Wireless technologies & applications

Tutorial on RF system issues - solution

Problem 1:

Components data

	LNA	Filter	mixer
Gain	31.6	0.63	6.31
F	1.58	1.58	3.16
IP3 (mW)	0.4	∞	5.01

1/ Global noise factor calculation

Configuration 1: $F_{global} = 1.58 + \frac{(1.58-1)}{31.6} + \frac{(3.16-1)}{(31.6\times 0.63)} = 1.71$ NF=2.32dB

Configuration 2: $F_{global} = 1.58 + \frac{(1.58-1)}{0.63} + \frac{(3.16-1)}{(31.6\times 0.63)} = 2.61$ NF=4.16dB

2/ Sensitivity calculation

From the graph, signal-to-noise ratio (SNR) must be ≥ 12dB

The minimum required input power is therefore: $P_{in\,min} = kTB \times F \times SNR$ (B = 1 MHz)

Configuration 1:

$$P_{in\,min} = -174(dBm) + 10 \times \log 10^6 \ (dB) + 2.32(dB) + 12(dB) = -99.68\ dBm\ (0.107\ pW)$$

Configuration 2:

$$P_{in\,min} = -174(dBm) + 10 \times \log 10^6 \ (dB) + 4.16(dB) + 12(dB) = -97.84\ dBm\ (0.164\ pW)$$

In configuration 2, 50% more power is required to achieve the same SNR. This is because the equivalent input noise is increased due to the fact that an attenuator (the filter) is placed at the beginning of the chain. This situation must be avoided if possible (but this is seldom possible) since the better F is obtained when a low-noise high-gain block is the first stage.

3/ transmission range

The theoretical transmission range is given by : $d = \sqrt{\frac{P_{TX}}{P_{RX}} \times G_{TX} \times G_{RX} \times \left(\frac{\lambda}{4\pi}\right)^2}$

Configuration 1 : d = 942m configuration 2 : d = 761m

Remark: the above formula applies in free space only. In practice, the received power decreases as a function of d^n, with $2 \leq n \leq 3$. If n = 2.5, the range decreases down to 240m (configuration 1) or 200m (configuration 2), which is more realistic.

Problem 2:

1/ Characteristics of filters and local oscillator LO2

Filter 1 is the image filter, its bandwidth is the bandwidth of the standard. Here, transmit frequency lies between 12.45 and 12.75 GHz, leading to a bandwidth of 300MHz. Its centre frequency is 12.6 GHz.

Before filter 2, the input signal is mixed with local oscillator LO1 (11.5 GHz). The result is a frequency translation of ±11.5 GHz yielding two frequency ranges:

Range 1 : (12.45 .. 12.75 GHz) + 11.5 GHz = 23.95 .. 24.25 GHz
Range 2 : (12.45 .. 12.75 GHz) - 11.5 GHz = 0.95 .. 1.25 GHz

Because the aim of the receiver is to translate RF towards baseband, the second range is chosen and the filter also has a 300 MHz bandwidth with a centre frequency of 1.1 GHz.

Local oscillator LO2 translates the frequency to the 50 MHz intermediate frequency. There are two possibilities :
0.95 .. 1.25 GHz + 50 MHz = 1 .. 1.3 GHz
0.95 .. 1.25 GHz - 50 MHz = 0.9 .. 1.2 GHz

The choice among these two possibilities is dictated by the availability and performance of components to build the local oscillator.

2/ Power at the LNA input

$P_{RX} = P_{TX} \times G_{TX} \times G_{RX} \times \left(\frac{\lambda}{4\pi d}\right)^2$ with $\lambda = \frac{300}{f}$ (m, MHz) $\lambda = \frac{300}{12600} = 2.38\ cm$
$P_{TX} = 10 * \log(160.10^3) = 62\ dBm$

$P_{RX} = 52 + 30 + 33 - 205.58 = -90.58\ dBm$ or $875\ 10^{-12}$ mW

3/ Input noise power, SNR

We must calculate the global noise figure using these data :

	LNA	Filter 1 (2)	Mixer 1	Filter 2 (2)	Coax (1)	Mixer 2	Filter 3 (2)
Gain	10	0.5	10	0.5	0.2	10	0.5
F	1.259	2	1.585	2	5	2.512	2

(1) Coaxial cable: 17 dB attenuation for 100 m, that is a «gain» of 0.02 for 100m. Here, the cable is only 10m long, therefore the attenuation (in **linear** value, **not** in dB !!) is 10 times lower, or the « gain » 10 times higher, hence the value of 0.2 in the table.

(2) for a passive attenuator (i.e. a passive filter, a coaxial cable…), NF = - (gain in dB), or F = 1/gain

$$F_{global} = 1.259 + \frac{(2-1)}{10} + \frac{(1.585-1)}{(10\times 0.5)} + \frac{(2-1)}{(10\times 10\times 0.5)} + \frac{(5-1)}{(10\times 10\times 0.5\times 0.5)} + \frac{(2.512-1)}{(10\times 10\times 0.5\times 0.5\times 0.2)} + \frac{(2-1)}{(10\times 10\times 0.5\times 0.5\times 0.2\times 10)} = 1.259 + 0.1 + 0.117 + 0.02 + 0.16 + 0.3024 + 0.02 = 1.9784$$

The intrinsic noise of the receiver is expressed as (F_{global} – 1) kTB, where B is the bandwidth at the antenna, that is 300 MHz. Expressed in dBm, this becomes 10 log (F_{global} – 1) – 174 + 10 log(B).

$N_{intrinsic} = -0.095 - 174 + 84.77 = -89.325\ dBm$ or 1.168 10^{-9} mW

$N_{antenna} = -174 + 10\log\left(\frac{50}{290}\right) + 84.77 = -96.864\ \mathrm{dBm}$ or 2.06 10^{-10} mW

$N_{input} = N_{intrinsic} + N_{antenna}$ = 1.374 10^{-9} mW or -88.62 dBm

SNR_{input} = -90.58 – (-88.62) = -1.96 dB

4/ SNR at output

At the output of filter 3, signal and noise were multiplied by the same gain, but now, the bandwidth is that of the filter located after mixer 2 which is 20 MHz (channel bandwidth). Noise power is therefore reduced by a factor 20/300:

$$SNR_{output} = SNR_{input} + 10\ log\left(\frac{300}{20}\right) = 9.8\ dB$$

5/ Number of channels = standard bandwidth / channel bandwidth = 15

Problem 3:

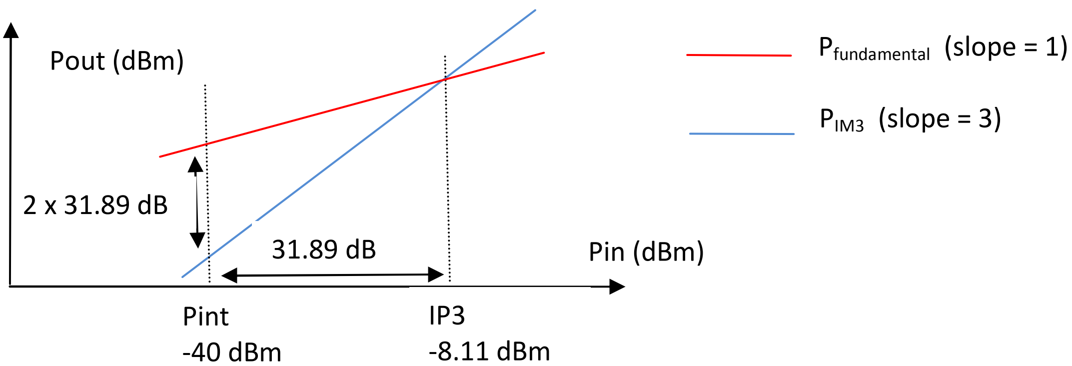
1/ Global IP3 calculation:

$$\frac{1}{IP3_{global}} = \frac{1}{0.4} + \frac{31.6}{\infty} + \frac{31.6\times 0.63}{5.01} = 6.47$$

$IP3_{global}$ = 0.154 mW or -8.11 dBm

2/ For a non-linear amplifier, the output voltage is in the form Vout = a Vin + b Vin^2 + c Vin^3 + ... The terms due to Vin^2 are out of band and therefore ignored. If Vin is composed of two tones wich frequencies are close, some terms due to Vin^3 fall within the bandwidth and create the so-called third order intermodulation distortion (IM3). If we sketch P_{out} versus P_{in} with the power expressed in dBm, we obtain the figure below and:

- the slope for the fundamental (useful) signal is 1 since it comes from the term « a Vin »
- the slope for the IM3 is 3 since it comes from the term « c Vin^3 »



The curves cross at IP3 (calculated before). The interferer signal is 31.89 dB below IP3 and therefore, at Pint, the difference between fundamental and IM3 is 2 x 31.89 dB (the difference of the slopes).

3/ SNR calculation (Pint = -40 dBm)

At the output of the receiver, intermodulation products are 63.78 dB below fundamental. IM3 power is: -40 (dBm) – 63.78 (dB) + $gain_{Rx}$ (dB) = -103.78 dB + $gain_{Rx.}$
The useful signal power is: -80 (dBm) + $gain_{Rx}$ (dB)

This gives a SNR of: -80 – (-103.78) = 23.78 dB

4/ SNR calculation (Pint = -35 dBm)

IP3 – Pint is now 26.89 dB and therefore, intermodulation products are 53.78 dB below fundamental.
IM3 power is: -35 (dBm) – 53.78 (dB) + $gain_{Rx}$ (dB) = -88.78 dB + $gain_{Rx.}$
The useful signal power remains: -80 (dBm) + $gain_{Rx}$ (dB)

This gives a SNR of: -80 – (-88.78) = 8.78 dB

This result shows that degradation of the signal quality increases rapidly with interferer power and therefore, linearity (i.e. low dependence on Vin^2, Vin^3 ... terms) is a key issue in RF systems, especially with complex modulation schemes which require high SNR.