RF SYSTEMS

Written Test of February 10, 2020

Surname & Name
Identification Number
Signature

Exercise 1 (8.5)

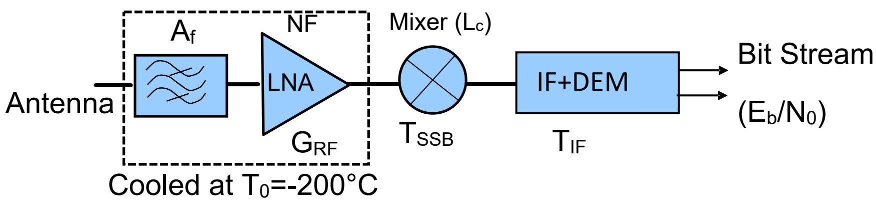
A communication system between Earth and Mars (distance $L=2\cdot10^8$ Km) must be realized using an antenna on Earth with beamwidth $\Delta\theta=0.15°$, efficiency $\eta=0.85$ and a dish antenna on Mars with diameter d=5m, aperture efficiency $e_a=0.6$. The uplink (Earth to Mars) operates at 10 GHz with bandwidth B=6 MHz; the received power at the output of Mars antenna must be P_R=-100 dBm.

1) Assuming constant the radiated power density inside the beamwidth and zero outside, evaluate the gain of the Earth antenna
2) Evaluate the effective area of the Mars Antenna
3) Compute the transmitted power of the transmitter connected to the Earth antenna necessary to guarantee the required received power on Mars
4) Assuming the equivalent noise temperature of the Mars receiving antenna Ta=20°K, evaluate the equivalent noise temperature of the receiver (T_{rec}) connected to the antenna, allowing the system SNR equal to 10 dB

Boltzmann Constant $K=1.38\cdot10^{-23}$

Exercise 2 (8.5)

The scheme in the figure represents the receiver connected to the Mars antenna of the previous exercise. Note that filter and LNA are cooled at -200° C. The signal bandwidth is B=6 MHz. The equivalent noise temperature of the receiver (T_{rec}) must be the one previously evaluated.

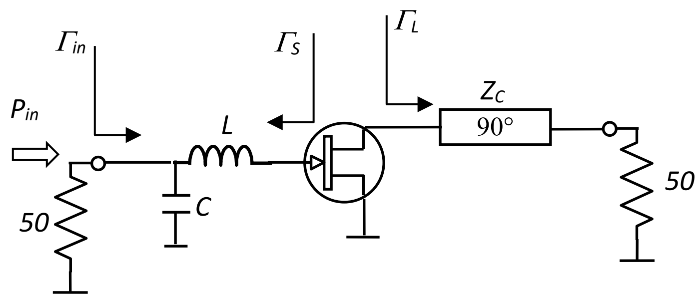


NF= 1 dB
G_{RF}= ? dB
T_a=20 °K
A_f=0.5 dB
L_c=6 dB
T_{SSB}=150 °K
T_{IF}=150 °K

a) Draw the equivalent scheme for the evaluation of the receiver noise temperature
b) Evaluate the value of G_{RF} determining the required T_{eq} of the receiver
c) Assuming E_b/N_0=10 dB evaluate the maximum data rate R (the SNR is specified in the last point of the previous exercise).

Exercise 3 (8)

We want design a single stage amplifier at 1 GHz using the scheme in the following figure (the output network is a section of transmission line whose electrical length is 90°):



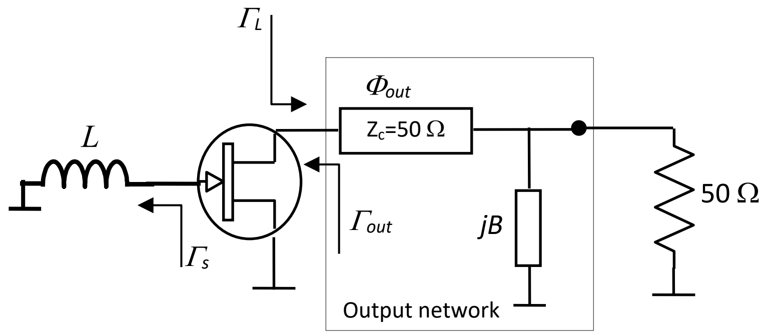
The transistor has the following parameters:
S_{11}=0.6987∠-66.5° S_{21}=12.315∠126.8° S_{12}=0.0474∠57.3° S_{22}=0.7908∠ -33.5°

The design goals are G_T=24 dB, Γ_{in}=0

1) What is the gain to choose for the design to have at the end the required G_T and Γ_{in}=0?
2) Evaluate Γ_L and Γ_S. (Note that Γ_L must be compatible with the output network)
3) Design the input network, i.e. determine L (nH) and C (pF) (must be positive values!)

Exercise 4 (8)

We want design the oscillator in the following figure, operating at 1 GHz:



The scattering parameters of the transistor are given by:

$S_{11}= 0.832\angle{-63.466°}$, $S_{21}=7.812\angle 130.39°$, $S_{12}=0.071\angle 56.027°$, $S_{22}=0.369\angle{-58.306°}$

a) Compute the minimum value of the inductor L (nH) so that $|\Gamma_{out}|=1.2$

b) Design the output network (i.e. compute Φ_{out} and B), once the required value of Γ_L has been determined

Solution

Exercise 1

Using the relationship between directivity gain D_{MAX} and beamwidth $\Delta\theta$ (for high directivity antennas) we get:

$$\Delta\theta = 2\cos^{-1}\left(1-\frac{2}{D_{MAX}}\right) \Rightarrow D_{MAX} = \frac{2}{1-\cos\left(\frac{\Delta\theta}{2}\right)} = 2.3344\cdot 10^6$$

The gain of the Earth antenna is then given by $G_E=\eta D_{MAX}=1.984\cdot 10^6$ (63 dB).
The effective aperture of the Mars dish antenna is given by:

$$A_e = e_a \frac{1}{4}\pi d^2 = 3.75\pi = 11.78\text{m}^2$$

The power received by the Mars antenna is given by: $P_R = \frac{G_E P_T}{4\pi L^2} A_e$

To have the received power PR equal to -100 dBm (10^{-13} W) the transmitted power from Earth must be:

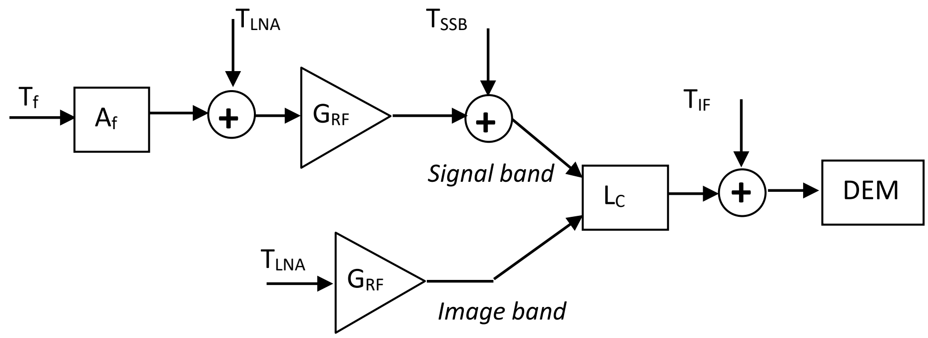
$$P_T = P_R \frac{4\pi L^2}{A_e G_E} = 2.15 \text{ KW}$$

The overall noise power reported at antenna terminal (due to the receiver (T_{rec}) and antenna (T_a) noise temperature) is given by $P_N=K(T_a+T_{rec})B = P_R/SNR=10^{-14}$ W. For the given T_a, the maximum value of T_{rec} is given by:

$$T_{rec} = \frac{P_N}{KB} - T_a = 120.77 - 20 = 100.77° \text{ K}$$

Exercise 2

Drawing of the noise equivalent scheme of the receiver:



The equivalent noise temperature reported at the input is given by:

$$T_{rec} = T_f + 2A_f T_{LNA} + T_{SSB}\frac{A_f}{G_{RF}} + \frac{T_{IF} A_f L_c}{G_{RF}} = 100.77° \text{ K}$$

The reference temperature for the cooled section is T_0=273-200=73° K. Then:
$T_f=T_0(10^{Af/10}-1)$=8.907° K, $T_{LNA}=T_0(10^{NF/10}-1)$=18.902° K.
T_{rec} can then be expressed as:

$$T_{rec}=51.32+\frac{838.382}{G_{RF}}=100.77°\text{ K}\Rightarrow G_{RF}=\frac{838.382}{49.45}=16.95\text{ (12.3 dB)}$$

For the data rate it has:

$$SNR=\left(\frac{E_b}{N_0}\right)\left(\frac{R}{B}\right)\Rightarrow R=B\frac{SNR}{E_b/N_0}=6\text{ Mbit/sec}$$

Exercise 3

Being requested the input matched, the Power gain Gp must be chosen for the design. We then draw the circle Gp=24 dB on the S.C. representing Γ_L and choose a point on this circle compatible with the output network. This latter imposes a real value for Γ_L, so the point to be selected is at the intersection of the mentioned circle with the real axis. Note that there are two intersections; the most convenient is the one closer to the center of the S.C.: Γ_L=-0.175 (it is outside the instability region of the load).
We then select the value of Γ_S which matches the input (Optimum Gamma Source on the S.C.): $\Gamma_S=0.729\angle 59.58°$ (it is outside the instability region of the source). In this way we have the required G_T (equal to the imposed G_P), with the input matched.
The input network can be designed either with the S.C. or by means of the formulas. In both cases must be selected the solution compatible with the assumed component, i.e. X_s and B_p must be positive. The following result is obtained:
Xs=2.078·50=103.9 → Ls=Xs/(2πf$_0$)=16.536 nH
Bp=0.833·0.02=0.01667 → Cp=Bp/(2πf$_0$)=2.65 pF

Exercise 4

First is verified that the device is potentially instable (k<1). Then the mapping circle of Γ_S is drawn imposing $|\Gamma_L|$=1.2. We have two intersection with the outer circle; the one to be selected is the one with the lower value of normalized reactance: Xs=0.82·50=41 → L= Xs/(2πf$_0$)=6.525 nH.
The required value of Γ_L is determined from $\Gamma_{out}=1.2\angle -28.114°$, to which corresponds z_{out}=-1.371-j3.492; we then have z_L=1.371/3+j3.492 → $\Gamma_L=0.934\angle 31.49°$.
The output network is a single stub network which can be designed with the S.C. with the following result: Φ_{out}= 127.577/2=63.79°, B=0.02.(-5.23)=-0.1046 S.