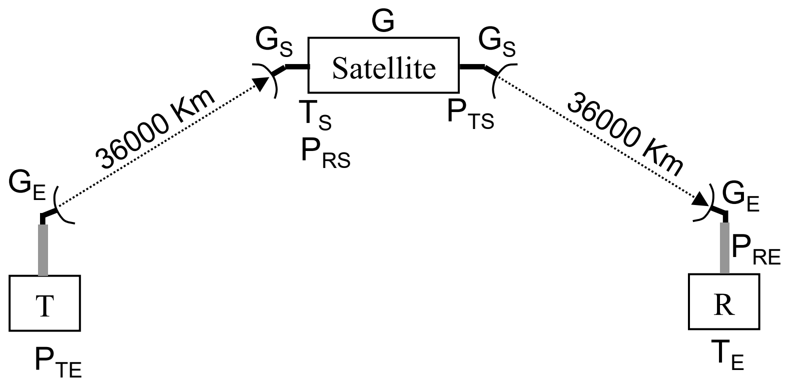
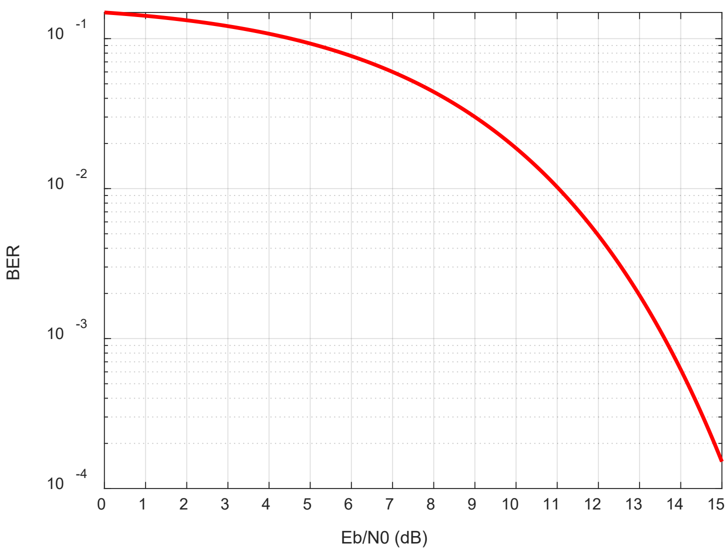
**RF SYSTEMS**
**Written Test of July 14, 2021**

Exercise 1

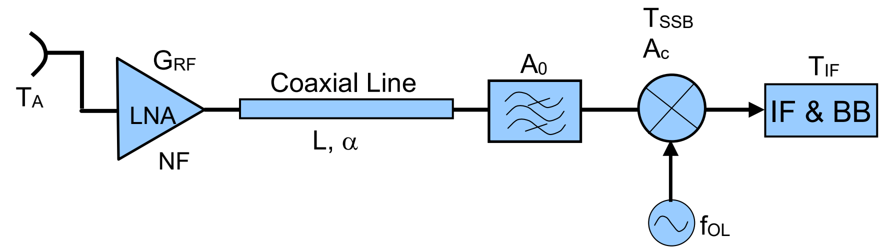



The figure shows a satellite communication system, defined by the following parameters: $G_E$=gain of the earth antennas; $G_S$=gain of the satellite antennas; G=Gain of the satellite (=$P_{TS}/P_{RS}$); $P_{TE}$=transmitted power from the earh station T; $P_{TS}$=transmitted power from the satellite; $T_S$=equivalent temperature of the satellite receiver; $T_E$=equivalent temperature of the earth station receiver; $P_{RE}$=Receiver power at earth station S; $P_{RS}$ received power at satellite; up-link frequency: 6 GHz; down-link frequency: 4 GHz. All antennas are oriented for the maximum gain.

1) Write the Friis equation defining the received power at the earth station R as function of the transmitted power $P_{TE}$ and the other system parameters.
2) It is known the directivity function of the earth antennas:
   $f_E(\theta)=1$ for $0<\theta<\theta_{max}$, $f_E(\theta)=0$ for $\theta_{max}<\theta<\pi$ $\theta_{max}=0.5°$.
   Assuming the antennas efficiency $\eta=0.8$ evaluate the gain $G_E$.
3) The following parameters are assigned: $P_{TE}$=500 W; $P_S$=100 W; $G_S$=20 dB; $T_S$=500°K; $T_E$=100°K. Evaluate:
   a. The total noise temperature $T_{RT}$ of the satellite communication system.
   b. The bit-error-rate (BER) with a data rate R=100 Mbit/s and 64-QAM modulation (the figure below shows the relationship between BER and $E_b/N_0$).
   c. The signal bandwidth, assuming the roll-off factor $\alpha=0.5$



Exercise 2

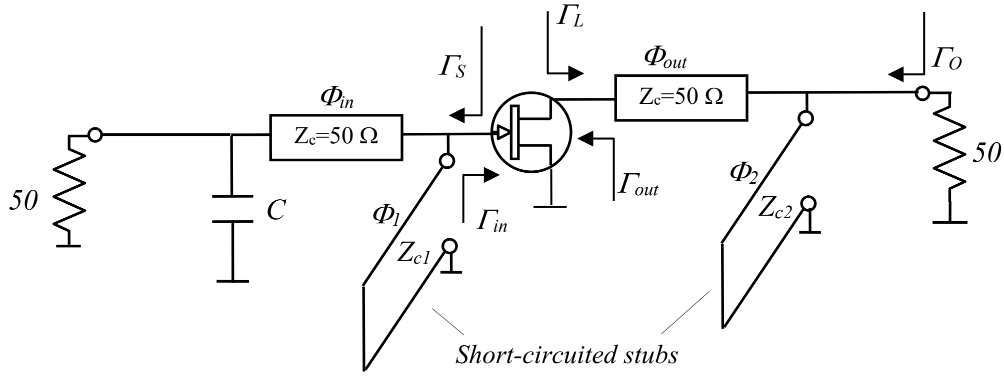



$G_{RF}$=20 dB
NF=2 dB
$A_0$=1 dB
$A_c$=5 dB
$T_{SSB}$=300 °K
$T_A$=50°K

The scheme in the above figure represents the RF front-end of a receiver operating in 1800-1900 MHz band. The LNA is directly connected to the antenna, placed on the top of a mast 15 m height. The following part of the front-end is connected by means of a coaxial cable with length L=15m and attenuation per unit length a=0.1 dB/m. Note that the attenuation in the cable is produced by dissipation.

1) Assuming $f_{IF}$=150 MHz the intermediate frequency (IF) and $f_{OL}$=2000 MHz the local oscillator frequency, discuss the role of the filter, specifying why it is required and where its rejection band is located.
2) Draw the scheme of the front-end referred to the equivalent noise temperature contributions. Evaluate the system noise temperature at the input of the receiver assuming all the contributions after the mixer represented by $T_{IF}$=1500 °K.
3) In the proposed scheme there is no filter between the antenna and the LNA. Mention a possible drawback produced by this choice (justify the answer!).

Exercise 3




The amplifier in the above figure has been designed to operate at 12 GH. The following data are given.

Parameters of active device: $S_{11}=0.7\angle{-116°}$, $S_{21}=2.11\angle 84°$, $S_{12}=0.1\angle 39°$, $S_{22}=0.48\angle{-56°}$, $\Gamma_{opt}=0.48\angle 155°$, $F_{min}$=2 dB, $R_n$=0.2.

Input network: C=0.023 pF, $\Phi_{in}=135°$, $\Phi_1=45°$, $Z_{c1}=26.58\ \Omega$

Output network: $\Phi_{out}=33.75°$, $\Phi_2=45°$, $Z_{c2}=24.15\ \Omega$.

1) Evaluate the reflection coefficients $\Gamma_S$ and $\Gamma_L$ determined by the networks connected to the transistor.
2) Compute $\Gamma_{in}$ and $\Gamma_{out}$ using the Electronic Smith chart. Identify which termination of the transistor is conjugately matched (input or output). Evaluate consequently the Transducer Power gain and the noise figure.
3) What is the reflection coefficient $\Gamma_O$ observed at the amplifier output ?

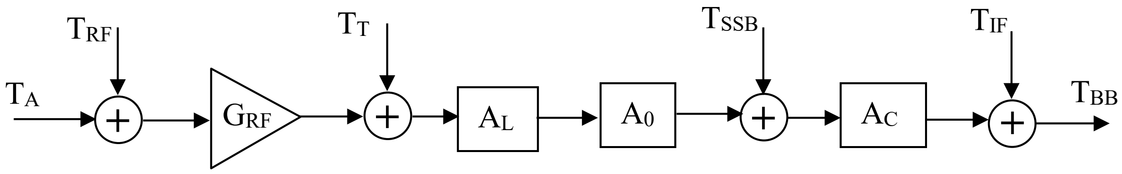
# Solution

## Exercise 1

1) $P_{RE} = P_{TE} \cdot G_E^2 \cdot G \;\; \cdot G_S^2 \left( \frac{\lambda_u}{4\pi R} \right)^2 \cdot \left( \frac{\lambda_d}{4\pi R} \right)^2$ R=$36 \cdot 10^6$ m, $\lambda_u$=0.05m, $\lambda_d$=0.075m
2) The formula to be used is: $G_E = \frac{2\eta}{1-\cos(\theta_{\max})} = 4.2 \cdot 10^4$ (46.23 dB)
3) The total noise temperature is given by: $T_{RT} = T_{RE} + T_{RS} \cdot \frac{P_{RE}}{P_{RS}}$ . The received powers are computed as follows: $P_{RS} = P_{TE} \cdot G_E G_S \cdot \left( \frac{\lambda_u}{4\pi R} \right)^2 = 2.5665 \cdot 10^{-11} W$ ,
   $P_{RE} = P_{TS} \cdot G_E G_S \cdot \left( \frac{\lambda_d}{4\pi R} \right)^2 = 1.1549 \cdot 10^{-11} W$ . Replacing: $T_{RT} = T_{RE} + T_{RS} \cdot \frac{P_{RE}}{P_{RS}} = 325$ °K
4) The overall SNR of the system can be expressed as:
   $SNR_{sys} = \frac{P_{RE}}{KT_{RT}B} = \left( \frac{E_b}{N_0} \right) \left( \frac{R}{B} \right) \quad \Rightarrow \quad \frac{E_b}{N_0} = \frac{P_{RE}}{KT_{RT}R} = 25.751$ (14.1 dB)
   From the graph we get BER≈$6 \cdot 10^{-4}$.
5) The signal bandwidth is expressed by: $B = \frac{R}{\log_2 M} \cdot (1+\alpha) = 25$ MHz

Exercise 2

1) The filter is required to eliminate the image band, which extends from $1800+2f_{IF}=2100$ to $1900+2f_{IF}=2200$ MHz.
2) The following scheme is required for the computation of $T_{eq}$ (the image band is not considered because eliminated by the filter). Note that the transmission line is equivalent to an attenuator with attenuation $A_L=\alpha L$ (in dB).




$$T_{RF} = (10^{\frac{NF}{10}} - 1)T_0 = 171.37\ °\text{K},\quad A_{T,dB} = A_L + A_0 = 0.1\cdot 15 + 1 = 2.5\ \text{dB}$$

$$T_T = (A_T - 1)T_0 = 228.04\ °\text{K}$$

$$T_{eq} = T_A + T_{RF} + \frac{T_T}{G_{RF}} + \frac{T_{SSB}A_T}{G_{RF}} + \frac{T_{IF}A_cA_T}{G_{RF}} = 319.56\ °\text{K}$$

3) The absence of a filter before the LNA limits the dynamic range of the receiver (strong interferers outside the receiver band can lead the LNA to saturation)

Exercise 3

1. Enter the S parameters on the S. C. → Device potentially instable with MSG=13.24 dB
2. Evaluation of $\Gamma s$: compute $b_C=2\pi f_0 C/Y_0$= 0.0867. Enter the normalized admittance y=1+j0.0867 in the S.C; give a phase of gamma increment equal to $-2\Phi_{in}$=-270°; evaluate the normalized susceptance of the stub: $y_n=-j(Z_0/Z_1)/\tan(\Phi_1)=-j1.8811$; give an increment to the susceptance equal to -j1.8811. Result: $\Gamma s=0.7\angle 131.9°$
3. Evaluation of $\Gamma_L$: evaluate the normalized susceptance of the stub: $y_n=-j(Z_0/Z_2)/\tan(\Phi_2)$= -j2.0704; Enter the normalized admittance y=1-j2.070 in the S.C; give a phase of gamma increment equal to $-2\Phi_{out}$=-67.5°. Result: $\Gamma_L=0.719\angle 68.48°$
4. Enter $\Gamma_L$ as current point and select 'gamma IN'. We get: $\Gamma_{in}=0.873\angle -126.816°$; Enter $\Gamma_S$ as current point and select 'gamma OUT'. We get: $\Gamma_{out}=0.719\angle -68.427°$. It is then $\Gamma_L \approx (\Gamma_{out})^*$, i.e. the output is matched. To evaluate $G_T$ with the S.C. we enter $\Gamma_S$ and select 'optimum gamma → Load': $G_T$=11.99 dB, NF=3.075 dB
5. Being the transistor output matched and the output network losses, the output reflection coefficient of the amplifier is zero.