ICS905 - Fundamentals in AMS & RF Electronics (FARE)

M2 ICS - Scholar Year 2023-2024(S1)

ICS905 - Exam

Duration 1h30 - Documents and calculator are allowed

Exercises

All exercises are independent.

Direction de la Formation Initiale
Département Communications et Électronique
École Nationale Supérieure des Télécommunications

Exercise 1 - Elements of communication theory and RF systems

The subsections of this exercise (1.1,1.2) can be treated independently

1.1 Complex baseband representation

Consider the following two passband signals :

$$u_p(t) = \sqrt{2}\,\mathrm{sinc}(2t)\cos(100\pi t) \tag{1}$$

$$v_p(t) = \sqrt{2}\,\mathrm{sinc}(t)\sin\left(101\pi t + \frac{\pi}{4}\right) \tag{2}$$

with :

$$\mathrm{sinc}(t) = \frac{\sin(\pi t)}{\pi t}, \qquad \text{the so-called normalized sinc function.} \tag{3}$$

Question 1.1 Find the complex envelopes $u(t)$ and $v(t)$ for $u_p(t)$ and $v_p(t)$, respectively, with respect to the frequency reference $f_c = 50$.

Question 1.2 What is the (bilateral) [1] bandwidth of $u(t)$?

Question 1.3 Using a graphical approach, sketch the spectrum of $v(t)$.

1.2 Modulation

Consider the pulse

$$p(t) = \begin{cases} 1 - \frac{|t|}{T}, & 0 \leq |t| \leq T, \\ 0 & \text{else.} \end{cases} \tag{4}$$

Let $P(f)$ denote the Fourier transform of $p(t)$.

Question 1.4 **True or False ?** The pulse $p(t)$ is Nyquist at rate $1/T$.

Question 1.5 Recognizing that $p(t)$ is the result of a convolution, give the expression of $P(f)$, the Fourier transform of $p(t)$.

1. Count bandwidth from negative to positive frequencies

Exercise 2 - Reception chain for 5G

The 5[th] generation of mobile communications (5G) specifies that cellular network equipment (mobiles and base stations) could use carriers with bandwidths very varied ranging from 1.4 MHz to 20 MHz. The standard also specifies the possibility of aggregating up to eight channels allowing you to achieve in certain conditions operating a downstream rate greater than 3 Gbits/s. We will focus in

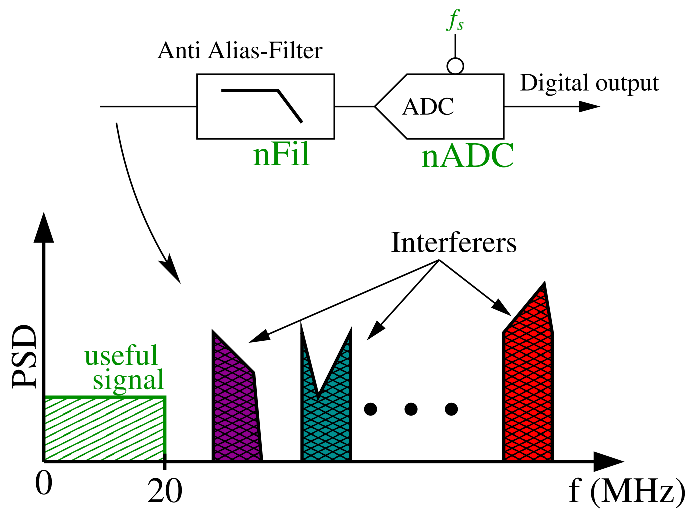

FIGURE 1 – 5G baseband signal acquisition chain

this exercice on the study of the baseband sub-part of a reception chain adapted to a 20 MHz band channel. As shown in figure 1, the baseband blocks are the anti-aliasing filter and the analog-to-digital converter (ADC).

Our goal is to optimise the chain parameters in order to obtain the lowest possible power consumption. We will be able to intervene on the following three parameters :

- the sampling frequency of the ADC f_s
- the order of the filter n_{fil}
- the number of bits of the ADCs n_{ADC}

The specifications require us to have a SNR greater than 68 dB at the ADC output and an attenuation greater than 50 dB for interferers which can corrupt the useful signal because of folding. Furthermore, the maximum attenuation within the passband must be less than 1 dB.

Question 2.1 Most modulation schemes require SNR lower than 42 dB to be decoded at sufficiently good BER. Explain why such a high SNR is needed here[2]. As an extension to your analysis, explain how a variable gain amplifier could reduce this constraint.

We decide to investigate three possibilities for f_s : 50 MHz, 200 MHz and 800 MHz.
For each value of f_s, we determine the values of n_{fil} and n_{ADC} that satisfy the specifications. This will allow us to compare the three solutions using the following metrics to evaluate power consumption :

$$P_{fil} = n_{fil} \times 5 \times 10^{-3} \quad [\text{W}]$$
$$P_{ADC} = 2^{n_{ADC}} \times f_s \times 5 \times 10^{-14} \quad [\text{W}]$$

Question 2.2 Plot the anti-aliasing filter template for the three possible values of f_s. The stop frequency f_2 should be set as the smallest frequency that could fold on the useful band for the 3 possible f_s.

Question 2.3 Determine the value of the selectivity criterion Ω_s for the three values of f_s

We decide to use a Tchebycheff approximation for the anti-aliasing filter. The Tchebycheff polynomials are expressed by :
$\forall x \geq 1, T_n(x) = \text{ch}(n\,\text{argch}(x))$, where ch represents the hyperbolic cosine and argch the inverse hyperbolic cosine[3], reciprocal of the function ch.

2. Please pay attention to the particular architecture under consideration and the target application.
3. $\text{argch}(x) = \ln\left(x + \sqrt{x^2-1}\right)$ for $x \geq 1$

Question 2.4 Deduce the order of the filter required in the three cases.

Now let us analyze the ADC. We decide to attribute 25% of the overall noise budget to the ADC.

Question 2.5 Show that the SNR of the ADC should be 74 dB

Let us now determine the number of bits of the ADC. For simplicity, we will assume that the only noise is the quantization noise. We will also assume that the input is an sinusoidal signal which occupies the entire ADC input dynamic range.

Question 2.6 Calculate the theoretical number of bits needed for each value of f_s to meet the specifications. We will round the number up to the next whole number.

Question 2.7 Compare the three solutions in terms of power consumption and conclude

Exercise 3 - RF front-end

Question 3.1 For a power amplifier (PA), explain the following :
- What is the 1 dB compression point ?
- What is the Adjacent Channel Power Ratio (ACPR) ?

Question 3.2 For a low noise amplifier (LNA), explain the following :
- Which is the role of a LNA at the receiver path of a transceiver ?
- What is the noise factor of a LNA ?

Question 3.3 Consider the transmitter topology shown in Fig. 2. The noise figure of the power amplifier (PA) is NF=2.5 dB, the gain of the PA is G=10 dB and the filter insertion loss is 3 dB. Calculate the following :
- Overall gain
- Overall noise figure

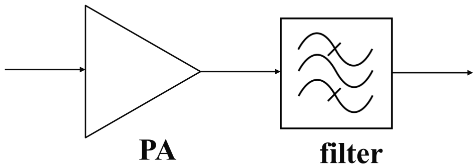

FIGURE 2 – Transmitter topology

Question 3.4 We need to design a power amplifier with an output power of 5 W, a power gain of 10 dB, a drain efficiency of 30 % and a supply voltage of 30 V at 1 GHz. Calculate the following :
- Required input power in dBm : P_{in}
- Power added efficiency : η_{PAE}