Texas A&M University
Electrical Engineering Department

ECEN 665

Laboratory #1: Gain, noise and linearity specifications and trade-offs
for the building blocks of a wireless receiver.

Objectives: To obtain the gain, noise figure and linearity specifications of the overall wireless receiver given these specifications for its building blocks.

Prelab Exercise: Programming of equations for computing cascaded Gain, NF and IIP3.

1. Select either Matlab or Excel to program your equations. In your script (MATLAB) or spreadsheet (Excel) you should be able to edit a table similar to the following (BBX – Baseband Block # X):

Parameter/Block	LNA	Mixer	BB1	BB2	BB3
NF [dB]	3	18	25	30	35
Gain [dB]	17	12	6	0	60
IIP3 [dBm] *	-10	0	12	20	25

Note: Values in dBm should be with respect to 50 ohm. Derive the equations to convert from dBm to Volts and Volts to dBm.

2. From the equations given in the lecture notes (and course references) for cascaded noise factor (F) and cascaded IP3 Amplitude (A_{IP3}) show that:

$$System\_NF = 10 \cdot \log\left(10^{NF,1/10} + \frac{10^{NF,2/10}-1}{10^{(A1)/10}} + \frac{10^{NF,3/10}-1}{10^{(A1+A2)/10}} + ...\right) \text{ [dB]}$$

$$System\_IIP3 = 10 \cdot \log\left(\frac{1}{\frac{1}{10^{IIP3,1/10}} + \frac{1}{10^{(IIP3,2-A1)/10}} + \frac{1}{10^{(IIP3,2-A1-A2)/10}} + ...}\right) \text{ [dBm]}$$

where NF,X , A,X and IIP3,X are the Noise Figure, Gain and input referred third order intercept point (IIP3) of the block number X (from antenna to baseband) in dB.

3. Set these equations in your spreadsheet or script so that the overall system performance metrics of NF and IIP3 can be computed from building block specifications like the ones in the table shown in step 1.

If you worked on Matlab attach a hard copy of your script. If you worked on excel write all of the equations on your report.

Texas A&M University
Electrical Engineering Department

ECEN 665

Laboratory #1: Gain, noise and linearity specifications and trade-offs
for the building blocks of a wireless receiver.

Objectives: To obtain the gain, noise figure and linearity specifications for the building blocks of a wireless receiver to achieve a given overall receiver performance. To understand the trade-offs involved in the assignment of specifications for different building blocks.

1. Introduction

Standards for wireless networks such as Bluetooth, Wi-Fi and ZigBee, have a number of requirements for the physical layer of the communication process such as sensitivity, bit-error-rate (BER), interference rejection, etc. The system-level design of a wireless receiver is the procedure to map the requirements of the standard into electrical specifications for the overall receiver performance and its building blocks. Figure 1 depicts a general flow diagram for this procedure.
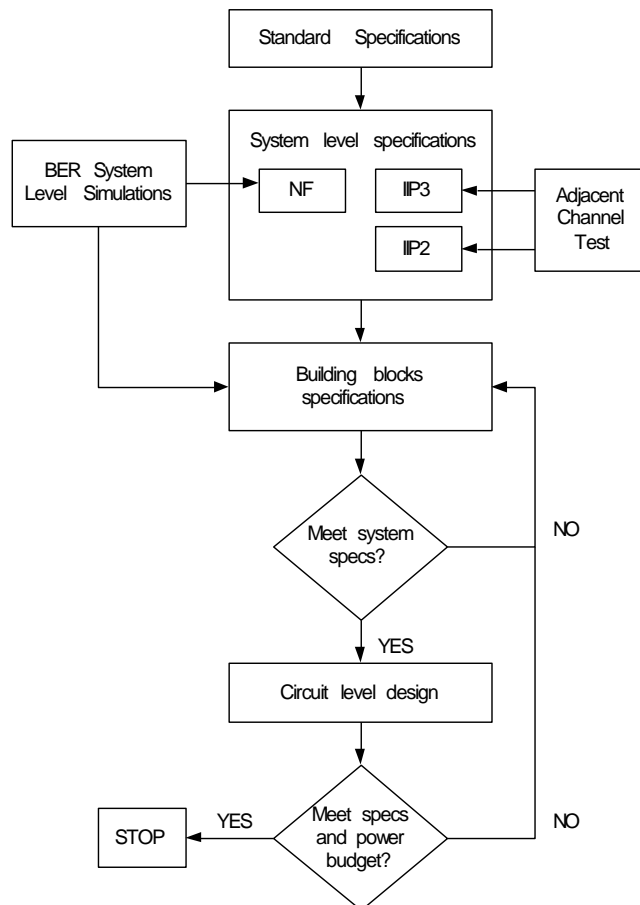

Figure 1. General flow diagram for the system-level design of a wireless receiver

To determine the optimum specifications for the building blocks of a receiver takes a relatively long process, which demands feedback from the circuit-level implementation. In this laboratory exercise you will understand an overall system design procedure and propose specifications for the building blocks of a ZigBee receiver. First, an example will be given.

II. Architecture and standard specifications for a ZigBee (IEEE 802.15.4) Receiver

Table 1 summarizes the system level requirements from the ZigBee standard. The required SNR is obtained from the BER Vs SNR plot of the modulation format employed (O-QPSK in this case). It is the minimum SNR that should be present at the input of the demodulator to comply with the required BER. The alternate channel rejection specification means that the receiver should keep the required BER performance in the presence of an alternate channel interferer with a power 30dB higher than the desired signal.

Table 1. ZigBee standard specifications for the physical layer

Carrier	2.4 GHz
Sensitivity	-85dBm
BER	5E-5
Required SNR	2dB
Channel bandwidth	2MHz
Alternate channel rejection	30dB

A possible ZigBee receiver implementation is the low-if architecture depicted in figure 2. It consists of a low noise amplifier (LNA), an image rejection mixer (IRM), a band-pass filter for channel selection (BPF), a variable gain amplifier (VGA) and a demodulator. For the design example given in the next session it will be assumed that the demodulator requires a signal amplitude of 0dBm at its input.
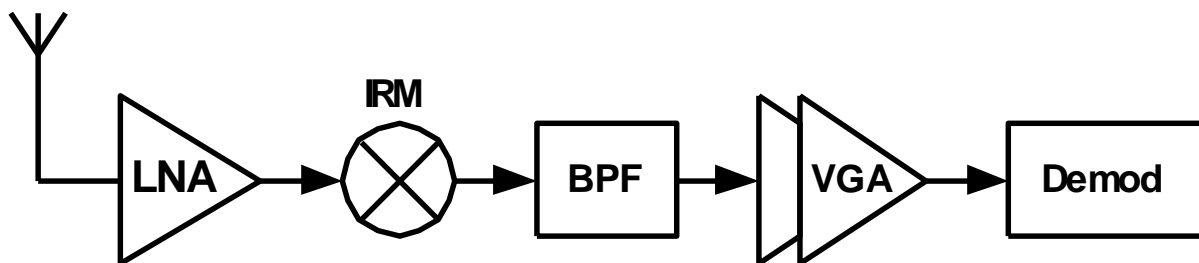

Figure 2. Low-IF Architecture for a ZigBee Receiver

III. Derivation of system-level receiver specifications:

1. Total receiver gain:

G = Required signal level at the input of the demodulator − Minimum detectable signal

G= 0dBm − (-85dBm) = 85dB

2. Total receiver noise figure:

NF = Sensitivity - (-174+10*log10(BW)) - SNR - NF_margin

NF= -85dBm − (-174+10*log(2MHz)) − 2dB − 3dB = 20dB

3. Total receiver IIP3:

Power of the signal of interest for the alternate channel test:

 Signal_Level_ACT = Sensitivity + 3dB = -82dBm

Minimum carrier (signal of interest) to interference ratio:

 C2IR = 5dB

Power of the jamming (alternate channel) signal:

 Alternate_Channel_Level = Signal_Level_ACT + 30dB = -52dBm

IM3 = Signal_Level_ACT-C2IR

IM3 = (-85dBm + 3dB) − 5dB = -87dBm

IIP3 = (Alternate_Channel_Level-IM3)/2 + Alternate_Channel_Level+IIP3_margin

IIP3 = (-52 − (-87))/2 + (-52) + 3 = -31.5dBm

IV. Sample set of specifications for the building blocks and achieved performance.

Table 2. Specifications for the building blocks of a Low-IF ZigBee receiver

Parameter/Block	LNA	Mixer	Filter	VGA
NF [dB]	4	30	40	40
Max. Gain [dB]	14	11	0	60
IIP3 [dBm]	-20	-10	0	0

Achieved overall performance: Gain = 85 dB   NF = 20dB   IIP3 = -30dBm
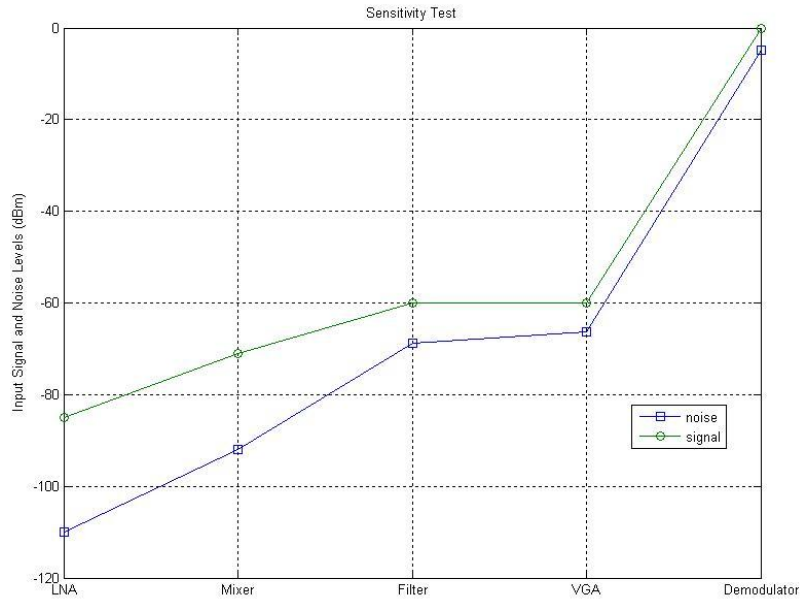

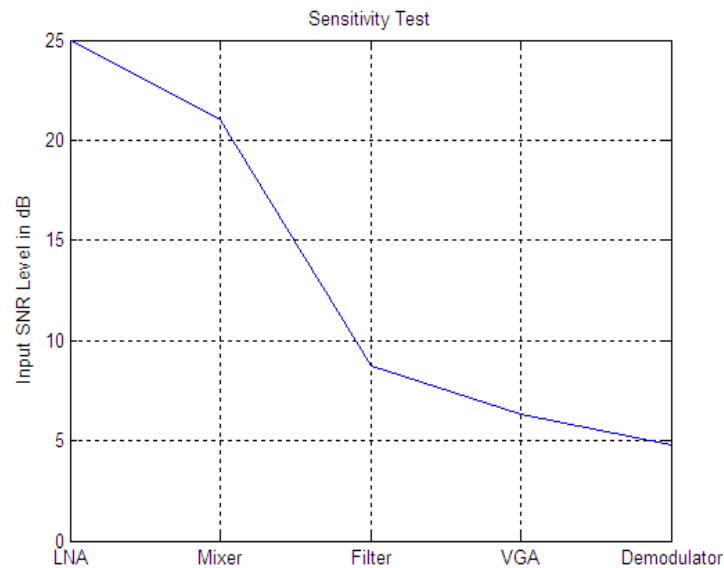Figure 3. Signal and noise levels at the input of each building block

Figure 4. SNR at the input of each building block

V. Exercises

1. For the Zigbee receiver described in Table 2, add a passive band-selection filter between the antenna and LNA with an insertion loss of 2 dB. Complete and verify the equations in your Matlab script or Excel chart to find the overall NF and IIP3 performance. Plot the signal levels, noise levels and SNR at the input of each block as shown in figure 3 and figure 4. Show explicitly how you calculate input signal and noise levels for building blocks of the receiver.

(For all the problems below, don't forget to include passive band-selection filter in your receiver)

2. Most commercial implementations achieve a performance that goes beyond the standard requirements. For example, the Motorola ZigBee receiver has a sensitivity of –92dBm. Compute the required system-level specifications (as in section III) for a ZigBee receiver with a sensitivity of –98dBm.

3. Assuming a CMOS receiver, (a) Propose a set of specifications for the building blocks of the receiver you designed in exercise 2 and obtain the overall specifications of the receiver using the program written in the prelab. (b) Plot the signal levels, noise levels and SNR at the input of each block. (c) Support the feasibility of your specs by citing articles or books that report the performance required by your building blocks that can be achieved. (d) Based on your citations, discuss and give an estimate for the total power consumption for the receiver front-end. (e) Comment on the trade offs advantages and disadvantages of your distribution of specs.

4. Sheng et al. proposed a systematic system level design methodology for determining the specification of each building block to minimize the power consumption [1]. Apply this methodology, for the Zigbee receiver to find the block level specifications. Provide plots for the signal levels, noise levels and SNR at the input of each block. Compare the obtained results with the one obtained in exercise 3, and draw your conclusion.

5. Modify the receiver architecture of Exercise 3. and include an IF amplifier, between the IRM and the BPF, with a gain of 14 dB. Also, assume that instead of the demodulator, there is an ADC which requires an input signal level of 8dBm. Sensitivity should be -98 dBm. Propose a new set of specifications for the building blocks of this receiver architecture. Does this IF amplifier help to relax the NF specifications of the base band building blocks? What is its effect on the linearity requirements?

VI. Final Remarks:

Lab report is due at the beginning of the next lab session.

If you worked on Matlab attach a hard copy of your script. If you worked on excel write all of the equations (including the ones you used to obtain the signal and noise plots) on your report.

VII. References:

[1] W. Sheng, A. Emira, and E. Sánchez-Sinencio, "CMOS RF Receiver System Design: A Systematic Approach", *IEEE Transactions on Circuits and Systems-I*, vol. 53, pp. 1023-1034.