Q1

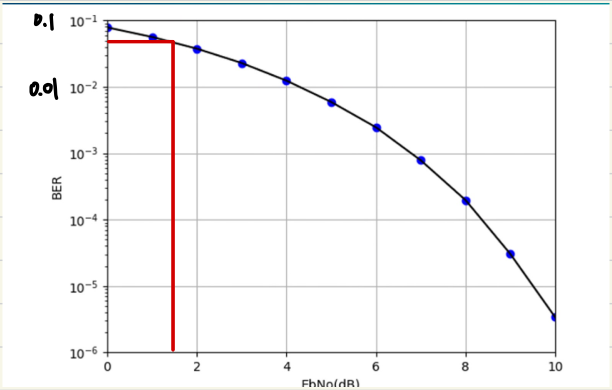
- Part A:
  - Step 1: Determine the reference sensitivity for single antenna (in dBm). (Hint: Take into account of the fact that a two-antenna system is being used). Assume occupied BW is 10MHz.
  - Step 2: Determine the bit error rate (BER) using page 7. BER = 1 – (Throughput).
  - Step 3: Determine Eb/No to achieve the BER using the BER graph provided on page 6 (in dB).
  - Step 4: Determine the throughput of the system modifying the throughput equation (hint: find the amount of data subcarriers, bits/symbol and code rate).
  - Step 5: Determine the SNR (in dB).
  - Step 6: Determine the noise figure of the system using the thermal noise and input noise (in dB).
  - Step 7: Determine the noise figure of the receiver (in dB). (Consider both NF_{PVT} (Only used in this step), and front end loss)

-91.8

Step1 From the Table, Two-antenna system is being used
The reference sensitivity is $-94.8\,dBm + 3\,dB = -91.8\,dBm$
for single antenna

Step2 $BER = 1 - 0.95 = 0.05 = 5 \cdot 10^{-2}$

Step3



EbNo(dB) = 1.5 dB

Step4 # of Data Subcarrier :
52 resource blocks
12 subcarrier per blocks = 624 scs

QPSK : 2 bits/symbols
Code rate : $\frac{1}{3}$
1 Radio frame = 10ms = 10 subframes (1ms) = 10 slots
14 symbols / slot

Throughput = $624 \cdot 2000 \cdot 7 \cdot 2 \cdot \frac{1}{3} \cdot 1$
= 5.824 Mbps

Step 5 SNR $\quad 1.5 + 10\log\left(\frac{5.824\text{ Mbps}}{10M}\right) = -0.8478$

$$SNR = \frac{E_b}{N_0} + 10\log\left(\frac{R_b}{BW}\right)$$
$$= -0.8478$$

$$SNR = S(dBm) - N(dBm)$$

Input Noise $\quad N = -91.8 - (-0.8478) \Rightarrow 10^{\frac{-90.9522}{10}} = 8.0312 \cdot 10^{-10}\,mW$

$$= -90.9522\text{ dBm}$$

Step 6 $\quad$ Thermal Noise: $-174\text{ dBm/Hz} + 10\log(10M)$

$$= -104\text{ dBm}$$
$$= 3.98 \cdot 10^{-11}\,mW$$

$$P_{Input} + P_{thermal} = 8.0312 \cdot 10^{-10} + 3.98 \cdot 10^{-11} = 8.4293 \cdot 10^{-10}\,mW$$

System: Rx + Frontend with antenna at the input.

$$NF_{sys} = NF_{put} + NF_{\substack{\text{front end}\\ \text{PLB loss}}} + NF_{Tx}$$

$$F_{sys} = \frac{N_{th} + N_{sys}}{N_{th}} = \frac{8.4293 \cdot 10^{-10}\,mW}{3.98 \cdot 10^{-11}\,mW} = 21.1734$$

$$NF_{sys} \Rightarrow 13.26\text{ dB}$$

Step 7 $\quad NF_{Rx} = NF_{sys} - NF_{put} - NF_{\text{front-end loss}}$

$$NF_{Rx} = 13.26 - 4 - 6$$
$$= 3.26\text{ dB}$$

$$F_{rx} = \frac{N_{Rx} + N_{th}}{N_{th}}$$

$$N_{Rx} = N_{th}(F-1)$$

1. P_{n_Rx}
2. P_{n_LNA}
3. NF_{LNA}

PartB

Part B:

- Step 1: Determine the input referred noise power of the receiver using NF of receiver. (in dBm/Hz)
- Step 2: Determine the input referred noise power of the LNA using fact that the LNA contributes 60% of noise to the receiver. (in dBm/Hz)
- Step 3: Determine the noise figure of the LNA. (in dB)

step1

$$N_{Rx} = 10\cdot\log\left(P_{th}\cdot\left(10^{\frac{NF_{Rx}}{10}}-1\right)\right) - 10\log(10M)$$

$$= 10\cdot\log(3.98\cdot10^{-11}_{mW}\cdot1.118) - 70$$

$$= -103.52 \text{ dBm} - 70 = -173.52 \text{ dBm/Hz}$$

N_{TE}

N_{RX}

N_{Rx}

N_{LNA}

N_{TH}

$$P_{N,Rx} = 3.98\cdot10^{-11}\cdot1.118 = 4.45\cdot10^{-11} \text{ mW}$$

step2

$$P_{N,LNA} = 4.45\cdot10^{-11}\cdot0.6$$

$$= 2.67\cdot10^{-11} \text{ mW}$$

$$N_{LNA} = 10\log(P_{LNA}) - 10\log(10M)$$

$$= -105.74 - 70 = -175.74 \text{ dBm/Hz}$$

$$\Rightarrow 2.67\cdot10^{-19} \text{ mW/Hz}$$

Step3

$$NF\_LNA = 10\log\left(\frac{N_{TH}+N_{LNA}}{N_{TH}}\right)$$

$$= 10\log\left(\frac{6.65\cdot10^{-18}}{3.98\cdot10^{-18}}\right) = 2.23 \text{ dB}$$

$$\underbrace{\overbrace{ADC + RxBBF}^{0.2} + {}^{0.8}DnC}_{0.4} + \underbrace{LNA}_{0.6} = P_{N,RX}$$

1. $P_{n\_DnC+RxBBF+ADC}$ @DnC

2. $I_{n\_DnC+RxBBF+ADC}$ @ DnC

Part C

Part C:
- Step 1: Determine the input referred noise power of the DnC + Rx BBF + ADC at the LNA input using fact that the DnC + Rx BBF + ADC contributes 40% of noise power to the receiver. (in dBm /Hz)
- Step 2: Determine the input referred noise current of the DnC + Rx BBF + ADC at the input of the DnC (in pA/sqrt(Hz))

Step1

$$N_{DnC+RxBBF+ADC} = 4.45 \cdot 10^{-11} \cdot 0.4$$

$$= 1.78 \cdot 10^{-11} \text{ mW}$$

$10\log(N) - 10\log(10\text{MHz})$

$$\Rightarrow = -107.5 \text{ dBm/Hz}$$

$$= -177.5 \text{ dBm/Hz}$$

Step2

$$G_{LNA} = 400 \frac{mA}{V} = \frac{I_{out}}{V_s/2}$$

I_{out}: differential output current of LNA

V_s : source voltage

$$P = \frac{V_{rms}^2}{R}$$

$$\frac{V_s}{2} = V_{rms} = \sqrt{10^{\frac{-177.5}{10}} m \cdot 50}$$

$$= \sqrt{8.89 \cdot 10^{-20}} = 2.98 \cdot 10^{-10} \ V/\sqrt{Hz}$$

$I_{ADC+BBF+DnC}$ @DnC

$$\frac{I_{out}}{2} = \frac{400 \cdot m \cdot V_{rms}}{2} = 5.96 \cdot 10^{-11} \ A/\sqrt{Hz}$$

$$= \boxed{59.64 \ pA/\sqrt{Hz}}$$

For each I and Q

$$I_{out} = 1.192 \cdot 10^{-10} \ A/\sqrt{Hz} = 119.2 \ pA/\sqrt{Hz}$$

1. I_{irn_DnC} @DnC

2. $I_{irn\_rxbbf+ADC}$ @ rxbbf

Part D:

- Step 1: Determine the input referred noise current of the DnC at the DnC input using fact that the DnC contributes 80% of noise power to DnC + Rx BBF + ADC . (in pA/sqrt(Hz))
- Step 2: Determine the input referred noise current of the Rx BBF + ADC at the Rx BBF input(in pA/sqrt(Hz))

Step1

$$P_{N,DNC} = P_{N,DNC+RxBBF+ADC} \cdot 0.8$$

$$1.78 \cdot 10^{-11} mW \cdot 0.8$$

$$= 1.424 \cdot 10^{-11} mW$$

$P = I_{rms}^2 \cdot R$

10log(ANS)−10log(10M)

$$\Rightarrow -178.47 \ dBm/Hz$$

$$V_{rms\_DNC} = \sqrt{10^{\frac{-178.4}{10}} \cdot 10^{-3} \cdot 50} = 2.688 \cdot 10^{-10} \ V$$

$$I_{DNC} = \frac{V_{rms\_DNC} \cdot G_{LNA}}{\underbrace{2}_{\text{split current}}} = 5.38 \cdot 10^{-11} \ A/\sqrt{Hz}$$

$$= \boxed{53.8 \ pA/\sqrt{Hz}}$$

Step2

$$G_{DNC} = -4dB = 10^{\frac{-4}{20}} = 0.63$$

$$I^2_{RxBBF+ADC @DNC} = I^2_{RxBBF+ADC+DnC@DNC} - I^2_{DNC @DNC}$$

$$= 59.64^2 p - 53.8^2 p$$

$$I_{RxBBF+ADC@DNC} = \boxed{25.74 \ pA/\sqrt{Hz}}$$

$$I_{RxBBF+ADC @BBF} = 25.74 pA/\sqrt{Hz} \cdot 0.63$$

$$= \boxed{16.22 \ pA/\sqrt{Hz}}$$

$$P = \frac{V^2}{R}$$

Part E:

- Step 1: Determine the signal voltage at the antenna in RMS (in mV)
- Step 2: Determine the signal current at the input of the BBF (in mA)
- Step 3: Determine the BBF Gain using the previous steps (in Ohms)

Part F:

Step1

$$PAPR = 20\log\left(\frac{V_{peak}}{V_{rms}}\right) = 9$$

$$P_{rms} = (-50-6)\,dBm \xrightarrow{10^{\frac{-56}{10}}} 2.51 \cdot 10^{-6}\,mW \xrightarrow{\sqrt{P_{sig} \cdot R_s}}$$

$$\boxed{\begin{aligned} &= V_{rms} \\ &= 3.54 \cdot 10^{-4}\,V \\ &= 0.35\ mV \end{aligned}}$$

$$V_{peak} = 0.35\,mV \cdot 10^{\frac{9}{20}} = 0.986\,mV$$

Step2

$$I_{LNA} = V_{rms} \cdot G_{LNA} = 0.35 \cdot \frac{400\,mA}{V} = 1.4 \cdot 10^{-4}\ A$$

$$I_{BBF} = \frac{I_{LNA}}{2} \cdot \overbrace{10^{\frac{-4}{20}}}^{\text{Gain of line}} = 4.42 \cdot 10^{-5}\ A$$

$$I_{peak\_BBF} = 4.42 \cdot 10^{-5} \cdot 10^{\frac{9}{20}} = 1.24 \cdot 10^{-4}\,A = \boxed{0.124\ mA}$$

Step3

$$G_{BBF} = \frac{V_{peak}}{I_{peak}} = \frac{2\,V}{0.124\,mA} = \boxed{15.9\ k\,Ohms}$$

Part F:

- Step 1: Determine the receiver gain (in dB)

$\frac{mA}{V} \cdot \frac{V}{mA}$

Gain (LNA + DAC + RxBBF)

$= 400m \cdot \frac{1}{2} \cdot 10^{\frac{-4}{20}} \cdot 15.9k$

$= 2019.06$

$\boxed{66.10 \text{ dB}}$

Part G:

- Step 1: Determine the input referred noise current of the BBF at the BBF input (in pA/sqrt(Hz))
- Step 2: Determine the input referred noise current of the ADC at the BBF input (in pA/sqrt(Hz))
- Step 3: Determine the input referred noise voltage of the ADC at the ADC input (in nV/sqrt(Hz))

Part H: (No Steps Required)

$T = 300k$

Step1

$$I_{Rx\text{-}BBF} = \sqrt{\frac{4kT}{R_f}} = 1.02 \cdot 10^{-12} \frac{A}{\sqrt{Hz}}$$

$$= \boxed{1.02 \ pA/\sqrt{Hz}}$$

Step 2

$$I^2_{ADC\,@BBF} = I^2_{ADC+BBF\,@BBF} - I^2_{BBF\,@BBF}$$

$$= 16.22^2\,p - 1.02^2\,p$$

$$= \boxed{16.19 \ pA/\sqrt{Hz}}$$

Step3

$$V_{ACC\,@ADC} = I_{ADC\,@BBF} \cdot G_{BBF}$$

$$= 16.19\,p \cdot 15.9\,K$$

$$= 2.57 \cdot 10^{-7} \ V/\sqrt{Hz}$$

$$= \boxed{257 \ nV/\sqrt{Hz}}$$

Part H

Part H: What is the dynamic range $\{20\log_{10}(Differential\ Peak\ Voltage/(Noise\ Voltage\ Density * \sqrt{BB\ BW}))\}$ of the ADC? Note: Baseband bandwidth on I and Q are each RF Bandwidth/2

$$\text{Dynamic range} = 20\log_{10}\left(\frac{2V}{257nV \cdot \sqrt{\frac{10M}{2}}}\right)$$

$$= \boxed{70.83\ dB}$$

Part I

Part I: (i) Determine the differential RMS signal voltage swing at the input of the ADC, when the in-band signal is (a) -50dBm and (b) sensitivity at the antenna. (ii) Determine the SNR of the ADC when the in-band signal is at (a) -50dBm and (b) sensitivity using the results in part G & part I(i).

i) a) in-band signal : -50dBm

$$P_{rms} = (-50-6)dBm \xRightarrow{10^{\frac{-56}{10}}} 2.5 \cdot 10^{-6} mW \xRightarrow{\sqrt{P_{sig} \cdot R_s}} = V_{rms} = 3.54 \cdot 10^{-4} V = 0.35\ mV$$

$$V_{rms\ @ADC} = 0.35mV \cdot \underbrace{10^{\frac{66.1}{20}}}_{\text{gain of RX}} = \boxed{0.706\ V}$$

b) Sensitivity: -91.8 dBm

$$V_{rms} = \sqrt{10^{\frac{-91.8-6}{10}} \cdot 10^{-3} \cdot 50} = 2.88 \cdot 10^{-6}\ V$$

$$V_{rms\_@ADC} = 2.88 \cdot 10^{-6} \cdot 10^{\frac{66.1}{20}} = \boxed{5.81\ mV}$$

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ii

$$V_{n\_ADC}\ @ADC = 257\ nV/\sqrt{Hz} \cdot \sqrt{5M} = 5.75 \cdot 10^{-4} V$$

a)

$$SNR : 20\log\left(\frac{0.706}{5.75 \cdot 10^{-4}}\right) = \boxed{61.78\ dB}$$

b)

$$20\log\left(\frac{5.81m}{5.75 \cdot 10^{-4}}\right) = \boxed{20.09\ dB}$$

Q2

- Part A:
  - Step 1: Determine the reference sensitivity for single antenna (in dBm).
  - Step 2: Determine the reference sensitivity for the system (in dBm).
  - Step 3: Determine total noise/distortion power (in dBm).
  - Step 4: Determine the IM3 distortion power at the receiver (in dBm).
  - Step 5: Determine the IIP3 of the receiver (in dBm).

Step1 $-94.8 + 3 = -91.8 \text{ dBm}$

Step2 $-91.8 + 6 = -85.8 \text{ dBm}$

Step3 $SNR = S - N$

$\Rightarrow N_{ant} = S - SNR$

$= -85.8 - (-0.8478)$

$= -84.95 \text{ dBm}$

$P_N = P_{noise} + P_{distortion}$

Step4 $P_{noise\_ant} = (-174 \text{ dBm/Hz} + \underbrace{NF_{sys}}_{9.26}) + 10\log(BW)$

$= -164.74 + 70 = -94.74 \text{ dBm}$

$P_{distortion\_ant,IM3} = P_{N\_ant} - P_{noise\_ant}$

$= 10^{\frac{-84.95}{10}} - 10^{\frac{-94.74}{10}} = 3.2 \cdot 10^{-9} \text{ mW} - 3.357 \cdot 10^{-10} \text{ mW}$

$= 2.86 \cdot 10^{-9} \text{ mW}$

$= -85.43 \text{ dBm}$

Step 5

$$\boxed{P_{in,IM3} = 3P_{in,Jam} - 2IIP_3}$$

$IIP_3 = \frac{3P_{in,Jam} - P_{in,IM3}}{2}$

$= \frac{3 \cdot (-46 - 6) - (-86.28 - 6)}{2}$

$= -32.285 \text{ dBm}$

Part B

- Step 1: Determine the IIP3 of the LNA (in dBm).
- Step 2: Determine the IM3 distortion power contribution of the LNA at the LNA input (in dBm).
- Step 3: Determine the IM3 distortion power contribution of the DnC + Rx BBF +ADC at the LNA input (in dBm).
- Step 4: Determine the IM3 distortion voltage of the DnC + Rx BBF +ADC and the jammer voltage at the ADC input (in mV or V).
- Step 5: Determine the jammer current at the DnC input (in mA).
- Step 6: Determine the IMR3 at the ADC input (in dB)
- Step 7: Determine the current IIP3 of the DnC + Rx BBF + ADC (in mA)

step1

$$P_{IIP3\_LNA} = P_{IIP3\_Rx} + 0.5\,dB = \boxed{-31.785\ dBm}$$

step2

$$P_{LNA\,@LNA,\,IM3} = 3 \cdot P_{in\_jam} - 2\,P_{IIP3\_LNA}$$

$$= 3 \cdot (-52) - 2\,(-31.36)$$

$$= \boxed{-92.43\ dBm}$$

step3

$$P_{DnC+BBF+ADC\,@LNA,\,IM3} = P_{distortion\_Rx} - P_{loss} - P_{LNA\,@LNA,\,IM3}$$

$$= 10^{\frac{-85.43\ -6}{10}} - 10^{\frac{-92.43}{10}}$$

$$= 1.48 \cdot 10^{-10}\,mW = \boxed{-98.3\ dBm}$$

step4

$$\frac{V^2}{R} = P$$

$$V_{rms\_DnC+RxBBF+ADC,\,IM3} = \sqrt{10^{\frac{-98.3}{10}}\,m \cdot 50}$$

$$= 2.72 \cdot 10^{-6}\ V$$

$$V_{rms\_jammer\,@LNA} = \sqrt{10^{\frac{-52}{10}}\,m \cdot 50} = 5.62 \cdot 10^{-4}\ V$$

$$V^{IM3}_{DnC+RxBBF+ADC\,@ADC} = 2.72 \cdot 10^{-6} \cdot 10^{\frac{66.1}{20}} = \boxed{5.49\ mV}$$

$$V_{jammer\,@ADC} = 5.62 \cdot 10^{-4} \cdot 10^{\frac{66.1}{20}} = \boxed{1.134\ V}$$

$$I^2 \cdot R = P$$

Step5

$$I_{jammer@DNC} = \frac{V_{rms\_jammer@LNA} \cdot G_{LNA}}{2}$$

$$= \frac{5.62 \cdot 10^{-4} \cdot 400 \frac{mA}{V}}{2} = \boxed{1.124 \cdot 10^{-4}\ A = 0.1124\ mA}$$

- Step 6: Determine the IMR3 at the ADC input (in dB)
- Step 7: Determine the current IIP3 of the DnC + Rx BBF + ADC (in mA)

step 6

$$IMR_3 = \frac{\text{Amplitude of the third order intermodulation distortion output}}{\text{Amplitude of the jammer output}} = \frac{\frac{3a_3.V_p^3}{4}}{a_1.V_p} = \frac{3a_3.V_p^2}{4a_1}$$

$$IMR_3 = \frac{15.49\ m|}{|1.134|} = 4.84 \cdot 10^{-3} = \boxed{-46.3\ dB}$$

Step7

$$4.84 \cdot 10^{-3} = \frac{3}{4}\frac{a_3}{a_1} \cdot I_p^2$$

$$\frac{a_3}{a_1} = \frac{4.84 \cdot 10^{-3}}{\underbrace{I_p^2}_{0.1124m}} \cdot \frac{4}{3} = 51080.69\ A^{-2}$$

$$IMR_3 = 1$$

$I_{IIP,DnC+RxBBF+ADC}$ $$\frac{3}{4}\frac{a_3}{a_1} \cdot I_p^2 = 1$$

$$I_p = \sqrt{\frac{1}{\frac{3}{4}\frac{a_3}{a_1}}} = \sqrt{2.61 \cdot 10^{-5}} = 5.11 \cdot 10^{-3}\ A = \boxed{5.11\ mA}$$

Steps to Guide Question #2 Cont.

- Part C:
  - Step 1: Determine the IIP3 of the LNA + DnC + Rx BBF (in dBm).
  - Step 2: Determine the IM3 distortion power contribution of the LNA + DnC + Rx BBF at the LNA input (in dBm).
  - Step 3: Determine the IM3 distortion power contribution of the ADC at the LNA input (in dBm).
  - Step 4: Determine the IM3 distortion voltage and the jammer voltage at the ADC input (in mV or V).
  - Step 5: Determine the jammer current at the BBF input (in mA).
  - Step 6: Determine the IMR3 at the ADC input (in dB)
  - Step 7: Determine the current IIP3 of the ADC at the Rx BBF input (in mA)
  - Step 8: Determine the voltage IIP3 of the ADC at the ADC input (in V)

Part C

Step1

$$P_{LNA+DnC+BBF,IIP_3} = P_{IIP3,RX} + 0.25\,dB$$
$$= -32.285\,dBm + 0.25\,dB = \boxed{-32.035\,dBm}$$

step2

$$P_{LNA+DnC+RxBBF@LNA,IM3} = 3\cdot P_{in\_jam} - 2P_{IIP3\_LNA+DnC+BBF}$$
$$= 3\cdot(-52) - 2(-32.035)$$
$$= \boxed{-91.93\,dBm}$$

step3

$$P_{ADC@LNA,IM3} = P_{distortion,TX@LNA} - P_{LNA+DnC+BBF@LNA,IM3}$$
$$10^{\frac{-85.43-6}{10}} - 10^{\frac{-91.93}{10}}$$
$$= 7.82\cdot 10^{-11}\,mW = \boxed{-101.06\,dBm}$$

step4

$$V_{ADC,IM3@LNA} = \sqrt{10^{\frac{-101.06}{10}}\cdot 10^{-3}\cdot 50} = 1.98\cdot 10^{-6}\,V$$
$$V_{ADC,IM3@ADC} : 1.98\cdot 10^{-6}\cdot 10^{\frac{66.1}{20}} = \boxed{4\,mV}$$

$$V_{rms\_jammer@LNA} = \sqrt{10^{\frac{-52}{10}}m\cdot 50} = 5.62\cdot 10^{-4}\,V$$

$$V_{jammer@ADC} = 5.62\cdot 10^{-4}\cdot 10^{\frac{66.1}{20}} = \boxed{1.134\,V}$$

- Step 5: Determine the jammer current at the BBF input (in mA).
- Step 6: Determine the IMR3 at the ADC input (in dB)
- Step 7: Determine the current IIP3 of the ADC at the Rx BBF input (in mA)
- Step 8: Determine the voltage IIP3 of the ADC at the ADC input (in V)

Step5

$$I_{jammer,BBF} = \underbrace{5.62\cdot10^{-4}}_{LNA} \cdot \frac{\overbrace{400M}^{G_{LNA}}}{2} \cdot 10^{\frac{-4}{20}}$$

$$= 7.09\cdot10^{-5}\,A = \boxed{0.07\,mA}$$

step6

$$IMR_3 = \frac{Amplitude\ of\ the\ third\ order\ intermodulation\ distortion\ output}{Amplitude\ of\ the\ jammer\ output} = \frac{\frac{3a_3.V_p^3}{4}}{a_1.V_p} = \frac{3a_3.V_p^2}{4a_1}$$

$$\underset{@ADC}{IMR_3} = \frac{|4mV|}{|1.134|} = 3.53\cdot10^{-3} = \boxed{-49.05\,dB}$$

step7

$$3.53\cdot10^{-3} = \frac{3}{4}\frac{a_3}{a_1}\cdot \underbrace{I_p}_{I_{jam}@BBF}{}^{2}$$

$$\frac{a_3}{a_1} = \frac{3.53\cdot10^{-3}}{(0.07m)^2}\cdot\frac{4}{3} = 960544.22$$

$$\underset{@BBF}{I_{ADC,IIP_3}} = \sqrt{\frac{1}{\frac{3}{4}\cdot\frac{a_3}{a_1}}} = \boxed{1.178\,mA}$$

step8

$$\underset{IIP_3}{I_{ADC}@ADC} = I_{ADC,IIP}@BBF \cdot G_{BBF}$$

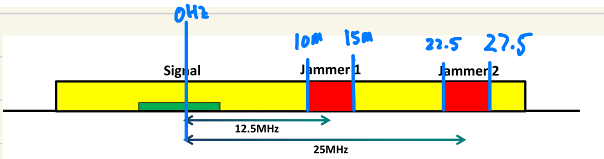
$$= 1.178mA \cdot 15.9k\frac{V}{A}$$

$$= \boxed{18.733\ V}$$

625'

Q3

Part A: Considering that both interferers in question #2 are modulated blockers, derive an expression for IM3 power in the signal bandwidth (10MHz) assuming interferer 1 and interferer 2 have the same bandwidth (5MHz).



Two IM3 Signal

① $\omega_1 + (\omega_1 - \omega_2)$

$12.5 + (12.5 - 25) = 0$

② $\omega_2 + (\omega_2 - \omega_1)$

$25 + (25 - 12.5)$

$\therefore$ Only $2\omega_1 - \omega_2$ land in the signal band

$P_{in,jam} = -46 - 6 = -52\ dBm$

$PSD = -52 - 10\log(5M) = -118.99\ dBm/Hz = 1.26 \cdot 10^{-12}\ mW/Hz$

$PSD_{,J1} = PSD \cdot (u(f - 10M) - u(f - 15M)) \cdot 0.5$ Single sided $\frac{mW}{Hz}$

$PSD_{,J2} = PSD \cdot (u(f - 22.5M) - u(f - 27.5M)) \cdot 0.5$ $\frac{mW}{Hz}$

$V_{in} = V_{J1} + V_{J2} \Longrightarrow \boxed{LNA} \longrightarrow V_{out} = a_1 V_{in} + a_2 V_{in}^2 + a_3 (V_{in})^3$

$a_3 V_{in}^3 = a_3 (V_{J1} + V_{J2})^2 = a_3 (V_{J1}^3 + 3V_{J1}^2 V_{J2} + 3V_{J1} V_{J2}^2 + V_{J3}^3)$

V_{in} can also be $V_{in,IM3}$, and we only care about the term $3V_{J1}^2 V_{J2}$, which is the signal lands in th signal band

$\because V_{in,IM3} = \frac{V_{out}\ IM3}{a_1} = \frac{1}{a} \cdot 3 a_3 (3V_{J1}^2 V_{J2})$

$V_{in,IM3} = 3 \frac{a_3}{a_1} \underbrace{V_{J1}^2(t) \cdot V_{J2}(t)}$ $\Rightarrow P_{in,IM3} = 9\left(\frac{a_3}{a_1}\right)^2 \cdot$ Convolution

In freq domain:

$(V_{J1} * V_{J1}) * V_{J2}$

$(PSD_{J1} * PSD_{J1}) * PSD_{J2}$

But we need the Double sided Power Spectrum Density

The new equation is

$$P_{in,IM3} = 9\times 2 \left(\frac{a_3}{a_1}\right)^2 \cdot \int_0^{10M} \left[\left(PSD_{J1} * PSD_{J1} \right) * PSD_{J2} \right] df$$

Part B

IIP 3 ,RX = -32.285 dBm when $IMR_3 = 1$

$$\left(\frac{\frac{V_{p,IIP3}}{\sqrt{2}}}{2}\right)^2 ?$$

★ $IIP_3 \to V_{IIP_3}$

order intermodulation Ratio (IMR) is given by:

$$IMR_3 = \frac{\textit{Amplitude of the third order intermodulation distortion output}}{\textit{Amplitude of the jammer output}} = \frac{\frac{3a_3 . V_p^3}{4}}{a_1 . V_p} = \frac{3a_3 . V_p^2}{4a_1}$$

$$IIP_3 = \left(\frac{V_p}{\sqrt{2}}\right)^2$$

$$2 \cdot IIP_3 = V_p^2$$

$$\frac{a_3}{a_1} = \frac{1}{\frac{3}{4} \cdot 10^{\frac{-32.285}{10}} \cdot 2} = 1128258.83$$

From matlab :

The result of convolution is 3.009^{-29} mW/Hz

$$\cdot 10MHz = 3.009 \cdot e^{-23} \text{ mW}$$

$$P_{in,IM3} = 18 \cdot \left(\frac{a_3}{a_1}\right)^2 \cdot 3.009 \cdot 10^{-23}$$

$2.75 \cdot 10^{-9}$ $$= 6.89 \cdot 10^{-10} \text{ mW} = \boxed{-91.61 \text{ dBm}}$$

Part C

$$\Delta IIP_3 = -85.43 - (-91.63)$$

$$= \boxed{6.1848 \text{ dBm}}$$ lower than answer from Q2.A

Q4

Part A: Determine the $P_{out,1dB}$ and OIP_3 of the Power Amplifier to meet the EVM requirements. Assume that the TxIC (Tx DAC, Tx BBF, UpC and DA) does not contribute any distortion.

$$EVM_i = \sqrt{\frac{|S_{err,i}|^2}{|S_{ref,i}|^2}} = \sqrt{\frac{Noise + Distortion\ Power}{Signal\ Power}} = \boxed{\frac{1}{\sqrt{SNDR}}}$$

From the table EVM = 8%

$$SNDR = \frac{1}{EVM^2} = 156.25 \overset{10\log}{=} 21.94\ dB$$

P_{sig} @ANT = 23 dBm

Then $P_{Distortion} = P_{TX} - P_{SNDR} - P_N$

$$= 23 - 21.94 - (-174\ dBm/Hz + 10\log(10M))$$

$$= 1.06\ dBm$$

With 3 dB Loss

$P_{Distortion@PA} = 1.06 + 3 = 4.06\ dBm$

$P_{out@PA} = 23 + 3 = 26\ dBm$

$$\boxed{P_{out,IM3} = 3P_{out,Jam} - 2OIP_3}$$

$$2OIP_3 = 3P_{out,Jam} - P_{out,IM3}$$

$$OIP_3 = \frac{3 \cdot 26 - 4.06}{2} = \boxed{36.97\ dBm}$$

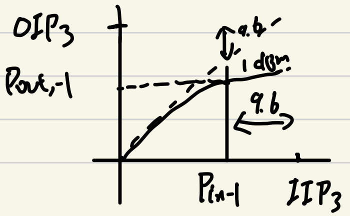
$$IIP_3(dBm) = 9.6 + P_{in,-1dB}(dBm) + 1$$

$$P_{out,1dB} = OIP_3 - 9.6 - 1$$

$$= 27.37 - 1$$

$$= \boxed{26.37\ dBm}$$

$$OIP_3 = 9.6 + P_{out,-1} + 1$$



Part B

Part B: Determine the $P_{out,1dB}$ and OIP_3 of the Power Amplifier (PA) to meet the ACLR requirements. Assume that the TxIC (Tx DAC, Tx BBF, UpC and DA) does not contribute any distortion.

$ACLR = 30\,dB = SDR$

$MBW = 15 \cdot (12 \cdot 52 + 1)/1000$
$= 9.375\,MHz$

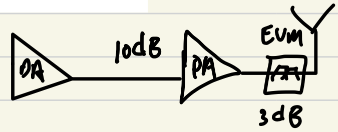
$P_{IM3@ANT} = P_{sig@ANT} - SDR$
$= 23 - 30$
$= -7\,dBm$

$P_{IM3}\ @\ PA = -7 + 3 = -4\,dBm$
$P_{sig}\ @\ PA = 23 + 3 = 26\,dBm$

$2OIP_3 = 3P_{out,Jam} - P_{out,IM3}$
$OIP_3 = \dfrac{3 \cdot 26 - (-4)}{2} = \boxed{41\ dBm}$

$P_{out,1dB} = OIP_3 - 9.6 - 1$
$= \boxed{30.4\ dBm}$

- Part C: Determine the $P_{out,1dB}$ and OIP_3 of the Driver Amplifier (DA) to meet the EVM and ACLR requirements assuming that the DA contribution is 10dB below the contribution of the PA. Assume that Tx DAC, Tx BBF and UpC do not contribute any distortion.



For EVM Requirement

From the table EVM = 8%

5-(0-10)

$SNR_{@PA} = \frac{1}{EVM^2} = 156.25 \overset{10\log}{=} 21.94\,dB$

SNDR @ DA = 31.94 dB = 21.94 + 10

P_{sig} @ DA = 7 dBm

Then $P_{Distortion@DA} = P_{sig@DA} - P_{SNDR}$

$= 7 - 31.94$

$= -24.94$ dBm

With 3 dB Loss

$P_{Distortion@DA} = -24.94 + 3 = -21.94$ dBm

$P_{out@DA} = 7 + 3 = 10$

$2\,OIP_3 = 3P_{out,Jam} - P_{out,IM3}$

$OIP_3 = \frac{3 \cdot 10 - (-21.94)}{2} = \boxed{25.97\ dBm}$

$P_{out,1dB} = OIP_3 - 9.6 - 1$

$= \boxed{15.37\,dBm}$

For ACLR

$$ACLR = 30\,dB = SDR$$

$$P_{IM3@DA} = P_{sig@DA} - SDR\,@DA$$
$$= 7 - (30+10)$$
$$= -33\ dBm$$

Duplexer Loss

$$P_{IM3}\ @DA = -33+3 = 30\ dBm$$
$$P_{sig}\ @DA = 7+3 = 10\ dBm$$

$$2OIP_3 = 3P_{out,Jam} - P_{out,IM3}$$
$$OIP_3 = \frac{3\cdot 10 - (-30)}{2} = \boxed{30}\ dBm$$

$$P_{out,1dB} = OIP_3 - 9.6 - 1$$
$$= \boxed{19.4\ dBm}$$