LAB-3

TRANSCEIVER ANALYSIS AND DESIGN

PRE-LAB

Introduction:

In this lab, we have learned about noise and distortion analysis of radio systems using System Vue. Noise analysis is very important in designing radio systems and carrying out link distance analysis. Not only noise analysis we have to analyze how linearity affects the transmitter and receiver output. All the simulations are to be carried out in System Vue.

System Vue Workspace:

The schematic contains three major parts. The first part, shown in Figure 1, includes the same signal generation structure used in Lab 2 plus a channel model consisting of path loss and additive white Gaussian noise (AWGN) to model the input noise to the receiver. For this lab, you will be using a 64-QAM modulation scheme with an ideal IQ modulator to generate the transmitted signal. A power amplifier (PA) is then used to increase the signal's power. The path loss is set to $100dB$ which corresponds to line-of-sight link distance of 2.65 km at 900 MHz. Notice that input noise spectral density is set to $-173.975\ dBm/Hz$ which is the standard value for a noise source at room temperature, $T0 = 17°C = 290K$. There is also a deactivated Signal Combiner and Oscillator components which will be used later to simulate a high-power interferer. For now, you can leave the components deactivated.

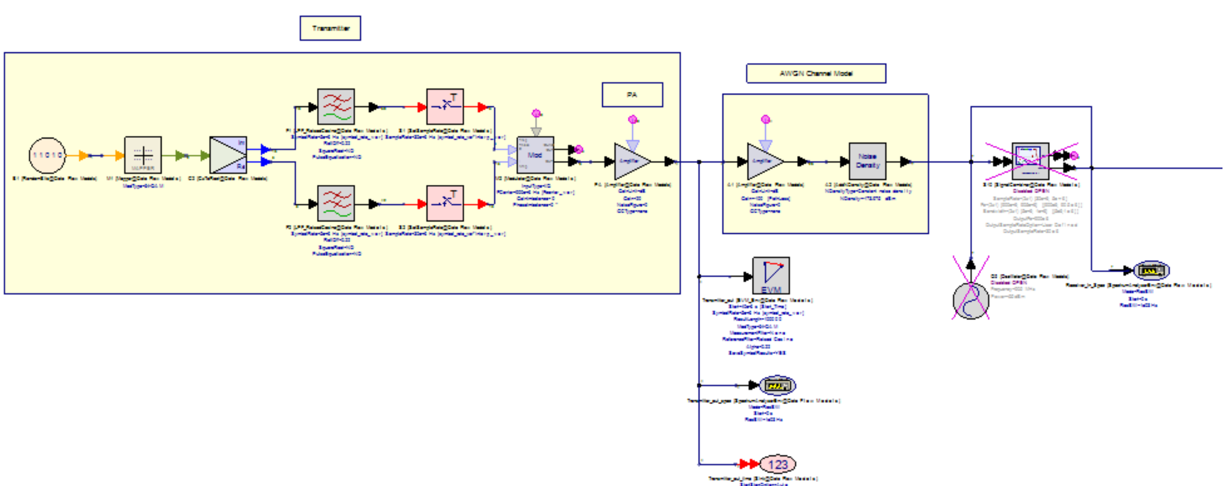


Figure 1 – Signal generation and the channel model (AWGN)

The second part, shown in Figure 2, is the receiver portion and consists of a band-select filter, low noise amplifier (LNA), down-converter mixer, and an intermediate frequency (IF) amplifier. The local oscillator (LO) frequency is set to our RF frequency, plus our target IF of 100 MHz. Band-selectfilter is a 5^{th} order Butterworth band-pass filter with 2 dB insertion loss which attenuates out-of-band signals by 100 dB. The LNA has a gain of 20 dB with a 3 dB noise figure. Note that the LNA is nonideal and has a 3^{rd} order output intercept point (OIP3) of -20 dBm.

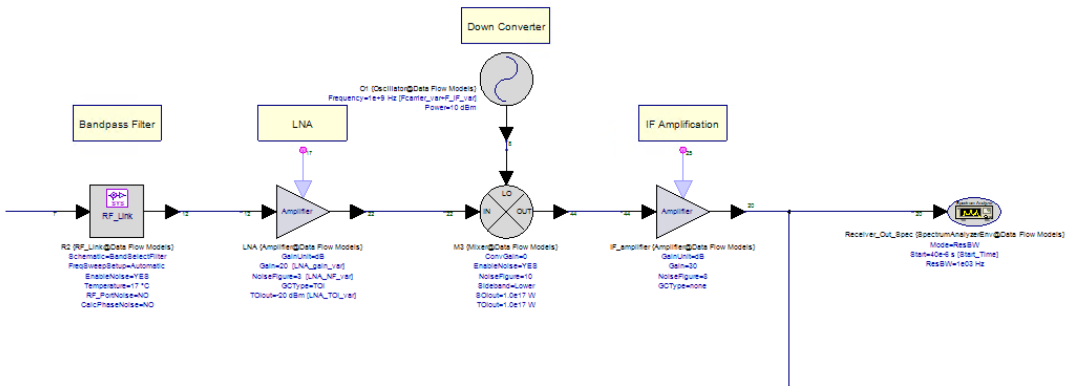


Figure 2 – Receiver block diagram.

Finally, the third part, shown in Figure 3, is the channel-select filter performed in the digital domain using an FIR filter. The EVM measurement for this lab should be after the channel select filter.

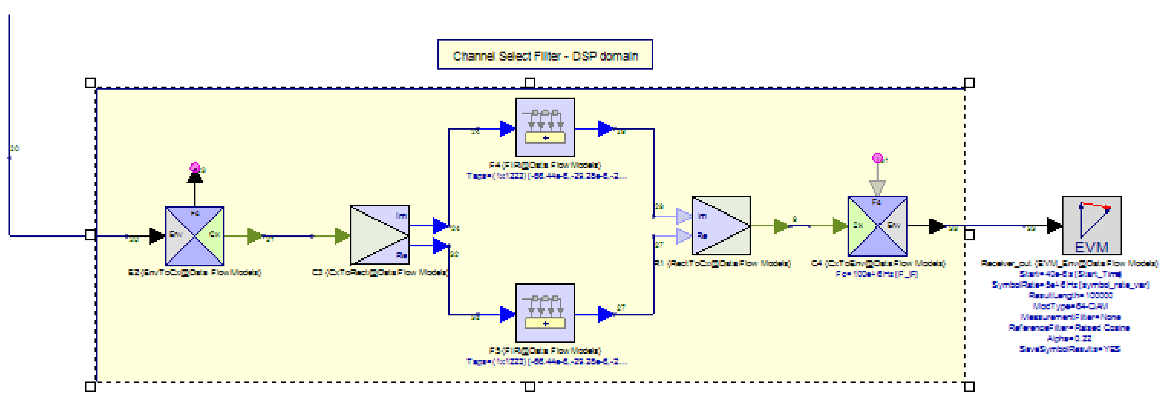


Figure 3 – Channel select filter in the digital domain

Part 1 – Noise figure of the receiver chain

a) Find input/out SNR and noise figure of the receiver from simulation.

To determine the SNR at input and output of the receiver chain we took input receiver signal power measurement for a 5MHz bandwidth ranging from 897.5MHz to 902.5MHz. Since the guard frequency is 500kHz the input put noise power is determined past guard frequency ranging from 904MHz to 909MHz. Similarly, out receiver signal power measurement for a 5MHz bandwidth ranging from 97.5MHz to 102.5MHz. Since the guard frequency is 500kHz the output noise power is determined past guard frequency ranging from 104MHz to 109MHz. We can calculate the SNR for the input and output of the receiver as follows

$$\frac{S+N}{N} - 1 = \frac{S}{N} + 1 - 1 = SNR\left(\frac{W}{W}\right)$$

	Signal Power(W)	Noise Power(W)	SNR(W/W)	SNR(dB)
Reciever Input	93.39e-12	20.13e-15	4638.34	36.66
Reciever Output	5.88e-6	4.596e-9	1278.34	31.066

Table-1: Receiver input and output SNR analysis

Noise Figure(dB) = SNR_{IN}(dB) - SNR_{OUT}(dB)

= 36.66-31.066

Noise Figure(dB) = 5.594(dB)

b) Find the receiver chain noise figure using hand calculations and compare it with the simulation result.

In the receiver chain, we have four units that are cascaded. So, we can find the noise figure using the Friss equation follows

Unit 1: Bandpass Filter

NF_1= 2dB

F_1=$10^{2/10}$=1.584 w/w

$G_1(dB) = -2dB$

$G_1(w/w) = 10^{-2/10} = 0.631\ w/w$

Unit 2: LNA

NF_2= 3dB

F_2=$10^{3/10}$=1.995 w/w

$G_2(dB) = 20dB$

$G_2(w/w) = 10^{20/10} = 100\ w/w$

Unit 3: Mixer

NF_3= 10dB

F_3=$10^{10/10}$=$10w/w$

$G_3(dB) \ = 0dB$

$G_3(w/w) = 10^{0/10} = 1\ w/w$

Unit 2: IF Amplifier

NF_4= 8dB

F_4=$10^{8/10}$=$6.31w/w$

$G_4(dB) \ = 30dB$

$G_4(w/w) = 10^{30/10} = 1000\ w/w$

Friis Equation

$$F_T = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2} + \frac{F_4 - 1}{G_1 G_2 G_3}$$

$$F_T = 1.584 \ + \frac{1.995 - 1}{0.631} + \frac{10 - 1}{(0.631)(100)} + \frac{6.31 - 1}{(0.631)(100)(1)}$$

$F_T = 3.387(w/w)$

$NF = 10log_{10}(3.387)$

$NF = 5.298(dB)$

Therefore, 1ab there is not much difference in the simulation result Noise Figure(dB) =5.594(dB) and hand calculated result $NF = 5.298(dB)$.

c) Plot the constellation at the output of the receiver and transmitter. Comment on the difference.

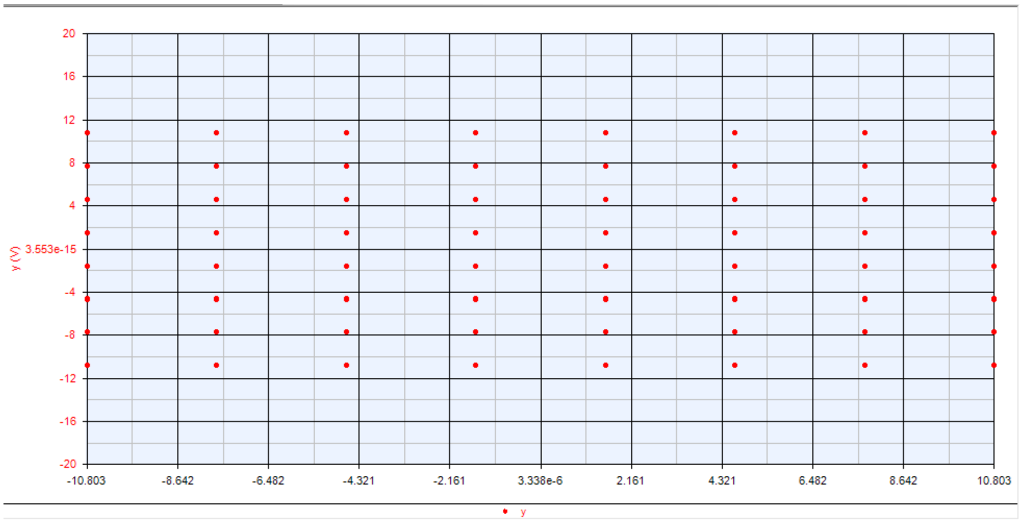


Figure 4: constellation at the output of the transmitter

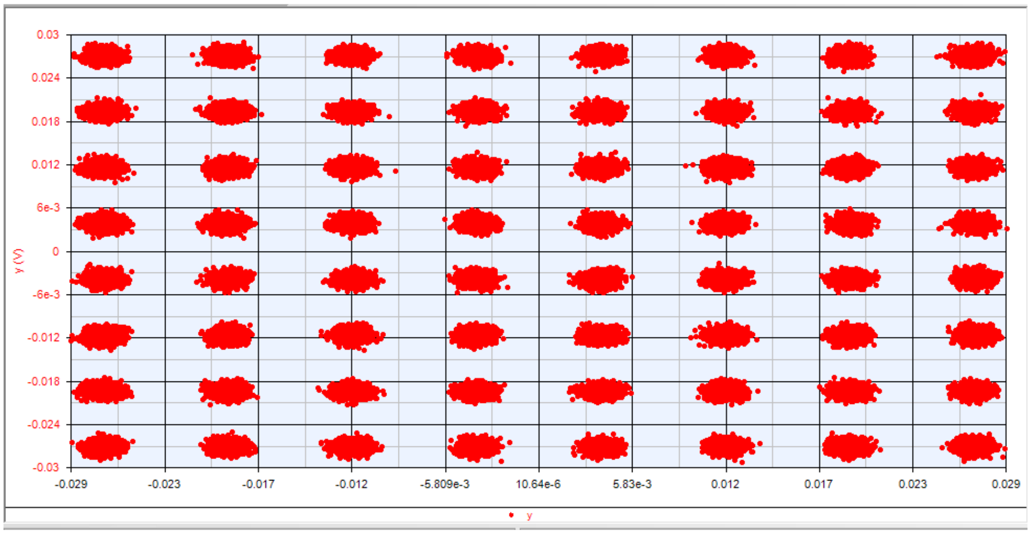


Figure 5: constellation at the output of the receiver

We can observe that the constellation of transmitter output is clear and more noise-free whereas the constellation of receiver output is affected by noise and the constellation points are like a cloud of samples.

d) Estimate the SNR at receiver output from the EVM measured after the channel select filter.

Index	Receiver_out_Index	Receiver_out_EVM_RMS
1	0	1.968

Figure 6 : EVM(%) at receiver output after the channel select filter

Therefore, EVM(%) at the receiver output after the channel select filter is 1.968.
Given that for 64-QAM signals, EVM(%) is approximate:

$$\text{EVM}(\%) \approx 100 \times 10^{(-\text{SNR(dB)}-3.7)/20}.$$

From the above equation, we can find the SNR_{out} (dB) with the EVM value obtained at the channel select filter. The above equation can be written as follows:

$$SNR_{out} = -(20log_{10}\left(\frac{EVM}{100}\right) + 3.7)$$

$$SNR_{out} = -(20log_{10}\left(\frac{1.968}{100}\right) + 3.7)$$

$$SNR_{out} = 30.34$$

SNR_{out} (dB)	31.066
SNR_{out} (dB) with EVM	30.34

Table 2: Comparing SNR out calculated with EVM(%) and simulated result

From the above table, we can see that both the values are almost equal and the EVM equation for SNR(dB) is valid.

Part 2 – Effects of LNA Gain and Noise Figure on the receiver chain

a) Find the maximum allowable LNA noise figure for an EVM of less than 3% using hand calculation and simulation.

Hand Calculation:

To find the LNA noise figure using the Friis equation we have to obtain Noise faction for max EVM(%) i.e.3%

$$\mathrm{EVM}(\%) \approx 100 \times 10^{(-\mathrm{SNR(dB)}-3.7)/20}.$$

$$SNR_{out} = -(20log_{10}\left(\frac{EVM}{100}\right) + 3.7)$$

$$SNR_{out} = -(20log_{10}\left(\frac{3}{100}\right) + 3.7)$$

$$SNR_{out} = 26.75(dB)$$

$$NF = SNR_{IN} - SNR_{OUT}$$

$$NF = 36.66 - 26.75$$

$$NF = 9.91(dB)$$

$$F = 10log_{10}(9.91)$$

$$F = 9.794(w/w)$$

From Friis equation,

$$F_T = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2} + \frac{F_4 - 1}{G_1 G_2 G_3}$$

Values from Part 1-b

$$9.794 = 1.584 + \frac{F_2 - 1}{0.631} + \frac{10 - 1}{(0.631)(100)} + \frac{6.31 - 1}{(0.631)(100)(1)}$$

$$\frac{F_2 - 1}{0.631} = 7.9844$$

$$F_2 = 6.038(w/w)$$

Noise Figure of LNA =7.809(dB)

	Maximum LNA Noise Figure	EVM(%)
Stimulation Results	**6.98**	**2.995**
Hand calculation Results	**7.809**	**3**

Table 3: Hand calculated and simulated result of Max LNA Noise Figure

b) Change the gain of the LNA to 10 dB and find the new maximum allowable LNA noise figure for an output EVM of less than 3% using hand calculation and simulation.

$$G_2(dB) = 10dB$$

$$G_2(w/w) = 10^{20/10} = 10\ w/w$$

From Friis equation,

$$F_T = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2} + \frac{F_4 - 1}{G_1 G_2 G_3}$$

$$9.794 = 1.584 + \frac{F_2 - 1}{0.631} + \frac{10 - 1}{(0.631)(10)} + \frac{6.31 - 1}{(0.631)(10)(1)}$$ Values from Part 1-b

$$\frac{F_2 - 1}{0.631} = 5.944$$

$$F_2 = 4.751(w/w)$$

Noise Figure of LNA =6.76(dB)

	Maximum LNA Noise Figure	EVM(%)
Stimulation Results	**4.45**	**2.992**
Hand calculation Results	**6.76**	**3**

Table 4: Hand calculated and simulated result of Max LNA Noise Figure with 10dB gain

c) Comment on how the LNA's gain affects its noise figure requirement.

The LNA's noise figure is affected by its gain. When we observe table-2 and table -3 there is a significant change in the noise figure when the gain is reduced from 20dB to 10dB. Therefore we can say that as the LAN gain decreases the noise figure decreases thereby signal quality increases. So, LNA gain is proportional to its noise figure.

Part 3– Effects of Power Amplifier Linearity on the Transmitter Output

a) Plot the constellation, spectrum, and signal envelope at the transmitter's output and find the EVM and ACPR at that point as well.

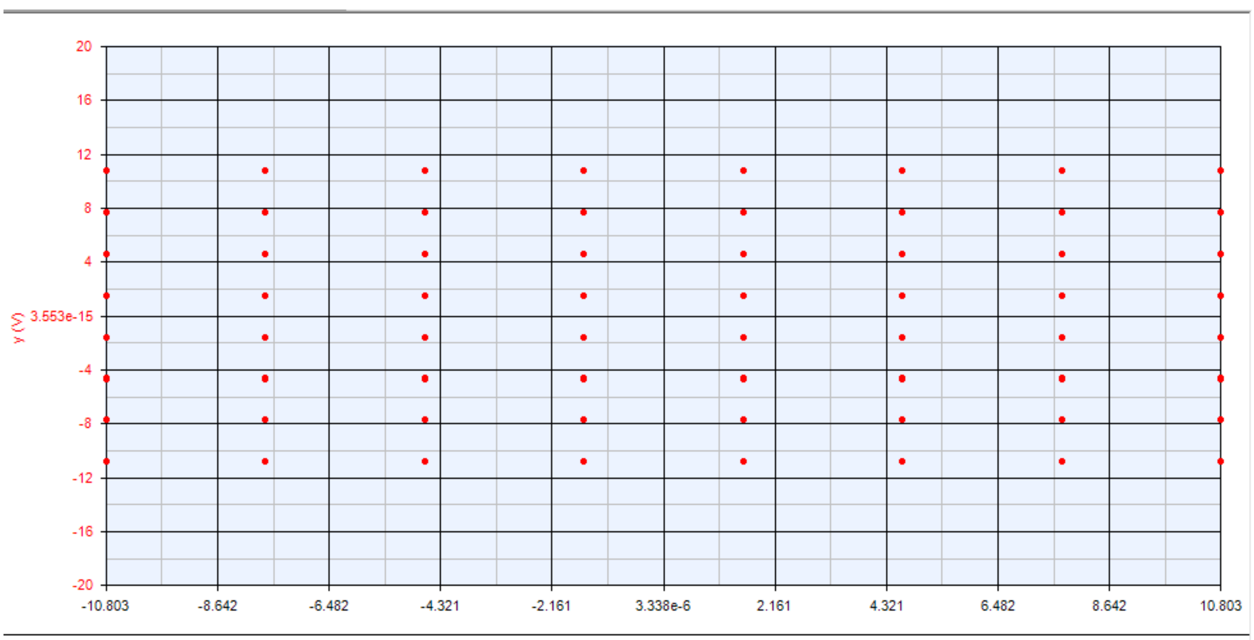


Figure 7 constellation at the output of the transmitter

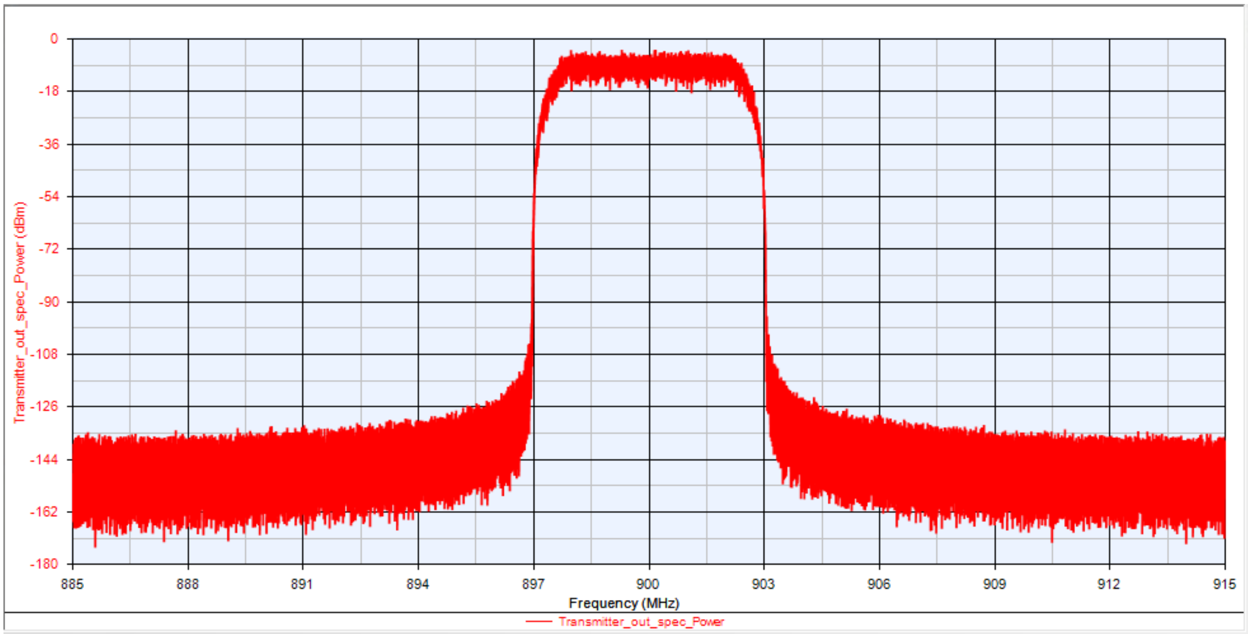


Figure 8 : Spectrum at the output of the transmitter

Lower Channel ACPR(dB)	Lower Channel ACPR(W/W)	Upper Channel ACPR(dB)	Upper Channel ACPR(W/W)	ACPR(W/W)	ACPR(dB)
-72.144	6.103e-8	-72.689	5.384e-8	11.487e-8	-69.39

Table 5: Stimulation Results of ACPR at transmitter output

Index	Transmitter_out_Index	Transmitter_out_EVM_RMS
1	0	4.845e-3

Figure 9: EVM(%) at transmitter output

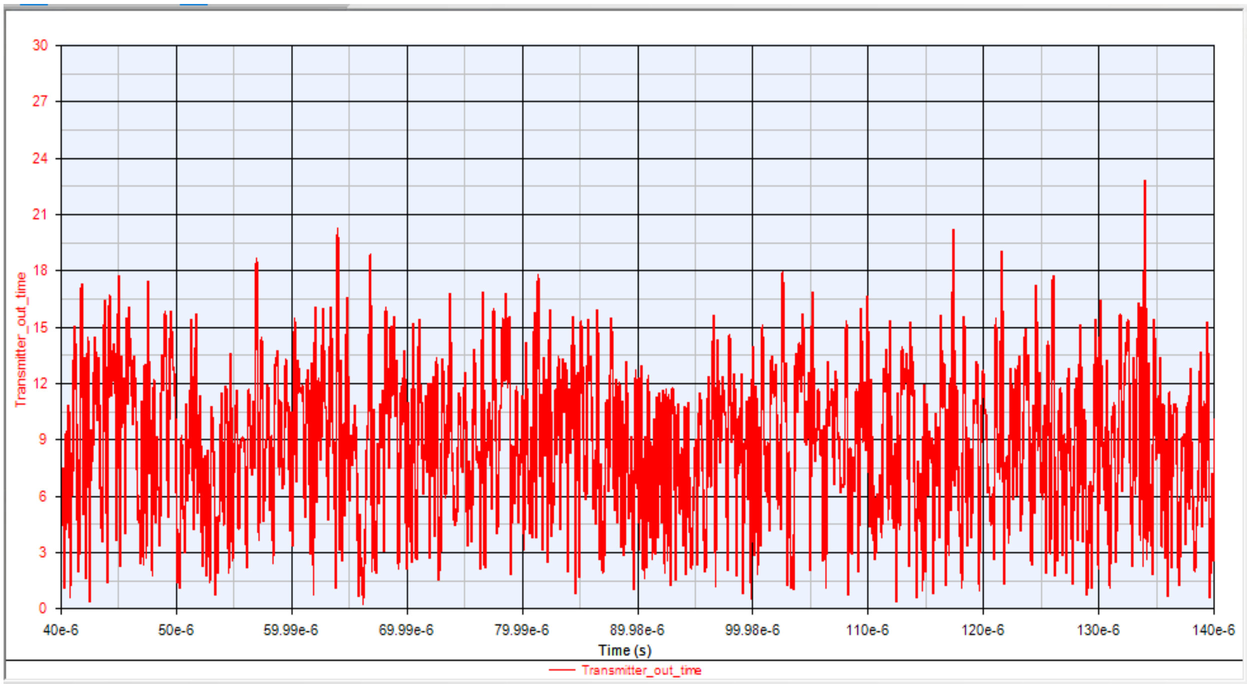
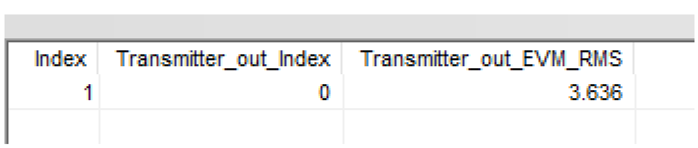


Figure 10: Signal envelope at transmitter

b) Repeat part a) with a nonlinear PA

Lower Channel ACPR(dB)	Lower Channel ACPR(W/W)	Upper Channel ACPR(dB)	Upper Channel ACPR(W/W)	ACPR(W/W)	ACPR(dB)
-30.672	8.566e-4	-30.64	8.629e-4	17.195e-4	-27.646

Table 6: Stimulation Results of ACPR at transmitter output with non-linear PA



Index	Transmitter_out_Index	Transmitter_out_EVM_RMS
1	0	3.636

Figure 11: EVM(%) at transmitter output with non-linear PA

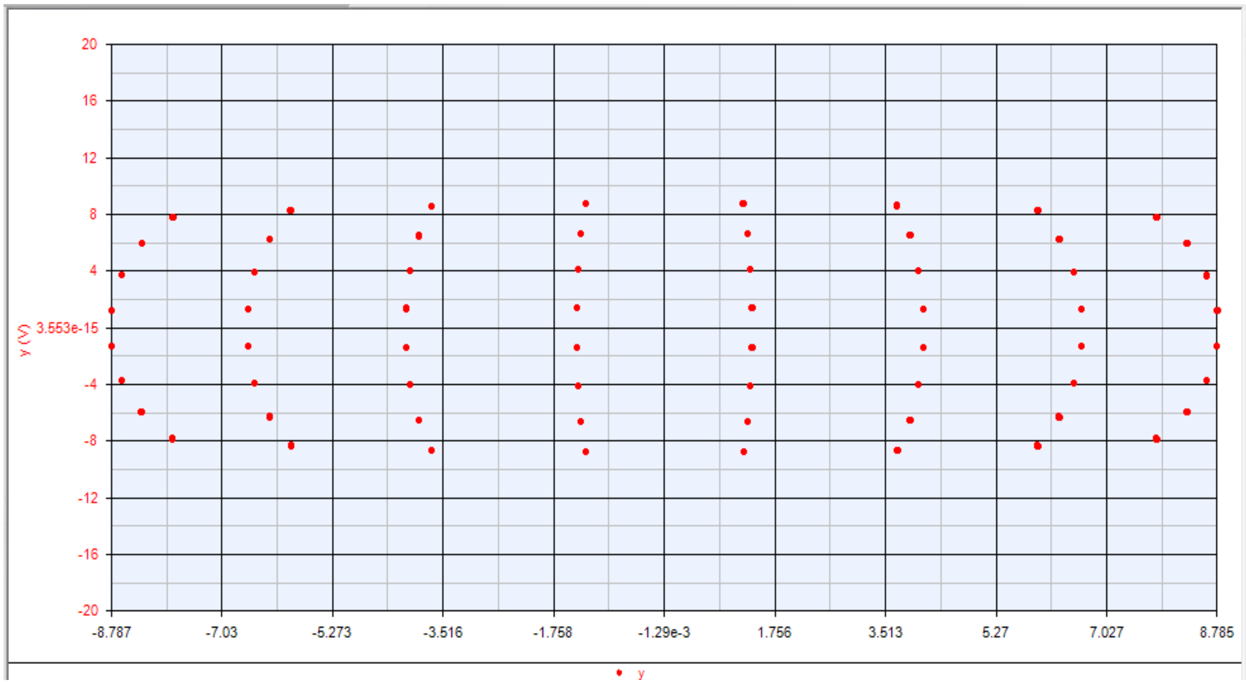


Figure 12 constellation at the output of the transmitter with non-linear

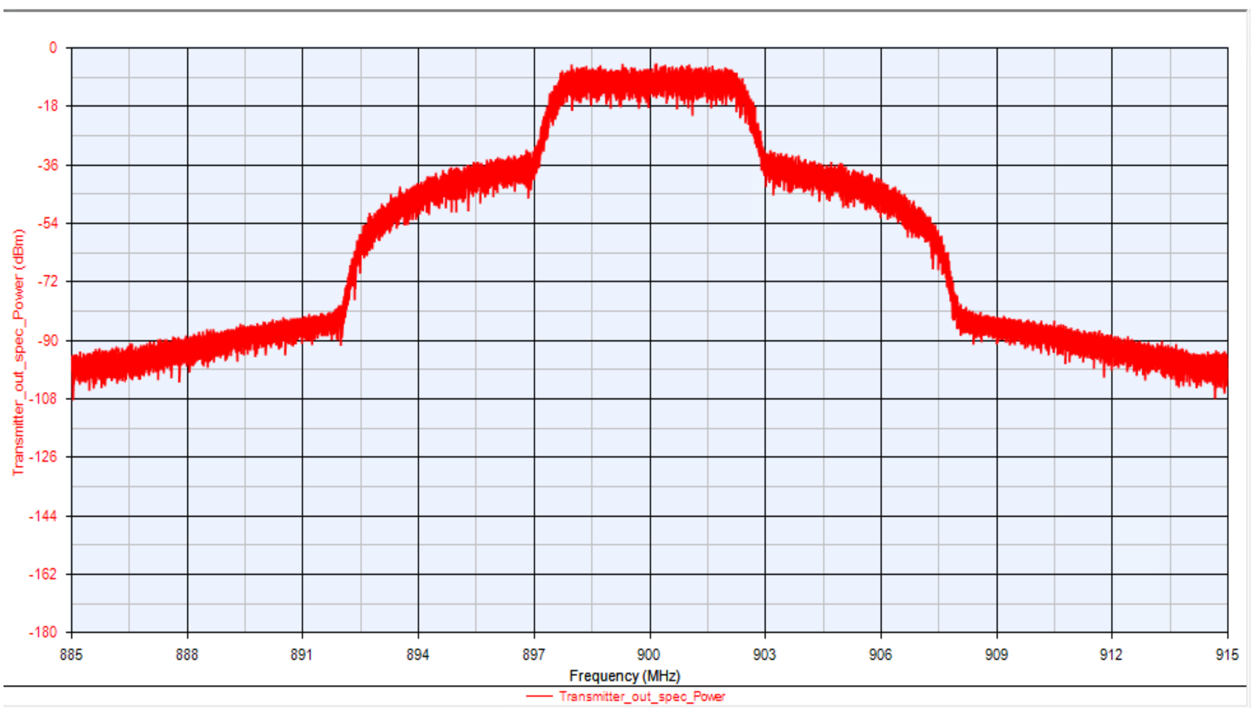


Figure 13 Spectrum at the output of the transmitter with non-linear PA

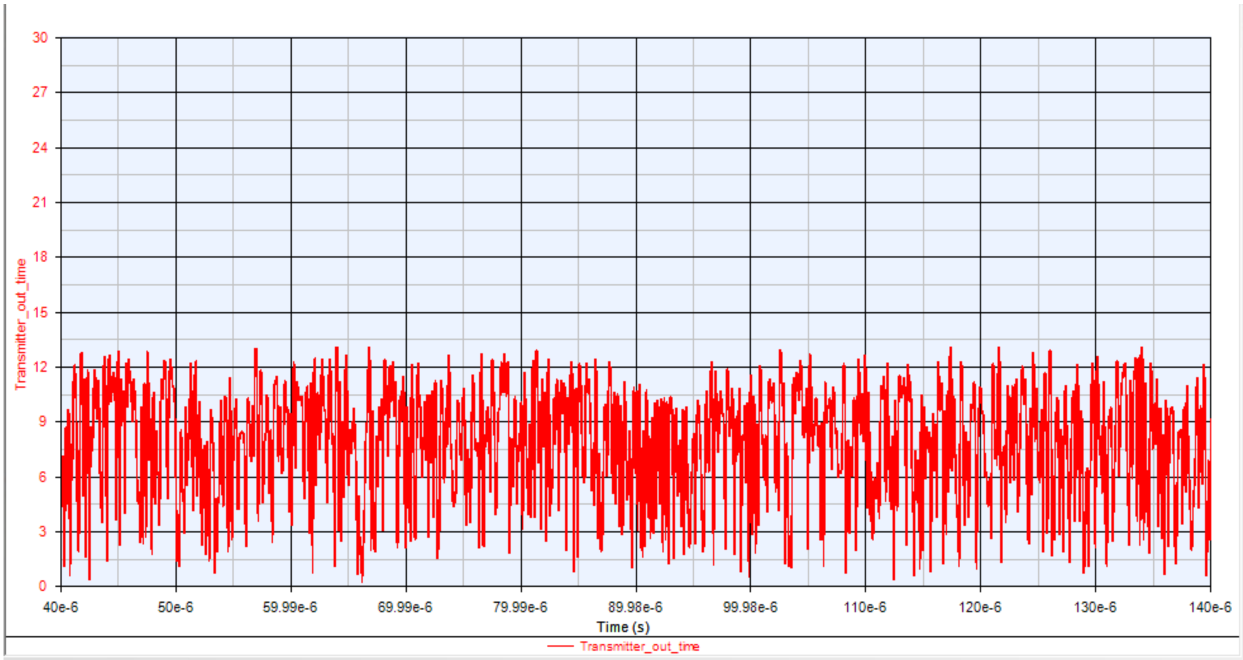


Figure 14: Signal envelope at transmitter output with non-linear PA

c) Comment on how and why the output of the transmitter is affected by degrading the PA's linearity.

By changing the power amplifier linearity all the factors such as constellation, ACPR, EVM(%), spectrum and signal envelop are affected. We can see there is a significant effect in these factors by degrading power amplifier linearity. All these are observed because when linearity is altered there are harmonics distortions and primarily are due to signal compression. There is a phase shift in the constellation which is observed clearly and it is difficult for the receiver to detect the signal. We can observe compression in the signal envelope and also the spectrum which is affected by harmonics due to non-linear PA.

Part 4– Blocker and LNA linearity

a) Simulate and comment on the effect of this blocker on signal quality (EVM and constellation after the channel selection filter)

Index	Receiver_out_Index	Receiver_out_EVM_RMS
1	0	3.869

Figure 15: EVM(%) at receiver output after the channel selection filter with blocker enabled

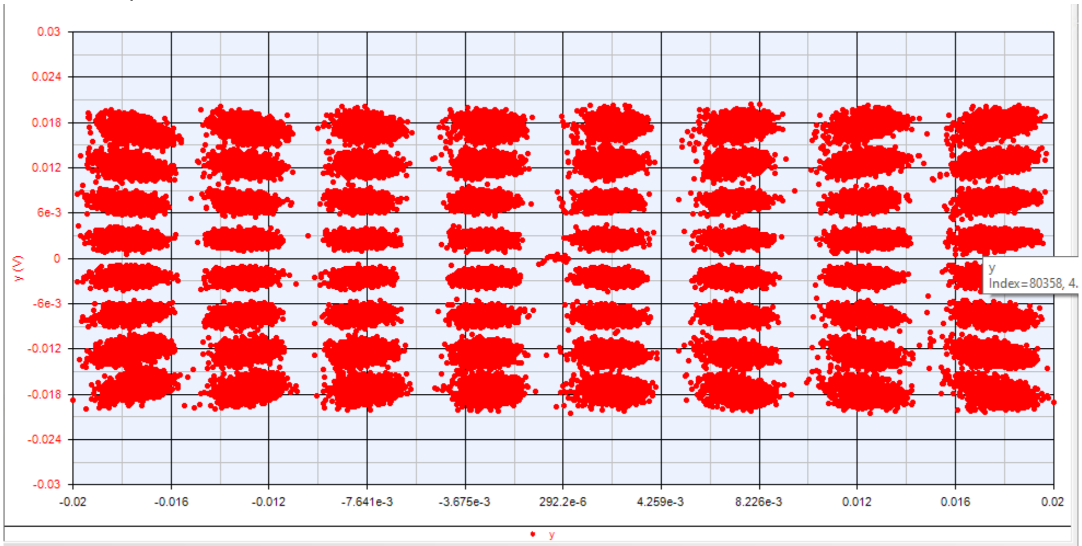


Figure 16: constellation at the receiver output after the channel selection filter with blocker

There is a significant effect on Constellation and EVM when the blocker is enabled. EVM(%) changed from 1.968 to 3.869 and constellation all cloud points are converged towards the center and these are because when the blocker is enabled an adjacent channel is transmitted within our desired band.

b) Find through simulation what the required LNA linearity is to achieve an EVM of less than 2.5% at the output of the channel select filter.

LNA linearity	EVM%
-30	3.869
-28.5	2.83
-28	2.68
-27.7	2.543
-27.6	2.515
-27.53	2.497
-27.5	2.489

Table 7: EVM(%) at receiver output after the channel selection filter with blocker enabled

c) Comment on why and how the LNA's linearity affects the output EVM

From table 7 we can observe that as the LNA's linearity increased EVM(%) value decreased and EVM(%) less than 2.5% is achieved at -27.53. This effect is because the blocker is enabled and an adjacent channel is transmitted within our desired band.

IN-LAB

Introduction

The goal of this lab is to familiarize the characterization and analysis of transmitters and receivers for RF communication systems. We measure the linearity and noise performance of a transmitter and receiver unit

Part 1 Power Amplifiers 1 dB Compression Point

a) Plot the output power and gain versus the input power

Input Power(dBm)	Output Power (dBm)	Gain (dB)
-20	-4.69	15.31
-18	-2.7	15.3
-16	-0.773	15.227
-14	1.25	15.25
-12	3.28	15.28
-10	5.18	15.18
-9	6.1	15.1
-8	6.97	14.97
-7	7.8	14.8
-6	8.57	14.57
-5	9.14	14.14
-4	9.59	13.59
-3	9.93	12.93

Table 8: input power output power and gain values of power amplifier in transmitter unit

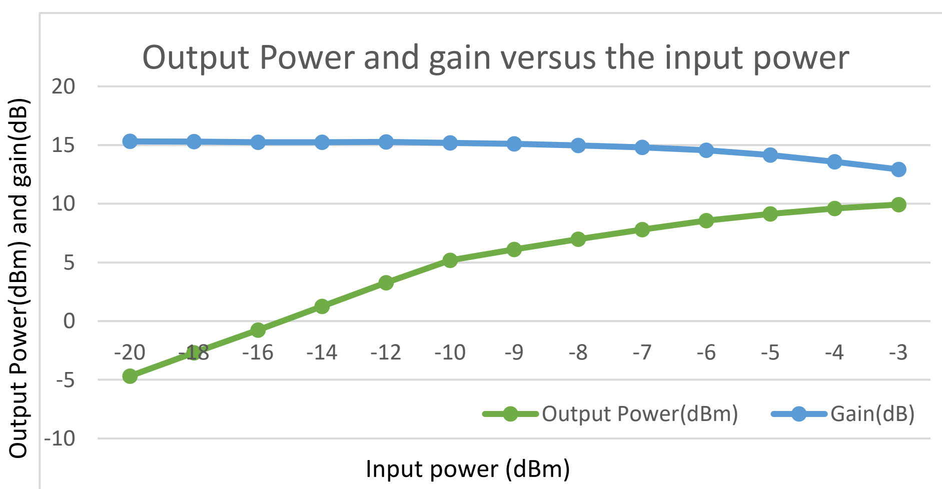


Figure 17: output power and gain versus the input power

b) Estimate the power amplifiers' 1 dB compression point as well as the small-signal gain.

From Table 8 and figure 17 we can observe that 1 dB compression where Pin is -5dBm and Pout are 9.59dBm. The gain at 1 dB compression point is 14.14 dB. Similarly, the small-signal gain can be estimated where Pin is -20dBm and Pout is -4.69 dBm. therefore the small-signal gain is 15.32dB.

	Input Power(dBm)	Output Power (dBm)	Gain (dB)
1 dB compression point	-5	9.14	14.14
small signal gain	-20	-4.69	15.31

Table 9: 1 dB compression point and small signal gain of power amplifier

Part 2 Power Amplifiers Two-Tone Measurements

a) Measure the upper and lower IM3 of the power amplifier under two-tone excitation versus the input power.

Input power(dBm)	P_{2f1-f2} (dBm)	P_{f1} (dBm)	P_{f2} (dBm)	P_{2f2-f1} (dBm)	$IM_{3\text{-lower}}$ (dB)	$IM_{3\text{-upper}}$ (dB)
-24	-69.66	-11.67	-11.67	-68.39	-57.99	-56.72
-22	-68.74	-9.68	-9.57	-68.54	-59.06	-58.97
-20	-62.1	-7.69	-7.71	-63.61	-54.41	-55.9
-18	-56.57	-5.72	-5.72	-57.23	-50.85	-51.51
-16	-51.45	-3.72	-3.72	-52	-47.73	-48.28
-14	-44.65	-1.71	-1.69	-44.85	-42.94	-41.25

Table 10: Calculation of upper and lower IM3 of power amplifier under two tone excitations

b) Use the IM3 measurements to estimate the IIP3 of the amplifier.

We can estimate IIP3 using IM3 measurement as follows

$$IIP3\ (dBm) = P_{in\text{-}f1}\ (dBm) - 1/2\ IM_{3\text{-lower}}\ (dB)$$

$$OIP3\ (dBm) = P_{out\text{-}f1}\ (dBm) - 1/2\ IM_{3lower}\ (dB)$$

We must select the input power level such that the 5th order nonlinear terms are negligible, and that the 3rd order intermodulation products are well above the noise floor for estimating IIP3 from IM3 measurements. Knowing IIP3, one can estimate the maximum linear output power of the amplifier to achieve a certain IM3. This will set the maximum transmitted power for the transmitter. From Table 8 we select the input power level to be -20(dBm) for IIP3 calculation.

$P_{in\text{-}f1}$ (dBm) = -20 and $P_{out\text{-}f1}$ (dBm) = -7.69

$$\text{IIP3 (dBm)} = -20 - \frac{1}{2}(-55.9)$$

$$\text{IIP3 (dBm)} = 7.95$$

$$\text{OIP3 (dBm)} = -7.69 - \frac{1}{2}(-55.9)$$

$$\text{OIP3 (dBm)} = 20.26$$

c) How is IIP3 and the 1 dB compression point relate?

IIP3 and the 1 dB compression point relate can be related as follows

$$\text{IIP3 (dBm)} = IP_{1-dB}(dBm)\text{+9.6}$$

Where $IP_{1-dB}(dBm)$ is input power at 1 dB compression point. Where $IP_{1-dB}(dBm)$= -5dBm

According to the above formula IIP3(dBm) is 4.6 as the but estimate IIP3 using IM3 measurement is 7.95(dBm)

<u>Part 3 Effects of Power Amplifier Nonlinearity</u>

a) EVM, ACPR, PAPR, spectrum, and the constellation of the 64-QAM signal at the output of the PA.

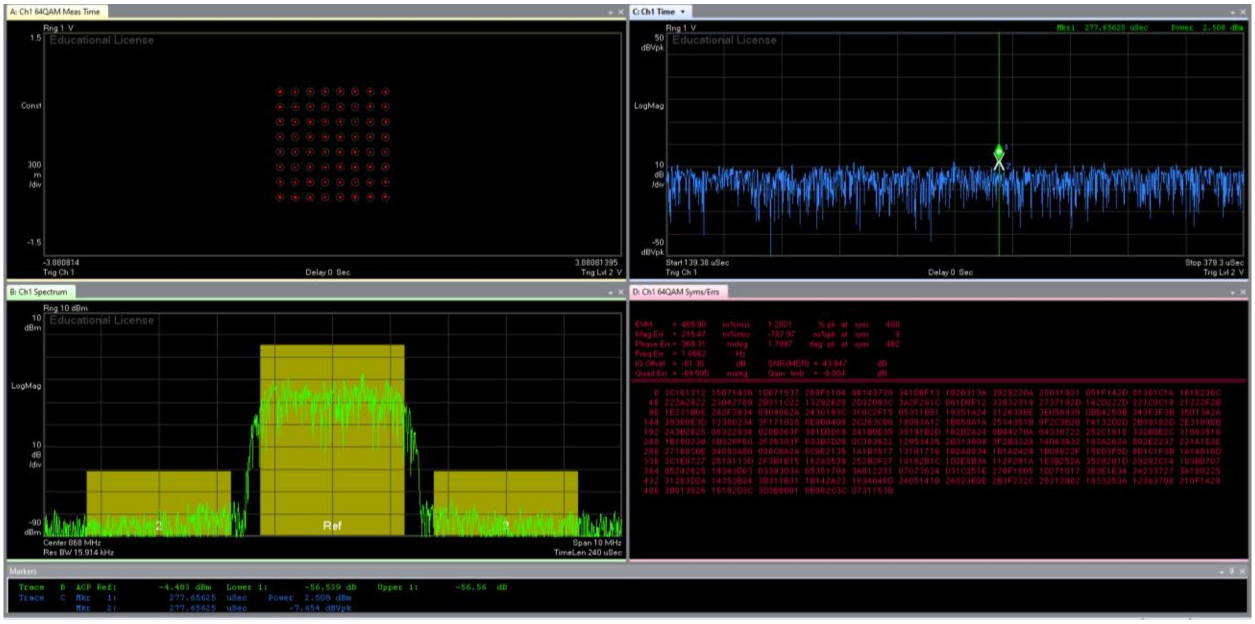


Figure 18: EVM, ACPR, PAPR, spectrum and constellation of the 64-QAM signal at the output of the PA.

EVM(%)	ACPR					PAPR (dB)
	Lower Channel ACPR(dB)	Upper Channel ACPR(dB)	Lower Channel ACPR(w/w)	Upper Channel ACPR(w/w)	ACPR(dB)	
0.405	-56.539	-56.56	2.218e-6	2.208e-6	-53.53	6.991

Table 11: Stimulation Results of ACPR EVM and PAPR of 64-QAM signal at the output of power amplifier

b) Measure again the EVM, ACPR, PAPR, spectrum and constellation of the 64-QAM signal when the EVM is worse than 3%.

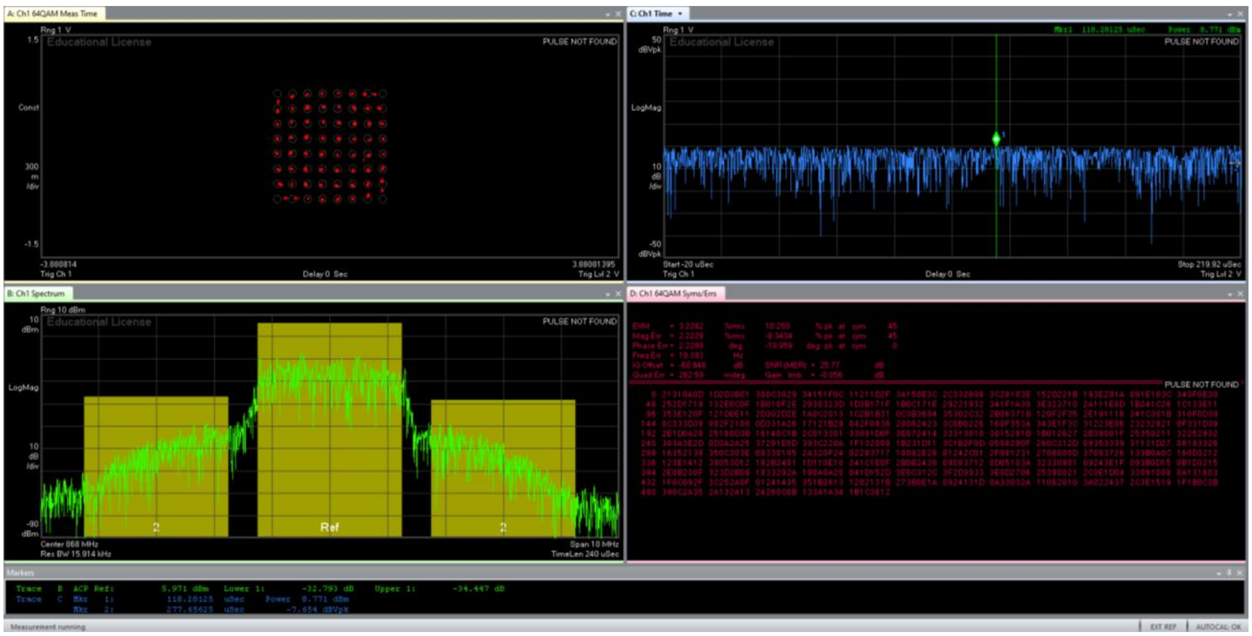


Figure 19: EVM, ACPR, PAPR, spectrum and constellation of the 64-QAM signal at the output of the PA when the EVM is worse than 3%.

EVM(%)	ACPR					PAPR (dB)
	Lower Channel ACPR(dB)	Upper Channel ACPR(dB)	Lower Channel ACPR(w/w)	Upper Channel ACPR(w/w)	ACPR(dB)	
3.22	-32.793	-34.447	5.256e-4	3.591e-4	-30.532	2.8

Table 12: Stimulation Results of ACPR EVM and PAPR of 64-QAM signal at the output of power amplifier when the EVM is worse than 3%.

c) Compare the two measurements and explain what is happening at the higher power level.

Part	EVM(%)	ACPR			PAPR(dB)
		Lower Channel ACPR(dB)	Upper Channel ACPR(dB)	ACPR(dB)	
a	0.405	-56.539	-56.56	-53.53	6.991
b	3.22	-32.793	-34.447	-30.532	2.8

Table 13: Comparison ACPR EVM and PAPR of part a and b

We can observe that at a higher power level all the values EVM(%), ACPR has increased but PAPR is reduced. The decrease in PAPR is due to an increase in average power at higher power levels. There is a change in constellation and spectrum because of the Power amplifier nonlinearity.

Part 4 LNA NF Measurement

Measure the noise figure and gain of the LNA from 863 MHz to 873 MHz

Now connect the noise source (Agilent 346A) to the LNA input and connect the LNA output to the CXA. Use RF Trainer software to power on the LNA. Now you can measure the LNA noise figure.

Figure 20: noise figure and gain of the LNA using noise source and CXAfrom 863 MHz to 873 MHz

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ECE-770 Lab-3 Report

Part 5 IF BPF NF Measurement

Measure the noise figure and gain of the IF BPF from 45 MHz to 55 MHz.

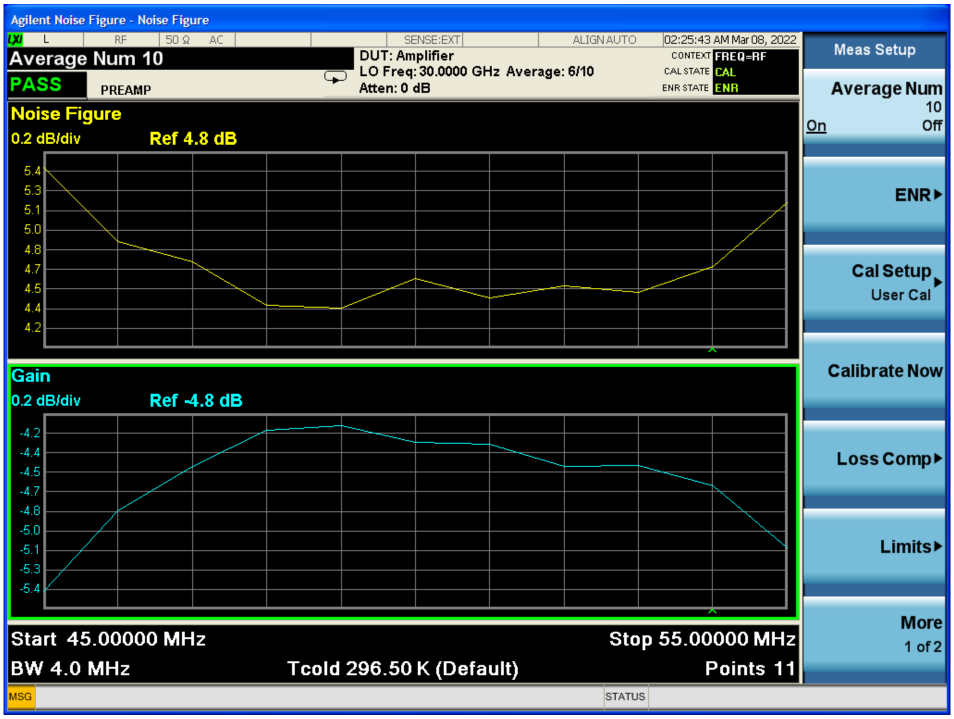

Figure 21: noise figure and gain of the IF BPF using noise source and CXA from 45 MHz to 55

Part 6 Mixer NF Measurement

Measure the noise figure and gain of the Mixer for IF between 45 MHz to 55 MHz.

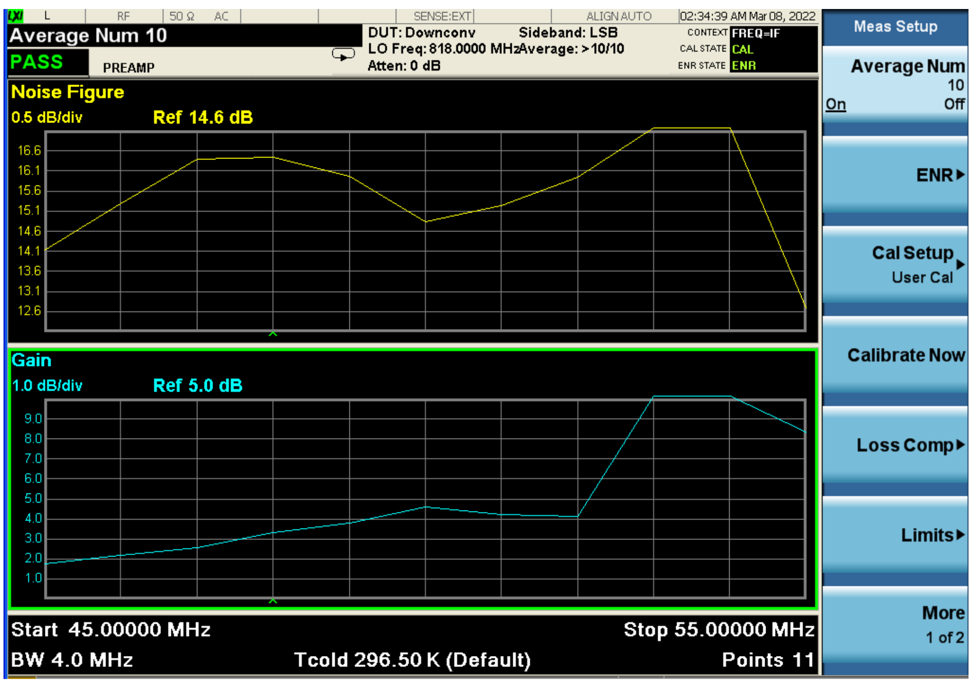

Figure 22: noise figure and gain of the IF BPF using noise source and CXA from 45 MHz to 55

Part 7 Receiver NF Measurement

a) Measure the noise figure and gain of the overall receiver chain.

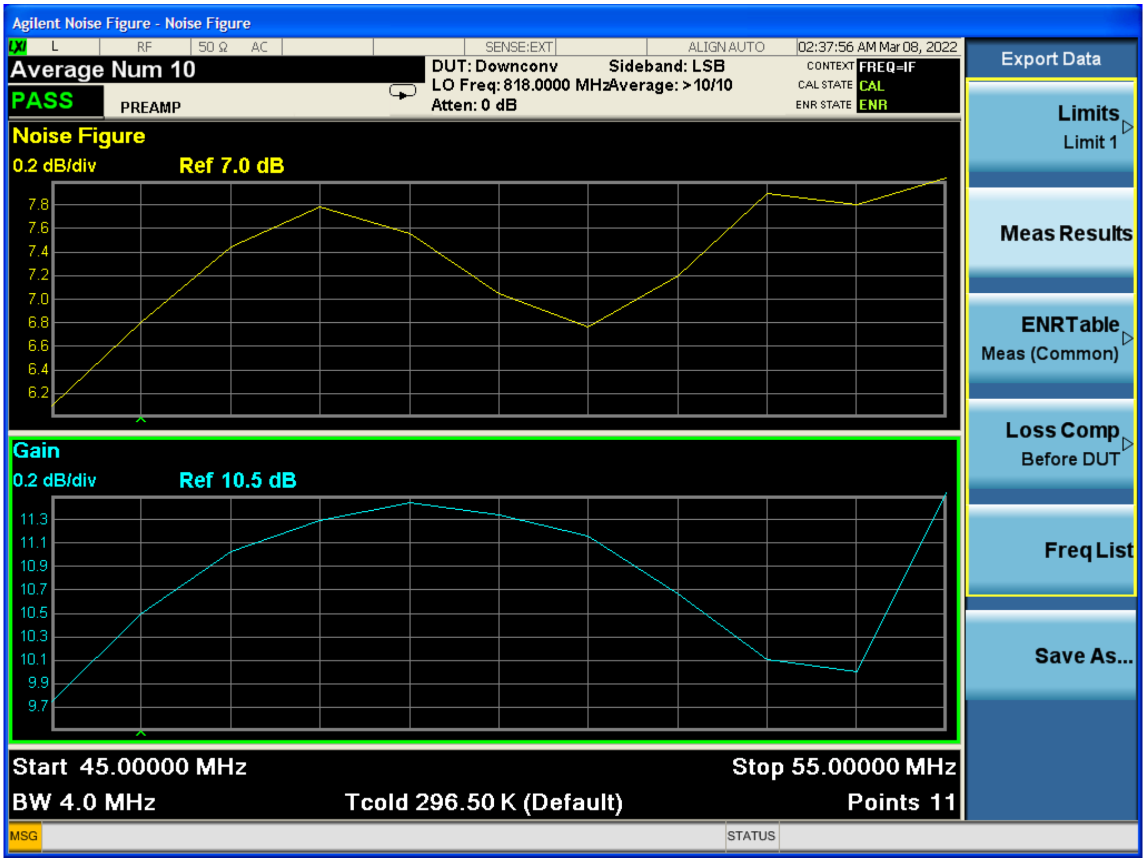

Figure 23: noise figure and gain of the reciever unit using noise source and CXA from 45 MHz to 55

Noise Figure (dB)	Gain (dB)
6.072283145	9.766577407
6.794831718	10.49482329
7.461349221	11.00715424
7.777969434	11.29613557
7.552139735	11.44664681
7.029598465	11.37347067
6.738753581	11.25744223
7.23508853	10.80257691
8.170712196	10.04010411
NaN	NaN
NaN	NaN

Table 14: Noise figure and gain of Reciever

b) Compare the measurement results with the performance of the individual stages at each measured frequency.

To compare the measurements at each stage we calculate and compare the noise figure of the receiver unit with the calculated value. In receiver unit LNA, mixer, and IF BPF are cascaded and their noise figure is calculated using the Friis equation.

$$F_T = F_{LNA} + \frac{F_{MIXER} - 1}{G_{LNA}} + \frac{F_{BPF} - 1}{G_{LNA}G_{MIXER}}$$

NF of LNA	NF of Mixer	NF of IF BPF	Noise Figure (dB)	Noise Figure Calculated(dB)
2.958358845	14.05524193	5.508519284	6.072283145	6.538237
2.982465446	15.21585792	4.910370456	6.794831718	7.147489
2.949241646	16.43504847	4.580396653	7.461349221	7.894533
2.914151707	16.48079454	4.35588863	7.777969434	7.985019
2.860041504	15.83919536	4.46504293	7.552139735	7.652729
2.787610738	15.04916742	4.549043626	7.029598465	7.29524
2.023666912	NaN	4.404501786	6.738753581	#VALUE!
1.797809463	NaN	4.648462924	7.23508853	#VALUE!
2.016058681	NaN	4.651090067	8.170712196	#VALUE!
2.1955843	NaN	4.822584994	NaN	#VALUE!
2.958358845	NaN	4.860021941	NaN	#VALUE!

Table 15: Noise figure of Reciever unit measured and calculated values at each

Gain of LNA	Gain of Mixer	Gain of IF BPF	Gain (dB)	Gain Calculated(dB)
11.50567951	1.815585083	-5.40659	9.766577	7.914674
11.56824519	2.241238518	-4.83171	10.49482	8.977772
11.42442364	2.494187386	-4.39625	11.00715	9.522364
11.35182689	3.237973492	-4.19602	11.29614	10.39378
11.42993225	3.869161283	-4.18826	11.44665	11.11084
11.41645744	4.17210197	-4.26195	11.37347	11.32661
14.76654887	NaN	-4.26695	11.25744	#VALUE!
10.0763838	NaN	-4.50024	10.80258	#VALUE!
9.65581252	NaN	-4.54511	10.0401	#VALUE!
NaN	NaN	-4.70139	NaN	#VALUE!
7.976575897	NaN	-4.8967	NaN	#VALUE!

Table 16: Gain of Reciever unit measured and calculated values at each frequency

c) Estimate the receiver sensitivity of the receiver kit to achieve an EVM of less than 3%.

Using the below formula we can find the minimum detectable signal

$$\text{EVM}(\%) \approx 100 \times 10^{-\text{SNR(dB)}-3.7/20}$$

$$SNR_{out} = -(20log_{10}\left(\frac{EVM}{100}\right) + 3.7)$$
$$SNR_{out} = -(20log_{10}\left(\frac{3}{100}\right) + 3.7)$$

$$SNR = 26.75(dB)$$

$$SNR_{IN\_MDS} = SNR_{out} + 10log_{10}KTB\text{+30+NF}$$

$$SNR_{IN\_MDS} = 26.75 + +10log_{10}(8.6137 * 10^{-5} * 290 * 4 * 10^{6}) + 30 + NF$$

$$SNR_{IN\_MDS} = 106.7464\text{+NF}$$

Frequency(MHz)	SNR_{IN_MDS}(dBm)
863	120.8016
864	121.9623
865	123.1814
866	123.2272
867	122.5856
868	121.7956
869	#VALUE!
870	#VALUE!
871	#VALUE!
872	#VALUE!
873	#VALUE!

Table 17: minimum detectable signal calculated values at each frequency

Conclusion: we have analyzed how linearity affects the transmitter and receiver output using System Vue in pre-lab and familiarized the characterization and analysis of transmitters and receivers for RF communication systems. We measure the linearity and noise performance of the transmitter and receiver unit using kits.