RF SYSTEMS
Written Test of June 17th, 2022

Surname & Name	
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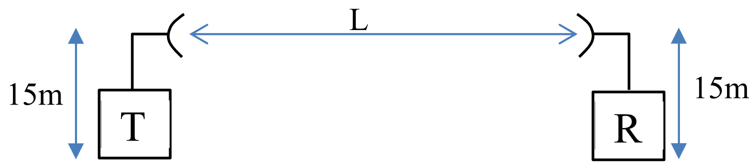
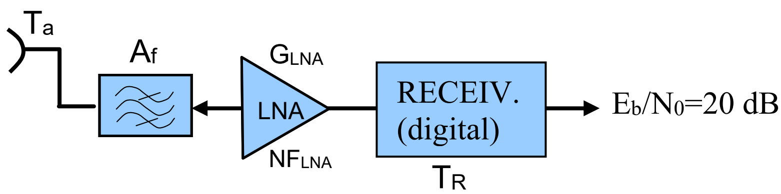
Exercise 1



The figure shows a terrestrial link operating at 24 GHz with bandwidth B=200 MHz. The two stations are located L km away and the antennas are both placed on top of 15 m high towers. The gain of both antennas is G=30 dB, the transmitted power from T is P_T=20 dBm and the equivalent noise temperature of the receiving station is T_{sys}=200 °K.

1) Evaluate the maximum value of L (L_{max}) due to the earth surface curvature
2) Assuming the antennas optimally pointed, evaluate the received power for L=L_{max}.
3) The required value of the signal-to-noise ratio (SNR_{sys}) at R must be ≥ 22 dB. Chose the largest value of L satisfying this requirement and compute the received power and the corresponding value of SNR_{sys}.

Consider the following scheme for the receiving station R:

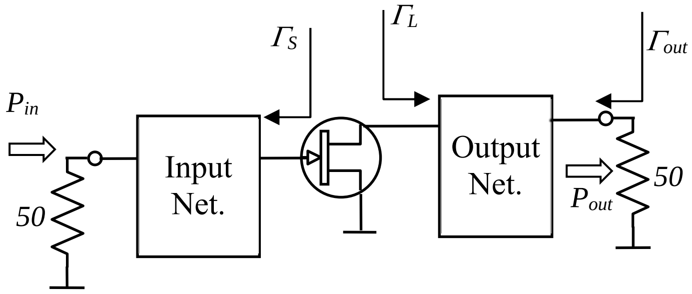


NF_{LNA}=1 dB
T_a=70°K
G_{LNA}=15 dB
A_f=0.5 dB
T_R=? °K

4) Evaluate the equivalent noise temperature of the digital receiver (T_R) compatible with the imposed T_{sys}.
5) Assuming E_b/N_0=20 dB at the receiver output, what is the maximum data rate DR?

Exercise 2

We want design a single stage amplifier at 10 GHz using the scheme in the following figure (input and output networks are lossless):



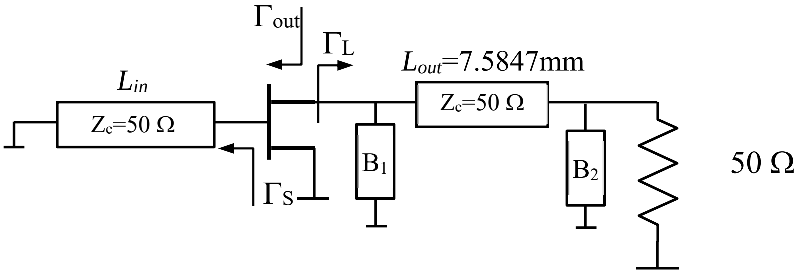
The transistor to be used has the following parameters:
$S_{11}=0.57\angle 166°$ $S_{21}=2.59\angle -21°$ $S_{12}=0.144\angle -50°$ $S_{22}=0.39\angle -148°$
$\Gamma_{opt}=0.435\angle 168°$ $F_{min}=1.15$ dB $R_n=0.095$ (Noise parameters)
3^{th} order Intercept point (IP3): 26 dBm

The amplifier must exhibit the transducer gain as high as possible compatibly with the stability requirement and the noise figure not larger than 2 dB.

1) Select a proper value for Γ_S and Γ_L in order to satisfy the above requirements
2) Select as desired the topology of the input network and evaluate the values of the components
3) Assuming at input a 2-tone signal (f_0=10 GHz, Δf=200 MHz) with available mean power (Pin) equal to 0 dBm, evaluate the output mean power Pout. Compute also the power at each intermodulation frequency (specify the value of these frequencies)

Exercise 3

We want to design the oscillator in the figure operating at 10 GHz. Assume the transmission lines (TEM) filled with a dielectric material having ε_r=2.2.



The S parameters of the active device at 10 GHz are given in the following table as function of the bias current:

Ibias	S11	S12	S21	S22
5 mA	0.745 ∠ -162.9°	0.063∠-7.1°	1.875∠25.1°	0.602∠-119.6°
10 mA	0.76∠-145°	0.06∠-1.2°	1.92∠43.6°	0.603∠-105.3°
15 mA	0.864∠-93.4°	0.064∠27.4°	2.545∠93.8°	0.627∠-64.2°

1) Select the bias current (checking the necessary condition for the oscillation)
2) Imposing $|\Gamma_{out}|$=1.1, evaluate the required Γ_S and the length L_{in} of the input line so that the oscillation can start.
3) Compute the reflection coefficient Γ_L to be presented at the transistor output and design the output network (i.e. evaluate the susceptances B_1 and B_2)

Solution

Exercise 1

The maximum value of L in Km is given by $L_{\max} = 3.57 \cdot \left(\sqrt{H_1} + \sqrt{H_2}\right)$ with $H_1=H_2=15$m. It is found $L_{max}=27.65$ Km.
The received power at R is obtained from the Friis equation (in logarithmic units):
$P_R = P_T - 20 \cdot \log\left(\frac{4\pi L}{\lambda}\right) + 2G$ with $\lambda=c/f_0=12.5$mm. Replacing we get: $P_R=-68.78$ dBm.
The signal-to-noise ratio is defined as $SNR_{sys}=P_R/P_N$, with $P_N=KT_{sys}B=5.52\cdot10^{-13}$ (-92.58 dBm) the noise power at R. Imposing SNRsys=22 dB we get $P_R=P_N\cdot SNR_{sys}=-70.58$ dBm. Replacing in the Friis equation the value of L can be derived: L=33.615 Km. This value is however largen than L_{max}, so the maximum value of L that can be chosen is $L=L_{max}=27.65$ Km. For this value we get $P_R=-68.78$ dBm and $SNR_{sys}=-68.78+92.58=23.8$ dB.

The expression of T_{sys} as function of the receiving front-end parameters is given by:
$T_{sys} = T_a + T_f + a_f T_{LNA} + \frac{a_f T_R}{g_{LNA}}$ with $a_f = 10^{A_f/10}$, $T_f = 293 \cdot \left(a_f - 1\right)$, $T_{LNA} = 293 \cdot \left(10^{NF_{LNA}/10} - 1\right)$, $g_{LNA} = 10^{G_{LNA}/10}$.
Deriving T_R we get: $T_R = \frac{g_{LNA}}{a_f}\left(T_{sys} - \left(T_a + T_f + a_f T_{LNA}\right)\right) = 257.22\ °\text{K}$.
We know that $SNR_{sys}=(E_b/N_0)(DR/B)$. Then, it has $DR=B\cdot SNR_{sys}/(E_b/N_0)=479.77$ Mbit/sec.

Exercise 2

After entering the transistor parameters in the S.C. we found that the device in potentially instable with Gmax=12.549 dB.
As the problem requires as minimum noise figure NF=2 dB, we draw on the S.C. the corresponding noise figure circle. Then we look for a point (Γ_S) on this circle determining the largest Available Gain (G_{AV}). This point is the one where the circle with constant G_{AV} is tangent to the circle with constant NF. It is found $\Gamma_S=0.648\angle -157.34°$ and $G_{AV}=11.825$ dB.
The value of Γ_L is obtained by imposing the conjugate matching at the transistor output. Using the S.C. we get $\Gamma_L=0.609\angle 174.95°$. Once this is imposed, it has $G_T=G_{AV}=11.825$ dB.

A single stub network can be easily designed for the input network:
The value of Γ_S is entered in the S.C. and stored in memory. The circle with constant gamma passing through the current point is drawn together with the circle with g=1. The first intersection of the two circles in the direction of the load is selected and the phase in the Delta Gamma tab gives the length of the transmission line: $\Phi=27.07/2=13.535°$. The imaginary part of Y (current point) gives the value of b=1.695.

The value of Pout is given by Pout=Pin+G_T=11.825 dBm. The power in each line is P_0=11.825-3 = =8.825 dB. The power in the intermodulation lines is computed by the following formula:
Pint=3P_0 -2IP3=-25.525 dBm.

Exercise 3

The bias selection is carried out by checking the oscillation condition (potential instability). It is found that only for IB=15mA this condition is verified.

To select Γ_S, we draw the source mapping circle with $|\Gamma_{out}|=1.1$. Being Γ_S generated by a lossless network (the short-circuited stub), the point to be selected on this circle must be on the intersection with the outer circle ($|\Gamma_S|=1$). We have selected $\Gamma_S=1\angle 89.78°$. Being generated by a S.C. stub, it holds true $\Gamma_S=\exp(\pi-2\phi_{in})$, where ϕ_{in} is the electrical length of the line: $\phi_{in}=\beta L_{in}=(\pi-\phi_S)/2$. From this latter we get: $L_{in}=\frac{\phi_{in}}{\beta}=\frac{c}{f_0\sqrt{\varepsilon_r}}\frac{\pi-\phi_S}{4\pi}=2.534$ mm.

Once Γ_S is assigned, the value of Γ_{out} can be obtained by the S.C.: $\Gamma_{out} = 1.1 \angle{-137.25°}$. y_{out} is also available: $y_{out}=-0.346+j2.514$. We then assign $y_L=-g_{out}/3-b_{out}=0.115-j2.514$, which corresponds to $\Gamma_L=0.969\angle 136.688°$.

The design of the output network starts drawing the circle g=1 rotated by $2\beta L_{out}=270°$ in the source direction, together with the circle with g=const passing trough Γ_L. The value of Γ_L is then entered and stored in memory. We select the first intersection between the two circles and read the value in the Delta Y tab (imaginary part). This value, with the sign reversed, represents $b_1=-3.98$. We then move the current point in the load direction by 270° and get as new current point y=1-j5.049. The value of b_2 is the imaginary part of y: $b_2=-5.049$.