RF SYSTEMS
9 July 2019

Surname & Name
Identification Number
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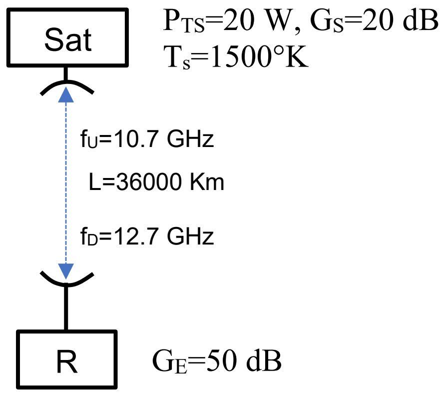
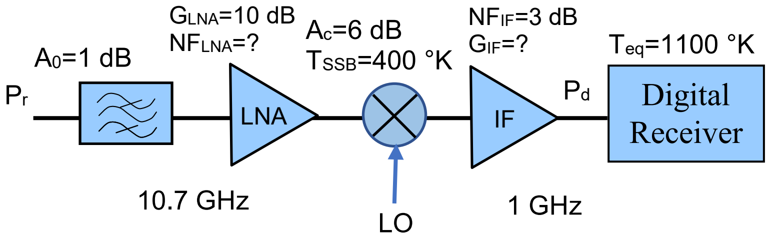
Exercise 1 (11)
Consider the bi-directional satellite link in the figure (f_U: Earth-to-Satellite, f_D: Satellite-to-Earth). The satellite parameters are given (Transmitter power P_T, Antenna Gain G_S, Equivalent Noise Temperature of the receiving system T_S). The Earth station has only the antenna gain G_E assigned. The required data rate R must be 100 Mb/sec with E_b/N_0=15 dB and B=36 MHz for both up and down link.



1) Evaluate the SNR that must be guaranteed by the receivers of satellite and Earth Station
2) Compute the required transmitted power from the earth station
3) Compute the required Equivalent Noise Temperature of the earth receiver

Exercise 2 (11)

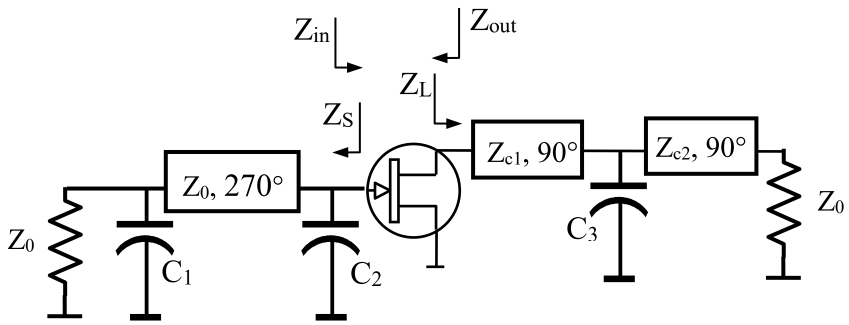


The scheme in the figure represents the receiver on board of the satellite (previous exercise).
The digital receiver guarantees E_b/N_0=15 dB with the input power $P_d \geq$-60 dBm.

1) Evaluate the gain of the IF amplifier in order to satisfy the constraint on P_d
2) Evaluate the two possible frequencies of the local oscillator. For each LO frequency specify the corresponding image frequency.
3) Draw the equivalent noise temperature scheme of the receiver (including the contribution from the antenna Ta=300 °K)
4) Write the expression of the noise temperature at the receiver input (T_S)
5) Compute the Noise figure NF_{LNA} of the low noise amplifier in order T_S is equal to the value specified in the previous exercise (1500 °K)
6) Can LNA be removed from the receiver by suitably decreasing T_{SSB}? Justify the answer quantitatively!

Exercise 3 (11)

The following scheme represents a power amplifier (PA) operating at 2 GHz. The matching networks are required to present at input and output of the amplifier the optimum loads Z_S and Z_L, which determine the conjugate matching condition. The amplifier is then unconditionally stable, and the transducer gain G_T is equal to 6 dB. P_{1dB} of the transistor is 50 W.



$Z_S=(Z_{in})^*=(20\text{-}j35)\ \Omega$
$Z_L=(Z_{out})^*=(2+j4)\ \Omega$
$Z_0=50\ \Omega$
$Z_{c1}=20\ \Omega$
$Z_{c2}=?$
C_1, C_2, C_3=?

1) Design the two networks (i.e. compute C_1, C_2, C_3, Z_{c2}). Hints: The networks can be assumed as matching networks that transform Z_{in} and Z_{out} into 50 Ohm respectively. Note that Z_S and Z_L are actual values (NOT normalized).
2) Assume a 2-tone as input signal. Compute the amplifier back off required for the carrier-to-intermodulation at output (CI) equal to 30 dB (assume Δ_P=9 dB).
3) Compute the PEP and average power at amplifier output
4) The PA is operating in class AB. With the 2-tone signal at input the DC current absorbed from the bias source is 2.5 A (with Vcc=16 V). Evaluate the Power Added Efficiency (PAE) of the amplifier

Solutions

Exercise 1

The SNR is given by:

$$SNR = \frac{E_b}{N_0}\frac{R}{B} = 87 \quad (19.3952 \text{ dB})$$

The noise power at the satellite receiver is given by:

$$N_S = KT_SB = 7.45 \cdot 10^{-13} W$$

Then the received power P_S must be: $P_S = N_S \cdot SNR = 6.55 \cdot 10^{-11}$ W.

Using the Friis equation we obtain the transmitted power from the Earth Station:

$$P_{TE} = \frac{P_S}{G_S G_E}\left(\frac{4\pi L}{\lambda_U}\right)^2 = 1704.2 \text{ W}$$

where λ_U is given by $c/f_U = 0.028$ m.

The Friis equation for the down link determines the Teq of the Earth receiver:

$$N_E = \frac{P_E}{SNR} = \frac{P_{TS} G_S G_E}{SNR}\left(\frac{\lambda_D}{4\pi L}\right)^2 = 6.2079 \cdot 10^{-15} \text{ W}$$

$$T_E = \frac{N_E}{KB} = 12.4957 \text{ °K}$$

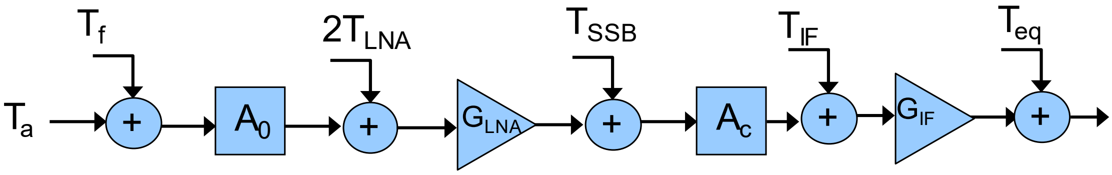
Exercise 2

The received power in dBm at the satellite receiver is P_{RS}=-71.84 dBm (from the previous exercise).
The gain GIF is obtained by imposing Pd=-60 dBm:

$$P_d = P_{RS} - A_0 + G_{LNA} - A_c + G_{IF} = -60 \text{ dBm} \quad \rightarrow \quad G_{IF} = 8.84 \text{ dB}$$

The possible local oscillator frequencies are given by
$f_{LO}=f_{up}\pm 1$ GHz=(9.7 GHz, 11.7 GHz)
The image frequencies are then:
$f_{IM1}=f_{LO1}-1$ GHz=8.7 GHz, $f_{IM2}=f_{LO2}+1$ GHz=12.7 GHz,

Equivalent scheme (the factor 2 in front of TLNA takes into account the image noise at the amplifier output):



The expression of T_{sys} results:

$$T_{sys} = T_a + T_f + 2T_{LNA}A_0 + \frac{A_0}{G_{LNA}}\left(T_{SSB} + T_{IF}A_c\right) + \frac{T_{eq}A_0A_c}{G_{LNA}G_{IF}}$$

Equating the above expression to the previously computed values we get the following expression for T_{LNA}:

$$T_{LNA} = \frac{1}{2A_0}\frac{A_0\left(T_{SSB} + T_{IF}A_c\right)}{T_{sys} - \left(T_a + T_f + \frac{T_{SSB}A_0}{G_{LNA}} + \frac{T_{eq}A_0A_c}{G_{LNA}G_{IF}}\right)} = 343 \ \text{°K}$$

$$NF = 10\cdot\log 10\left(1 + \frac{T_{LNA}}{293}\right) = 3.3659 \text{ dB}$$

Removing the amplifier the expression for T_{sys} becomes:

$$T_{sys} = T_a + T_f + A_0\left(T'_{SSB} + T_{IF}A_c\right) + \frac{T_{eq}A_0A_c}{G_{IF}} = 2477.4 + A_0T'_{SSB} = 1500$$

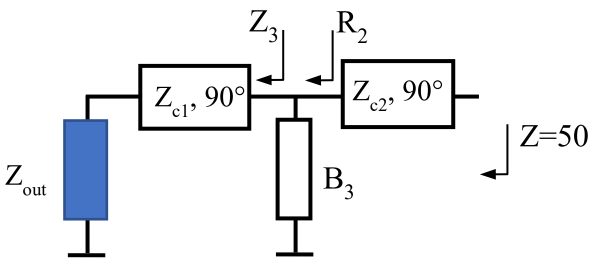
Obviously, this equation has no positive solution for T'_{SSB}, so the LNA cannot be removed.

Exercise 3

The first network is a double stub with load given by Zin=20+j35. Using the Smith Chart we get for C_1 and C_2:

$B_1=0.786\cdot 0.02=0.0157$ → $C_1=B_1/(2\pi f_0)=1.25$ pF
$B_2=1.568\cdot 0.02=0.0314$ → $C_2=B_2/(2\pi f_0)=2.495$ pF

For the second network, let consider the impedance Z_3 at the input of line 1 (loaded by Zout=(2-j4) Ohm:



$$Z_3=\frac{Z_{c1}^2}{Z_{out}}=\frac{400}{2-j4}\Rightarrow Y_3=\frac{1}{Z_3}=5\cdot 10^{-3}-j0.01$$

The susceptance B3 must cancel the imaginary part of Y_3 so that the impedance Z_2 is real (R_2):

$$Z_2=Y_3+jB_3=\frac{1}{R_2}\Rightarrow B_3=j0.01,\ R_2=\frac{1}{5\cdot 10^{-3}}=200\Omega$$

The capacitance C_3 is then given by: $C_3=B_3/(2\pi f_0)=0.796$ pF.
The resistance R2 is transformed into 50 Ohm by selecting Z_{c2} as follows:
$50=Z_{c2}^2/200\Rightarrow Z_{c2}=100$ Ohm

$$BO=\frac{CI}{2}-\Delta_p-3=3\text{ dB}$$
$$\mathrm{P}_m=P_{1dB}-BO=25\text{ W},\quad PEP=P_m+3=50\text{ W}$$
$$P_{in}=P_m-G_T=6.25\text{ W},\ P_{DC}=16\cdot 2.5=40\text{ W}$$
$$PAE=\frac{P_m-P_{in}}{P_{DC}}=0.4688$$