AMS and RF functions

M2 ICS - Scholar Year 2019-2020(S1)

ICS905 - Test

Duration 1h30 - Documents and calculator are allowed

Exercises

All exercises are independent.

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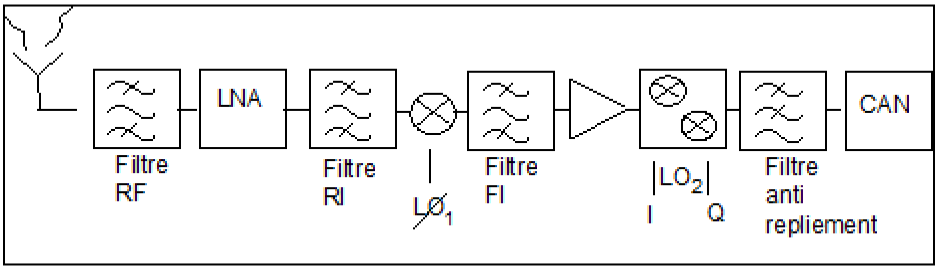
Exercise 1 - Bluetooth receiver

A bluetooth receiver has the following specifications :
— Receiving band : [2400 MHz ; 2479 MHz] ;
— Channel spacing : 1 MHz ;
— Sensitivity : - 70 dBm.
We will use a heterodyne type receiver as shown in the figure below.



The chosen intermediate frequency is 10 MHz. We have some elements already designed and the purpose of this exercise is to choose a few elements from those proposed.

Question 1.1 The RF filtering, corresponding to the filters noted "filtre RF" and "filtre RI", is to be chosen from :
- F1 : Central frequency = 2450 MHz / Bandwidth = 100MHz ;
- F2 : Central frequency = 2400 MHz / Bandwidth = 200MHz ;
- F3 : Central frequency = 2450 MHz / Bandwidth = 30MHz ;
- F4 : Central frequency = 2400 MHz / Bandwidth = 500MHz.

Indicate and justify the choice of the RF filtering.

Answer 1.1

Question 1.2 The low noise amplifier, LNA, is to be chosen from :
- LNA1 : Noise Figure = 2dB, Gain = 30dB or 0dB, Input signal frequency around 2.4GHz ;
- LNA2 : Noise Figure = 5dB, Gain = 20dB or 0dB, Input signal frequency around 2 GHz.

Indicate and justify the choice of LNA.

Answer 1.2

Question 1.3 The intermediate frequency filter, "Filtre FI" is to be chosen from :
- FI1 : Central frequency = 10 MHz / Bandwidth = 300KHz ;
- FI2 : Central frequency = 10 MHz / Bandwidth = 1MHz ;
- FI3 : Central frequency = 25 MHz / Bandwidth = 2MHz ;
- FI4 : Central frequency = 25 MHz / Bandwidth = 100MHz.

Indicate and justify the choice of the IF filter.

Answer 1.3

Exercise 2 - PLL phase noise

A phase locked loop (PLL) with an integer N frequency divider is used for the receiver local oscillator.

Firstly, the phase noise of the PLL is considered only linked to the controlled oscillator of the loop. This is given, in the frequency band considered in the vicinity of the synthesized frequency f_o, by :

$$L(\Delta f) = -80 - 20\,\log_{10}(\Delta f)$$

where L is expressed in dBc/Hz and Δf is the deviation from f_o in kHz.

To simplify the analysis, we will assume throughout the exercise that the loop is of the first order (loop filter $H = 1$) and we will denote by K the loop gain

Question 2.1 What type of filtering is carried out by the PLL on the phase noise of the controlled oscillator ?

Answer 2.1

$$T_o = \frac{\Theta_o}{\Theta_{vco}} = \frac{N \cdot p}{p \cdot N + K} = \frac{p}{p + \omega_c} \qquad \omega_c = \frac{K}{N} = 2\,\pi\, f_c$$

C'est un filtrage passe-haut de gain unitaire et de fréquence de coupure f_c

Question 2.2 Knowing that the PLL has a cutoff frequency $f_c = 10\ kHz$, deduce the phase noise at the loop output for $\Delta f = 100kHz$.

Answer 2.2 $\Delta f\ >>\ f_c$, le bruit de phase en sortie est quasiment identique à celui de l'oscillateur contrôlé : $S_o(f) = S_{vco}(f) \cdot |T_o(f)|^2 \approx S_{vco}(f)$

$$L_o = -80 - 20\ \log_{10}(100) = -120\ dBc/Hz$$

The reference frequency is provided by a crystal oscillator which has a phase noise $L_r = -130\ dBc/Hz$ at $\Delta f = 10kHz$ of the reference frequency. The PLL uses a frequency divider by N = 30.

Question 2.3 What type of filtering is carried out by the PLL on the phase noise of the reference oscillator ?

Answer 2.3

$$T_r = \frac{\Theta_o}{\Theta_r} = \frac{N \cdot K}{p \cdot N + K} = N \cdot \frac{\omega_c}{p + \omega_c} \qquad \omega_c = \frac{K}{N} = 2\,\pi\, f_c$$

C'est un filtrage passe-bas de fréquence de coupure f_c et de gain N.

Question 2.4 Compare, at the output of the PLL and at $\Delta f = f_c = 10kHz$ of the frequency f_o, the phase noise of the reference to that of the controlled oscillator.

Answer 2.4 Pour l'oscillateur contôlé on a pour $f = f_c$:

$$S_1(f_c) = S_{vco}(f_c) \cdot |T_o(f_c)|^2 = \frac{S_{vco}(f_c)}{2}$$

$$L_1 = -80 - 20\ \log_{10}(10) - 10\ \log_{10}(2) \approx -103\ dBc/Hz$$

Pour l'oscillateur de référence on a :

$$S_2(f_c) = S_r(f_c) \cdot |T_r(f_c)|^2 = N^2\, \frac{S_r(f_c)}{2}$$

$$L_2 = -130 + 20\ \log_{10}(N) - 10\ \log_{10}(2) \approx -103,5\ dBc/Hz$$

Les deux bruits de phase sont comparables

Exercise 3 - Digital modulation

3.1 Generalities about OFDM

Question 3.1 What is the main feature of cyclic prefix in OFDM systems and what is its requirement ?

Answer 3.1 The cyclic prefix :

- provides a guard interval to eliminate intersymbol interference from the previous OFDM symbol.
- it guaranties the orthogonality of the sub-carriers on frequency-selective multipath channels because, the linear convolution with the channel response can be modeled as circular convolution, which in turn transforms to simple multiplication via a discrete Fourier transform.

Its length should be slightly greater than the channel delay spread.

Question 3.2 In the previous answer, you should have stated the minimal length of the cyclic prefix ; discuss the effect of oversizing the cyclic prefix ? [1]

Answer 3.2 The problem of having a lengthy cyclic prefix is that it consumes the useful channel with redundant data ; so oversizing the cyclic prefix reduces the *useful* bit rate since it takes more time to send the amount of information.

Question 3.3 What is the origin of the channel delay spread ? (Explain with words and sketch.)

Answer 3.3 Trivial : multipath...

Question 3.4 What is the main disadvantage of OFDM from the transmitter circuit point of view and the signal dynamics ?

Answer 3.4 The PAPR.

Question 3.5 Basically, an OFDM symbol consists in generating a particular time waveform given its spectral composition. Based on this interpretation, explain how a piano or a guitar can be used as an FDM generator.

Answer 3.5 A piano or a guitar can generate an FDM symbol by hammering several notes at the same time. It is called a *chord* in music theory.

Question 3.6 Based on the previous answer, what is the maximum number of subcarriers that :

— a *normal*[2] piano player can generate.

— a *normal*[3] guitar player can generate using a *normal*[4] guitar.

(In any case, explain your result)

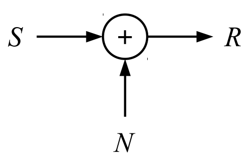
Answer 3.6 The number of available subcarriers is limited either by the number of fingers of the players, either by the instrument.

— A piano player will be limited by his 10 fingers but there are actually as many piano notes as subcarriers.

— A guitar player will be limited by his 5 fingers but there are actually 6 strings on guitar which can all be used as subcarriers.

3.2 Binary digital baseband communication system

Let us consider a simple binary communication system model. It is made up of a signal source which is modeled by a binary random variable S representing the message bit sent. The random variable S can take the values 0 and 1 with equal probability. This signal is degraded by an additive Gaussian noise which is represented by a Gaussian random variable N of zero mean and variance σ^2. The received value is a random variable $R = S + N$. This is illustrated in the figure below :



Question 3.7 You must have noticed that the probability law of S is a discrete law. However, for the rest of the exercise, we need to write it as a distribution. Give the expression of $\mathbb{P}_S(s)$, the probability distribution of S, using Dirac delta distributions $\delta(\cdot)$.

Answer 3.7

$$\mathbb{P}_S(s) = \frac{1}{2}\,\delta(s) + \frac{1}{2}\,\delta(s+1) \tag{1}$$

1. for example, explain its effect on the *useful* bit rate ?
2. Please do not consider special cases like "hammering two notes with only one finger"
3. Please do not consider special cases like "hammering notes with the left hand on the neck"
4. Please consider a classical guitar with six strings

Question 3.8 Given that the probability density of N is :

$$\mathbb{P}_N(n) = \frac{1}{\sqrt{2\pi\sigma^2}} \,\mathrm{e}^{-\frac{n^2}{2\sigma^2}}, \tag{2}$$

give the expression of $\mathbb{P}_{R|S}(r)$ the conditional probability density function of R given a value of $S = s$. [5]

Answer 3.8

$$\mathbb{P}_{R|S}(r) = \mathbb{P}_N(r - s) = \frac{1}{\sqrt{2\pi\sigma^2}} \,\mathrm{e}^{-\frac{(r-s)^2}{2\sigma^2}} \tag{3}$$

Question 3.9 Find $\mathbb{P}_R(r)$ the probability density function of R. [6]

Answer 3.9

$$\begin{aligned}
\mathbb{P}_R(r) &= \mathbb{P}_{R|S=1}(r)\,\mathbb{P}_S(s=1) + \mathbb{P}_{R|S=0}(r)\,\mathbb{P}_S(s=0) && (4)\\
&= \mathbb{P}_N(r-1) \times \frac{1}{2} + \mathbb{P}_N(r) \times \frac{1}{2} && (5)\\
&= \frac{1}{2\sqrt{2\pi\sigma^2}} \left[\mathrm{e}^{-\frac{(r-1)^2}{2\sigma^2}} + \mathrm{e}^{-\frac{(r)^2}{2\sigma^2}}\right] && (6)
\end{aligned}$$

5. You can begin by writing $\mathbb{P}_{R|S=0}(r)$ and $\mathbb{P}_{R|S=1}(r)$, and then $\mathbb{P}_{R|S}(r)$
6. Remember the law of total probability : $\mathbb{P}(A) = \sum_n \mathbb{P}(A \mid B = b_n)\mathbb{P}(B = b_n)$