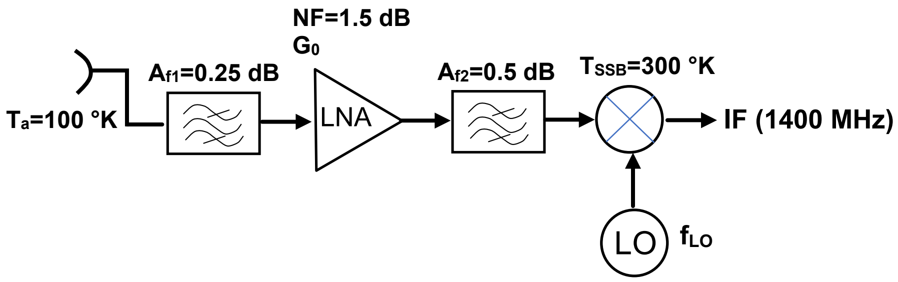
RF SYSTEMS –Midterm test
8 November 2022

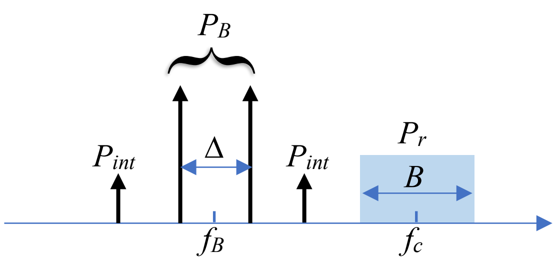
Surname & Name
Identification Number
Signature

Exercise 1 (10 points)



The scheme in the figure refers to the RF frontend of a receiver operating in 9.8-10.2 GHz band. The 64QAM modulation is used, with roll-off factor α=0.34 and data rate R=34 Mbit/sec. The receiver sensitivity is S=-84 dBm (for E_b/N_0=15 dB). The filters are assumed with infinite attenuation in the stopband.

1. (1p) Evaluate the signal bandwidth (B) and specify the minimum passband width of the filters
2. (1p) The IF frequency is f_{IF}=1.4 GHz and the local oscillator frequency is above the signal band. What are the limits of the image band? Consider the signal channel tuned at f_c=10 GHz; what is the frequency of the local oscillator?
3. (2p) Draw the scheme for the noise temperature evaluation and write the expression of the equivalent noise temperature of the receiver defined at the input (T_{eq}). Note that T_{eq} depends on G_0 whose value is not given.
4. (2p) Evaluate the minimum value of G_0 (LNA gain) necessary to satisfy the quality requirement of the receiver. Assume T_0=293 K. (Hint: this requirement is represented by the signal-to-noise ratio (SNR) of the receiver with the signal power at the antenna output equal to S)

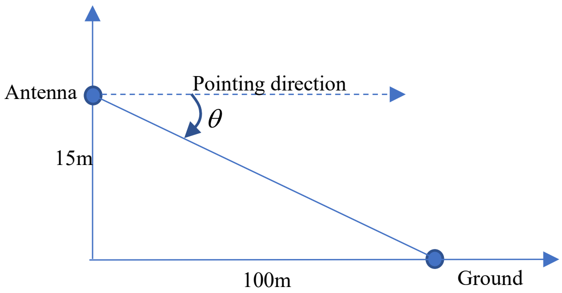


Consider now a blocking signal received by the antenna (in addition to the signal in the tuned channel at f_c=10 GHz). The blocking signal is constituted by two tones of equal amplitude, separated by Δ=40 MHz and centred at f_B. The average power of the two tones is P_B=-20 dBm. Due to the non-linearity of the RF frontend (represented by the 3rd order intercept power IIP3 defined at the receiver input), two intermodulation lines are produced at IF (the overall spectrum reported at the receiver input is shown in the above figure). When the upper intermodulation line falls inside the channel band, the quality of the demodulated information is degraded (the intermodulation behaves like a noise).

5. (1p) Evaluate the minimum value of f_B so that the upper intermodulation line is inside the band of the channel centred at f_c=10 GHz.
6. (1p) Evaluate the power of the blocking signal (the received two tones) at the output of the mixer (assume the conversion loss of the mixer L_c=6 dB)
7. (2p) The system SNR with the intermodulation line inside the signal band is defined as SNR'=$P_r/(P_N+P_{int})$, where P_N is the noise power referred to the input of the receiver and P_{int} the power in the upper intermodulation line (referred to the input). If the quality of the demodulated signal must remain unchanged (i.e., it is the same as when the blocking signal is absent), the power of the signal received at the input (P_r) must be increased (with respect to S). Imposing the value of SNR' equal to the one obtained without the blocking signal (SNR=$S/KT_{eq}B$), compute the required value of P_r (assume IIP3=20 dBm).

Exercise 2 (5 points)

A transmitting antenna for aircrafts communications operates at 1215 MHz and it is placed on top of a tower 15m height. It is pointed in the direction parallel to ground. The urban environment in which the antenna is located imposes strict rules regarding electromagnetic pollution. In particular, the magnitude of the electric field (E) at 100m (on ground) from the antenna must not exceed 1 V/m.



The antenna is omnidirectional around the pointing direction, so the directivity function depends only on the angle θ in the figure: $f(\theta)=\cos^4(\theta)$ for $0<\theta<90°$, $f(\theta)=0$ elsewhere.

1. (2p) Assuming the efficiency η=0.8, evaluate the gain G of the antenna. Hint:

$$\int \cos^4(x)\sin(x)\,dx = -\frac{\cos^5(x)}{5}$$

2. (3p) Compute the maximum power transmitted by the antenna (P_T) so that the magnitude of the electric field (|E|) does not exceed 1V/m at 100m from the antenna (on ground).

Solutions

Exercise 2

The gain of the antenna is given by $G = \frac{4\pi\eta}{\int_0^{\pi}\int_0^{2\pi} f(\theta)\sin(\theta)\,d\theta\,d\varphi} = \frac{2\eta}{\int_0^{\pi/2} \cos^4(\theta)\sin(\theta)\,d\theta} = \frac{1.6}{0.2} = 8$

The power density of a plane wave in the free space can be expressed as $S_R = \frac{1}{2}\frac{|\mathbf{E}|^2}{Z_W}$ with Z_W=377 Ω (intrinsic impedance of vacuum). Equating this expression to the one of the radiated power density from an antenna we found: $S_R = \frac{P_T G}{4\pi R^2} f(\theta) = \frac{1}{2}\frac{|\mathbf{E}|^2}{Z_W}$. The transmitted power can then be derived: $P_T = \frac{2\pi R^2 |\mathbf{E}|^2}{Z_W G \cos^4(\theta)}$. The angle θ is computed from the figure: θ=$\tan^{-1}$(15/100)=8.53°. The distance between the antenna and the point on the ground is $R = \sqrt{100^2 + 15^2} = 101.12\text{m}$. Replacing |E|=1, R=101.12, G=8 and θ=8.53° in the above formula we get finally P_T=22.27 W.

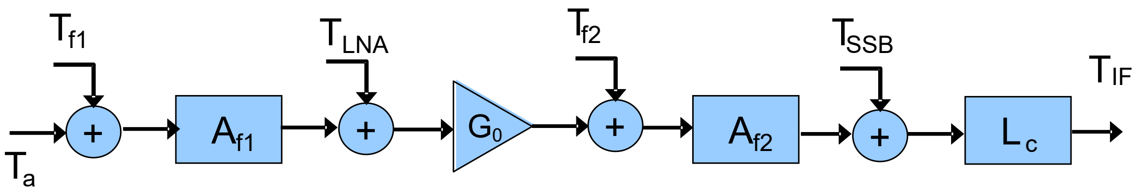
Exercise 1

T_a=100 K; a_{f1}=1.0593; t_{f1}=17.3613 K; t_{lna}=120.8735 K; a_{f2}=1.122; t_{f2}=35.7514; t_{ssb}=300 K.
M=64; R=34e6; S=$3.98 \cdot 10^{-12}$; E_b/N_0=31.6228.
f_{IF}=1.4 GHz

The signal band for an M-QAM signal is given by $B=R\cdot(1+\alpha)/\log_2(M)$=7.5933 MHz.
The filters must leave to pass all the signals in the tuning band. Then their bandpass width coincides with the tuning band (400 MHz).

When the local oscillation frequencies are above the tuning band, the image band frequencies (f_I) are related to the tuning band frequencies (f_S) by: $f_I = f_S + 2\cdot f_{IF}$. Replacing the limits of the tuning band, the image band is obtained: 12.6 – 13.00 GHz. The local oscillator frequency is given by $f_{LO}=f_c+ f_{IF}$=11.4 GHz.

To evaluate the equivalent noise temperature, we refer to the following scheme for the noise sources (infinite attenuation of the filters in the stopband completely removes the noise contributions from the image band):



Reporting each source at the input we get:

$$T_{eq} = T_a + T_{f1} + T_{LNA} a_{f1} + \left(\frac{T_{f2} a_{f1} + T_{SSB} a_{f1} a_{f2}}{g_0} \right) = 245.4 + \frac{394.42}{g_0}$$

The SNR at the input with the signal power equal to the receiver sensitivity is given by

$$SNR = S / \left(K T_{eq} B \right) = \frac{R}{B} \frac{E_b}{N_0} = 4.48 \cdot 31.6230 = 141.59 \text{ (21.51 dB)}$$

We can then derive: $T_{eq} = \dfrac{S}{K \cdot B \cdot SNR} = 268.31K$. Replacing T_{eq} in the above equation we obtain finally $g_0 = \dfrac{394.42}{T_{eq} - 245.4} = 17.21 \; (G_0 = 12.35 \text{ dB})$

To have the intermodulation line inside the signal band we must have: $f_B+1.5\Delta > f_c - B/2$, from which: $f_B > f_c - B/2 - 1.5\Delta$=9.936 GHz.

The power of the blocking signal at IF is given by (in dBm)

$$P_{B,IF} = P_B - A_{f1} + G_0 - A_{f2} - L_c = -14.35 \text{ dBm}$$

The power in each intermodulation line is given by:

$$P_{\text{int}} = 3\left(P_B - 3\right) - 2IIP_3 = -69 - 40 = -109 \text{ dBm } (1.26 \cdot 10^{-14} \text{ W})$$

The noise power at the input is $P_N = KT_{eq}B = 2.81 \cdot 10^{-14}$ W

Imposing SNR'= $P_r/(P_N+P_{int})$=141.59 we can derive P_r=$141.59 \cdot 4.072 \cdot 10^{-14}$=$5.77 \cdot 10^{-12}$ W (-82.39 dBm).