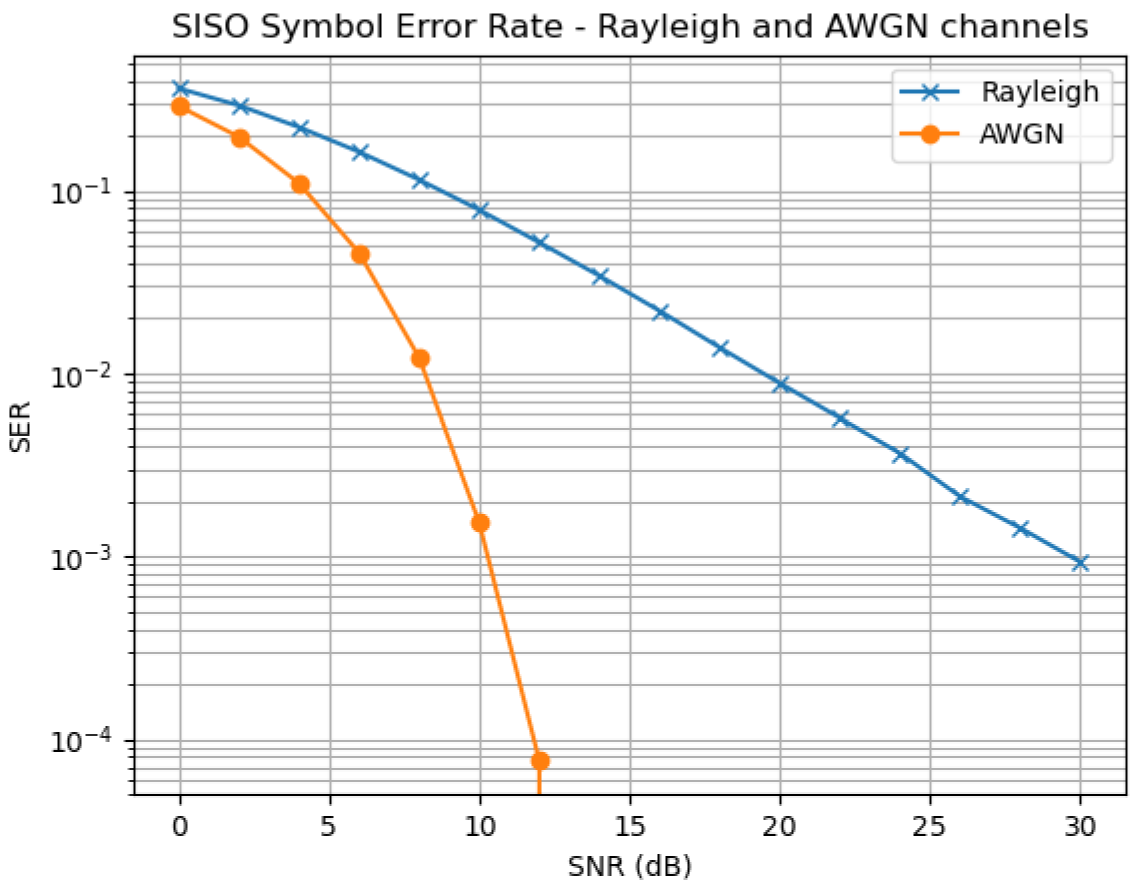
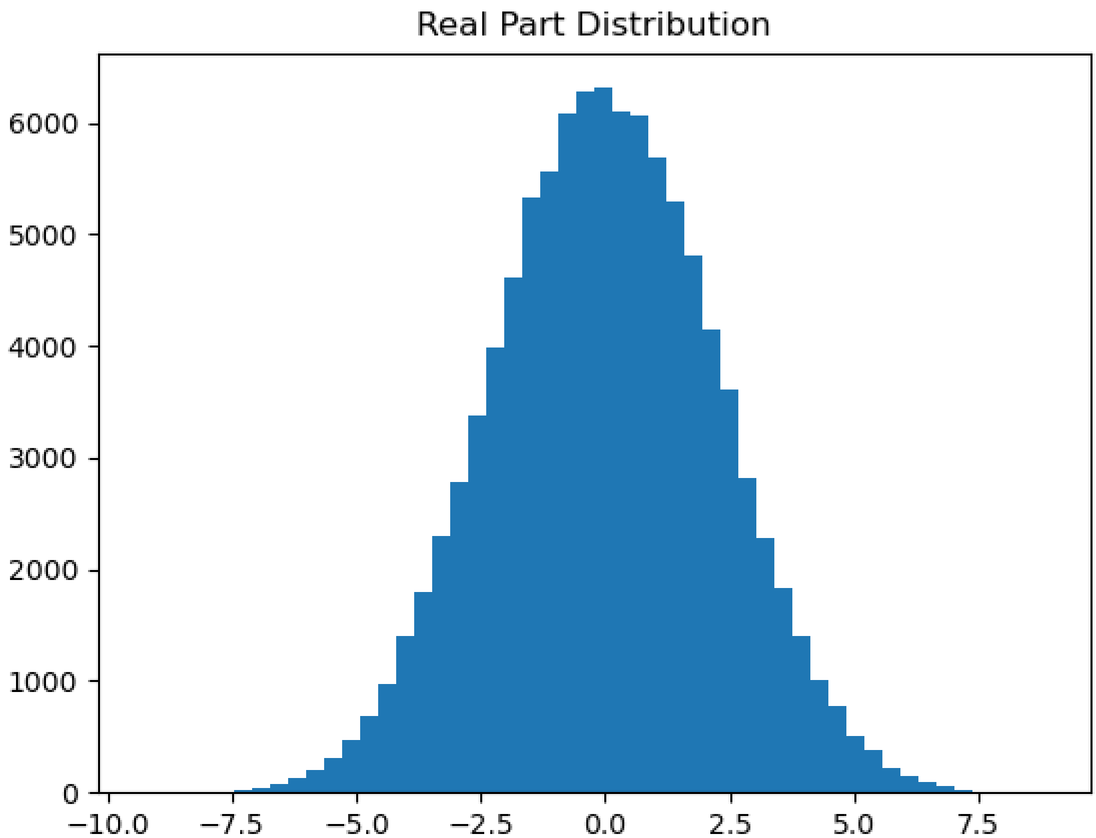
Exercise 1

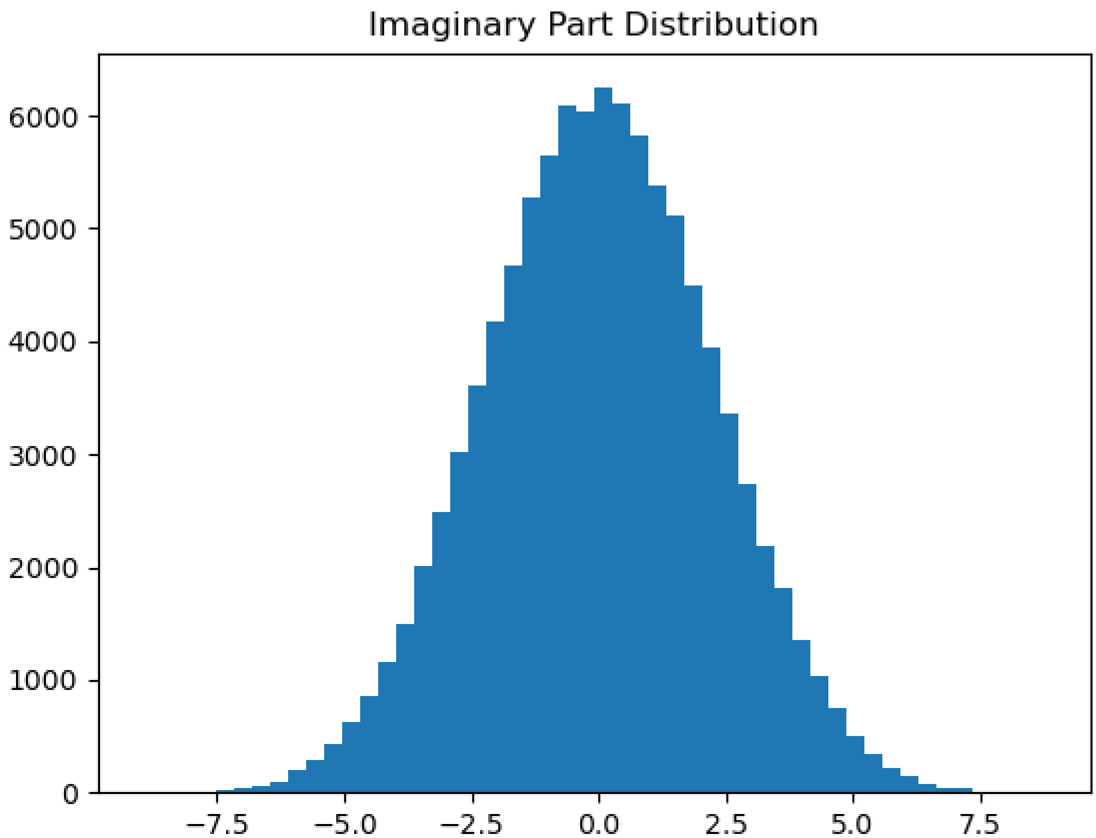
In this exercise we were asked to generate the SISO SER curve from the lecture, for Rayleigh (multipath) and AWGN channels.
Then, we were asked to justify the gaussian distribution of the channel in the case of multipath, by plotting the real and imaginary parts of h in a delay spread scenario (10 paths with uniformly distributed delays):



We can indeed see that in SISO scheme, the performance in AWGN channel is much better than in Rayleigh.

And for the distribution of H:

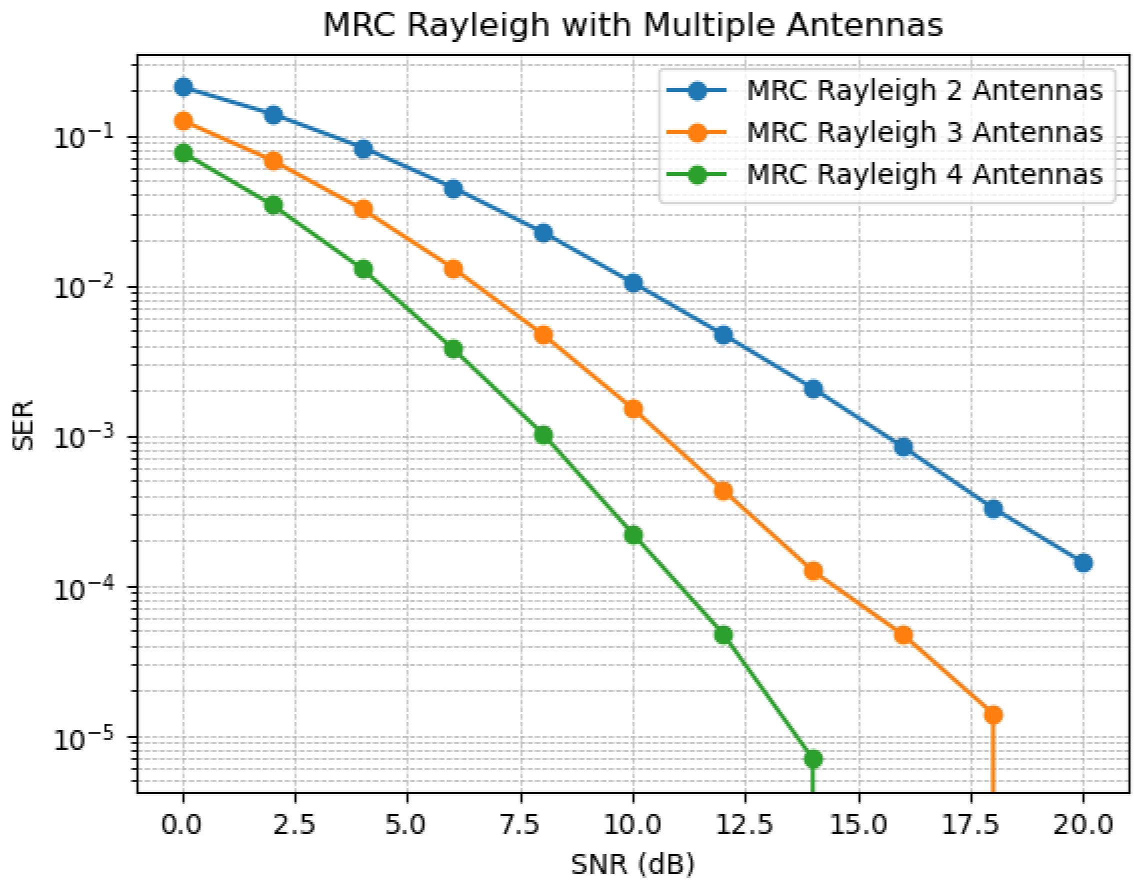

Real Part Distribution
6000
5000
4000
3000
2000
1000
0
−10.0
−7.5
−5.0
−2.5
0.0
2.5
5.0
7.5



Indeed gaussian with the same variance, around 0 as expected

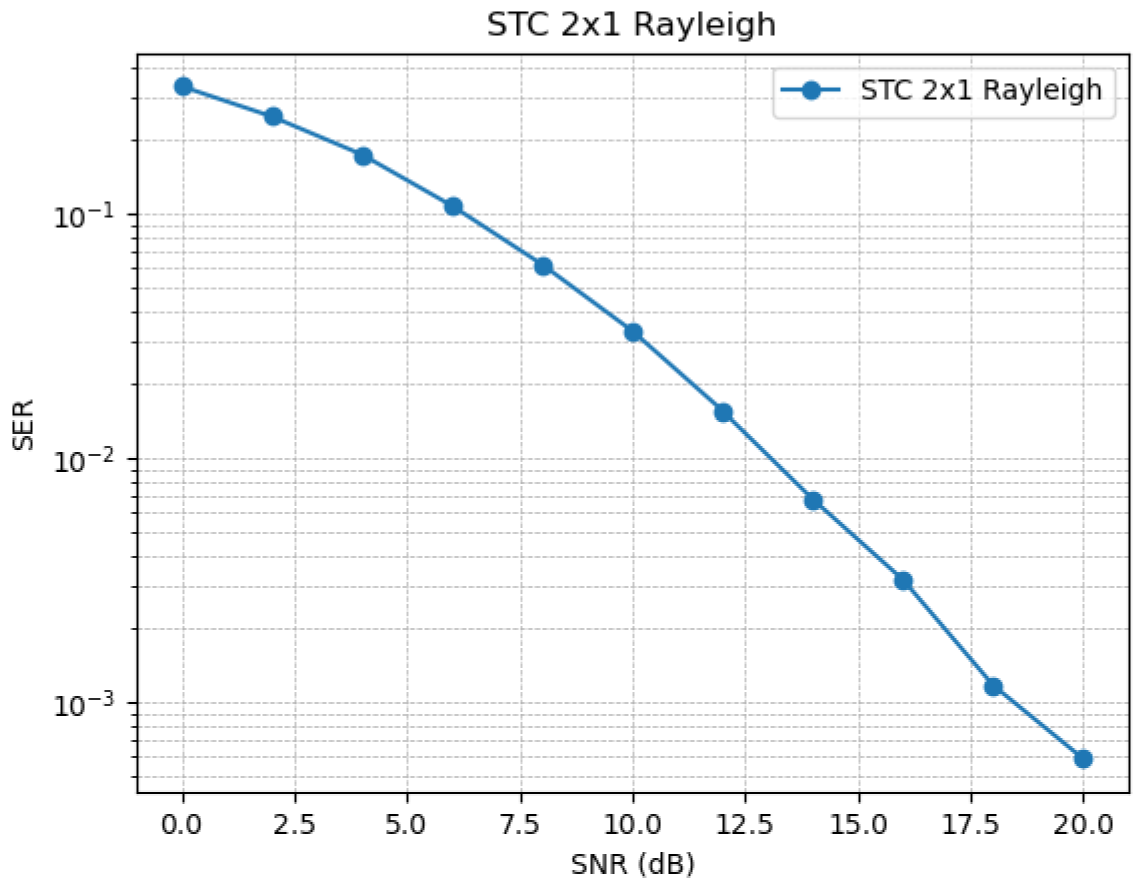
Exercise 2

In this exercise, we were asked to evaluate the performance of MRC decoder for 1x2 and 1x4 schemes, and the performance of STC 2x1 scheme (which should give similar results to MRC2).
The expected DO in the MRC scheme is N (2 for the 1x2, and 4 for the 1x4) and DO of 2 for the STC scheme.
Let’s see:



We can indeed see DO’s of 2,3 and 4 respectively, as expected.

And for the STC 2x1:



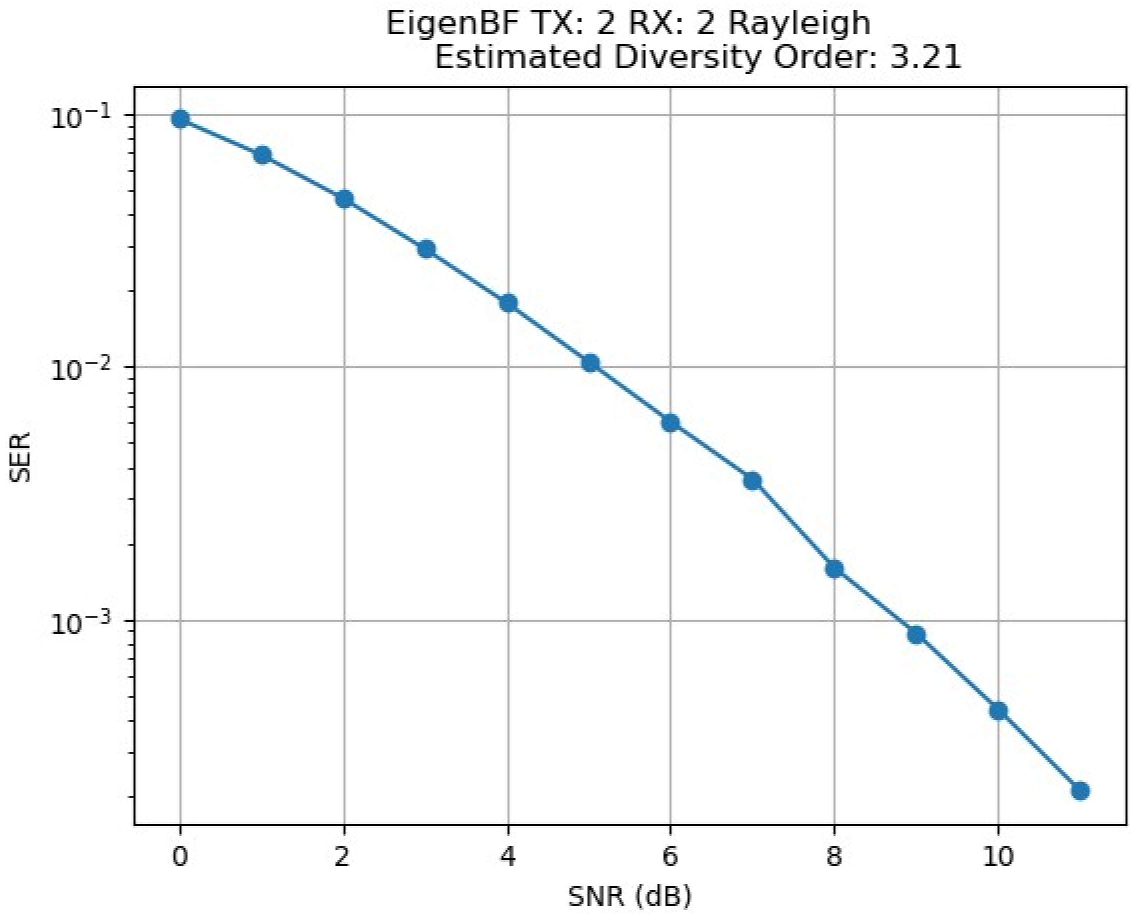
DO of around 2 as well (the estimation from the curve is ~ 1.7)
very similar results to MRC2 indeed.

Exercise 3

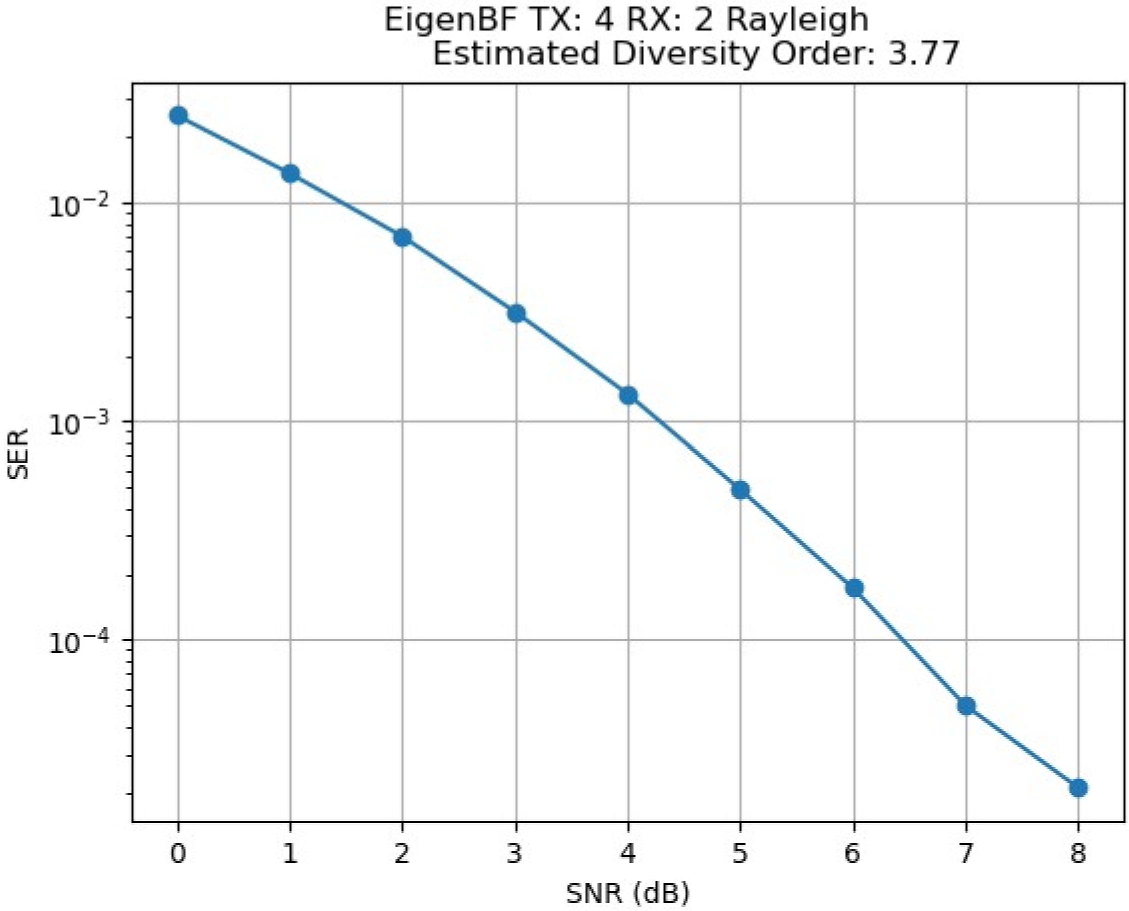
In this exercise, we were asked to evaluate the performance of an EigenBF precoding in 2x2 and 2x4 schemes, and then compare to STC 2x2

In Eigen Beamforming, we expect full diversity! so DO=4 for 2x2 and DO=8 for 2x4.
In STC 2x2, we expect DO=2N=4.

The results:

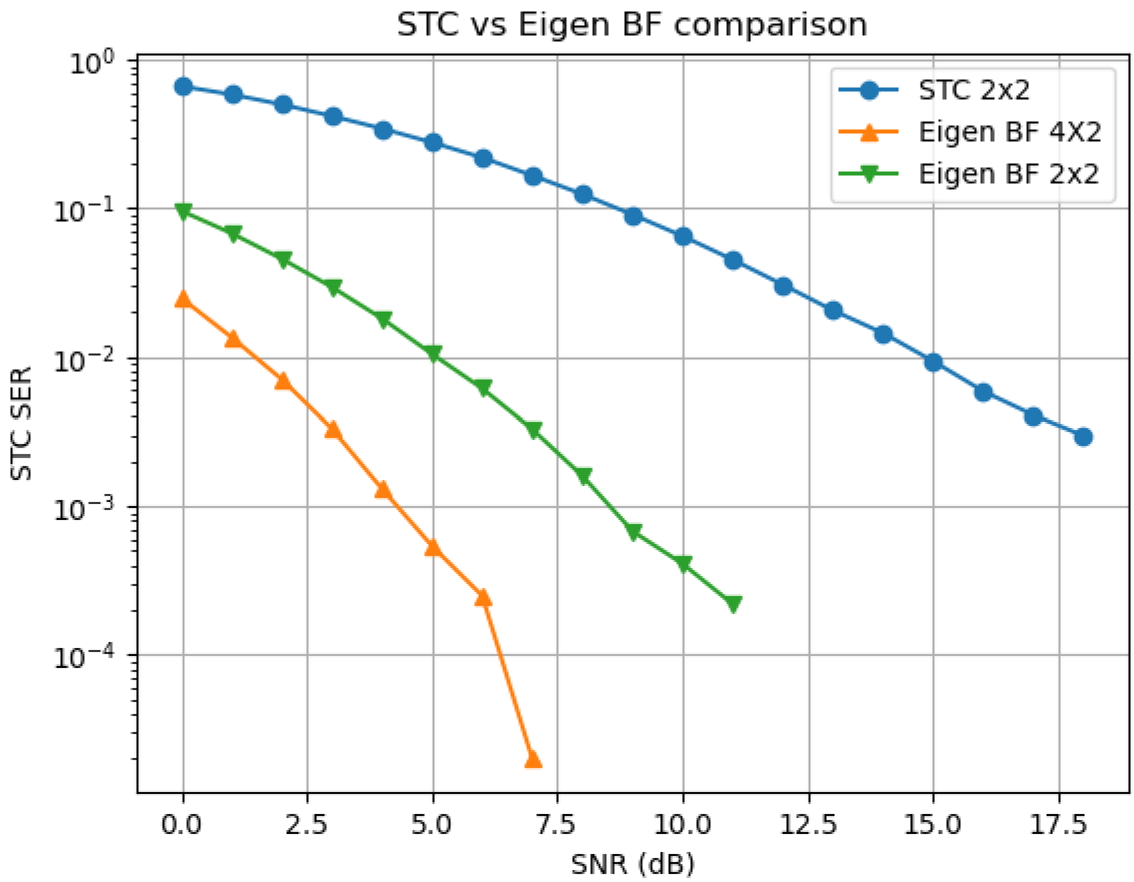


(Please ignore the ‘Estimated DO’ in the title - it was my attempt to automate the estimation of DO from the curve analytically, based on the last points on the curve).
We can actually see the DO is approaching 4.



Here we can see a DO of around 5 (if looking at the second from the end pair of points). I guess II just should've continued the curve to larger SNRs, with more samples, to get the expected DO=8.

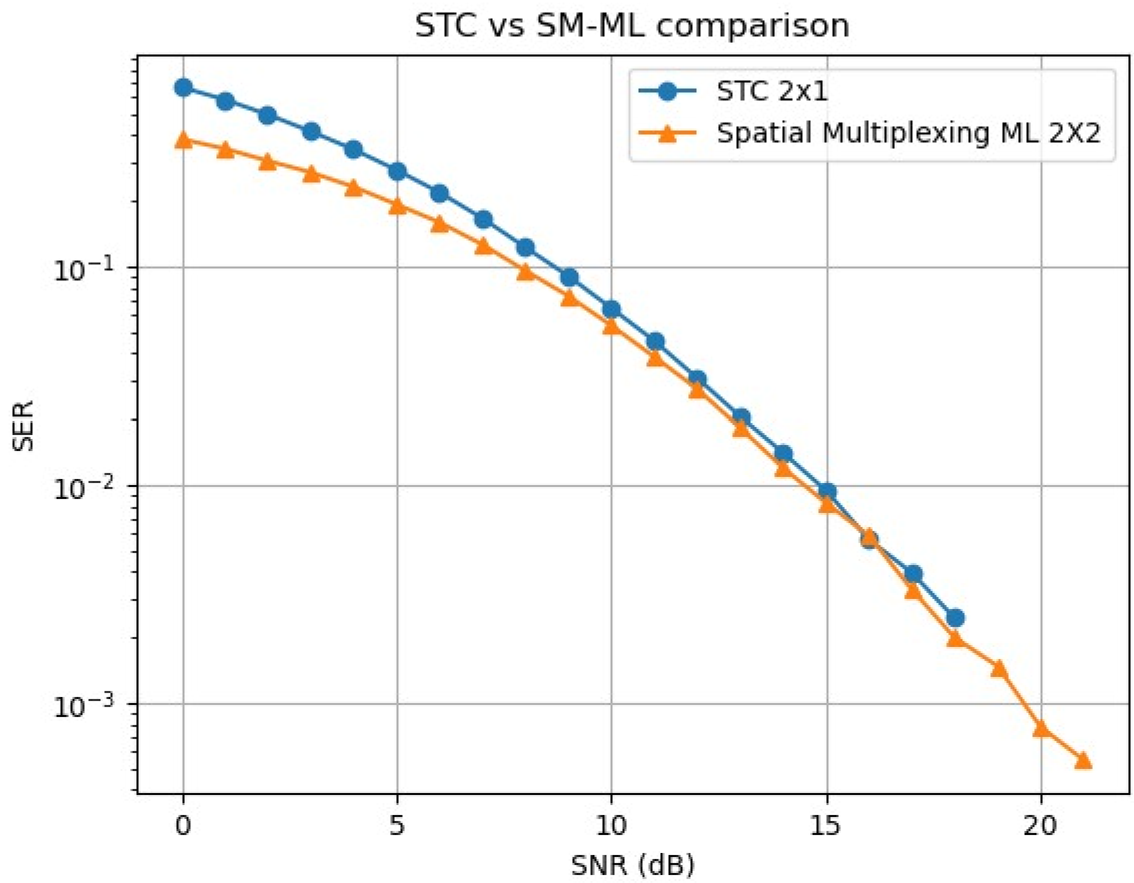
Now for STC:



STC vs Eigen BF comparison
STC 2x2
Eigen BF 4X2
Eigen BF 2x2
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
STC SER
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
SNR (dB)

Exercise 4

In this exercise we were asked to evaluate the performance of (exhaustive search) ML detector in a 2x2 SM scheme, and then compare it to the STC 2x1 performance.
We expected DO=N from the SM ML detector, so here expected DO is 2.
In STC we also expect DO=2 so the curves should be really close to each other (same array gain as well, because M/N=1)



The curves are really close indeed , and exhibit DO=1

Exercise 5

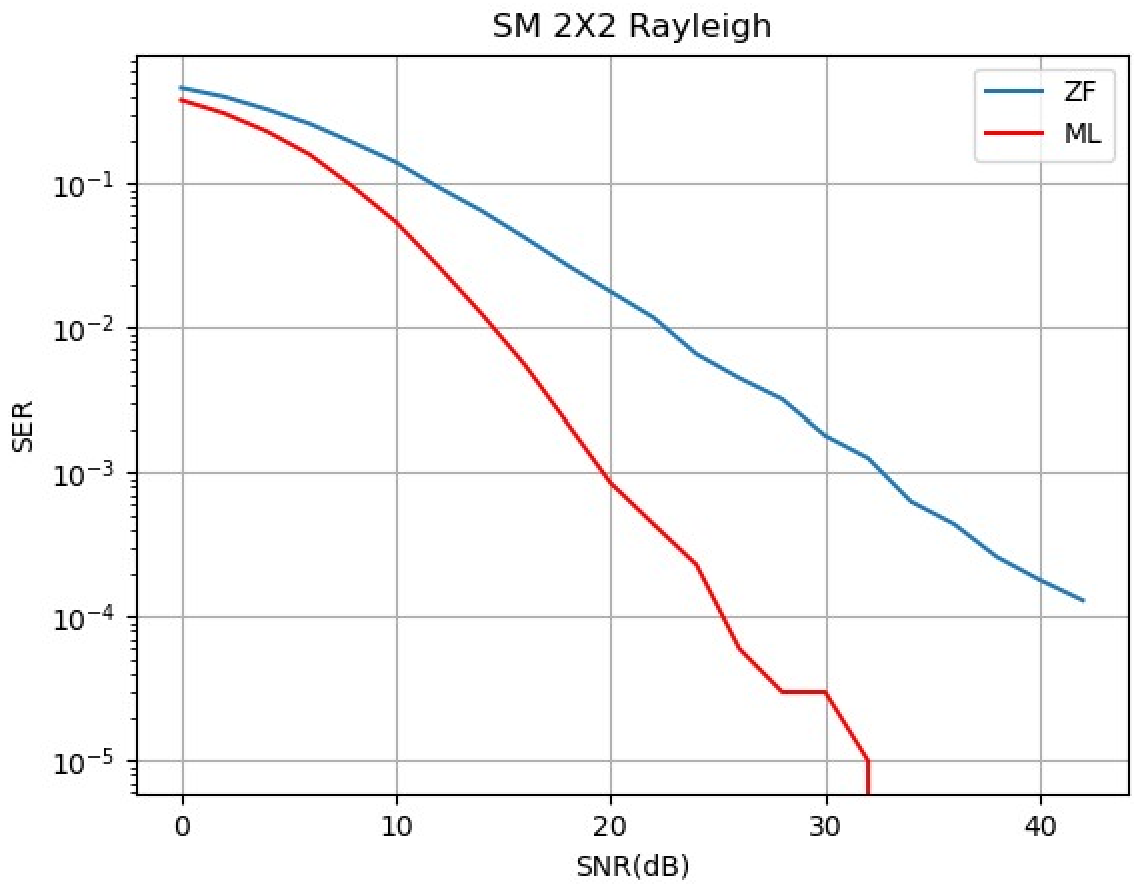
In this exercise we were asked to evaluate and compare the performance of ZF and ML detectors in 2x2 and 2x4 SM schemes.
For zero forcing, we expect:

$$\mathrm{DO} = N - M + 1, \qquad \mathrm{AG} = \frac{N - M + 1}{M}$$

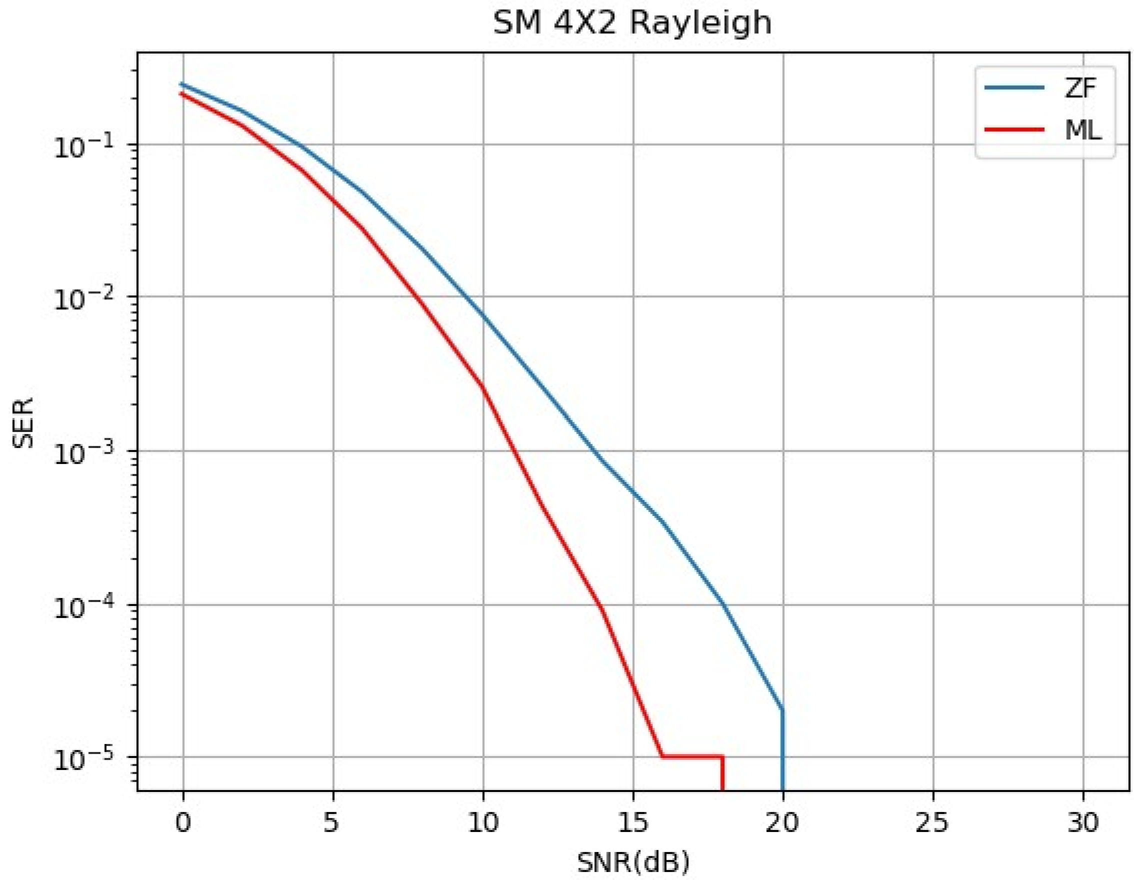
so DO=1 for 2x2, and DO=3 for 4x2

and for ML:
DO=N, so DO=2 for 2x2 and DO=4 for 4x2

The results:



Here we can indeed see DO=2 for the ML curve (1/100 SER decrease every 10dB SNR increase) and DO=1 for the ZF curve as expected.



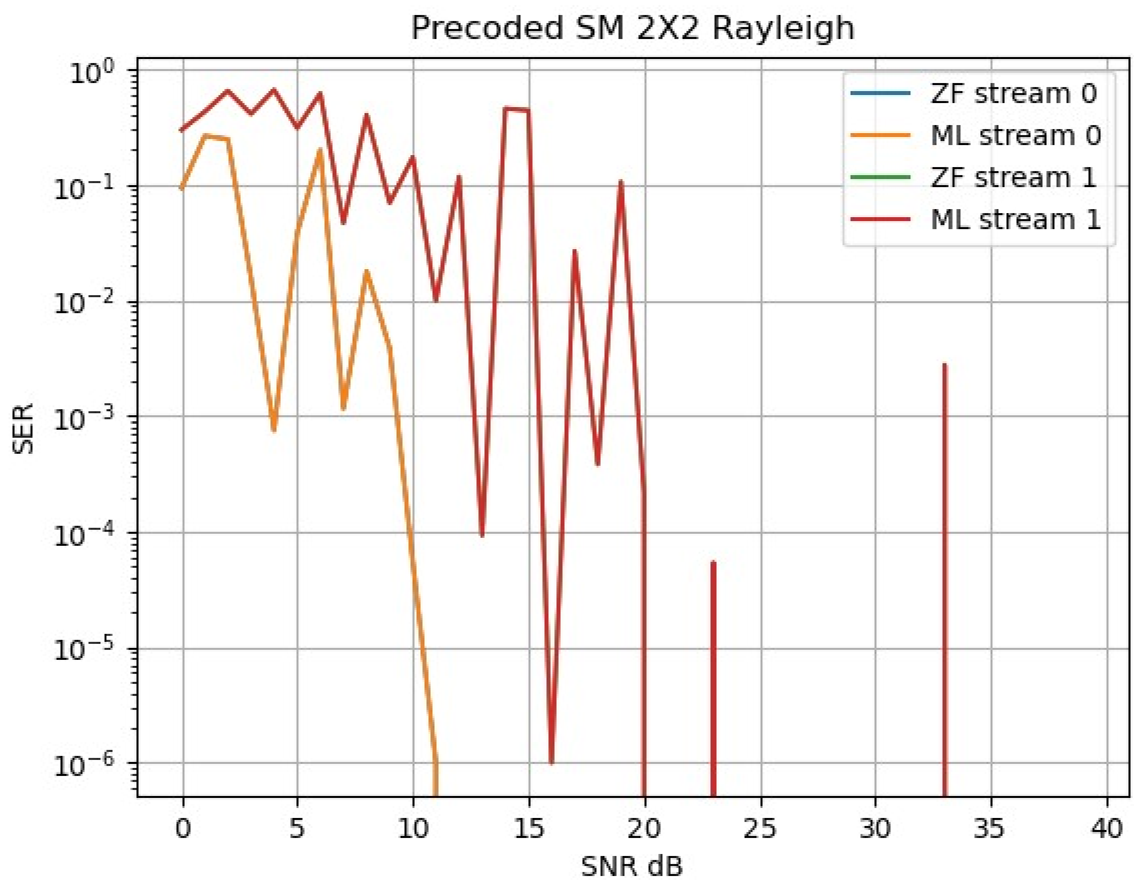
And also here, DO=4 for ML and DO=3 for ZF as expected.

Exercise 6

In the first section, we were asked to use SVD precoding in a 2x2 MIMO system, and compare the SER curve between the two streams.
Each stream performance depends on the corresponding singular value, so in an 2X2 system we'll expect a DO of 4 for the first stream, and DO of 1 for the second stream:

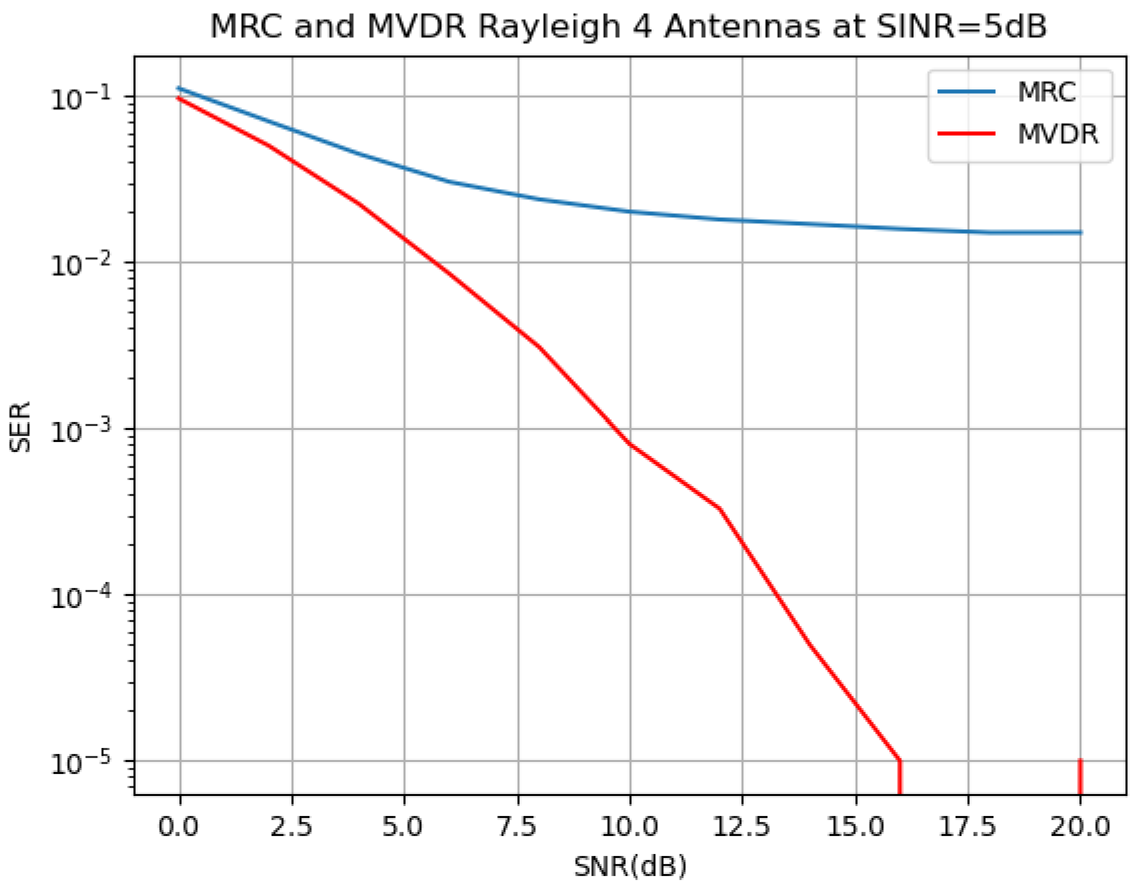
$$\mathrm{DO}_i = (M - i + 1)(N - i + 1), \qquad i = 1, \ldots, K$$

The simulation results:



First, we can see that the ML (exhaustive search) results achieves the exact same performance as the ZF method, thanks to the SVD orthogonal precoding.
Then, we can see that the performance of the second stream is worse than the first one, although it looks pretty noisy (weird fluctuations).

In the second section we were asked to examine a 1X4 model with interference, and compare the performance of the regular MRC decoding and MVDR decoding.

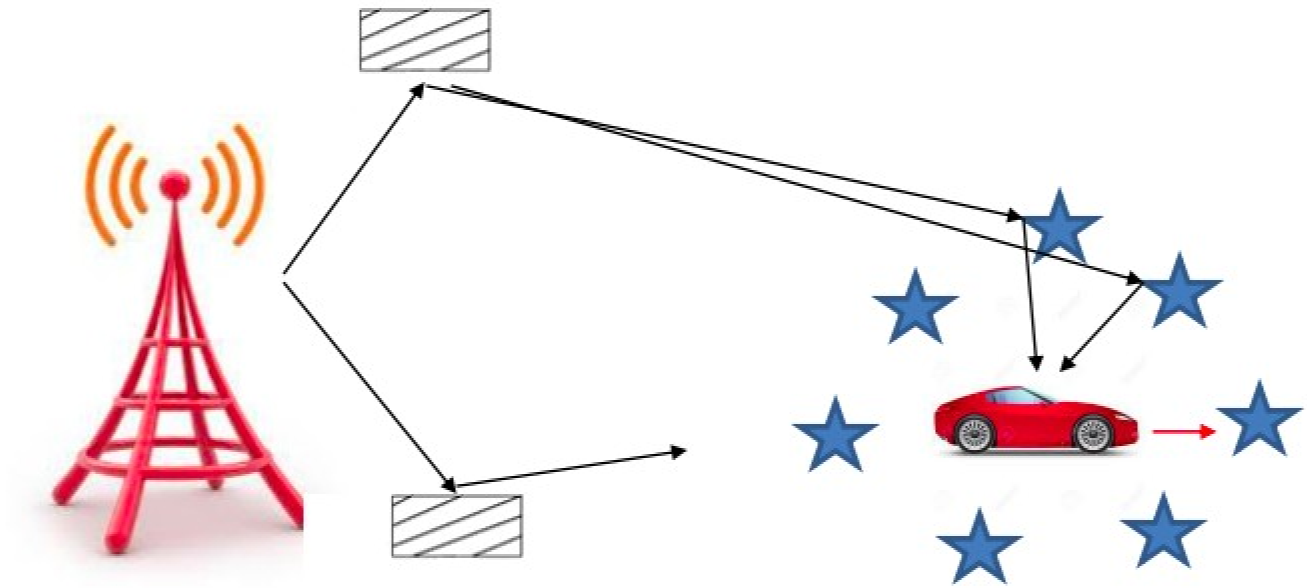


It can be seen that we got very similar results to the ones shown in the lecture, and the MVDR curve has DO around 3, while classic MRC saturates with DO ~ 0.

This also means that MVDR in this case achieves similar performance to MRC3 ("sacrificing" one antenna for the interference nulling)

OFDM/MIMO - Exercise 7 (The Wireless Channel)

In this exercise, we were asked to evaluate a channel modeling method using the Jakes PSD. The model based on the Jakes PSD simulates a classic scenario of a high base station, small number of big scatters around the base station, and many small scatterers around the UE.

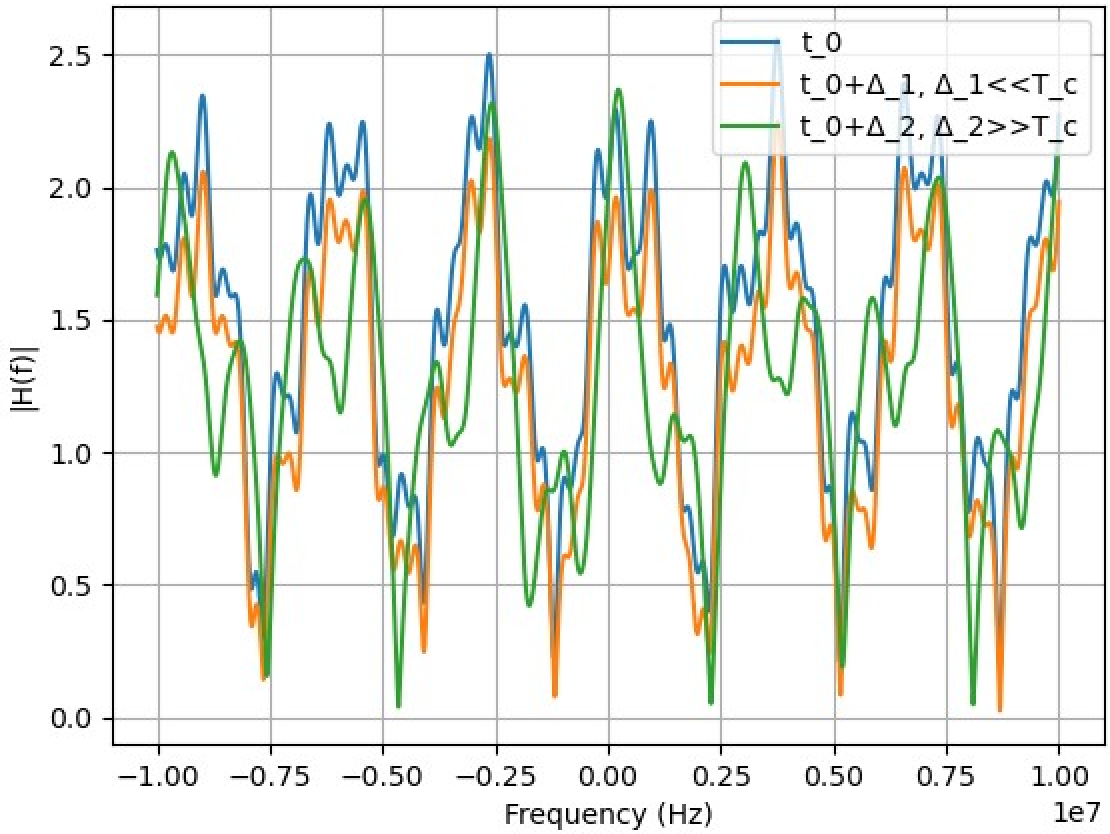


We were asked to evaluate a specific physical scenario, defined by the following measures (a.k.a “Channel A”):

Tap	Channel A		
	Relative Delay (ns)	Average Power (db)	Relati
1	0	0	
2	310	–1.0	
3	710	–9.0	8
4	1,090	–10.0	12
5	1,730	–15.0	1
6	2,510	–20.0	2

Table 3.5 Delay and Power value for Veh A and

We were asked to evaluate the channel response in different time offsets, which are small/big relative to the coherence time of the channel T_c.



We can see multiple effects:
First, the frequency deeps (fades) that are caused by the delay spread introduced by channel A. It can be seen in every single one of the curves (blue, green and orange) as this effect is frequency dependent (and not time dependent).
The second effect is the time domain fluctuations, introduced by the Doppler effect. This effect can be seen by examining the different curves against each other - the channel behaves differently at different times. (this is the essence of the “Coherence Time”).

Exercise 8

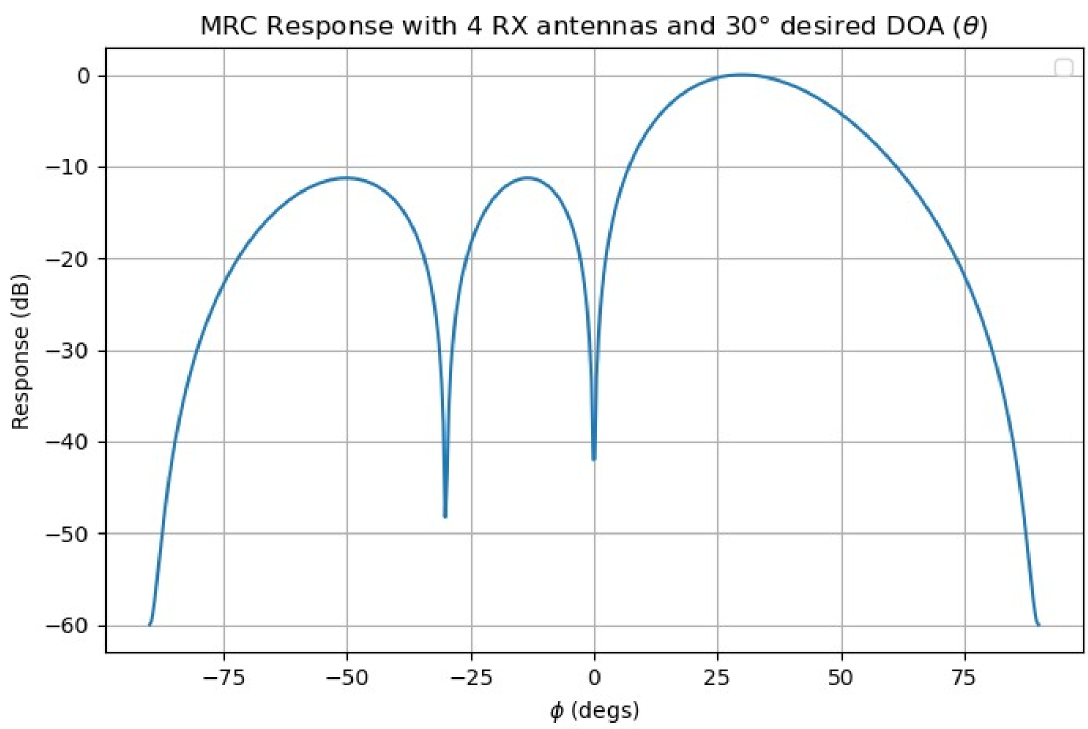
In this exercise, we were asked to examine the response of an MRC processor for a uniform linear array consisted of N RX antennas, spaced $\lambda/2$ from each other.
The MRC decoder is fine tuned for an expected direction of arrival (DOA) of a far field signal.

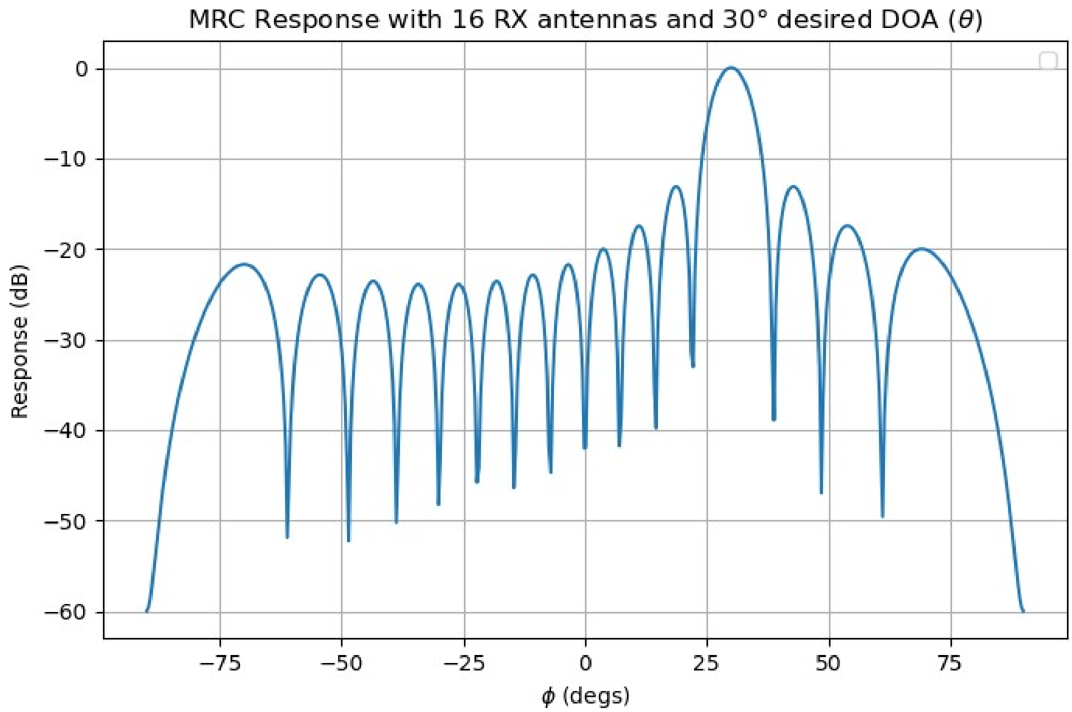
The MRC processor is designed for an expected DOA (θ) using the following expression from the lecture:

$$\frac{\mathbf{h}^*(f)}{\|\mathbf{h}(f)\|^2} = \frac{a^* e^{j2\pi f\tau} \mathbf{x}_N^*(\theta)}{|a|^2 \cdot N}$$

The response was realized for a range of actual DOA's (ϕ) to check how our MRC processor accommodates DOA's that differs from the DOA it was designed for.

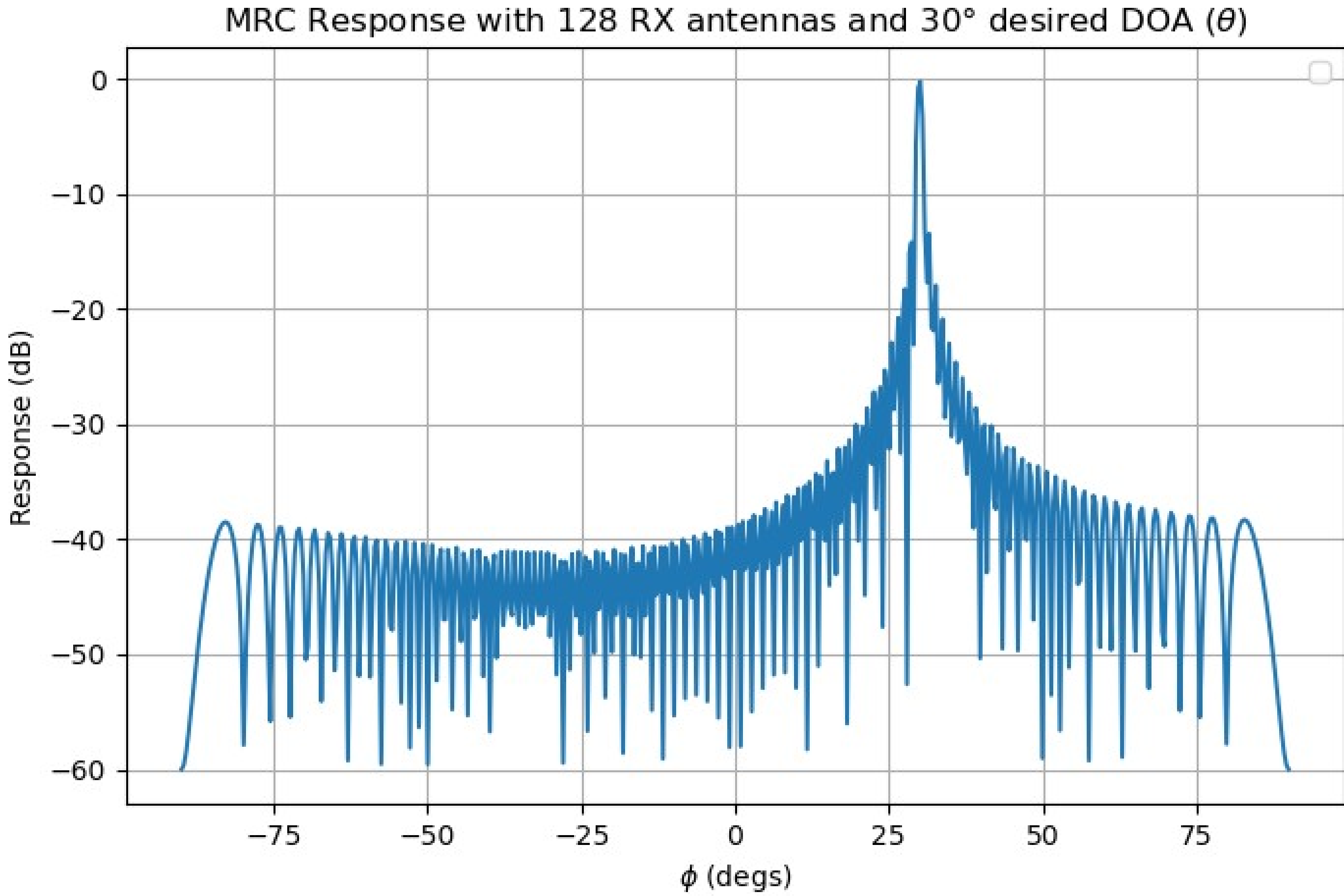
The expected DOA was set to 30 degrees, and the response was realized for actual DOA's from -90 to 90 for both 4 RX antennas, and 16 RX antennas:





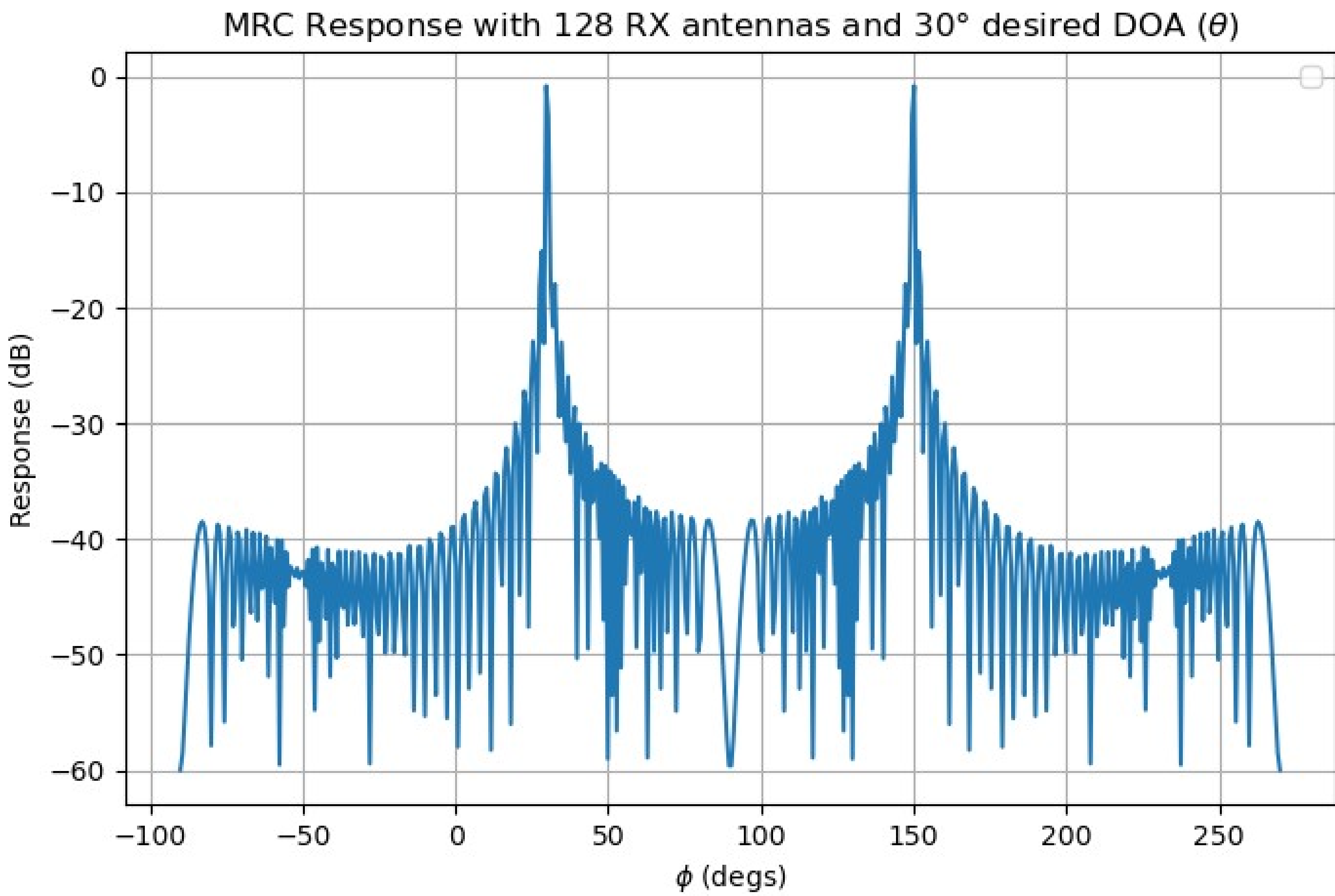
The results are quite similar to the plots from the lecture. We can see the global maximum when $\theta = \phi$ in both schemes, as expected.

Let’s explore a little bit - we’ll try now a scheme with 128 RX antennas:



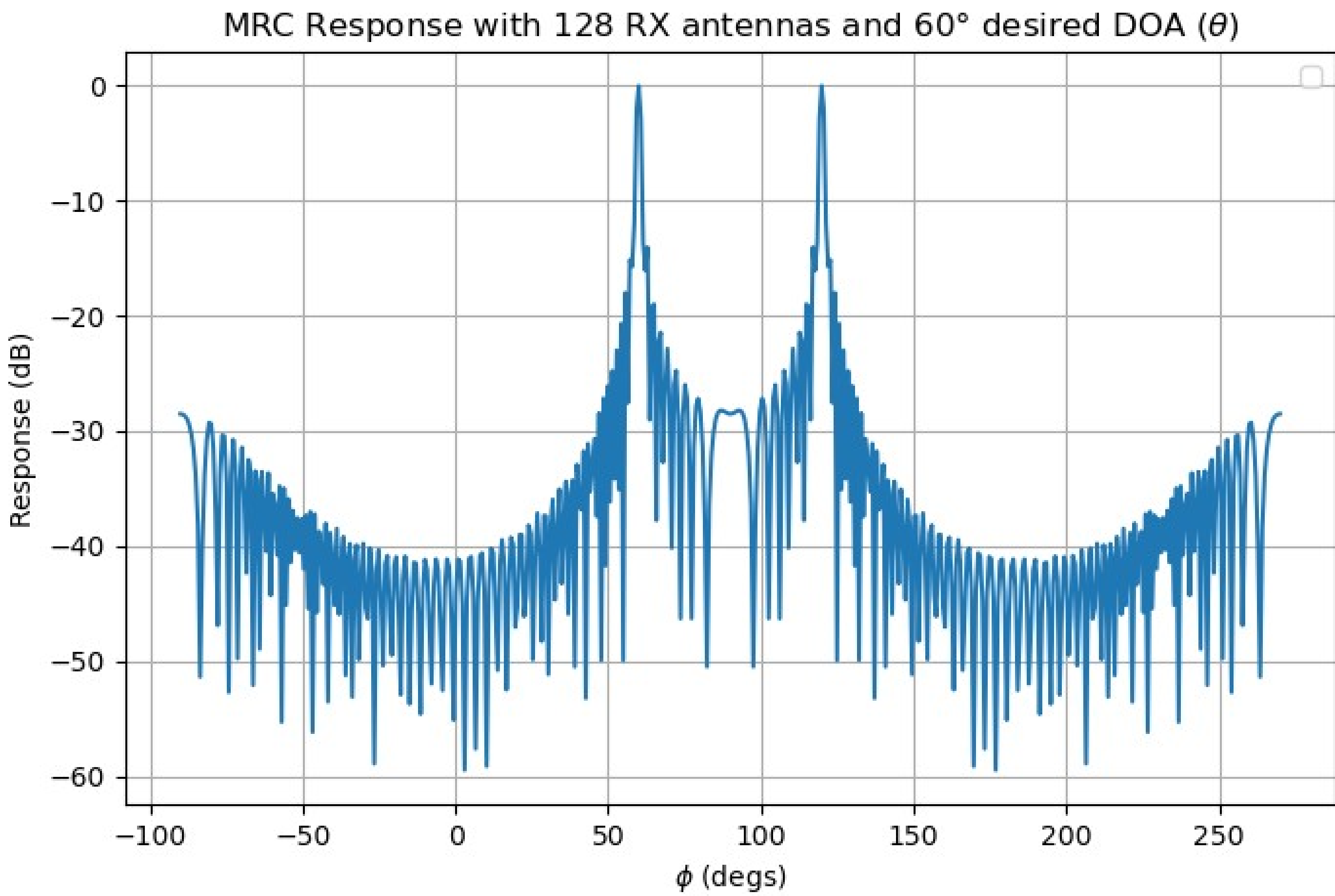
From this figure, we can see that as we have more antennas, the more “directional” our processing is. It really emphasizes the idea of “**Adaptive Directional Antenna**” from the lecture.

Now, let’s examine the “lost of uniqueness” that Doron talked about, when realizing for ϕ’s in the full range of 360 degrees:

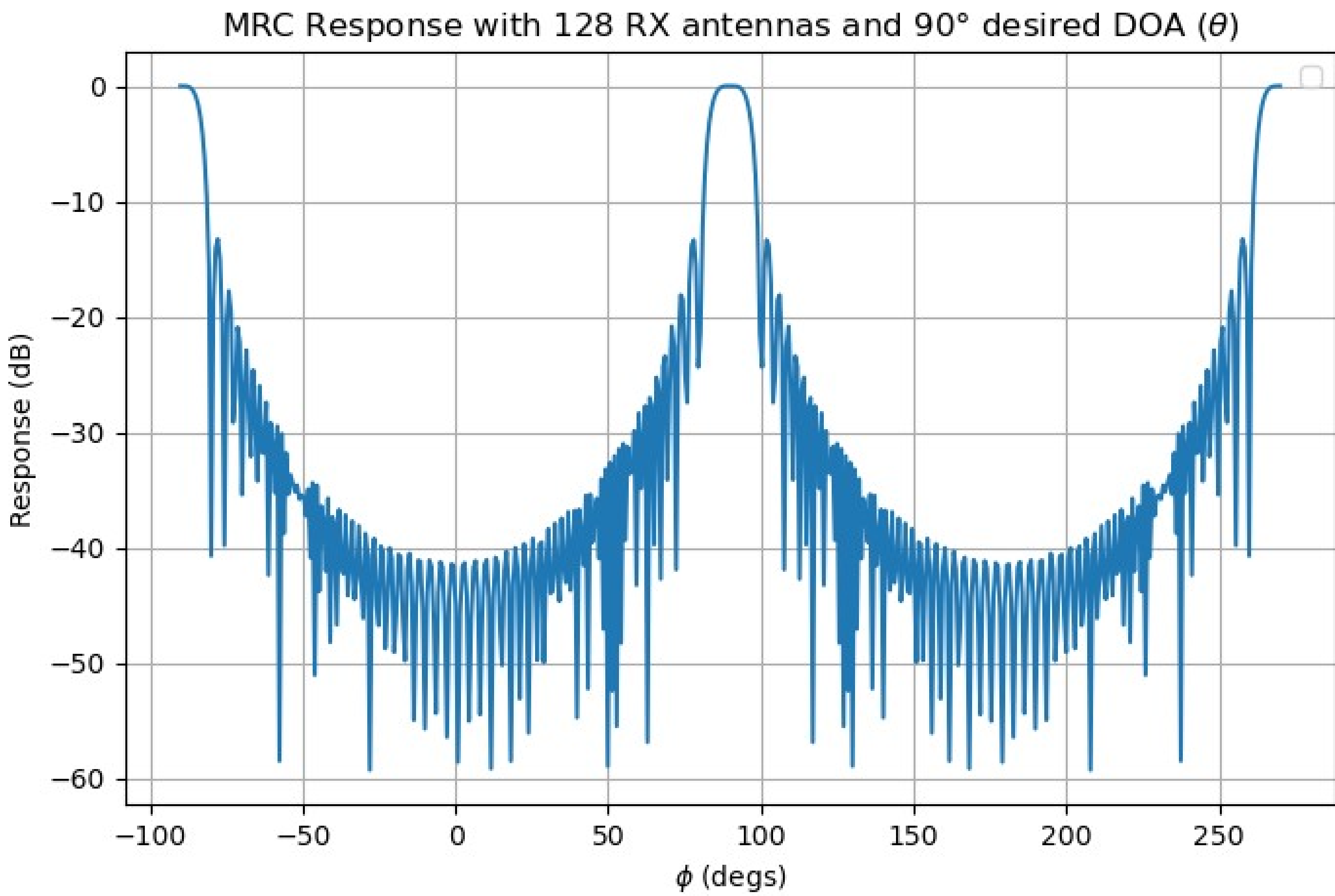


We can clearly see the symmetry around 90 degrees, and global maximas at 30 and 150 degrees (equivalence of x and 180-x)

Now, same for different DOA's:



MRC Response with 128 RX antennas and 60° desired DOA (θ)
Response (dB)
0
−10
−20
−30
−40
−50
−60
−100
−50
0
50
100
150
200
250
ϕ (degs)


MRC Response with 128 RX antennas and 90° desired DOA (θ)
Response (dB)
ϕ (degs)
0
−10
−20
−30
−40
−50
−60
−100
−50
0
50
100
150
200
250

Exercise 9

In this exercise we were asked to simulate a QAM-4 with OFDM scheme over a noisy AWGN channel.
The scheme consists of 256 subcarriers (frequency bins), 1 pilot symbol and 20 payload symbols.
We were required to simulate with 2 channel types:

- “Identity” channel: $h_1(n) = \delta(n)$
- “Delay Spread” channel: $h_2(n) = \delta(n) + 0.9j\delta(n-9)$

Additionally, we were asked to use different methods of channel estimation within the equalization process:

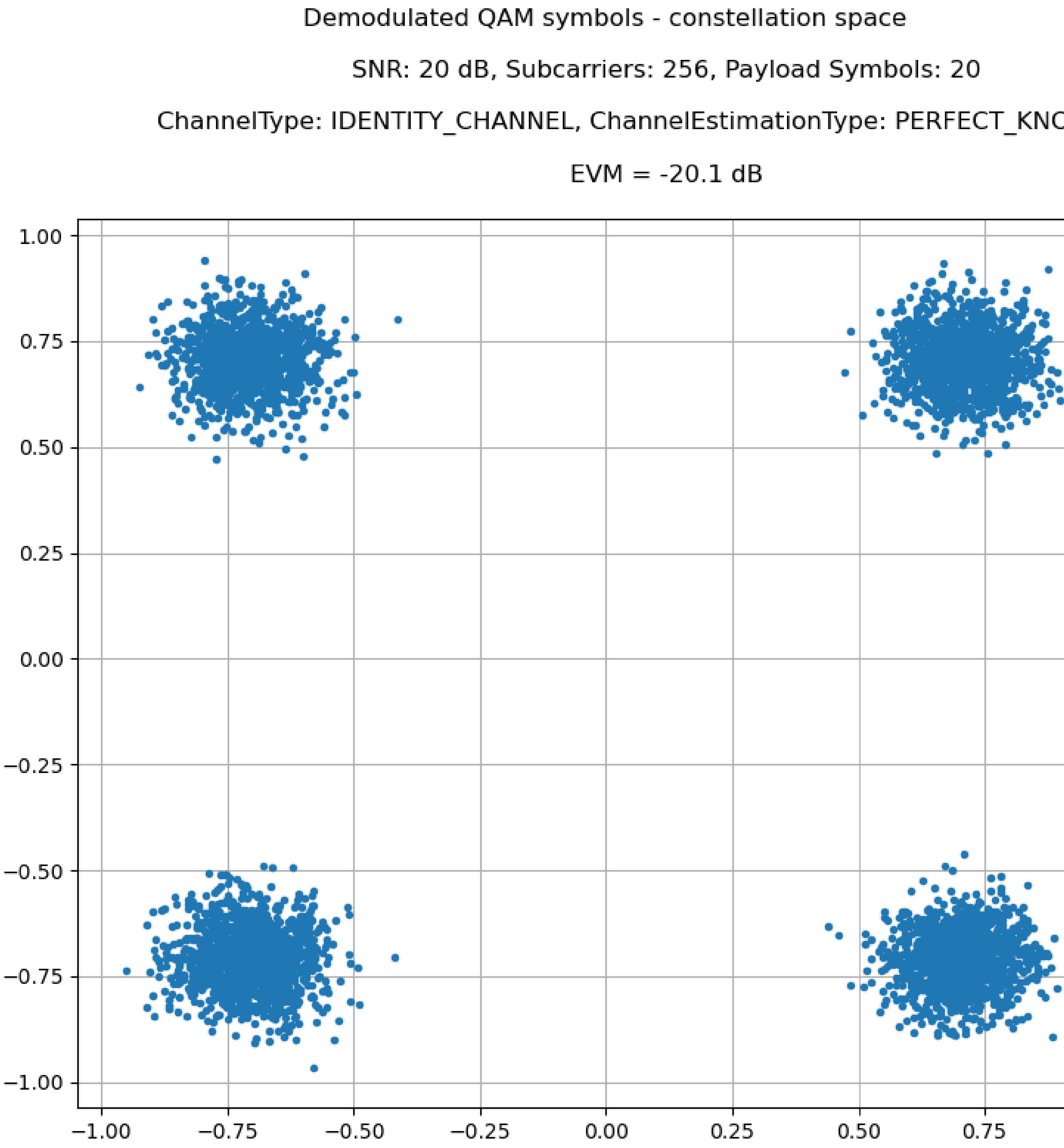
- Estimation by Pilot Symbol: This method implicitly assumes that the channel frequency response is fixed in time (or at least won’t change within the following payload transmission time)
- Estimation by Perfect knowledge: Impractical method. Used only to examine the errors induced by our practical estimation method.

$$H(k) = \sum_n h(n) e^{-j\frac{2\pi}{N}kn}$$

Attached are the results for all the 4 combinations (Channel Types and Estimation Types):

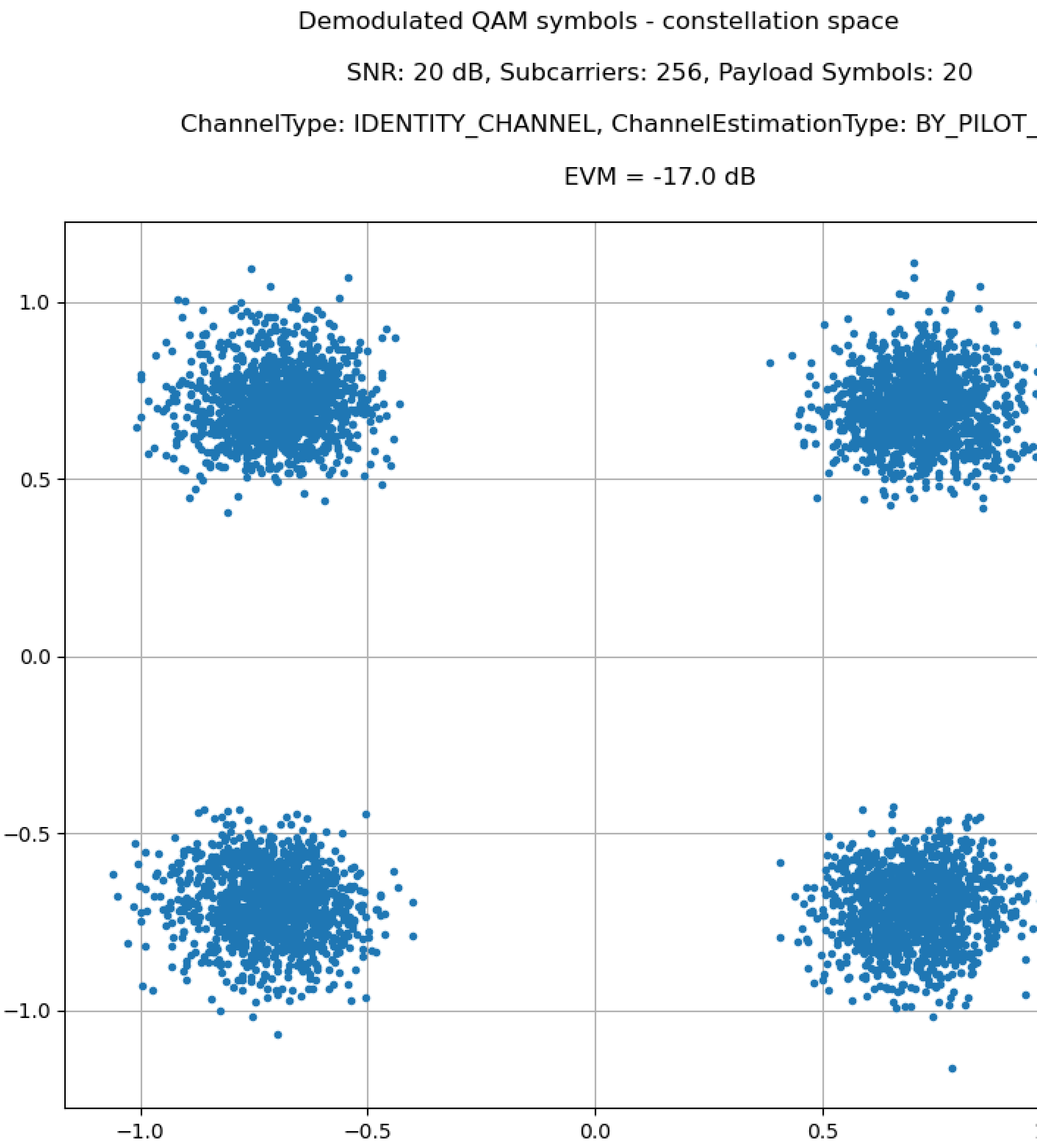
<u>Identity Channel + Perfect Knowledge</u>

This is the best scenario. I got here consistent results of ~ -20dB EVM



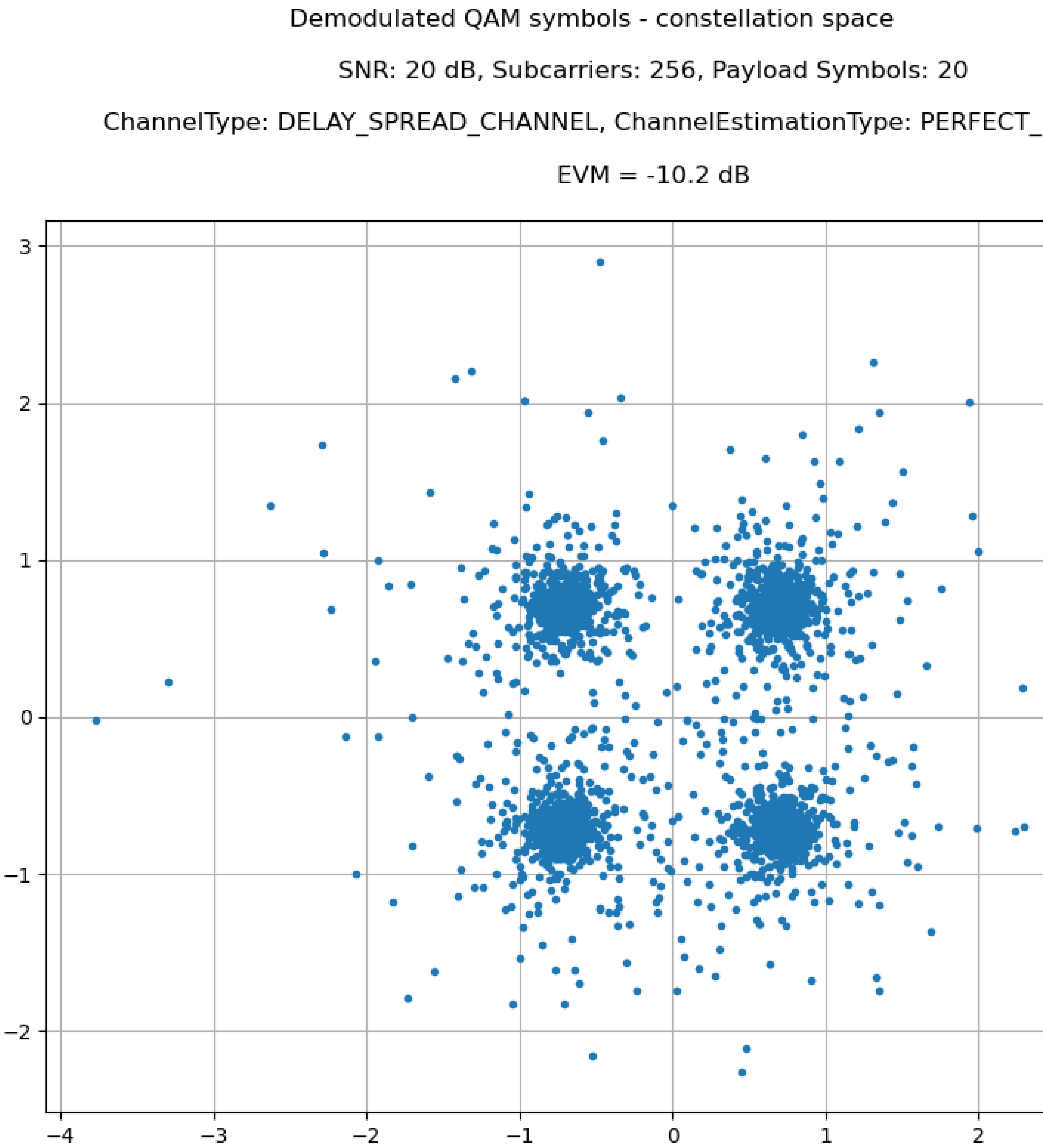
Identity Channel + Pilot Estimation

Second best case. We can see that the estimation solely by the symbol pilot doesn’t cost that much in the EVM sense. Probably because essentially our channel is indeed fixed in time (the only thing that changes in time is the additive noise).
Even by solely looking at the plot - it’s clear that the receiver will perfectly output the transmitted bits.



Delay Spread Channel + Perfect Estimation

Third best case. We can see that the delay spread causes major loss of EVM (10dB). It can be seen that a “slicer” classifier will output some errors in that case.



Delay Spread Channel + Pilot Estimation

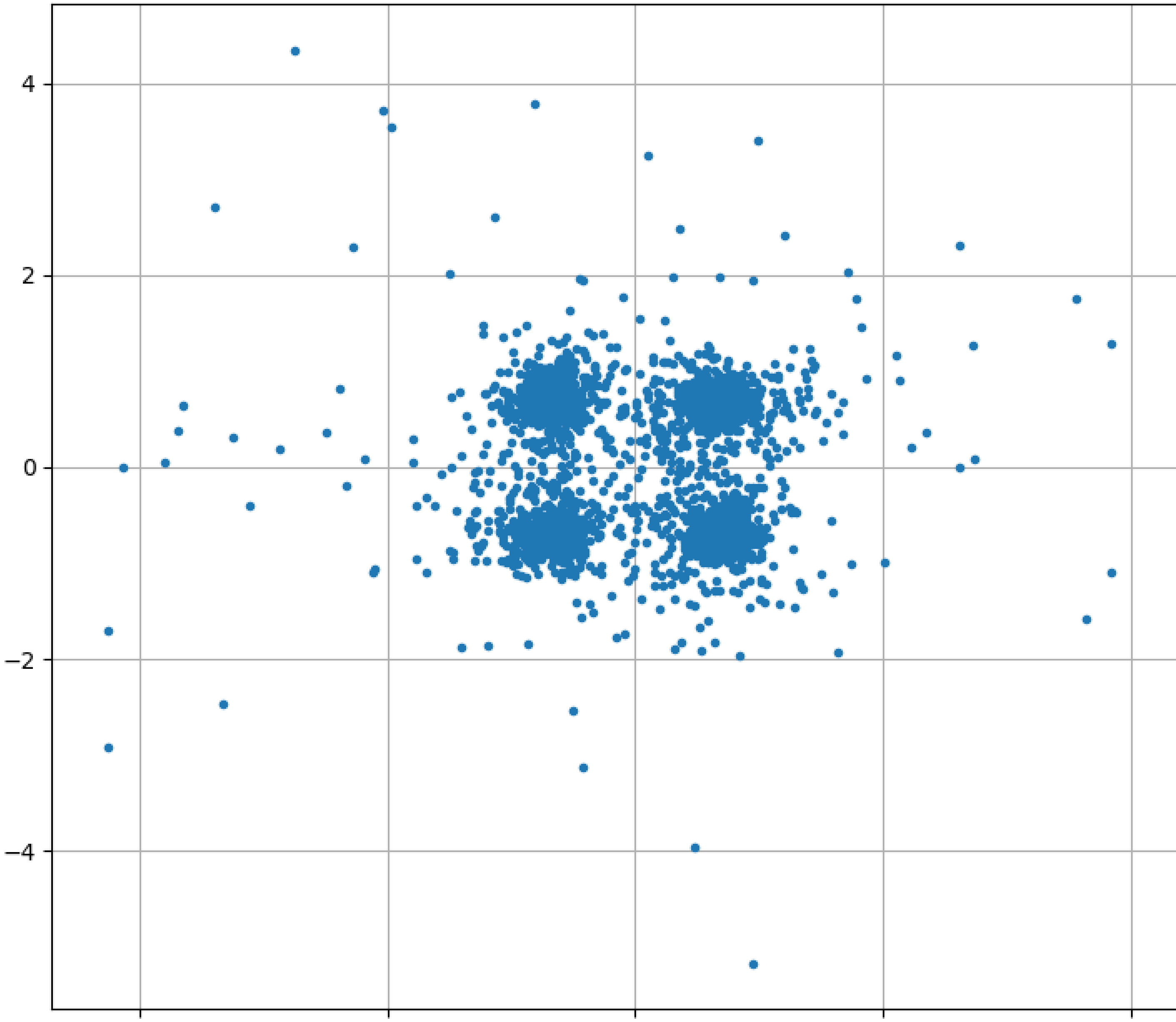
Worst case - also here, a serious amount of errors will be received at the output of a ‘slicer’ classifier.

Demodulated QAM symbols - constellation space

SNR: 20 dB, Subcarriers: 256, Payload Symbols: 20

ChannelType: DELAY_SPREAD_CHANNEL, ChannelEstimationType: BY_PILO

EVM = -7.8 dB



Exercise 10

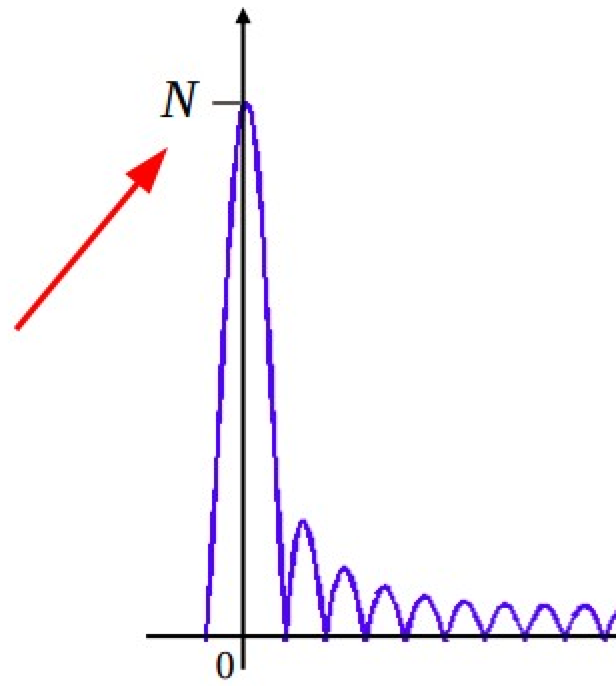
In this exercise we were asked to explore the PAPR behavior of OFDM.
We were asked to illustrate the dependence of the PAPR in the modulation scheme in use (QPSK, 16QAM, 256QAM) and in the number of the subcarriers used in our OFDM scheme (a.k.a "N_FFT").

First, we'll discuss the dependence of the PAPR in the number of the subcarriers, N_FFT. This dependence was shown in class, using the "provocative" example of a stream composed of equal QPSK symbols.

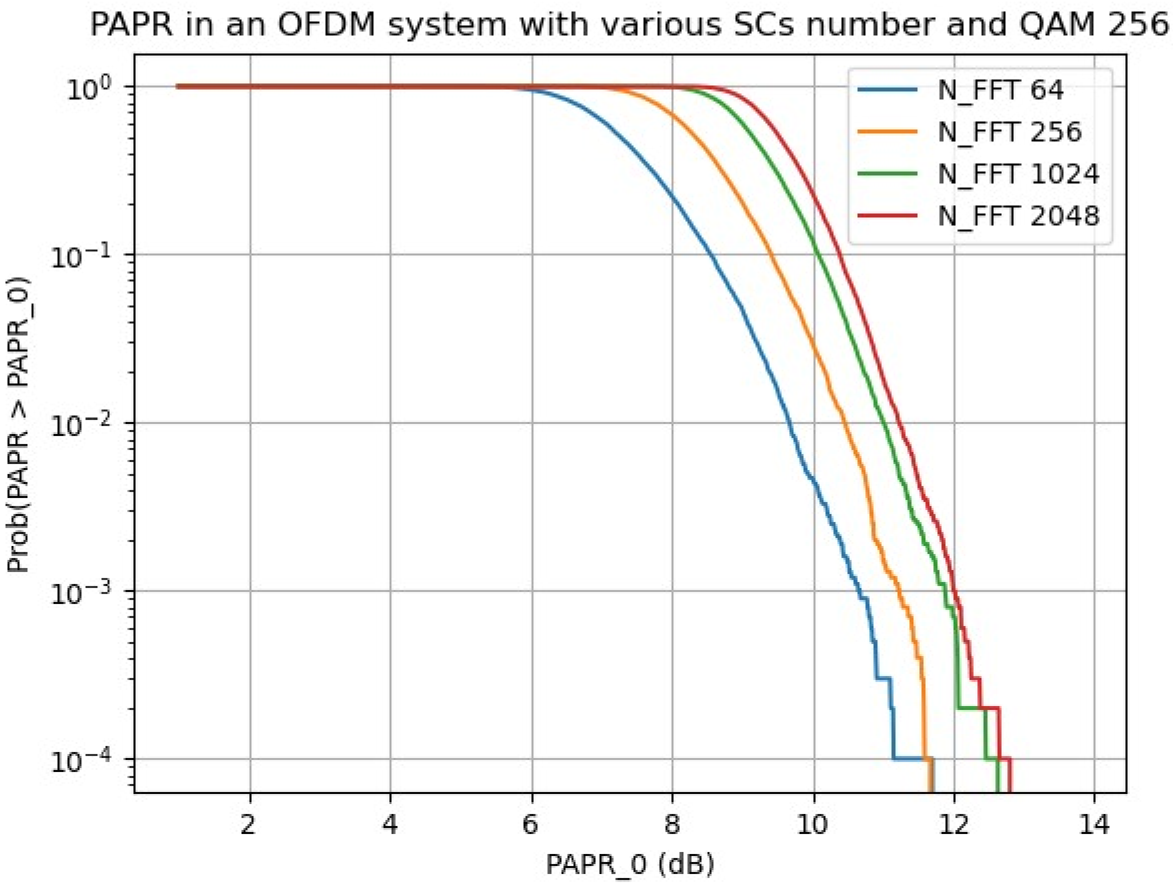
$$s(t) = \sum_{k=-N/2}^{N/2-1} a_k e^{j2\pi\frac{k}{T}t}$$

$$= a \sum_{k=-N/2}^{N/2-1} 1 \cdot e^{j2\pi\frac{k}{T}t}$$

$$\Rightarrow |s(t)| = |a| \left| \frac{\sin\left(\frac{\pi N}{T}t\right)}{\sin\left(\frac{\pi}{T}t\right)} \right|$$

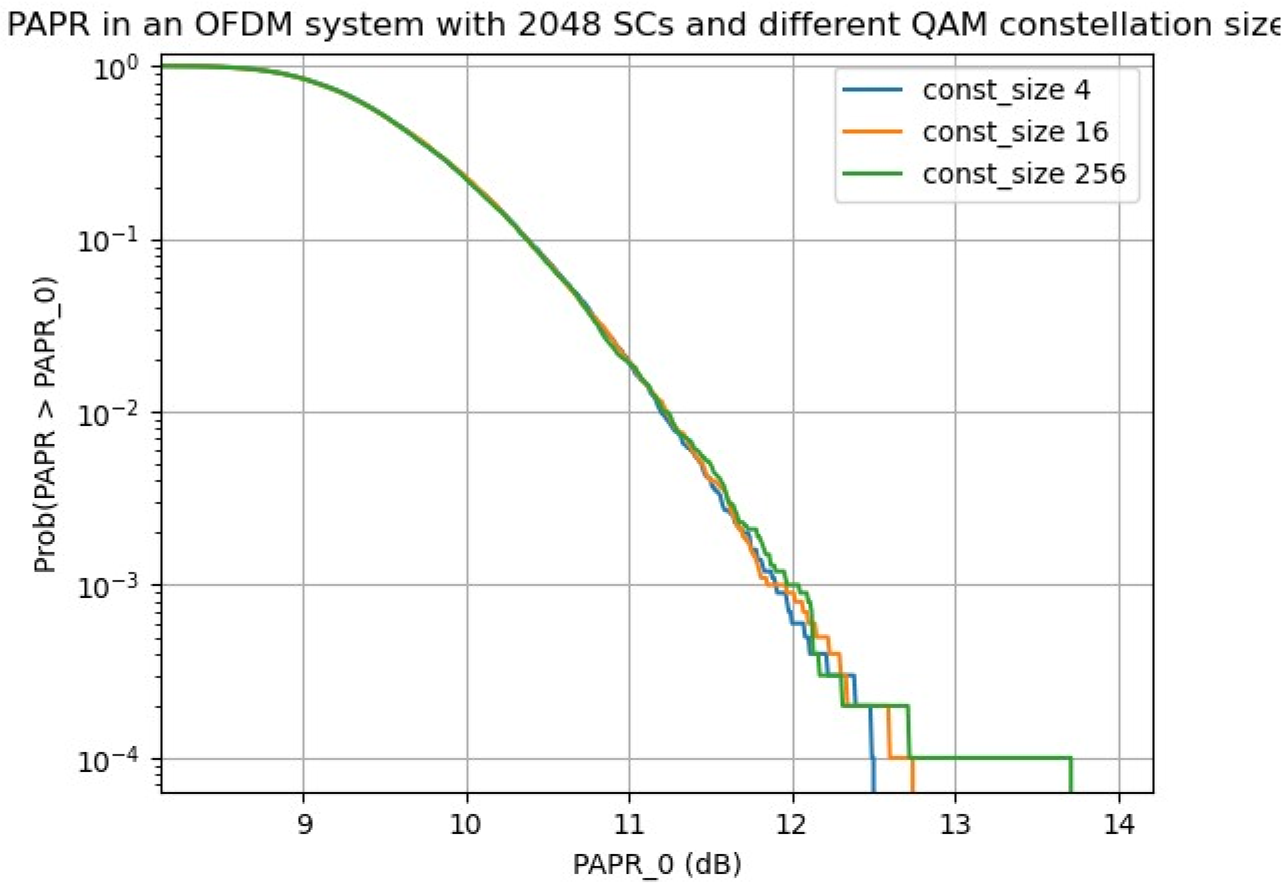


Let's see the results from our simulation:



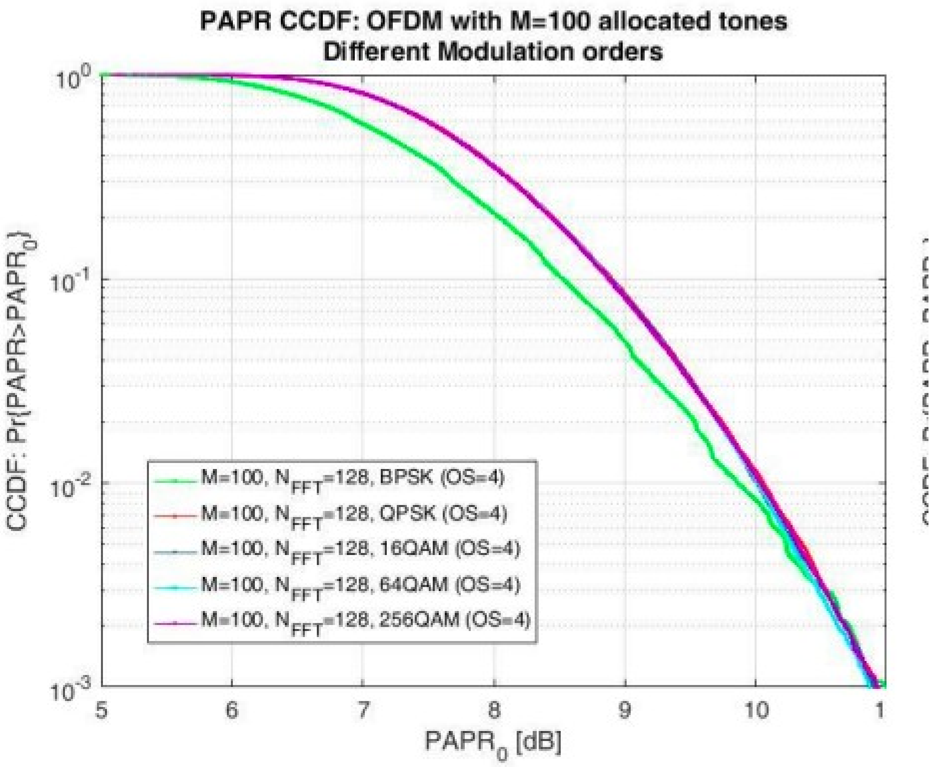
We can see that indeed as expected, as N_FFT grows, the PAPR gets bigger.

Now to the dependence on the modulation size - It's clear that in modulations bigger than QPSK, the power will be different between symbols (the distance of each constellation point from the constellation space origin is not fixed anymore). So we expect worse PAPR behavior as the modulation size grows.
Our simulation results:



We can indeed (kind of) see it. The dependence is, however, much weaker than in the N_FFT case.

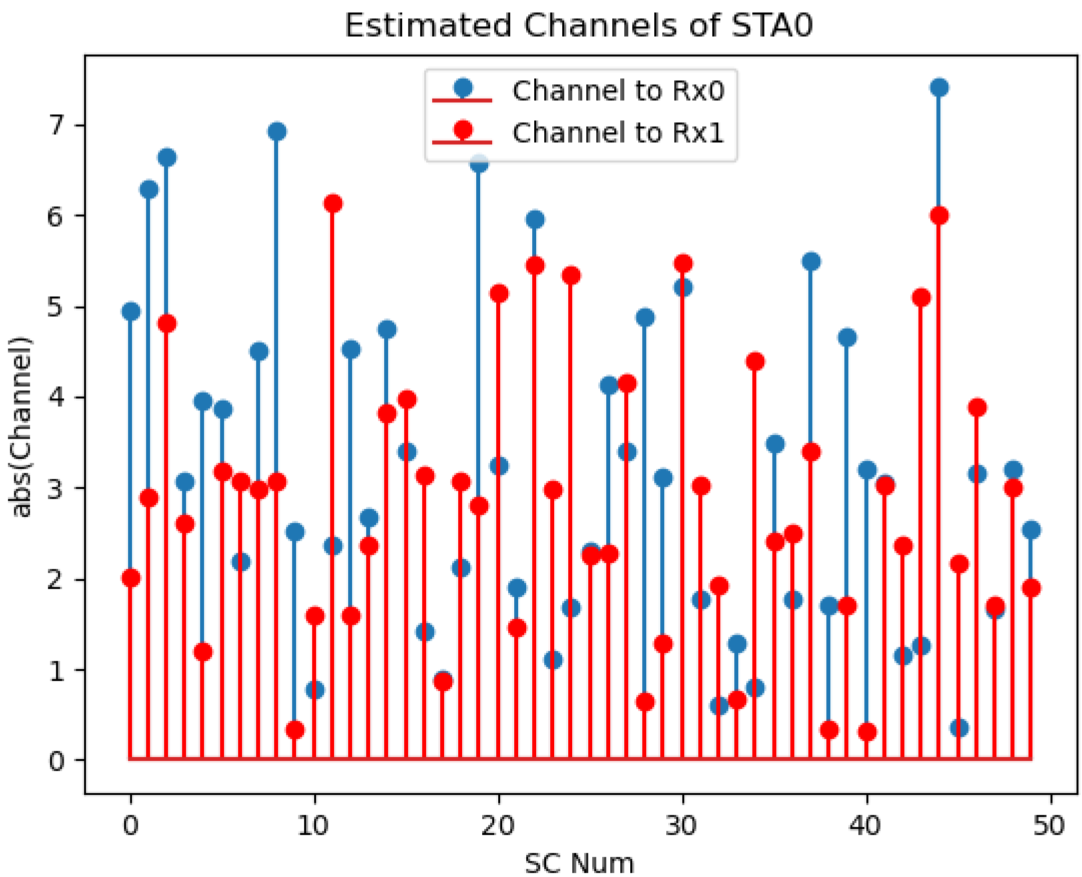
It doesn’t surprises us, because in the attached figure on the lecture it was also barely noticeable (except BPSK, which wasn’t in the requested modulations in this exercise)


PAPR CCDF: OFDM with M=100 allocated tones
Different Modulation orders
CCDF: Pr{PAPR>PAPR0}
PAPR0 [dB]
M=100, NFFT=128, BPSK (OS=4)
M=100, NFFT=128, QPSK (OS=4)
M=100, NFFT=128, 16QAM (OS=4)
M=100, NFFT=128, 64QAM (OS=4)
M=100, NFFT=128, 256QAM (OS=4)

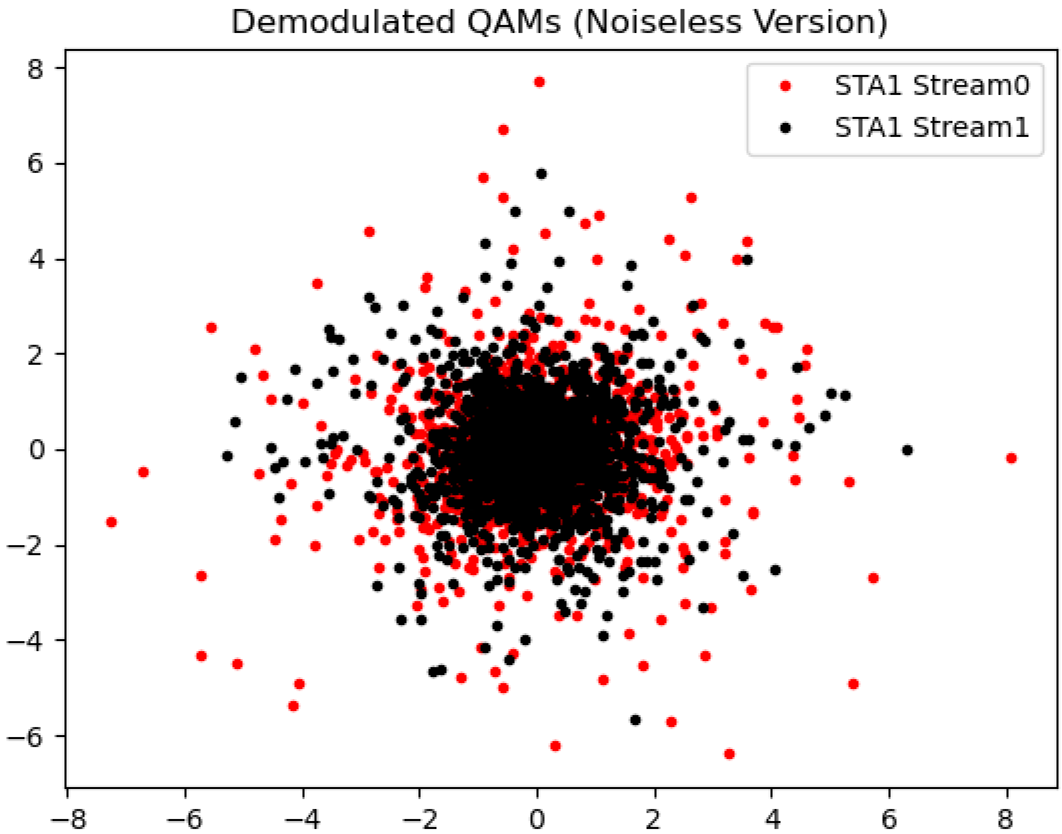
Exercise 11

in this exercise we were asked to simulate (without noise) the allocation of our UL OFDM resources to two STAs - one is transmitting single stream, and the other transmits two independent streams.
The AP is composed of ULA of antennas spaced lambda/2 from each other, and the channel introduced a random delay spread, DoAs and DoDs.

The channel estimation from the simulation, for both STA0 (single preamble symbol) and STA1 (two preamble symbols):



Now, I'll attach the demodulated symbols for STA0, STA1 - even though we haven't introduced any noise, the demodulation came out really shitty, so I guess my code is wrong somewhere, but I couldn't figure out where.
This are the results:



Our expectation was, of course, to get “clear cut” 4 points in the +-1 corners of the constellation space.