.

Radio Frequency Project

Prof. Macchiarella Giuseppe

ARSALAN MODIRKHAZENI – MATRICOLA 994855, Person Code 10764127

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Summary

Introduction

- The project concerns the RF front-end of a conversion receiver
- The blocks of the RF front-end are defined in a VSS system diagram. The parameters of the blocks are in part specified and in part must be determined
- The unspecified parameters must be extracted from circuit simulations of the relative blocks (the MWOffice schematics of the blocks are provided)
- The RF front-end must be analyzed (by simulations) in order to assess its performances

Configuration of the RF front-end

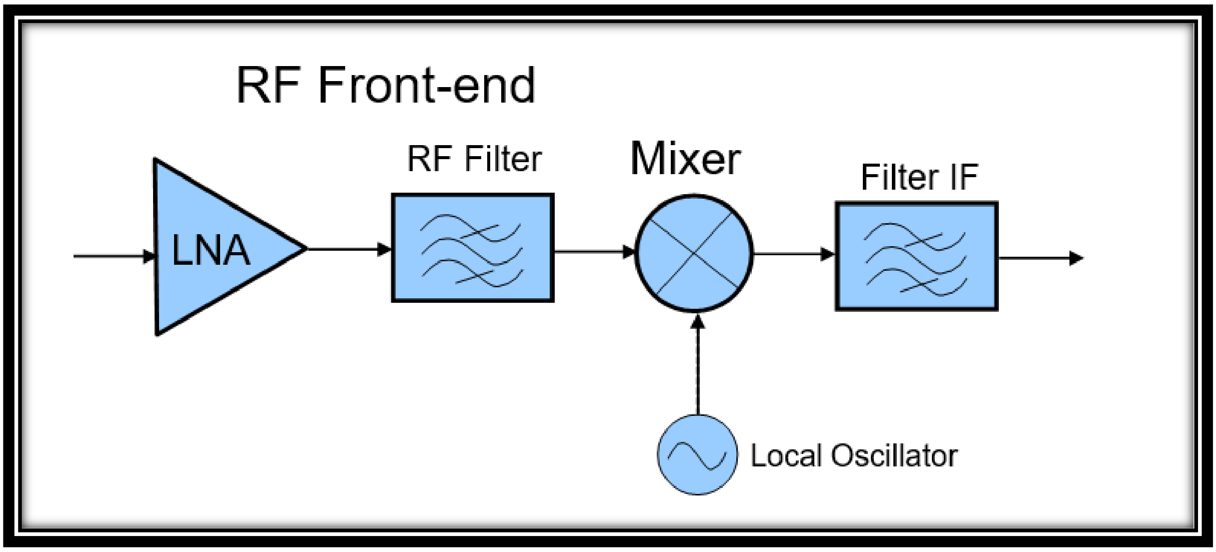


Figure 1. The RF Front-end

- Input RF carrier frequency: 4.25 GHz
- Modulation: 16-QAM with data rate R=94.8 Mbit/s (Bandwidth 32 MHz)
- Intermediate frequency: 500 MHz
- Local Oscillator frequency: 3.75 GHz

Parameters of the blocks

- **LNA**
  - Gain (dB)
  - Noise Figure (dB)
  - 3rd Intercept Power (dBm)
  - Power at 1 dB compression (P1dB)

- **Mixer**
  - Conversion loss (dB)
  - Equivalent noise temperature (SSB) (°K)
  - 3rd Intercept Power at input (dBm)
  - Power at 1 dB compression at input (P1dB)
- **Local Oscillator**
  - Output power (dBm) and Oscillation frequency (MHz)
  - Phase noise (mask)

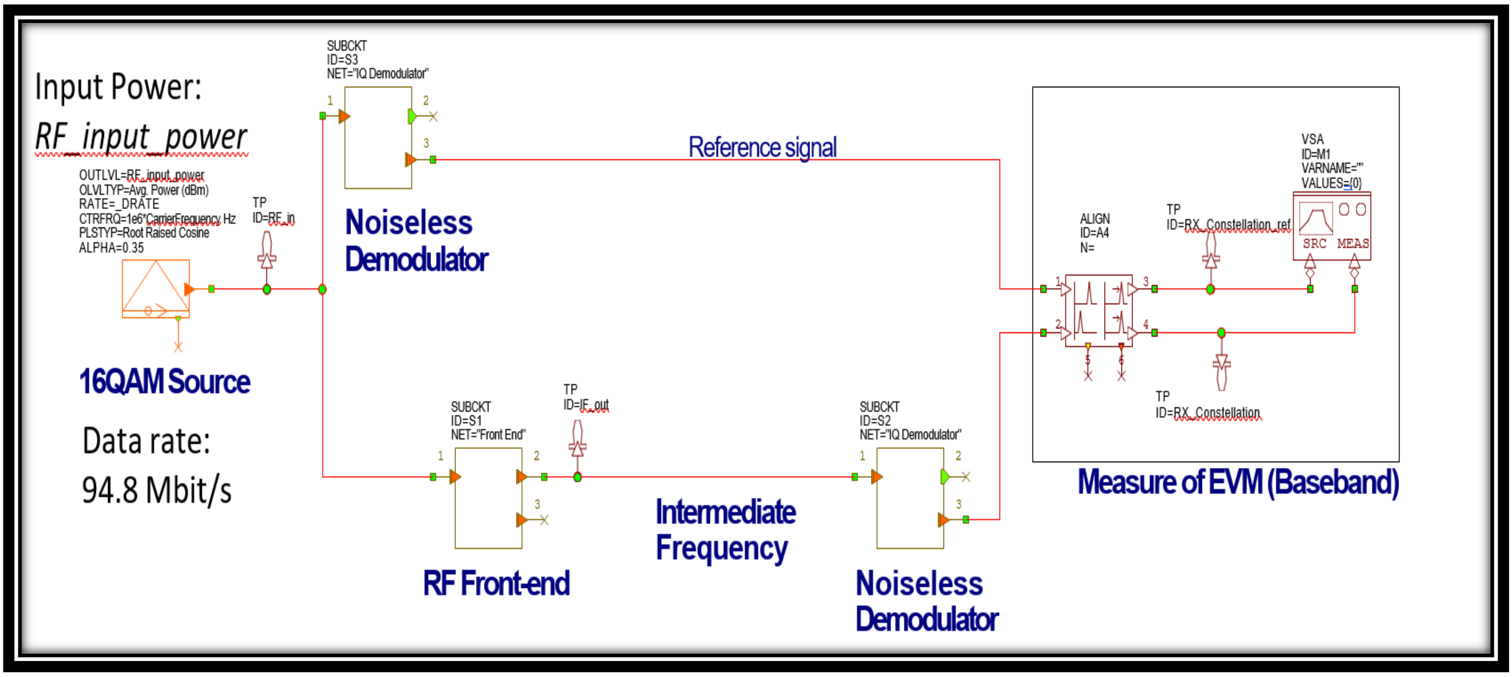


Figure 2. The Overall schematic

Circuit evaluation of LNA parameters

- All schematics are included in the file LNA_circuit.emp
- The balanced configuration is used for the LNA. The identical amplifiers employ a FET device represented with a non-linear model in MWOffice. The device is properly biased and suitable values of GammaS and GammaL are realized at its terminal by means of ideal components (Ltuner)

You can see the biased FET and Single Amplifier in the figure 13, and 14 respectively.

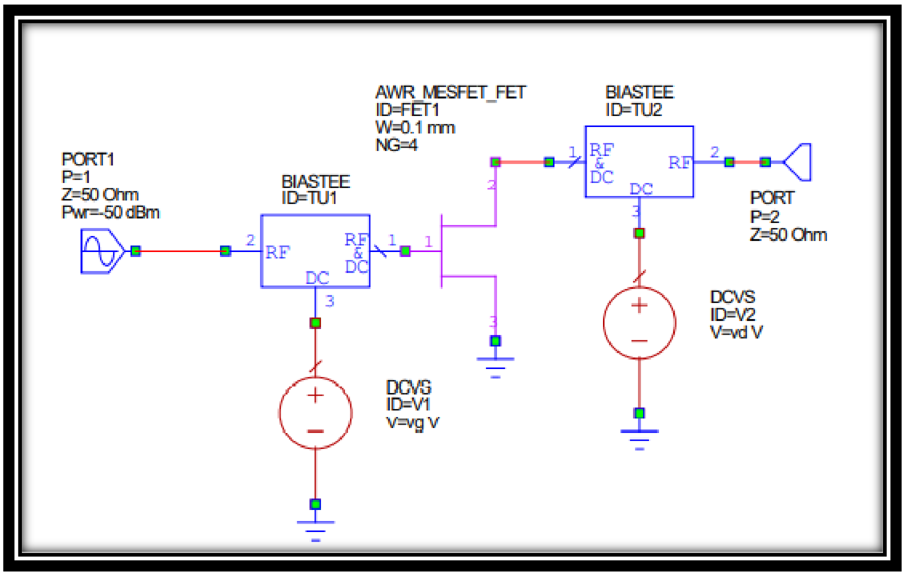


Figure 3. the Biased FET

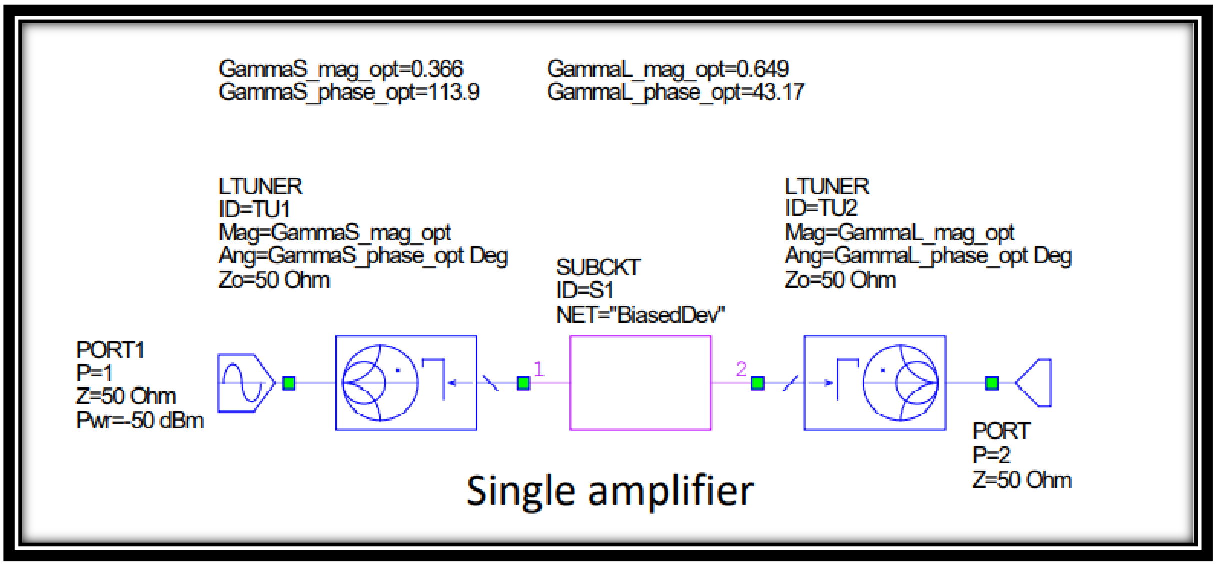


Figure 4. the Single Amplifier

Simulation:

- The balanced configuration employs two 90° hybrids. Initially these hybrids are represented by and ideal model
- It is requested to replace the ideal hybrids with Branch Line hybrids whose scheme is available in the schematic “Branch Line Hybrid”, see the figure 15.

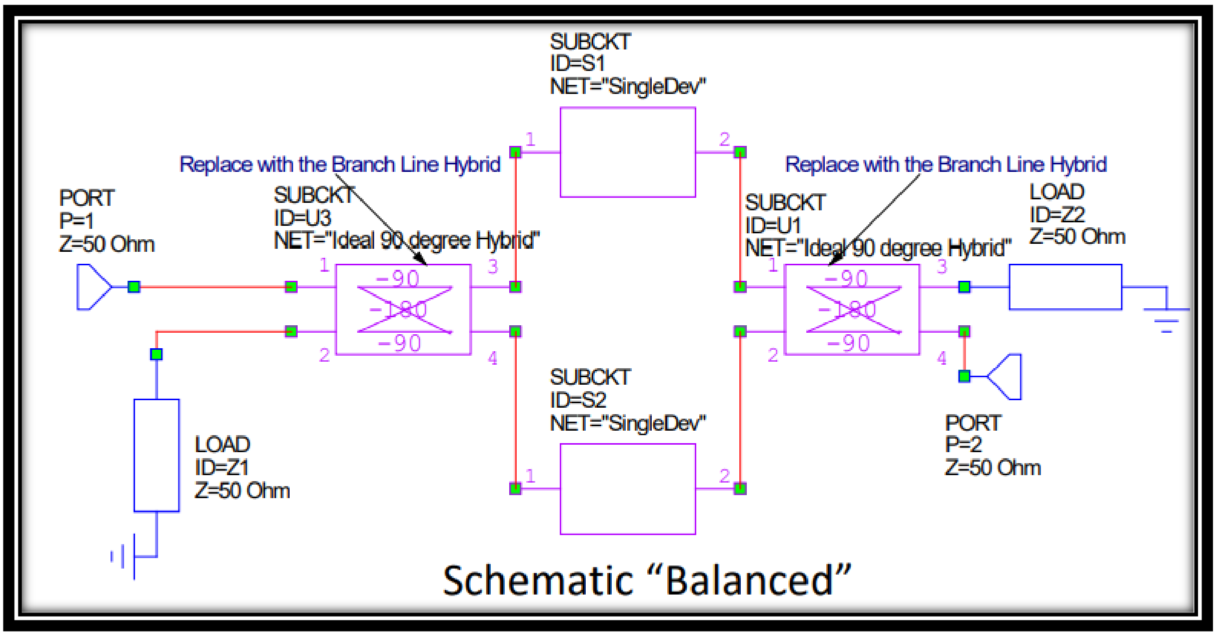


Figure 5. the Schematic Balanced

For designing the Branch line Hybrid, the following construction need to implement in the desire section “Branch Line Hybrid”.

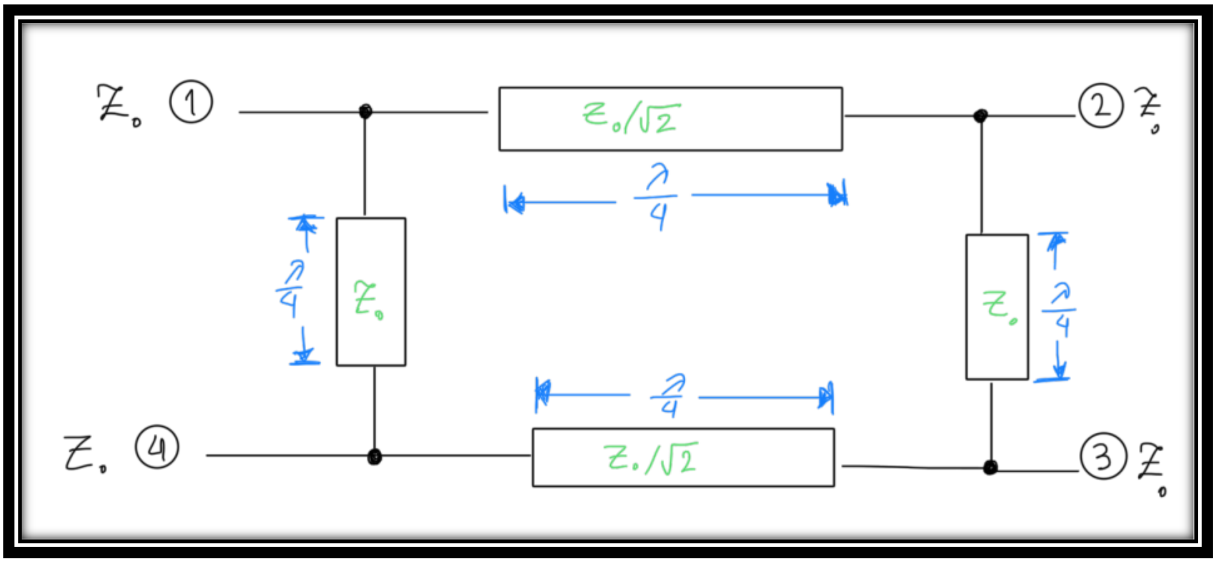


Figure 6. the Design of the Branch line

As you can see in the above figure, we need to design the distance to lambda / 4. We must assign the impedance of each line with Z_0 and $Z_0/\sqrt{2}$ based on the mentioned port. Thus, the new design of “Branch Line Hybrid” has been shown in the figure 17. In order to calculate the lambda, we use the following formula:

Lambda = c / f = (3 * 10^8) / (4.25 * 10 ^9) = 70.54
Lambda / 4 = 17.635
$Z_0 = 50$, $Z_0/\sqrt{2} = 35.36$

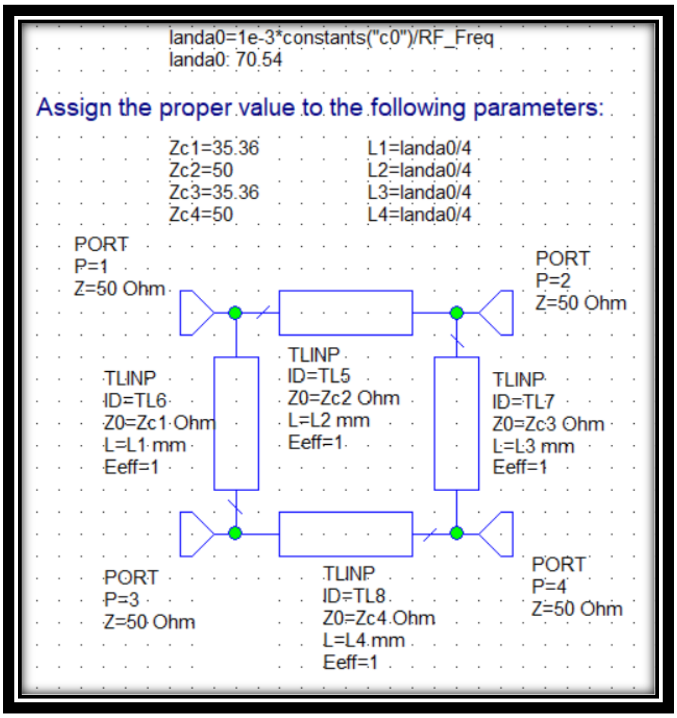


Figure 7. the new Design of the Branch line

Before starting the simulations, the proper value of the gate voltage must be assigned. The global variable “vg” must be set so that the drain current is equal to the nominal value (ID=33mA). Note that the result of the measurement is available in the Global Definitions window. For this purpose, we change the “vg = -0.4099” to find the Drain Current to equal 33 mA.

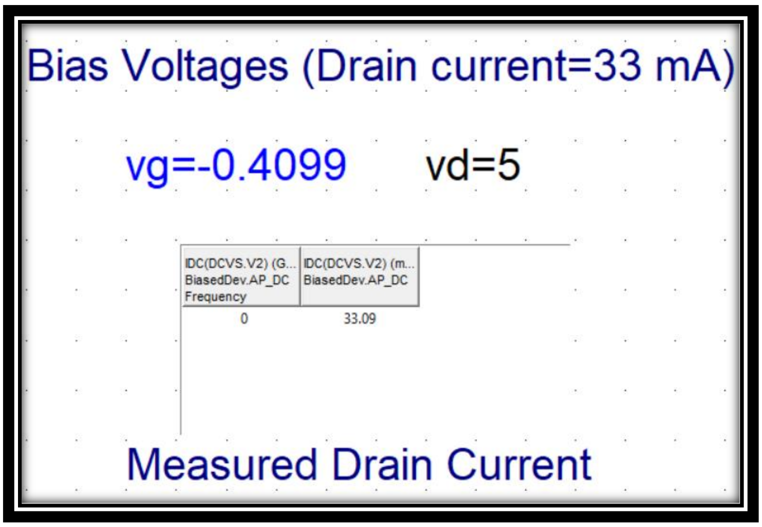


Figure 8. vg and drain current

Extraction of LNA parameters from circuit simulations

We need to extract, "Gain_LNA", "NF_LNA", "IP3_LNA" and "P1dB_LNA" from "Transducer gain and matching", "Noise Figure", "IP3 vs. Pin" and "Gain and output power vs Pin" respectively. Thus, the following graph has been depicted in the following section.

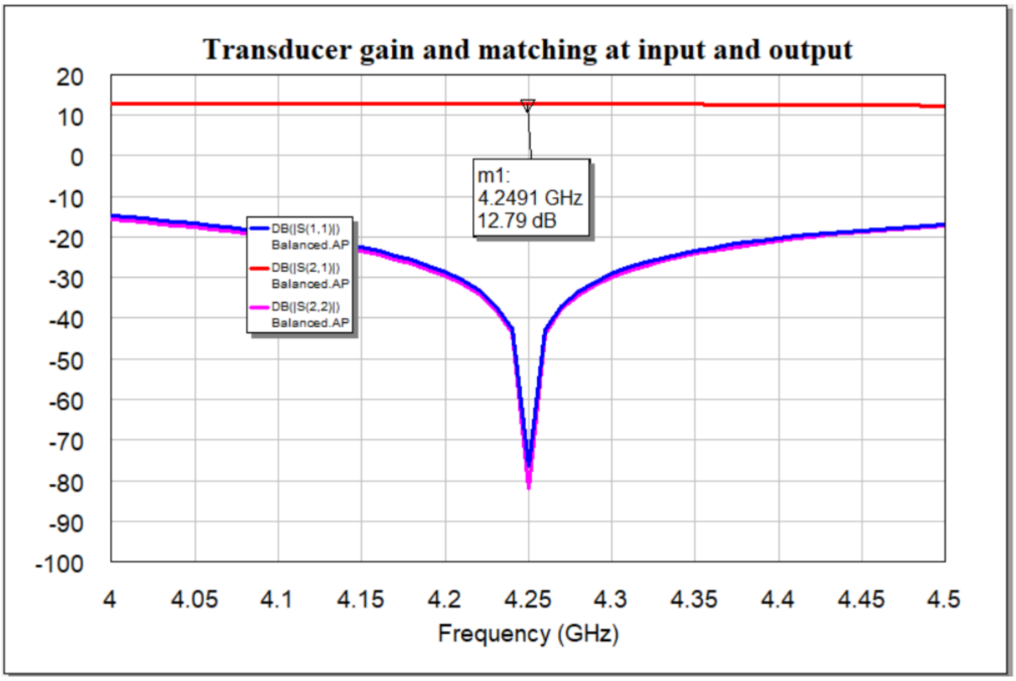


Figure 9. Transducer gain and matching

From above graph the "Gain_LNA" is equal to 12.79.

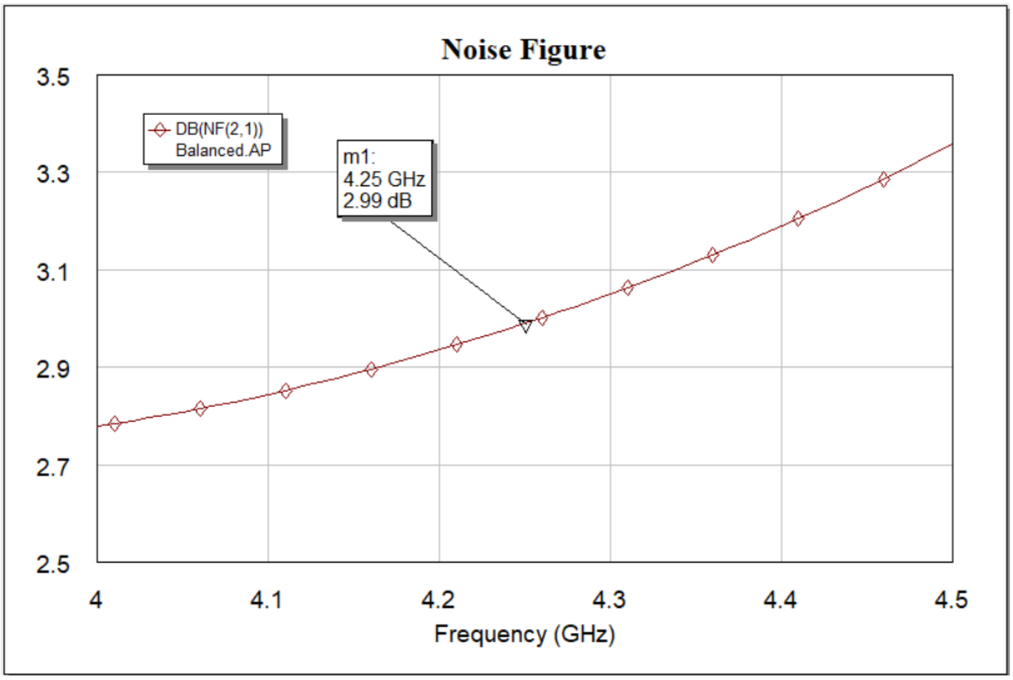


Figure 10. Noise Figure

From the “Noise Figure” the “NoiseFigure_LNA” is equal to 2.99.

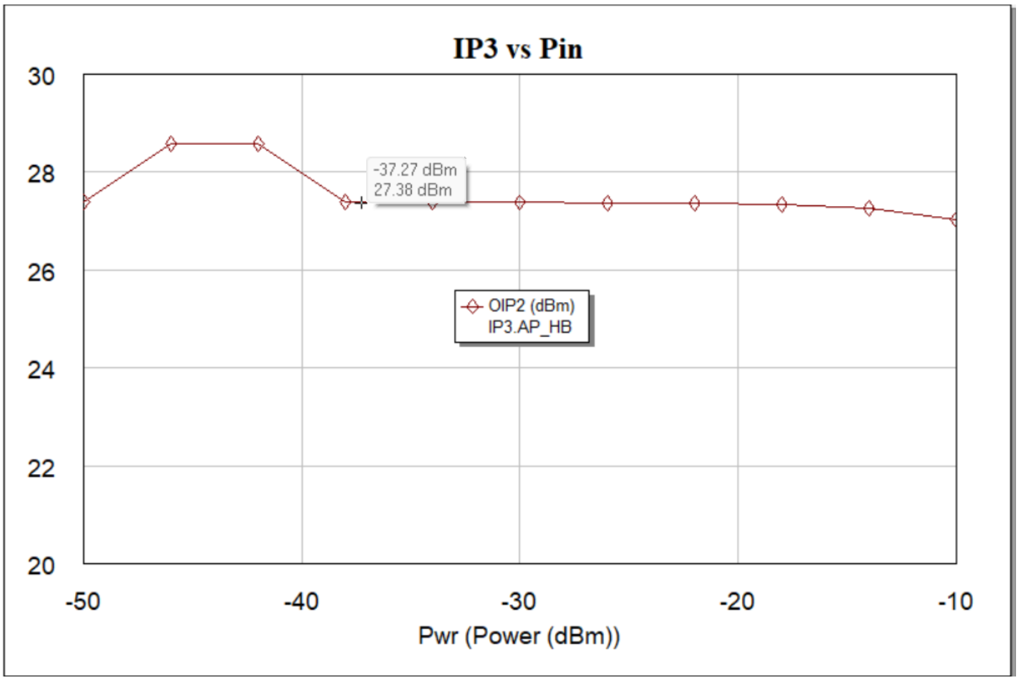


Figure 11. IP3 vs Pin

From the “IP3 vs Pin” the “IP3_LNA” is equal to 27.38.

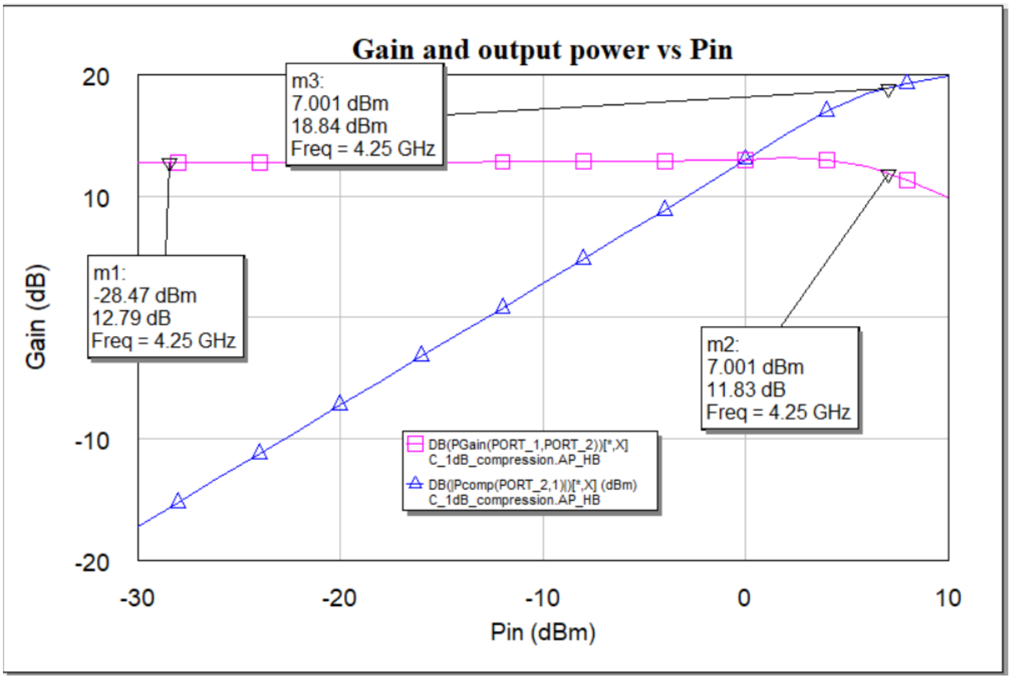


Figure 12. Gain and output power vs Pin

From the “Gain and output power vs Pin” the “P1dB_LNA” is equal to 18.84.

All the result from the LNA can be seen from the following photo.

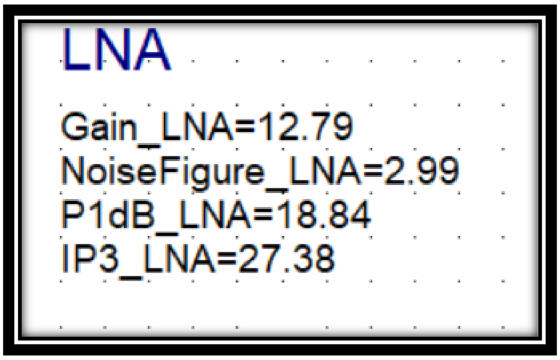


Figure 13. The desired parameters for LNA

Circuit evaluation of Mixer parameters

- The circuits are defined in the file Mixer_circuit.emp
- The balanced configuration with 2 diodes and a 180° hybrid is used
- All the circuit elements are assigned and must not be modified
- The simulations include a filter at IF which is not part of the mixer
- The ideal hybrid must be replaced with a Rat-race hybrid to be dimensioned which can be seen in the figure 14.

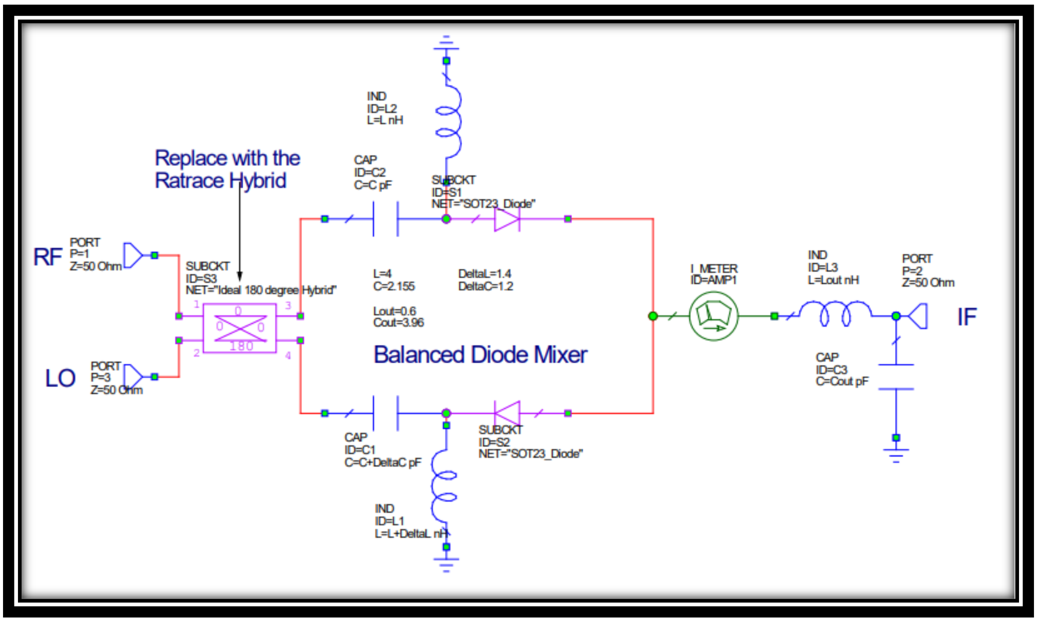


Figure 14. The Balanced Diode Mixer

Dimensioning of the Rat-race Hybrid

For designing the "Rat-race Hybrid", the following construction need to implement in the desire section "Rat-race Hybrid".

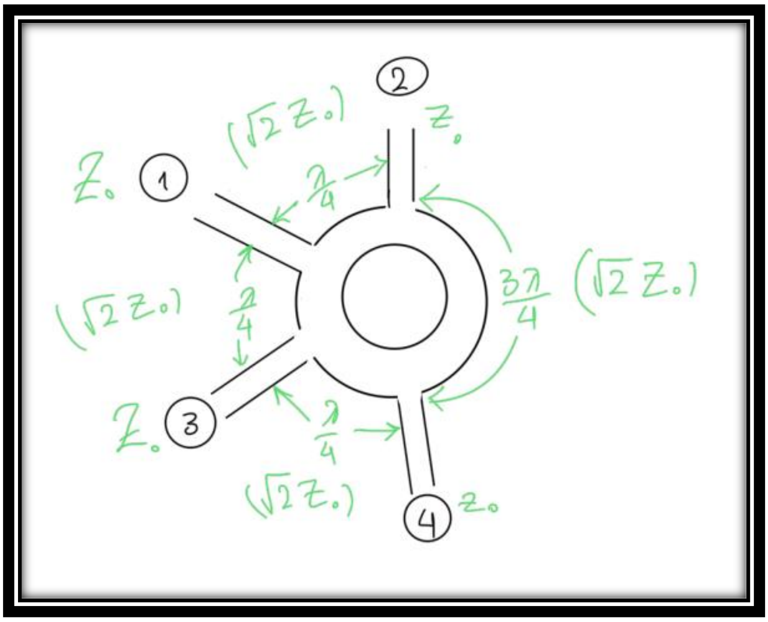


Figure 15. The Design of the Rat-race Hybrid

As you can see in the above figure, we need to design the distance to lambda / 4 for 3 port and 3 * lambda / 4 for the last port. We must assign the impedance of each line with $Z_0*\sqrt{2}$ for all the mentioned port. Thus, the new design of "Rat-race Hybrid" has been shown in the figure 25. In order to calculate the lambda, we use the following formula:

Lambda = c / f = (3 * 10^8) / (4.25 * 10 ^9) = 70.54
Lambda / 4 = 17.65
3 * Lambda / 4 = 52.95
$Z_0*\sqrt{2}$ = 70.71

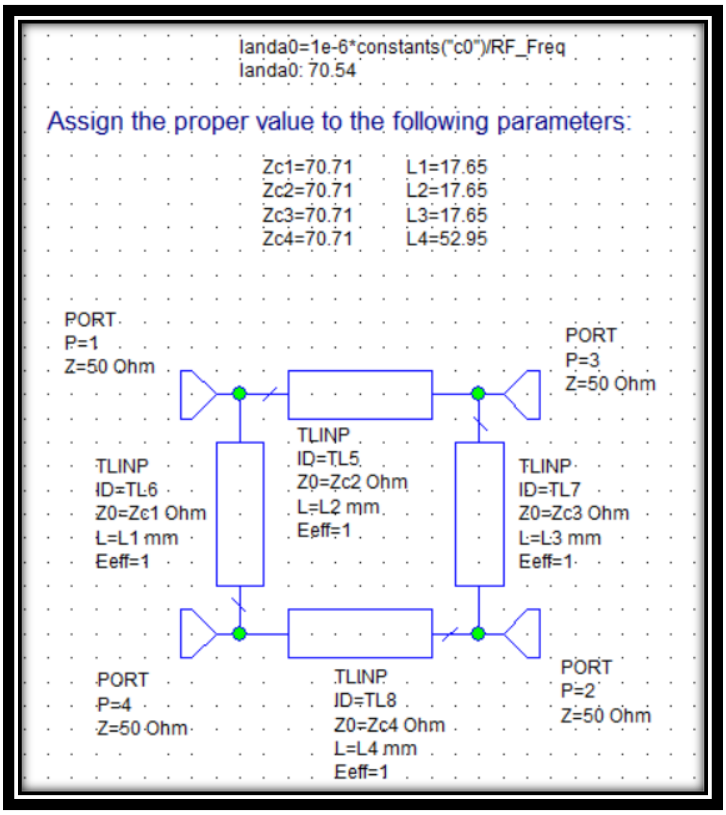


Figure 16. The implementation of the Rat-race Hybrid

Extraction of Mixer parameters from circuit simulations

We need to extract, "Conversion_gain_mixer", "TSSB_mixer", "Input_IP3_mixer" and "Input_P1dB_mixer" from "Conversion Gain vs LO Power", "Noise temperature (Kelvin Degree) vs LO Power", "P1dB Evaluation for PL0 equal to nominal" and "Gain and output power vs Pin" respectively. Thus, the following graph has been depicted in the following section.

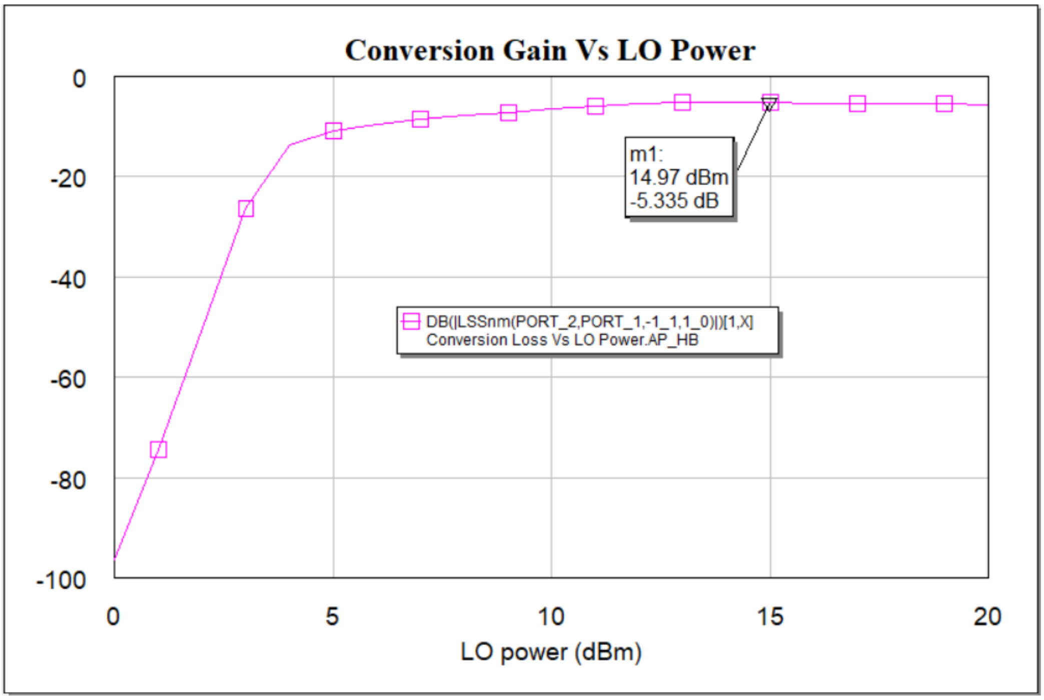


Figure 17. The Conversion Gain Vs LO Power

From the "Conversion Gain Vs LO Power" graph, the "conversion_gain_mixer" is equal to -5.335.

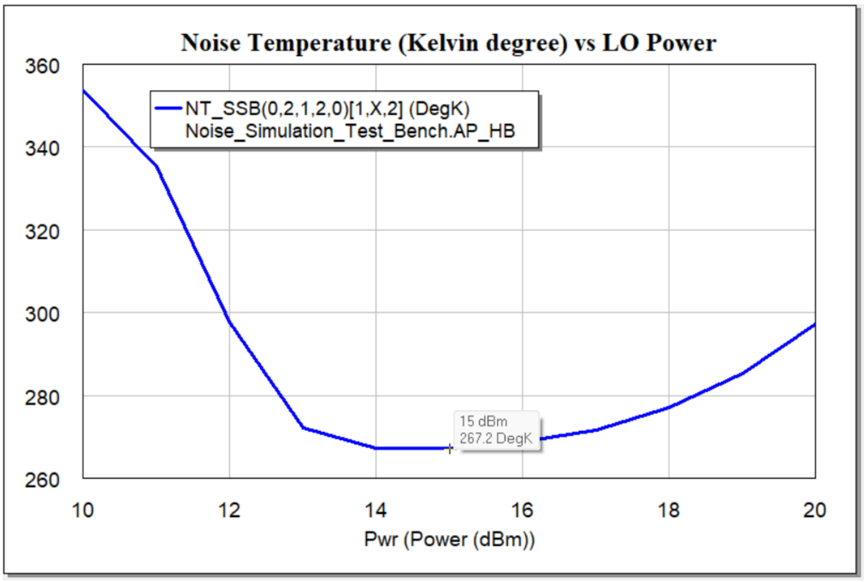


Figure 18. The Noise Temperature (Kelvin degree) vs LO Power

From the “Noise Temperature (Kelvin degree) vs LO Power” graph, the “TSSB_mixer” is equal to 267.2.

The Input_IP3_mixer, can be calculated from the following formula:

Input_IP3_mixer = 14 - Conversion_gain_mixer

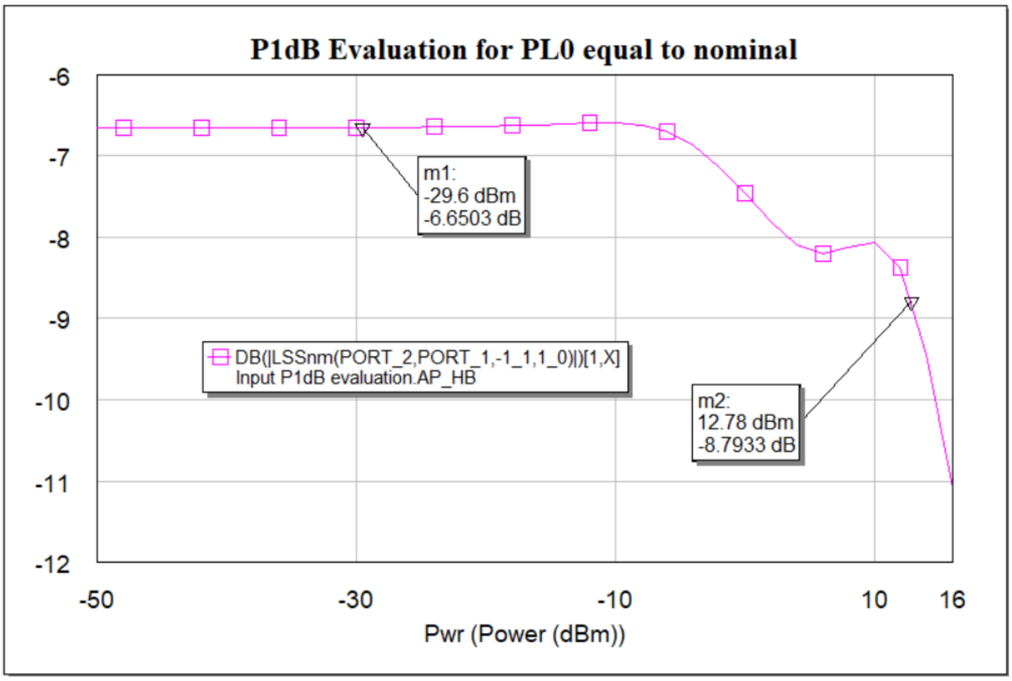


Figure 19. The P1dB Evaluation for PL0 equal to nominal

From the “P1dB Evaluation for PL0 equal to nominal” graph, the “Input_P1dB_mixer” is equal to 12.78.

All the result from the Mixer can be seen from the following photo.

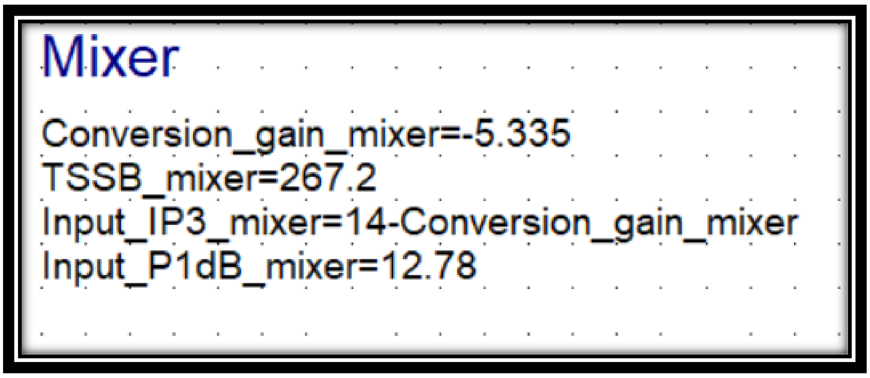


Figure 20. The desired parameters for Mixer

Finally, in this step, we can consider the extraction value and put it in the global definition, in the “VSS File for the RF Front-end simulation.emp”. the following result has been shown in the figure below:

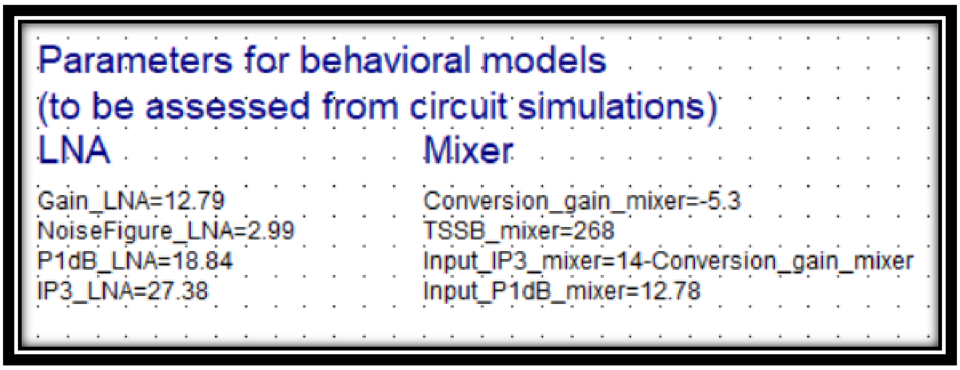


Figure 21. The desired parameters for Mixer

Measure of EVM

- Both EVM and Constellation measurements are available with VSS simulation
- The global variable RF_input_power is varied starting from a very low value (e.g.-100 dB). When EVM arrives to 5% the value of the variable represents the minimum admissible power (due to the noise produced by LNA, Mixer and Filters).
- Further increasing the input power causes EVM to decrease until the non-linearity effects (due to LNA and Mixer) degrades the signal and EVM starts to increase again. We keep increasing the input power until EVM is again 5%. The value of RF_input_power is the maximum admissible power

Simulation

In the Global definition section, there is a part which is called “RF_input_power”. The first value would be -100, in order to get the EVM value below 5.2, we increase the “RF_input_power” to -73.5.

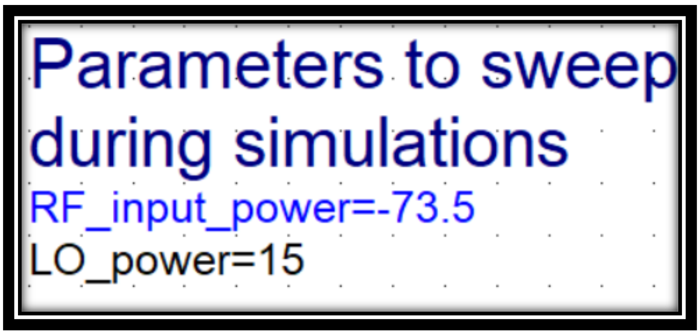


Figure 22. the new Value for RF_input_power

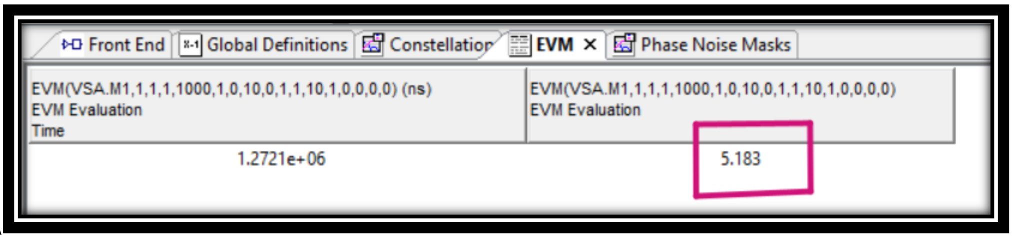


Figure 23. the EVM Evaluation

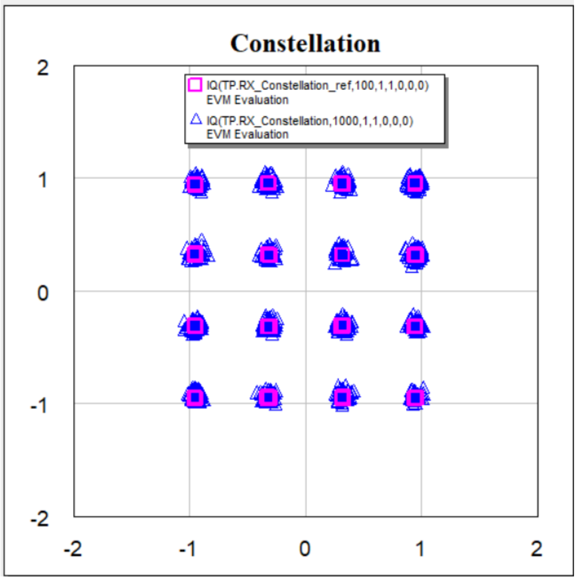


Figure 24. the Constellation graph

The mean value of the fluctuation is 5.16.

Recall of Phase Noise

- **Phase noise (PN)** represents the effects of the instantaneous phase fluctuations (jitter) of the sinusoidal signal produced by a real oscillator

- When the oscillator affected by PN is used in a mixer, the random variations of the LO phase are transferred to the carrier frequency of the translated signal. When this signal is de-modulated, the extracted information is distorted (quality degraded)

- The degradations produced depend on the maximum deviation of the instantaneous phase of the carrier. They are independent on the power of the RF signal

- Phase noise is practically defined by means of a mask representing the relative level of the power density produced by the oscillator at a distance Δf from the carrier frequency, for various values of Δf

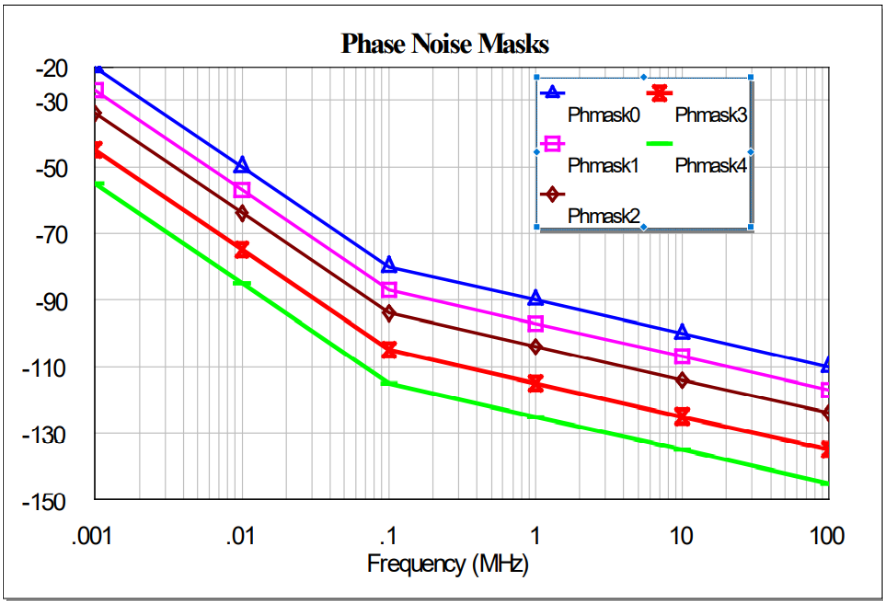


Figure 25. the Phase Noise Mask

Simulation om Local Oscillator phase noise mask

The next step of the simulation needs some modification. The first step is changing the "PNOISE" in the local oscillator with the phase noise to "Generate phase noise". The second step is to choose the "PNMASK" to the desire mask which the EVM value fluctuated between the 4.9 % and 5.1 %. In this step, we try many phases noise mask, Thus the desire mask would be "Phmask3". In the following figure, the result has been shown.

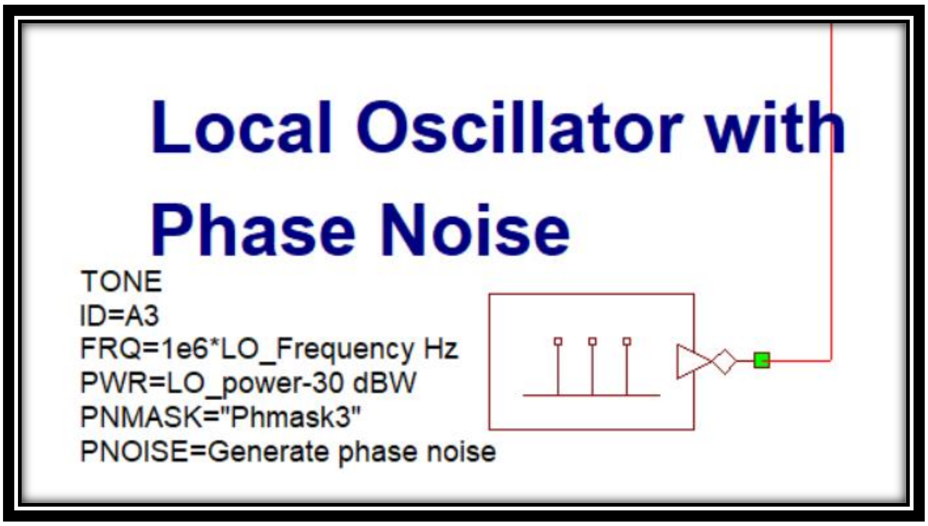


Figure 26. the Local Oscillator with Phase Noise

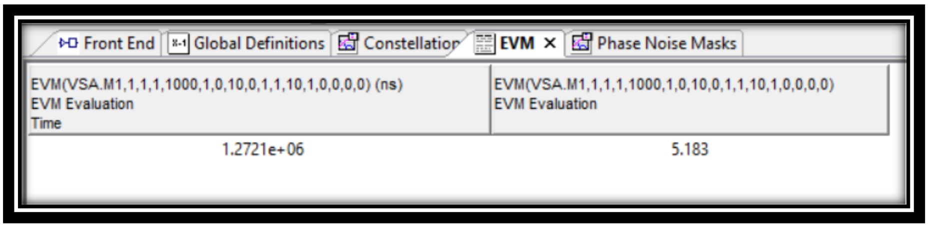


Figure 27. the EVM evaluation

As it can see in the above figure, the value of EVM is 5.183. In addition, the desired "PNMASK" is not the last one since the cost is important.

Degradation due to an image interferer

- An image interferer is a signal at the input of the RF frontend, whose carrier frequency is equal to the image frequency of the mixer

- This interferer should be eliminated by the image filter. In the practice, it appears at the input of the mixer, with a level depending on the filter selectivity

- Even if the attenuation of the image filter is large, when the received RF signal is much weaker than the interferer level, the converted signal at IF is distorted. The quality of the demodulated signal at baseband is then degraded

Evaluation of the interferer maximum power

- The interferer is represented by a single tone with the power defined by the variable ImagePower (defined in the diagram)
- The power is initially set to -100 dBm and RF_signal_power to the minimum value previously found. The resulting EVM should be around 5%
- The goal is to find the maximum value of ImagePower for which EVM is equal to about 5.2% (including Phase Noise due to LO)

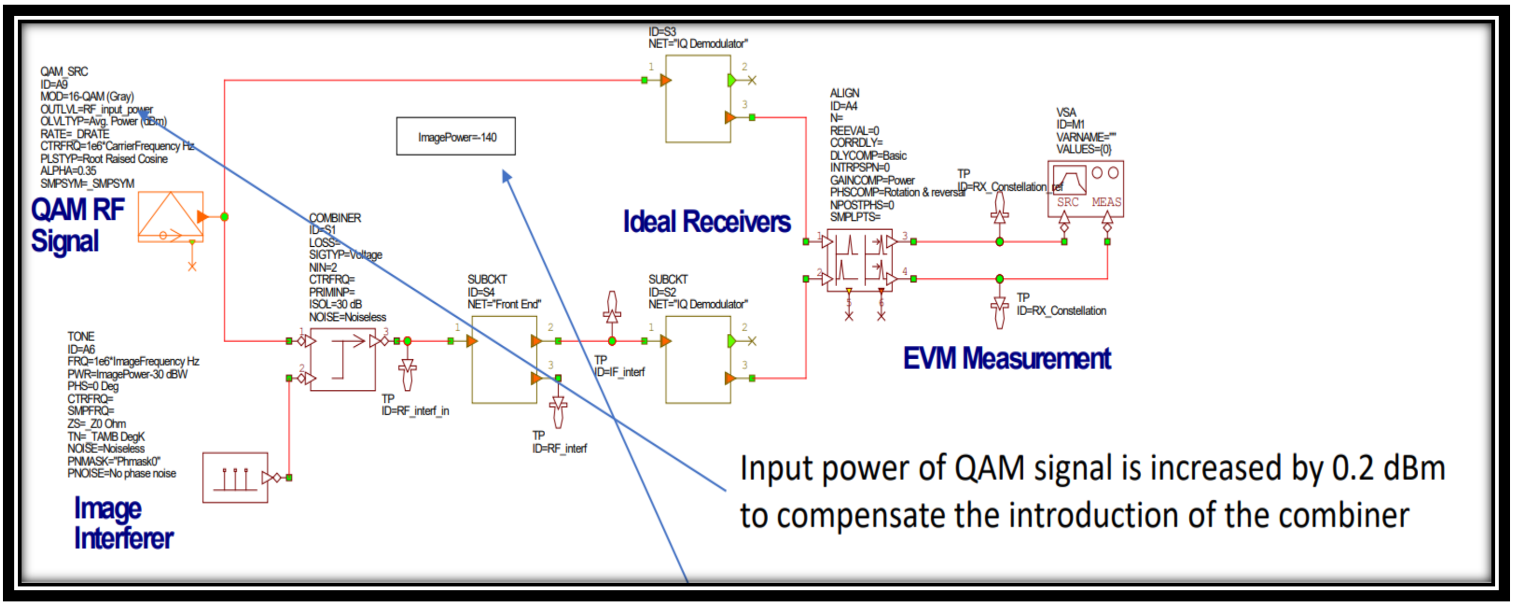


Figure 28. the Schematic for adding ImagePower

Simulation:

First of all, the measurement should be enables in the graph of "“EVM_Image Interf” and the “Constellation_Image Interf”. The second row should be added in this picture.

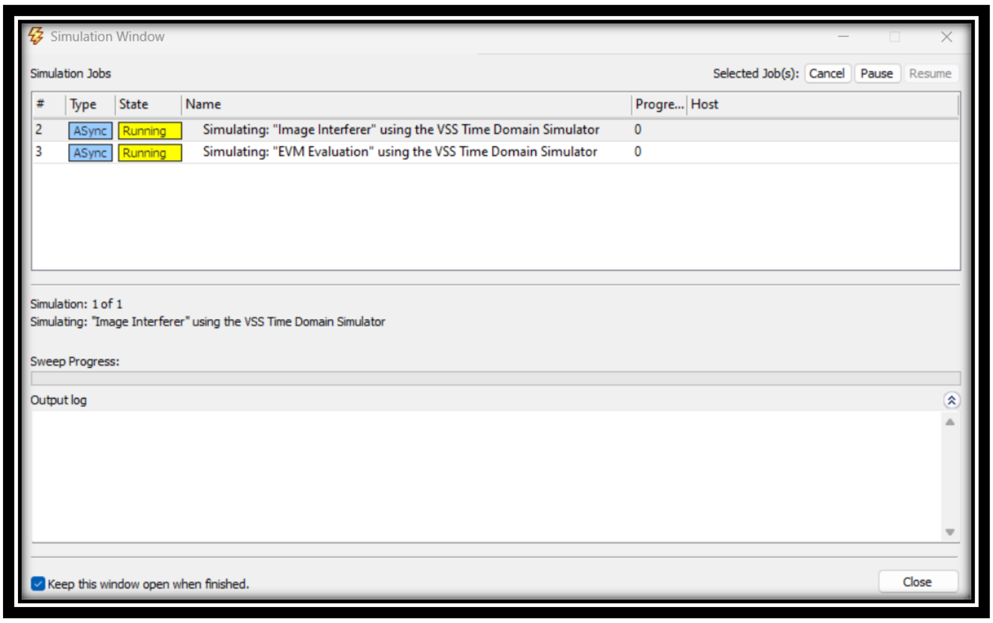


Figure 29. the simulation window

Secondly, we should assign the ImagePower = -100, then keep increasing the Image power until the EVM, should be around at 5.2 %. I put the value to ImagePower = -17, the EVM with image_interf is

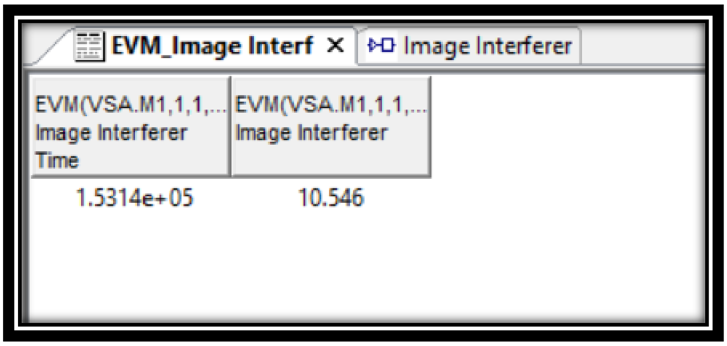


Figure . the EVM_Image_Interf

The value of ImagePower = -39, So the EVM_Image_interf would be around at 5.2 %. The result has been shown in the following picture.

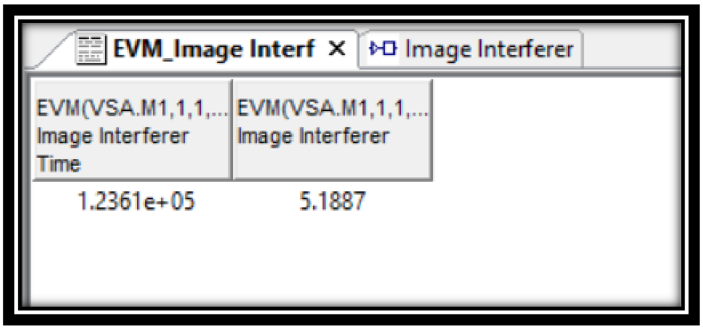


Figure 30. the EVM_Image_Interf

Budget evaluation

- Use Budget simulation of VSS to evaluate the equivalent noise temperature and the equivalent IP3 at the input of the RF frontend
- The simulations are carried out in the diagram "Budget Evaluation".

The "Budget_IP3" and the "Budget_Teq" has been shown in the figure 11 and figure 12 respectively.

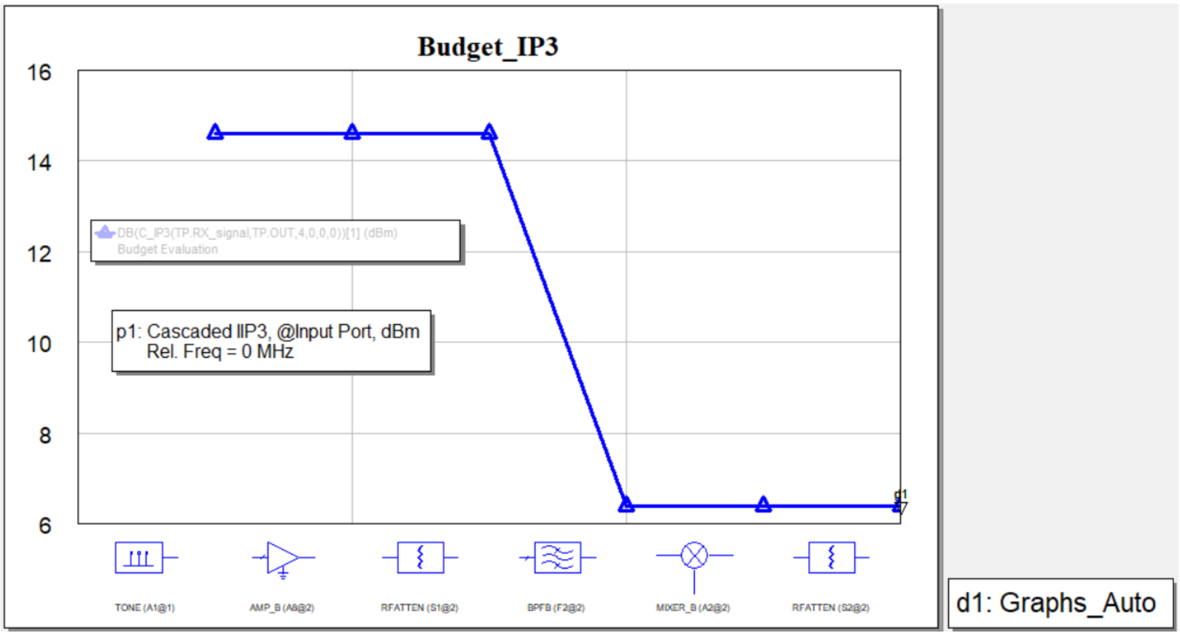


Figure 31. the Budget_IP3

From the above graph the Budget_IP3 the "IP3" is 6.364 dBm. The "IIP3" has been calculated from the following formula:
Conversion_gain_mixer = -5.3
IIP3 = Input_IP3_mixer=14 - Conversion_gain_mixer = 14 + 5.3 = 19.3

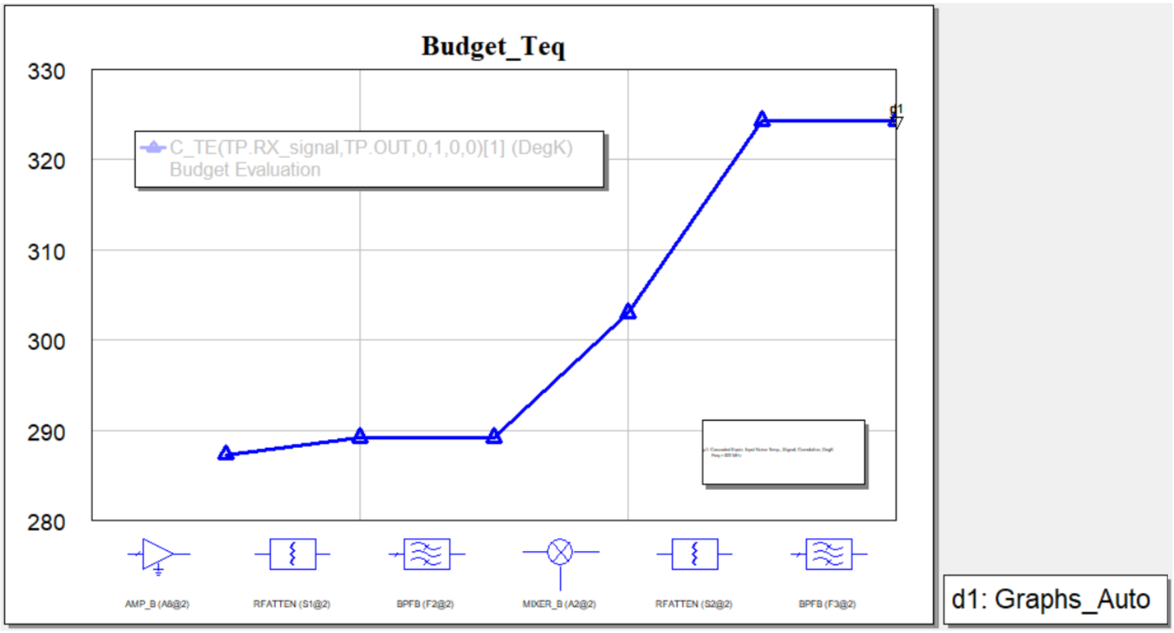


Figure 32. the Budget_Teq

From the Budget_Teq figure, the "the equivalent noise temperature" is 324.14.

For the better comparison, the RF Spectrum also has been depicted in the following section.

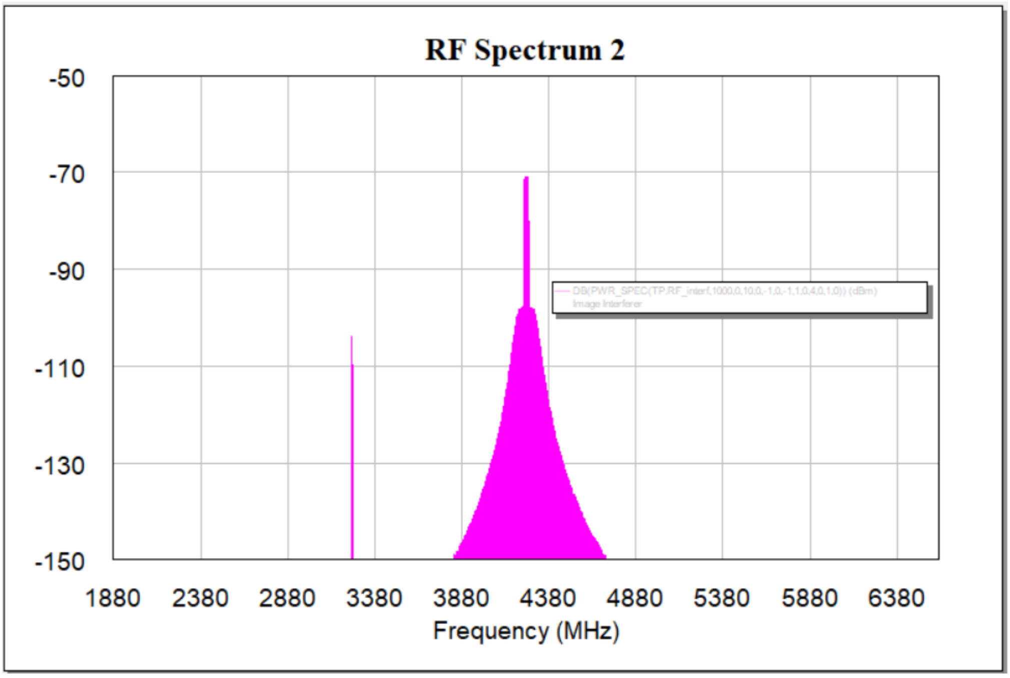


Figure 33. the RF Spectrum

For the calculation of LO_Power, as it mentioned in the report, we can obtain the "LO_Power" from the following graph.

It should be between 14 and 15, So we choose the average.
LO_Power = 14.5 w

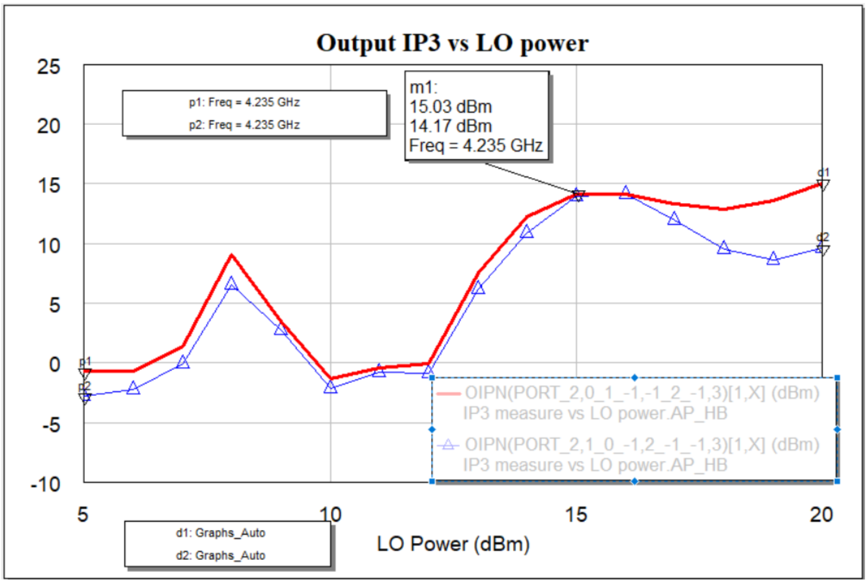
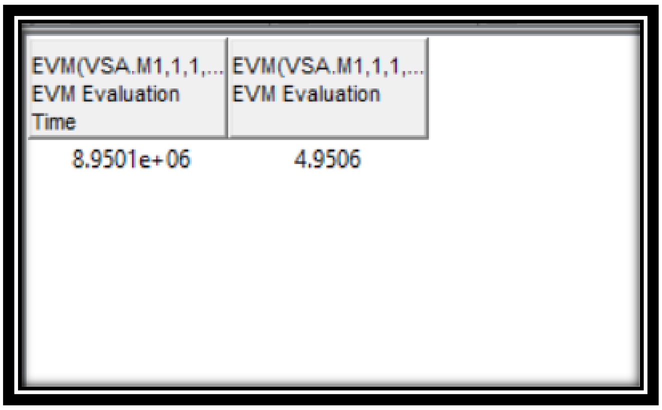


Figure 34. the Output IP3 vs LO Power

Calculating Data Range

As the definition illustrated the data_range = Pmax – Pmin. In this example, we consider, Pmin = -100 = RF_Input_Power, in the second step, we try to calculate the Pmax, by increasing the "RF_Input_Power" to reach the EVM to under 5%. If we consider the "RF_Input_Power" equal to -73, we reach the EVM under the 5% which will be sown in the figure below.



EVM(VSA.M1,1,1,... EVM Evaluation Time	EVM(VSA.M1,1,1,... EVM Evaluation
8.9501e+06	4.9506

Figure 35. The EVM evaluation

The Constellation figure also shows in the following section:

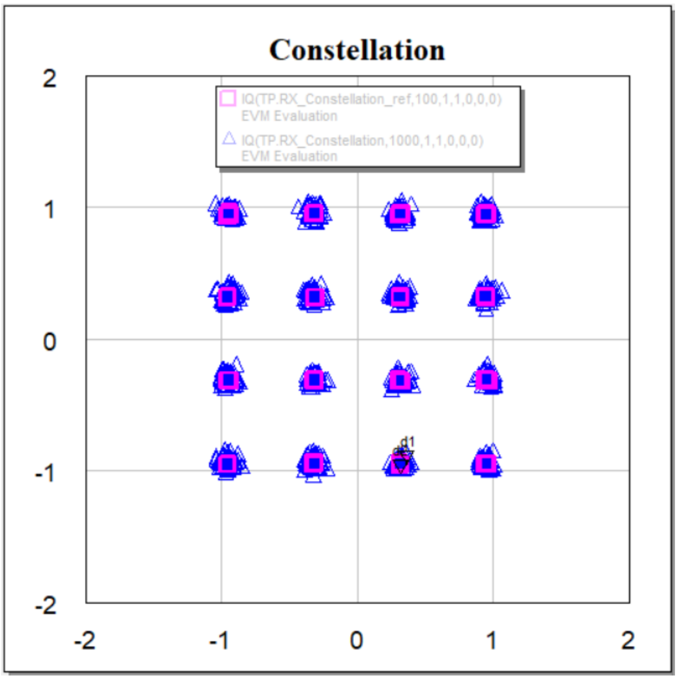


Figure 36. The Constellation

In addition, we need to increase the power again, So, the EVM is decreasing. If we continue increasing the power due to the non-linearity the EVM again goes to 5%. For this purpose, we use the tuner, for finding the best vale. The next value is 0.45, which has been shown in the following photo

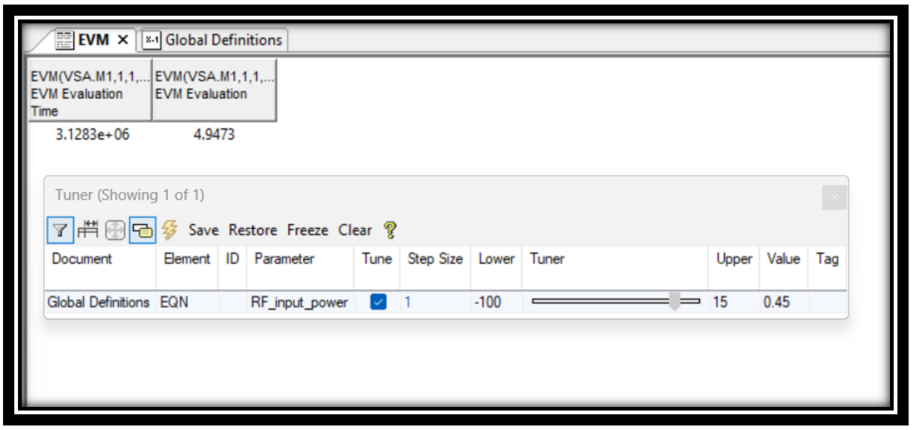


Figure 37. The EVM with the Tuner

DR = 0.45 – (-73) = 73.45.