length ϕ_{out}=110.532/2=55.266. The current admittance tab gives Y=1-j5.468 then B=-5.468.