TELECOM 201

Introduction to transceiver specifications

1 Reminders (or not) ?

Signal Power in a resistor

$$P_{lin} = \frac{V^2}{R}$$

Power in dBm

$$P_{dBm} = 10 \cdot \log(\text{Power in mW})$$

Relation between Power and Power Spectral Density (PSD)

$$P_{lin} = \int_{Bw} PSD_{lin} \cdot df$$

In case, the signal or noise distribution is uniform in the band

$$P_{lin} = PSD_{lin} \cdot Bw$$

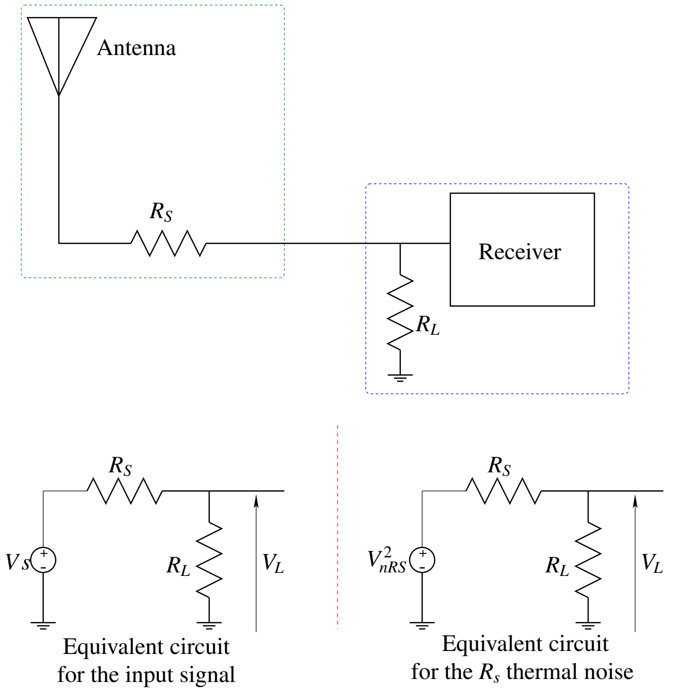
In dBm

$$P_{dbm} = PSD_{dBm/Hz} + 10 \cdot log_{10}(Bw)$$

2 How to optimise power transfer ?

Question 2.1 *Calculate the power at the receiver input P_{in}.*

Réponse 2.1 It is important to remind that the source resistor R_S and the load resistor R_L are not real physical resistors. They are equivalent resistors for the antenna and the receiver input resistance.



$$PSD_{nRs} = V^2_{nRS\ in\ 1\ Hz} = 4KTR_S$$

FIGURE 1 – Equivalent model of the receiver front-end

The power at the receiver input is given by :

$$P_L = \frac{V_L^2}{R_L}$$

V_L is given by

$$V_L = \frac{R_L}{R_L + R_S} V_s$$

Replacing V_L in P_L, we obtain

$$P_L = \frac{R_L}{(R_L + R_S)^2} V_s^2$$

Question 2.2 *Let $\alpha = \frac{R_L}{R_S}$, determine α that allows to maximize P_{in} for a given R_S*

Réponse 2.2 By replacing R_L by αR_S

$$P_L = \frac{\alpha}{(1+\alpha)^2} \frac{V_s^2}{R_S}$$

It is easy to demonstrate that the maximum of P_L is obtained for an $\alpha = 1$. So the optimum matching is obtained for $R_L = R_S$, this is called impedance matching, as we are sizing R_L to be equal to R_S. The most common value for the R_S impedance is 50 Ω but values such as 75 or 100 are also used in practice.

Question 2.3 *Set α to the value obtained in the previous question, determine the thermal noise PSD at the receiver input.*

Réponse 2.3 To calculate the noise PSD, we use the thermal noise equivalent model and since the noise is white (uniformly distributed in frequency)

$$PSD^2_{noise-L} = \frac{R_L^2}{(R_L + R_S)^2} PSD^2_{noise-R_S} = \frac{PSD^2_{noise-R_S}}{4R_S}$$

$$PSD_{noise-L} = \frac{4KTR_S}{R_S} = KT$$

Question 2.4 *Calculate the noise PSD in dBm/Hz for a temperature of 17 ^oC. (Blotzmann constant K=1.38×10^{-23} J/K)*

Réponse 2.4

$$PSD_{noise} = KT = 290 \times 1.38 \times 10^{-23} = 4 \times 10^{-21} \text{ W/Hz} = 4 \times 10^{-18} \text{ mW/Hz}$$

$$PSD_{noise-dBm} = 10 \log(PSD_{noise-mW}) = -174 \text{ dBm/Hz}$$

This value is very important because it is the lowest value for the thermal noise PSD that can be obtained for a matched system.

Question 2.5 *Chadi claims that he has designed a magnificent receiver : The SNR in a 10 MHz band at his receiver output is 20 dB for an input signal of -90 dBm.*
What do you think about Chadi, are his pants on fire ?

Réponse 2.5 To check if Chadi's claim is true, let us calculate the signal to noise ratio SNR at the receiver input :

$$SNR_{lin} = \frac{P_{Signal-lin}}{P_{noise-lin}}$$

$$SNR_{dB} = 10 \log \left(\frac{P_{Signal-lin}}{P_{noise-lin}} \right) = P_{Signal-dBm} - P_{noise-dBm}$$

The signal power is given, the noise power could be easily calculated as we know the PSD and the bandwidth :

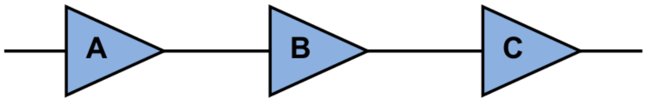
$$P_{noise-lin} = PSD_{noise-lin} \times B$$

$$P_{noise-dBm} = PSD_{noise-dBm/Hz} + 10 \log(B) = -174 + 10 \log(1e7) = -104 \text{ dBm}$$

Hence the SNR at the receiver input is

$$SNR_{dB} = P_{Signal-dBm} - P_{noise-dBm} = -90 + 104 = 14 \text{ dB}$$

Chadi claims that the SNR at the receiver input is 20 dB which is 6 dB higher than the receiver input. This is not possible because the SNR is always[1] degraded in a electronic system and therefore obviously Chadi is a fraud.



Gain (dB)	6.0	12.0	20.0
Gain	4.0	16.0	100.0
Noise Figure(dB)	2.3	3.0	6.0
Noise Factor	1.7	2.0	4.0

Figure 2 – Chain Architecture

3 Noise Figure, what for ! !

Question 3.1 *Calculate the noise figure of the chain ABC using Friis equation*

Réponse 3.1 To calculate the noise floor, we apply Friis equation

$$F_{tot} = F_1 + \frac{F_2 - 1}{G_1} + ... + \frac{F_N - 1}{G_1 \cdot G_2 \cdots G_{N-1}}$$

Hence

$$F_{tot} = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2}$$

$$F_{tot} = 1.7 + \frac{2-1}{4} + \frac{4-1}{4 \times 16} = 2$$

So the noise figure in dB is equal to

$$F_{tot} = 3 \text{ dB}$$

Question 3.2 *Compare the calculated result to the one given by the script AmplifierChain.m*

Réponse 3.2 The simulation gives the same result. It is important to mention that the simulation is not redoing the same calculation, the simulation operation is based on generating an input signal with a given SNR and to propagate it through 3 blocks that emulate the behavior of A, B and C. The antenna noise as well as the added noise for each stage are generated as a Gaussian distribution whose variance is adjusted according to the simulation parameters.

Question 3.3 *Simulate the configurations BCA and CAB, compare the obtained NFs with ABC.*

Réponse 3.3 In the configuration BCA, we obtain a NF of 3.4 dB which confirms that the block order has an impact of the NF. In the configuration CAB, the NF is also different 6.1 dB. It is worth mentioning that this value is almost equal to the NF of C. Actually, since C has a high gain, the impact of the other blocks become negligible.

Question 3.4 *G_a is flexible, it can be set to 0 dB, 6 dB or 12 dB. Try the 3 possibilities and analyze the impact of this change on the NF of the complete chain.*

Réponse 3.4 For a G_a of 0 dB, the NF is 4.6 dB. For a G_a of 6 dB, the NF is 3 dB. For a G_a of 12 dB, the NF is 2.5 dB. This shows that the higher G_a, the better the NF.

1. There are some few exceptions for which the SNR is improved but it does not apply in this case

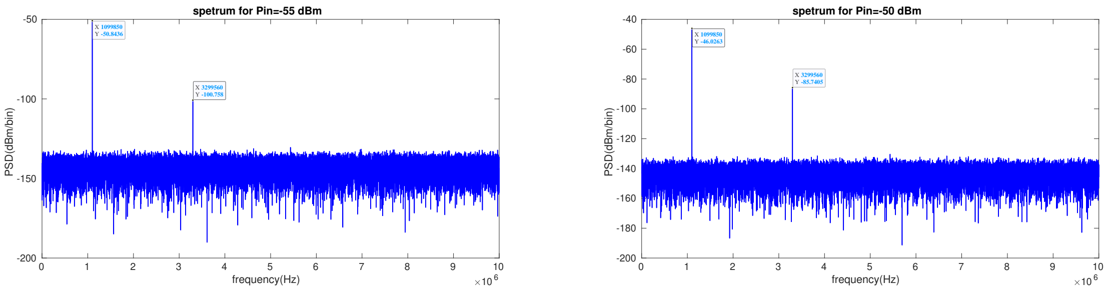


FIGURE 3 – Spectrum for input powers of -55 and -50 dBm

4 Nonlinearity ! !

Question 4.1 *Use the script Amplifier_NL.m to plot the SNDR vs Pin curve. Explain the behavior of the curve*

Réponse 4.1 The curve shows two parts, a rising one with a slope of 1 and a falling part with a slope of 2. Let us analyze the reason. Actually the SNDR is the ratio between the signal power and the sum of noise and distortions.

$$SNDR_{lin} = \frac{P_{Signal}}{P_{Noise} + P_{Distortion}}$$

$$SNDR_{dB} = P_{Signal-dBm} - PNoise\&Distortions - dBm$$

We know that P_{Signal} is proportional to the $(\alpha_1 A)^2$ and the that the $P_{Distortion}$ is proportional to the $(\alpha_3 A^3)^2$ since we have 3^{rd} order distortions.
When the signal power is very low, the distortion power is very negligible with respect to the noise and therefore increasing P_{Signal} also noted P_{in} increases just the numerator without almost increasing the denumerator, that is why the SNDR increases. Then as we increase P_{Signal}, $P_{Distortion}$ increases 3 times faster (in dBm) and at one point its power becomes equal to the noise power and as we continue increasing the noise power becomes negligible compared to it. At this point, increasing P_{in} by 1 dB increases the signal by 1 dB but increases also $P_{Noise\&Distortions-dBm}$ by 3 dB and therefore SNDR is degraded by 2 dB.

Question 4.2 *Observe two plotted spectrums for the two input powers. Compare the HD3 values and explain the obtained difference.*

Question 4.3 *Calculate the IIP3 of the amplifier.*

Réponse 4.2 The IIP3 could be calculated for any input value using the following expression

$$IIP3_{dBm} = Pin_{dBm} + \frac{\overbrace{P_{signal-dBm} - P_{harmonic-dBm}}^{IM3\ or\ HD3}}{2}$$

For $Pin_{dBm} = -50$ dBm, the HD3 is (-46+85.7) 39.7, which gives an IIP3 of -30.1 dBm.
For $Pin_{dBm} = -55$ dBm, the HD3 is (-50.8+100.8) 50 dB, which gives also an IIP3 of -30 dBm

The gain of amplifier A is not sufficient to receive very low input signals ($P_{in} < -90dBm$). We will use the complete chain ABC.

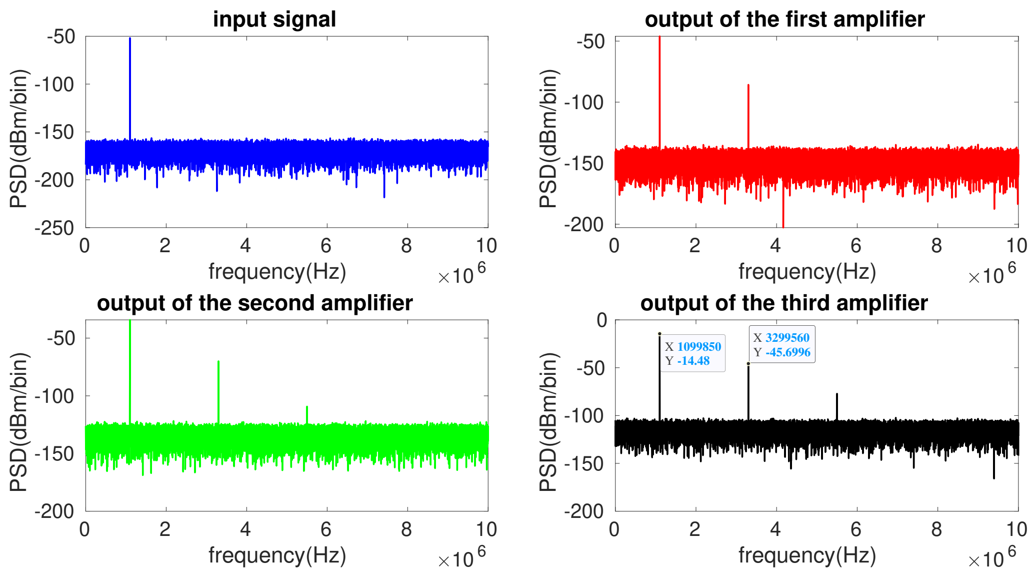


FIGURE 4 – Spectrum for the NL amplifier chain

Question 4.4 *Calculate the IIP3 of the full chain using the script AmplifierChain_NL.m.*

Réponse 4.3 To calculate the IIP3 of the whole chain, we measure the HD3 at the output of the last stages and inject into the IIP3 formula

$$IIP3 = -50 + \frac{-14.5 + 45.7}{2} = -34.4 \text{ dBm}$$

Question 4.5 *Observe carefully the output spectrums of the second and third stages. What can be noticed ?*

Réponse 4.4 We can observe that we have distortions arising at 5 and 7 times the input frequency. Actually, as the signal goes through several non linear stages, the overall polynomial model of the chain contains now orders higher than 3.

Question 4.6 *G_a is flexible, it can be set to 0 dB, 6 dB or 12 dB. Try the 3 possibilities and analyze the impact of this change on the IIP3 of the complete chain.*

Réponse 4.5 We run these simulations for an input power of -50 dBm. We obtain a NF of 39 dB for G_a of 0 dB, 39.7 dB for G_a of 6 dB and 48 dB for a G_a of 12 dB. We can hence observe that the NF is degraded when G_a is increased showing that when are limited by Nonlinearity, in contrast to the case when we were limited by noise, increasing the gain has a negative impact on the performance. Designing electronic systems has always to obey to a tradeoff between these two non-idealities : noise and non linearity