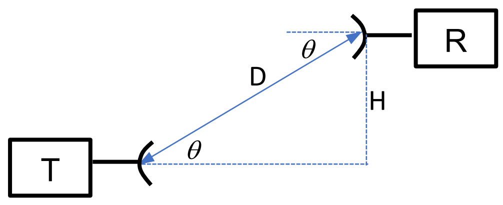
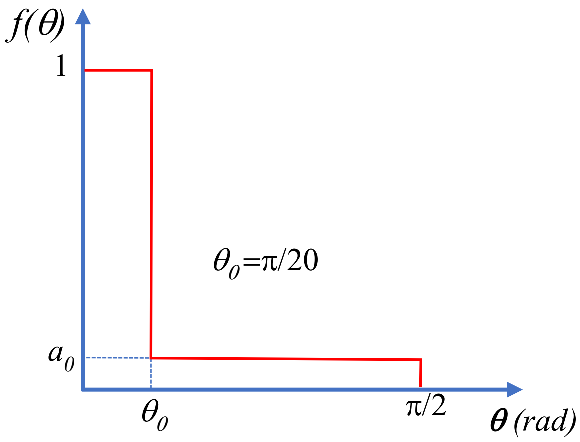
**RF SYSTEMS**
**Written Test of June 12, 2020**

Exercise 1



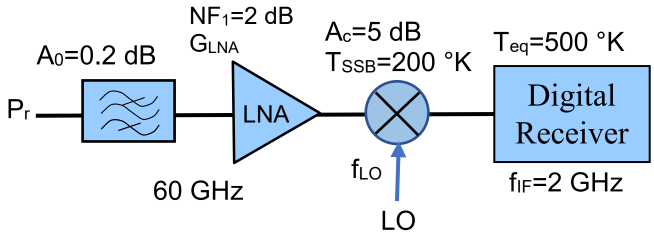




The communication system in the above figure is composed by the transmitter T ($P_T$=1 W, $f_0$=60 GHz) and the receiver R located at distance D and altitude H from T. The antennas of T and R are directed horizontally and the line connecting the antennas forms the angle $\theta$ with respect the horizontal line. The antennas are equal and their directivity function is shown in the above figure (assume $f(\varphi)$=cost for $0<\varphi<2\pi$)

1) Compute the parameter $a_0$ of the directivity diagram to have the gain G of the antennas equal to 10 dB. Assume the radiation impedance $Z_R$=50 Ω e the loss resistance $R_p$=5Ω.
2) Evaluate the received power in R for D=1Km and H=150m.

Exercise 2

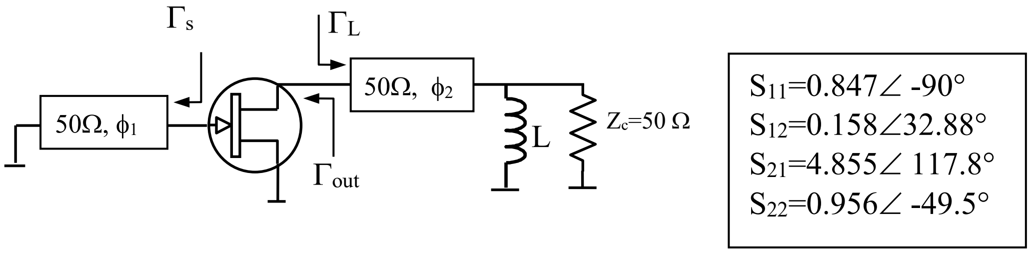
Consider the link in the previous exercise operating at 60 GHz and the received power $P_r$=-78 dBm. The architecture of the receiving station is shown in the following figure:




1) Assuming the local oscillator frequency ($f_{LO}$) smaller than the frequency of the received signal, determine $f_{LO}$) and the image frequency of the receiver.
2) It is know that the digital receiver must operate with ($E_b/N_0$)=10 dB in order to get the data rate R=200 Mbit/sec. Compute the $SNR_{sys}$ of the system for a signal bandwidth B=100 MHz.
3) Evaluate the equivalent noise temperature of the system ($T_{sys}$) imposing $SNR_{sys}$ and $P_r$ (received power). Hint: Boltzmann Constant $K=1.38 \cdot 10^{-23}$.
4) Draw the equivalent scheme of the receiver with the noise temperature sources. Write the expression of $T_{sys}$ as function of the blocks parameters. Imposing the required $T_{sys}$ evaluate the gain $G_{LNA}$ (assume the equivalent noise temperature of the receiving antenna equal to 150 °K)

Exercise 3

The following scheme refers to an oscillator working at 1 GHz. The S parameters of the transistor are also reported on the figure. The input line ($Z_c$=50 Ω, electrical length $\phi_1$) is short-circuited.




1) Evaluate $\Gamma_L$ and $\Gamma_S$ so that the starting of the oscillation is guaranteed (Hint: impose $|\Gamma_{out}|=1.4$ and chose for $\Gamma_S$ the closest point to the short circuit)
2) Evaluate the length $\phi_1$ determining the required $\Gamma_S$.
3) Design the output network, i.e. compute $\phi_2$ and the inductance L.

# SOLUTION

## Exercise 1

1) The gain is expressed as follows ($\eta$=50/55=0.9091):

$$G = \frac{4\pi\eta}{\int_{-\pi}^{\pi}\int_{0}^{\pi} f(\theta)\sin(\theta)\,d\varphi\, d\theta} = \frac{4\pi\cdot 0.9091}{2\pi\left[\left(1-\cos(\theta_0)\right)+a_0\cos(\theta_0)\right]} = 10$$

$$a_0 = 0.1716$$

2) From the Friis equation:

$$P_r = P_t + G_T + G_R - L_f + f_{dB} = 50 - 20\log\left(\frac{4\pi D}{\lambda_0}\right) + f_{dB}$$

Being $\theta=\sin^{-1}(H/D)=0.1507<\pi/20 \rightarrow f_{dB}=0$. Then: $P_r = 50-128 = -78$ dBm.

## Exercise 2

1) $f_{LO}=f_{RF}-f_{IF}$=58 GHz, $f_{IM}=f_{LO}-f_{IF}$=56 GHz.

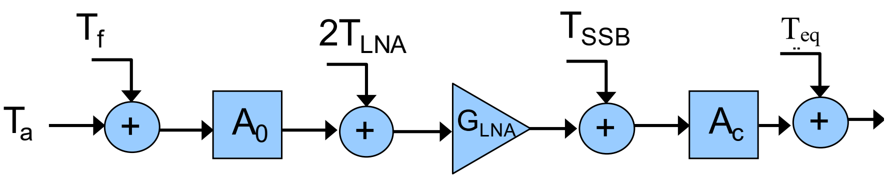
2) The SNRsys is related to Eb/No as follows:

$$SNR_{sys} = \frac{E_b}{N_0}\frac{R}{B} = 10 + 10\log\left(\frac{200}{100}\right) = 13 \text{ dB}$$

3) It has:

$$SNR_{sys} = \frac{P_r}{KT_{sys}B} = 13 \text{ dB} \Rightarrow T_{sys} = 575.6\ °K$$

4) Equivalent scheme (the factor 2 in front of $T_{LNA}$ is due to the contribution from the image band):




The expression of Tsys results:

$$T_{sys} = T_a + T_f + 2T_{LNA}A_0 + \frac{A_0}{G_{LNA}}\left(T_{SSB} + T_{eq}A_c\right) = 575.6$$

We get the following expression for $G_{LNA}$:

$$G_{LNA} = \frac{A_0\left(T_{SSB}+T_{eq}A_c\right)}{T_{sys} - \left(T_a + T_f + 2T_{LNA}A_0\right)} = 35.3 \ \ (15.5 \text{ dB})$$

Exercise 3

- Draw the mapping circle of $\Gamma_s$ ($|\Gamma_{out}|$=1.4). Choose the intersection with the outer circle closest to the c.c: $\Gamma_s = 1\angle 173°$.
- Evaluate $Z_{out}$ =-1.988-j2.7. Assign $Z_L$=1.988/3+j2.7=0.663+j2.7
- Evaluate $\phi_s=(180-\angle \Gamma_s)/2=3.5°$
- Design the output network (single stub):
  Draw the circle $|\Gamma|$=const passing for $\Gamma_L$. Store $\Gamma_L$. Draw the circle g=1. Select the intersection where b<0.
- Read the phase variation of $\Gamma$ ($\Delta\Phi$=110.18°). Then $\phi_2=\Delta\Phi/2$=55.08.
- Read the susceptance of the current point: b=-3.316. X=-50/b=15.08=ωL→ L=2.4 nH.