802.11ac Transmit Beamforming

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PROBLEM DEFINITION

To simulate the performance of an IEEE 802.11ac link and compare the performances of spatial expansion to that of transmit beamforming when Channel State Information at Transmitter (CSIT) is known.

INTRODUCTION

- For the purposes of this project an IEEE 802.11ac link is considered. IEEE 802.11ac is a Wi-Fi networking standard that provides high throughput WLAN on the 5 GHz band.
- **Channel State Information** (**CSI**) refers to known channel properties of a communication link. This information describes how a signal propagates from the transmitter to the receiver and represents the combined effect of, for example, scattering, fading, and power decay with distance. The CSI makes it possible to adapt transmissions to current channel conditions, which is crucial for achieving reliable communication with high data rates in multiantenna systems.
- The channel, for this project, as specified by IEEE Task Group is a Very High Throughput(VHT) Channel. It is defined as a comprehensive MIMO broadband channel models, with support for 40 MHz channelization and 4 antennas. The improvements of this channel over previous channels are specified as follows:
- Higher order MIMO (greater than 4x4) Higher Bandwidth (greater than 40 MHz)
- Multi-User MIMO with greater than 4 Access Point antennas OFDMA (Orthogonal Frequency Division Multiple Access).
- The model of the channel specified as Model – B. The multipath fading is modeled as a tapped-delay line with the number of taps and the delay and gain of each tap specified by parameters for each Channel Model type. For each tap, the method of filtered noise is used to generate a matrix of time-varying channel coefficients with the correct distribution and spectrum. Rician K-factor (dB) is defined as the ratio of signal power in dominant component over the (local-mean) scattered power.

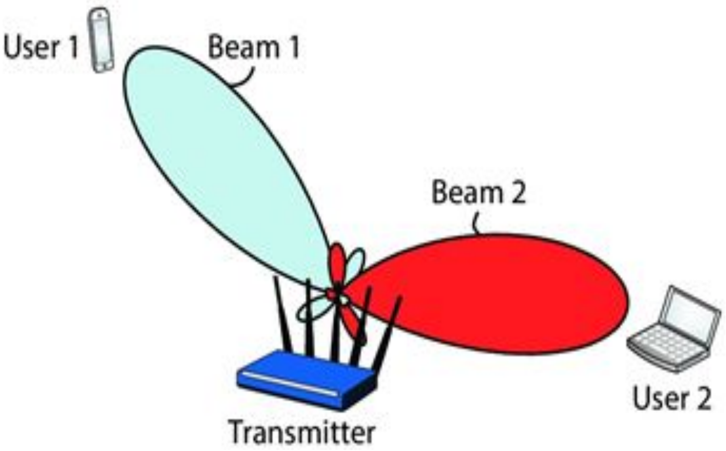
Delay profile model, specified as 'Model-A', 'Model-B', 'Model-C', 'Model-D', 'Model-E', or 'Model-F'. To enable the FluorescentEffect property, select either 'Model-D' or 'Model-E'.

The table summarizes the models properties before the bandwidth reduction factor.

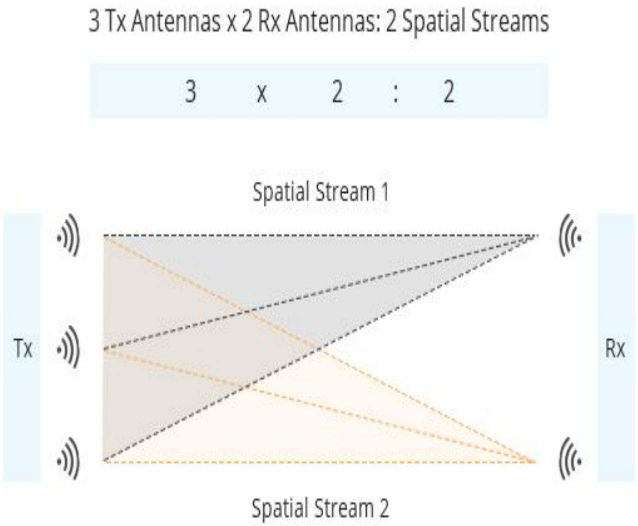
Parameter	Model					
	A	B	C	D	E	F
Breakpoint distance (m)	5	5	5	10	20	30
RMS delay spread (ns)	0	15	30	50	100	150
Maximum delay (ns)	0	80	200	390	730	1050
Rician K-factor (dB)	0	0	0	3	6	6
Number of taps	1	9	14	18	18	18
Number of clusters	1	2	2	3	4	6

The number of clusters represents the number of independently modeled propagation paths.

- Spatial expansion method includes generating a plurality of spatial streams from a digital signal and transforming the spatial streams into a plurality of space-time streams. Each of the space-time streams are cycled in the frequency domain among each of a plurality of transmit antennas. The space-time streams are wirelessly transmitted from the plurality of transmit antennas.
- Transmit beamforming is a versatile technique for signal transmission from an array of N antennas to one or multiple users . A high signal power is achieved by transmitting the same data signal from all antennas, but with different amplitudes and phases, such that the signal components add coherently at the user. Low interference is accomplished by making the signal components add destructively at non-intended users.



Transmit Beamforming



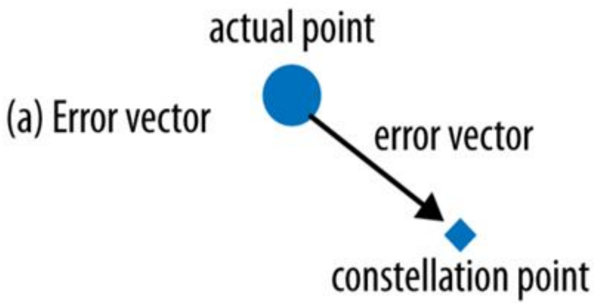
Spatial Expansion

METHODOLOGY

- For the simulation of this project, MATLAB is used.
- In this example a 4x2 MIMO configuration is considered between a transmitter and receiver, with two space-time streams used for a data packet transmission and transmit a VHT (Very HIgh Throughput) waveform with:
    - bandwidth of 20MHz. .
    - The Modulation and Coding Scheme(MCS) is 16-QAM with coding rate of 3/4. Meaning 75% of data is for transmitting usable data.
    - Data payload is 4000 bytes.
- First the scenario of a receiver which is not capable of being a beamformee is considered. A transmission is made using spatial expansion and the data symbols are recovered and the signal quality measured. To show the benefits of transmit beamforming the data packet is then transmitted over the same channel realization, but this time using transmit beamforming. The performance of the two schemes are then compared.
- Channel is a TGac(802.11ac with multipath fading) channel with delay profile Model-B and some finite noise power.
- The Transmitter-Receiver distance is set to 100m. We also add AWGN noise to the channel of -37dBW.

- After the channel has been specified, we calculate parameters such as expected noise variance, no. of spatial streams and no. of occupied subcarriers in VHT fields. We also a generate a random PSDU (a data unit) which is used for transmission.
- We first transmit data using spatial expansion technique. For this, we create a spatial expansion matrix, generate a waveform and pass it through a fading channel with added noise. We then carry out channel estimation and estimate symbol timing
- The received data is then demodulated and equalized to get back (OFDM) symbols for each spatial stream. We then plot the constellations.
- To simulate transmit beamforming, we use the available channel state information to create a steering matrix. To calculate a beamforming steering matrix, we first create a NDP (Null Data Packet) and pass it through the channel (sounding) and then perform spatial mapping. The no. of space-time streams is equal to no. of Tx antennas- this allows Very High Throughput Long Training Field(VTF-LTF) to sound channels which is important in in MIMO channel estimation.

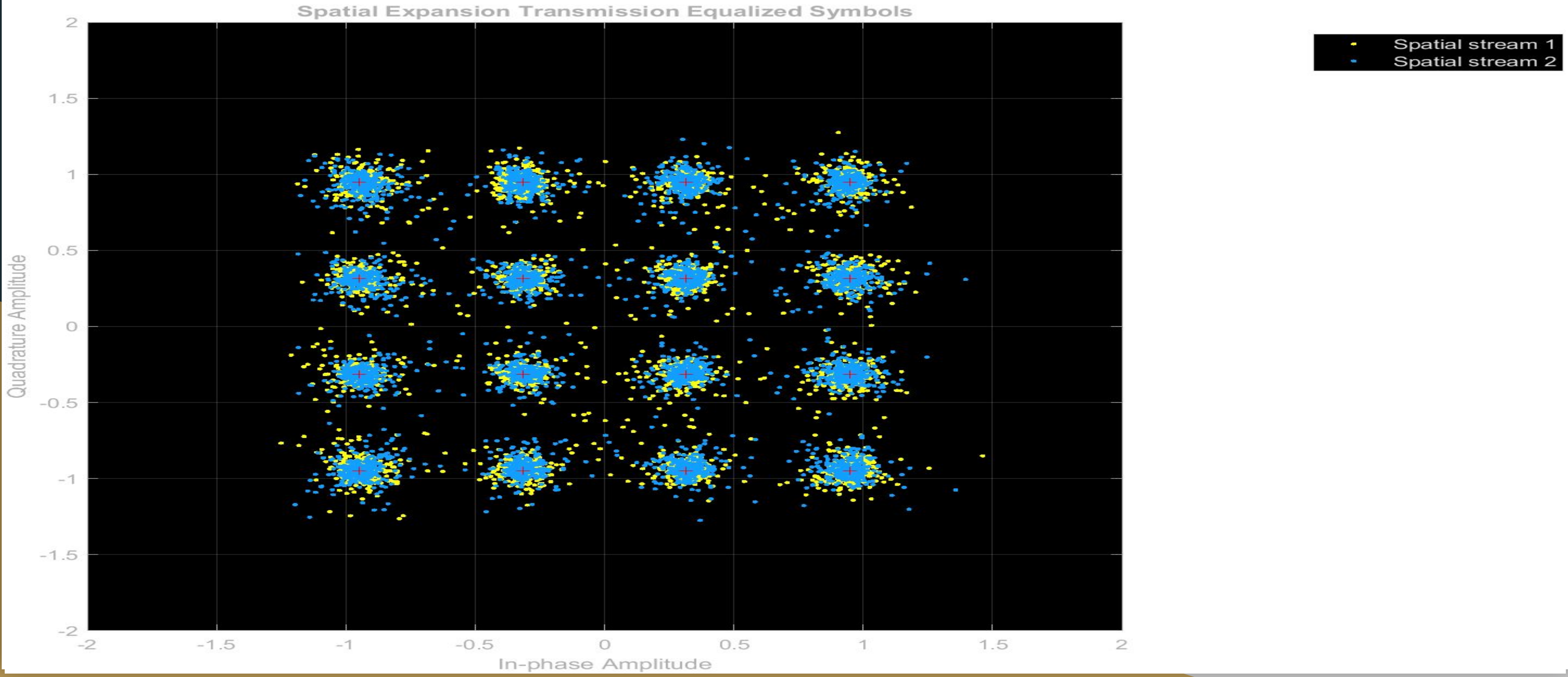
- The calculated beamforming matrix is then used to beamform a transmission through the channel. The same channel realization is used for sounding and data transmission and there is no feedback compression between beamformee and beamformer. Channel estimation is done using wlanVHTLTFChannelEstimate() function. Here, the beamforming steering matrix is calculated using singular value decomposition (SVD) . The SVD of the channel matrix results in two unitary matrices, U and V, and a diagonal matrix of singular values S. The first NumSTS columns of V per subcarrier are used as the beamforming steering matrix. The SVD is computed using the function svd. The beamforming steering matrix calculated above is applied as a custom spatial mapping matrix and is used to send data through the same channel. The received data field is demodulated and equalized to recover OFDM symbols for each spatial stream and the equalized constellation for each spatial stream is plotted.
- We then plot the equalized constellation from the spatial expansion and beamformed transmissions for all spatial streams. We also calculate the RMS and Maximum Error Vector Magnitude (EVM) (which is a measure if demodulated signal quality).

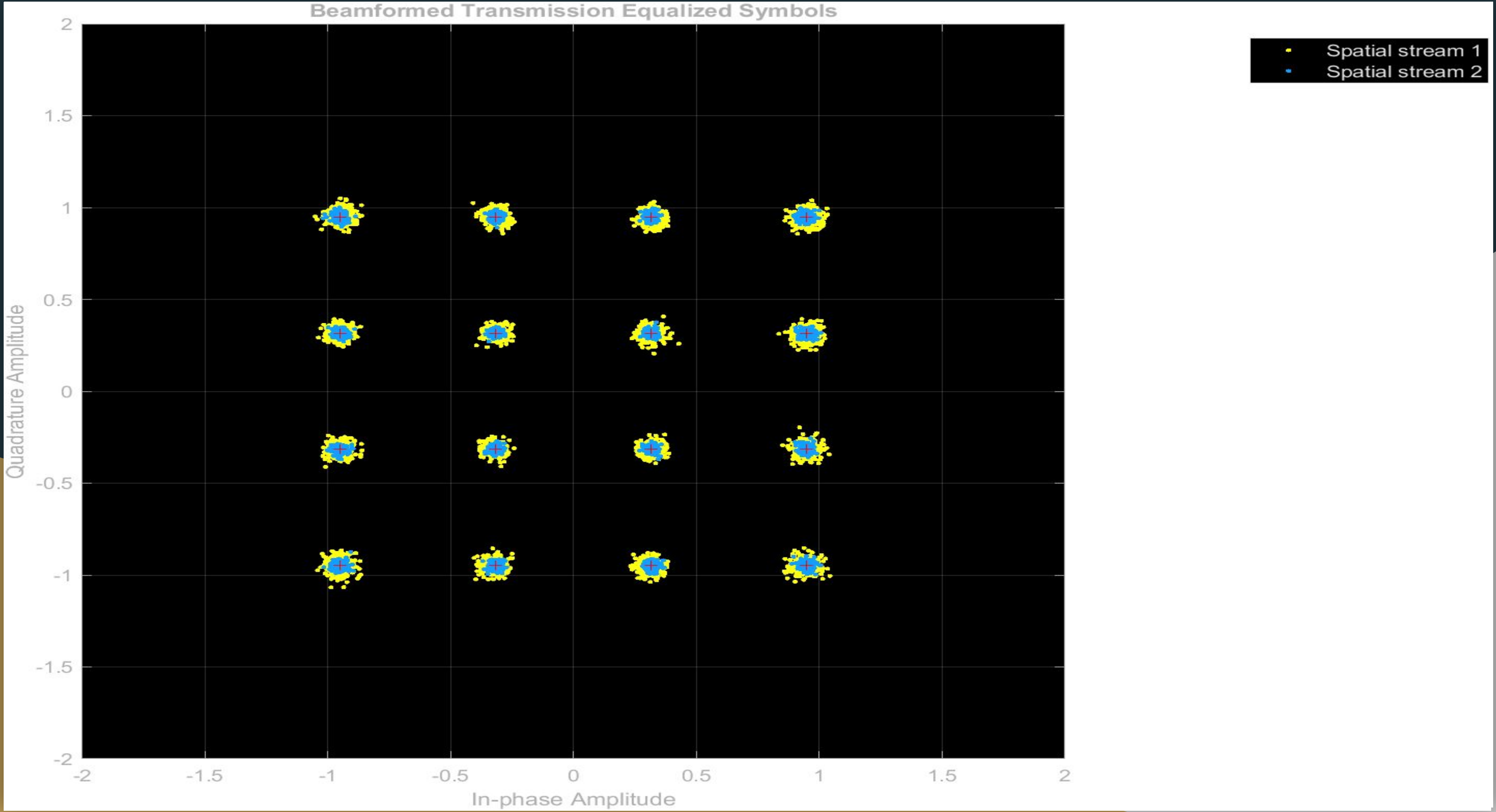


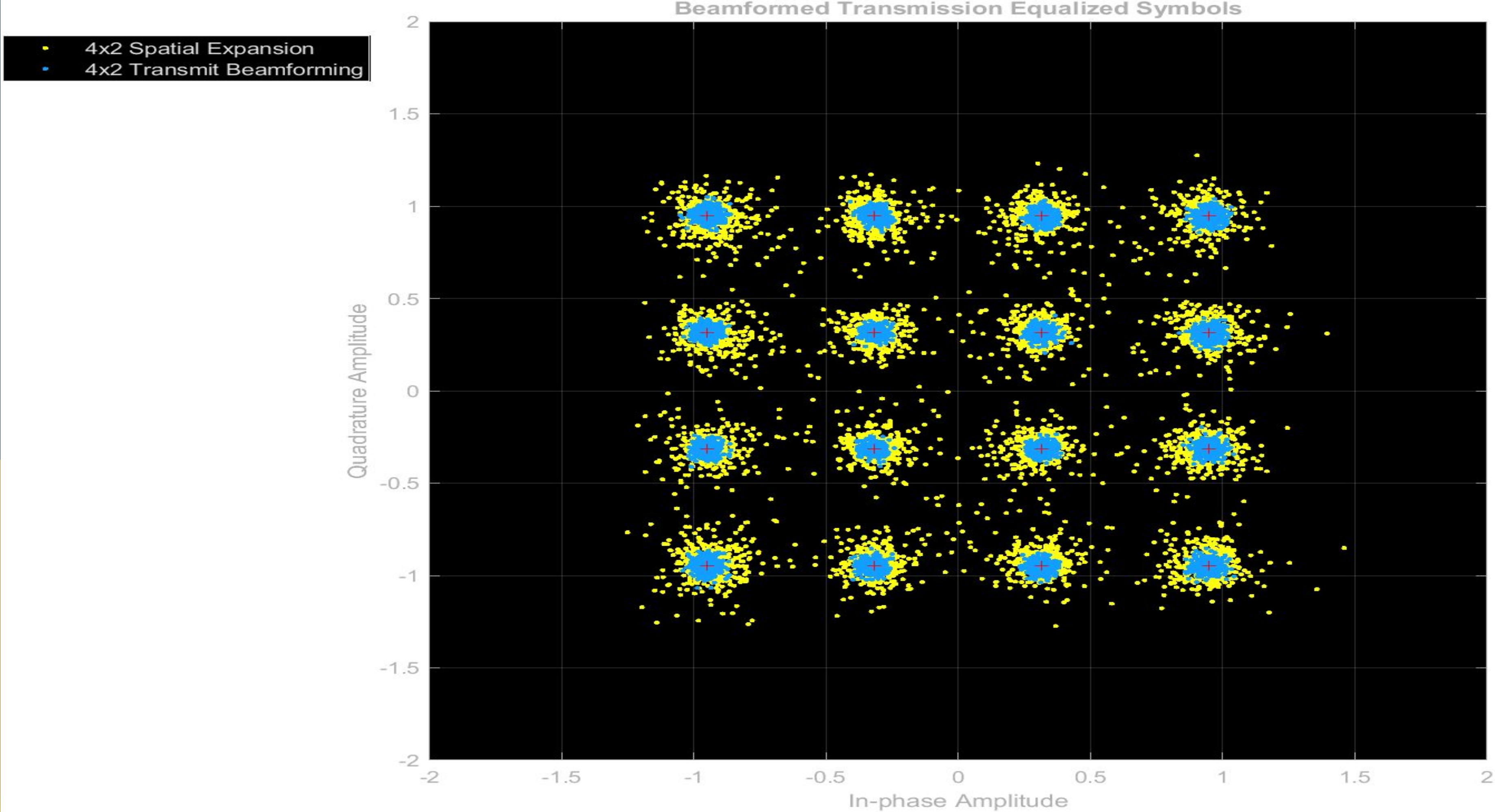
MATLAB Helper functions used :

1. helperSpatialExpansionMatrix.m : Returns a spatial expansion matrix.
2. vhtBeamformingNoiseVariance.m : Returns the noise variance after OFDM demodulation for a given noise power.
3. vhtBeamformingPlotConstellation.m : It helps plot signal constellation.
4. vhtBeamformingRemoveCSD.m : It removes the effect of transmitter cyclic shifts.

CONSTELLATION DIAGRAMS FOR 4X2 ANTENNA CONFIGURATION USING 2 SPATIAL STREAMS



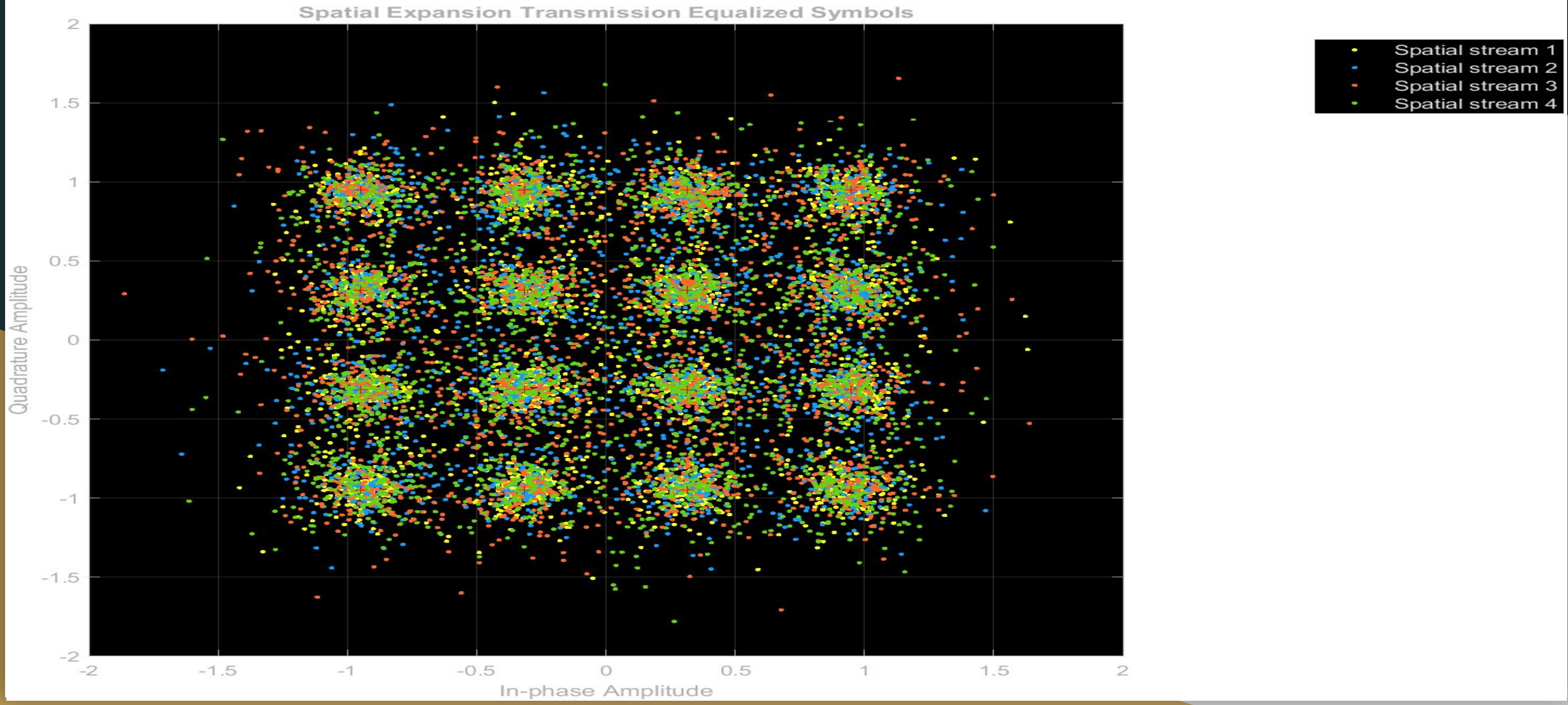

Beamformed Transmission Equalized Symbols
Quadrature Amplitude
In-phase Amplitude
Spatial stream 1
Spatial stream 2
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2

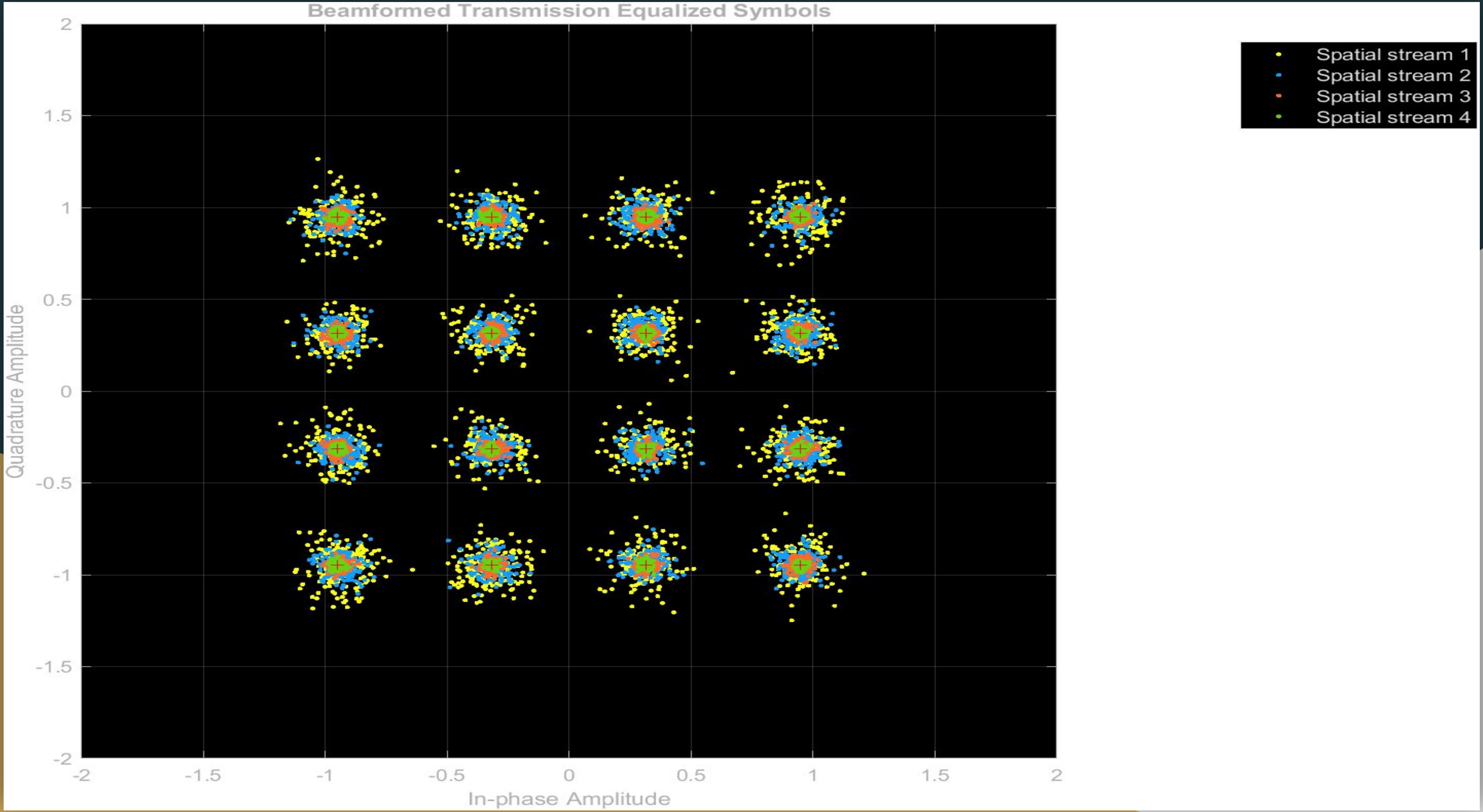


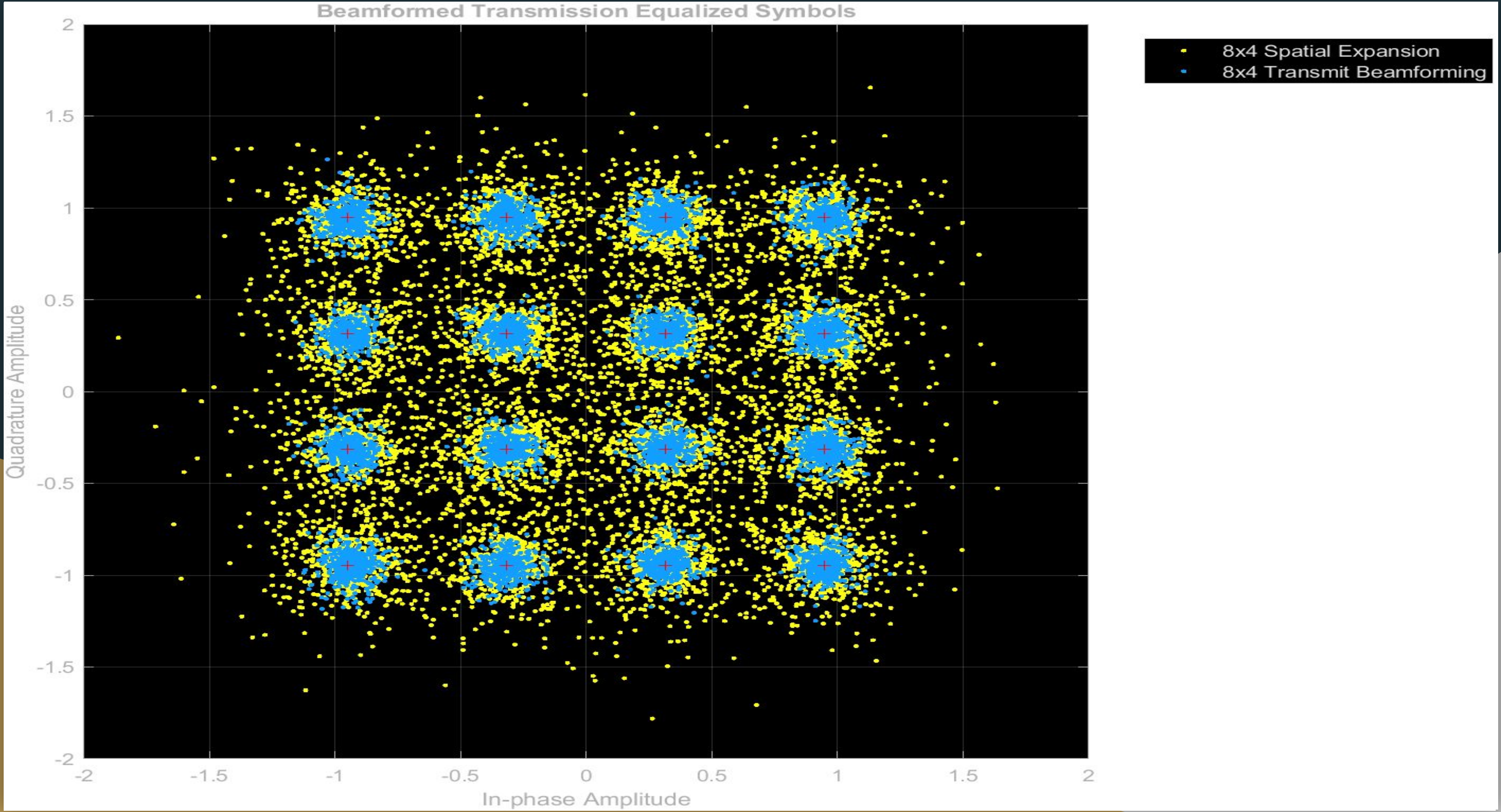
Beamformed Transmission Equalized Symbols
4x2 Spatial Expansion
4x2 Transmit Beamforming
Quadrature Amplitude
In-phase Amplitude
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2

```
>> transmitbeamforming
Mean received channel power per space-time stream with spatial expansion:
  Space-time stream 1: 0.73 W
  Space-time stream 2: 0.50 W
Mean received channel power per space-time stream with SVD transmit beamforming:
  Space-time stream 1: 2.08 W
  Space-time stream 2: 0.45 W
Spatial stream 1 EVM:
  Spatial expansion:    9.2% RMS, 44.8% max
  Transmit beamforming: 2.0% RMS, 8.6% max
Spatial stream 2 EVM:
  Spatial expansion:    9.2% RMS, 52.3% max
  Transmit beamforming: 4.1% RMS, 12.7% max
fx >>
```

CONSTELLATION DIAGRAMS FOR 8X4 ANTENNA CONFIGURATION USING 4 SPATIAL STREAMS



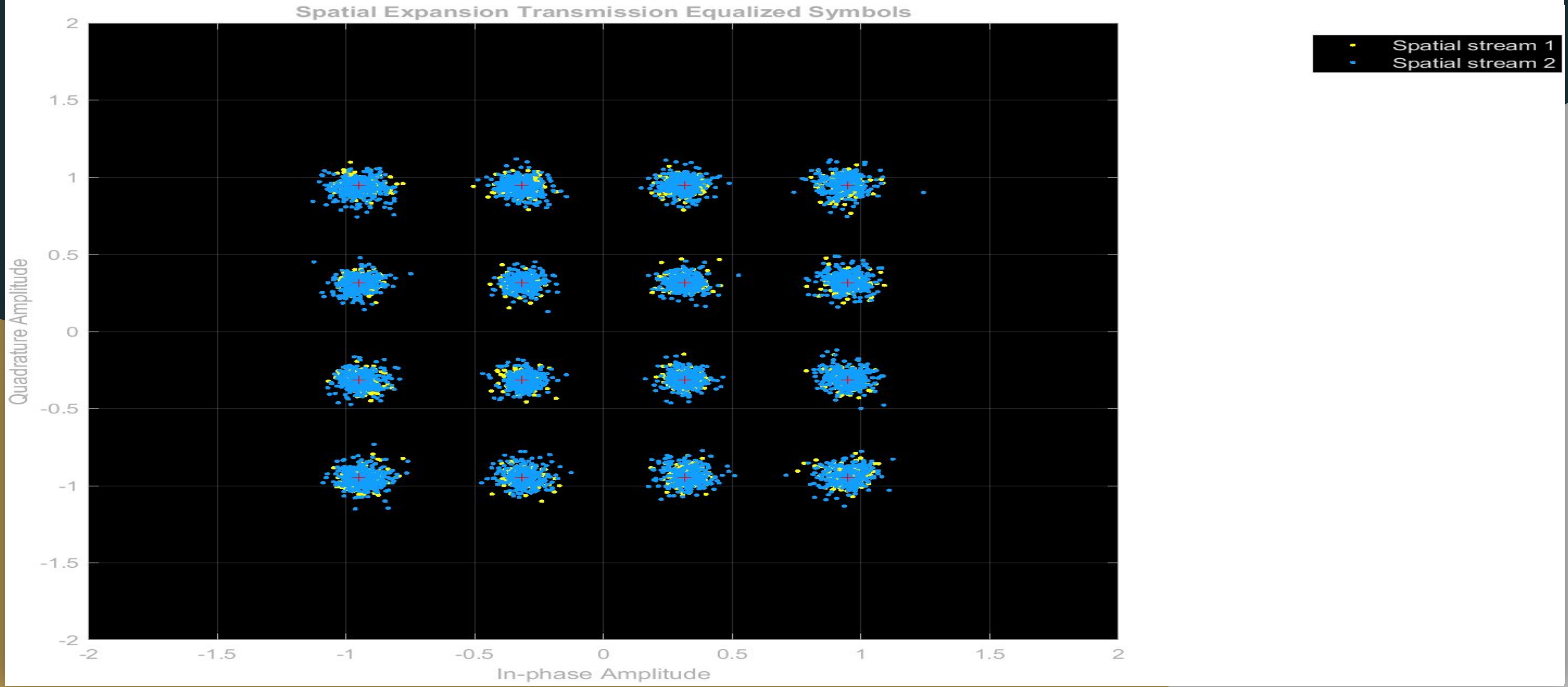

Beamformed Transmission Equalized Symbols
Quadrature Amplitude
In-phase Amplitude
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
Spatial stream 1
Spatial stream 2
Spatial stream 3
Spatial stream 4

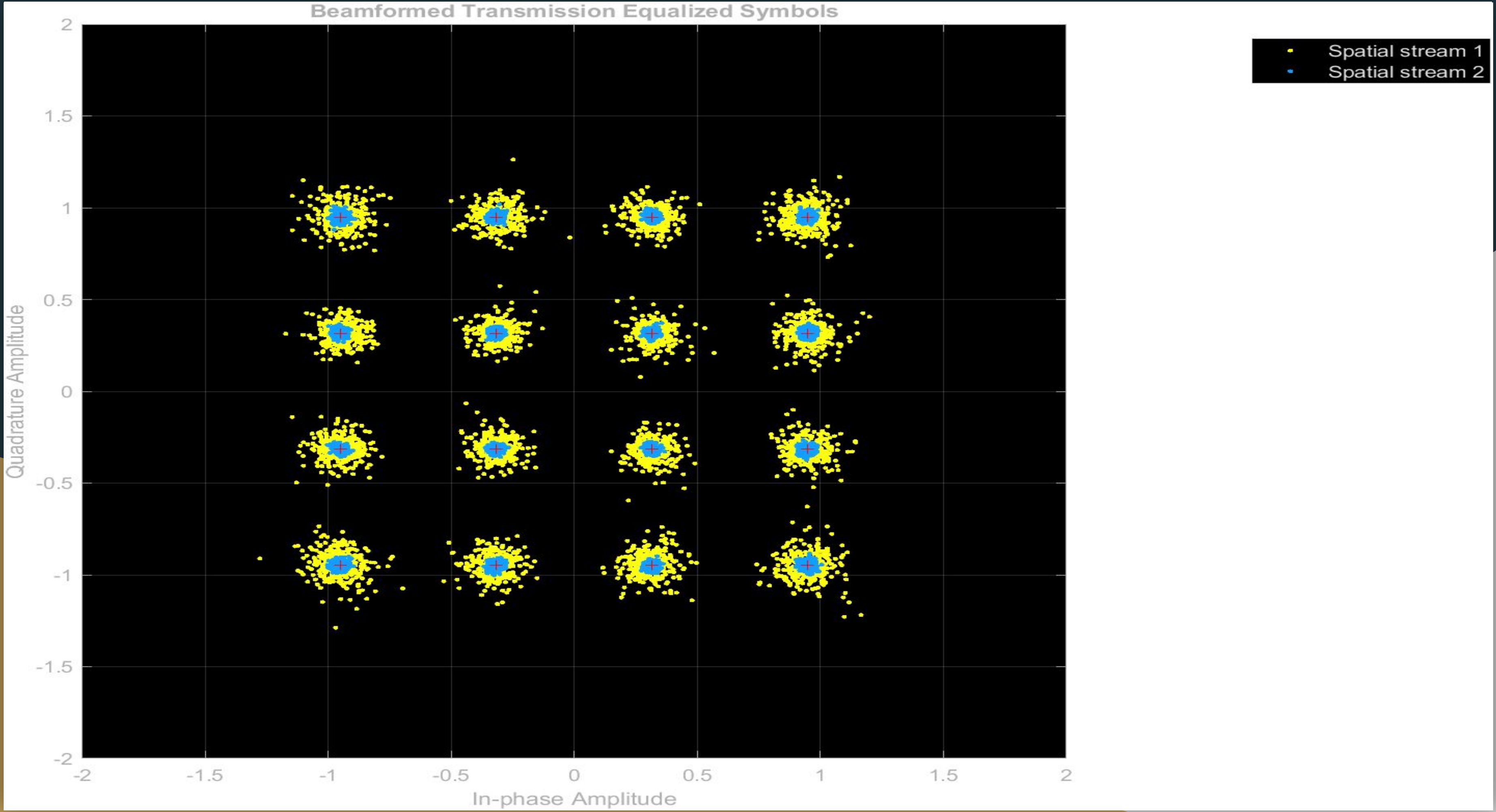


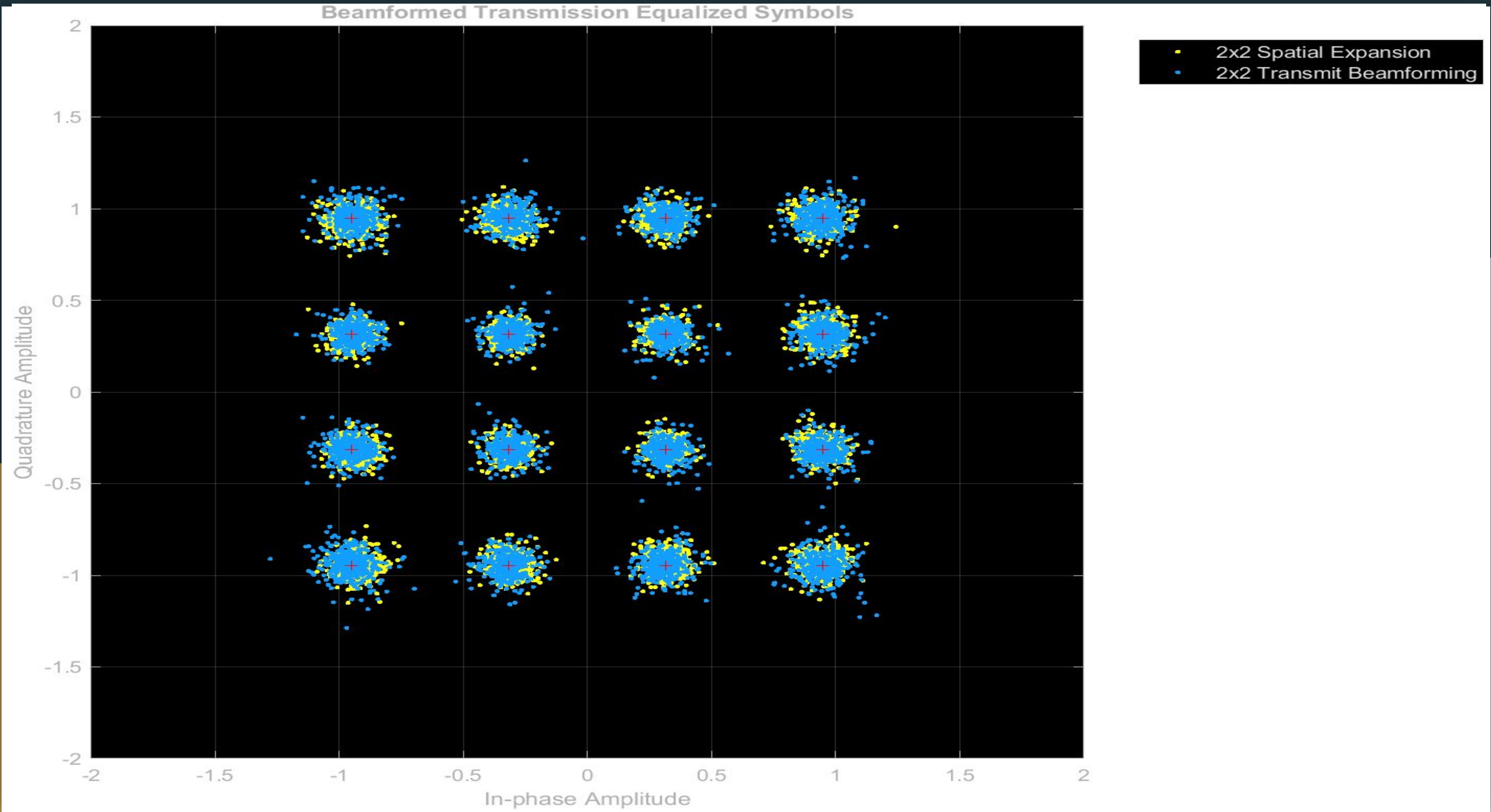
Beamformed Transmission Equalized Symbols
Quadrature Amplitude
In-phase Amplitude
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
8x4 Spatial Expansion
8x4 Transmit Beamforming

```
>> transmitbeamforming
Mean received channel power per space-time stream with spatial expansion:
  Space-time stream 1: 0.64 W
  Space-time stream 2: 0.80 W
  Space-time stream 3: 1.02 W
  Space-time stream 4: 0.87 W
Mean received channel power per space-time stream with SVD transmit beamforming:
  Space-time stream 1: 4.86 W
  Space-time stream 2: 1.26 W
  Space-time stream 3: 0.29 W
  Space-time stream 4: 0.12 W
Spatial stream 1 EVM:
  Spatial expansion:    21.2% RMS, 85.1% max
  Transmit beamforming: 1.8% RMS, 5.9% max
Spatial stream 2 EVM:
  Spatial expansion:    20.4% RMS, 92.3% max
  Transmit beamforming: 3.3% RMS, 9.5% max
Spatial stream 3 EVM:
  Spatial expansion:    18.3% RMS, 78.7% max
  Transmit beamforming: 7.2% RMS, 24.5% max
Spatial stream 4 EVM:
  Spatial expansion:    16.3% RMS, 73.7% max
  Transmit beamforming: 11.3% RMS, 35.3% max
fx >>
```

CONSTELLATION DIAGRAMS FOR 2X2 ANTENNA CONFIGURATION USING 2 SPATIAL STREAMS




Beamformed Transmission Equalized Symbols
Spatial stream 1
Spatial stream 2
Quadrature Amplitude
In-phase Amplitude
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2


Beamformed Transmission Equalized Symbols
2x2 Spatial Expansion
2x2 Transmit Beamforming
Quadrature Amplitude
In-phase Amplitude
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2

```
>> transmitbeamforming
Mean received channel power per space-time stream with spatial expansion:
  Space-time stream 1: 0.43 W
  Space-time stream 2: 1.06 W
Mean received channel power per space-time stream with SVD transmit beamforming:
  Space-time stream 1: 1.36 W
  Space-time stream 2: 0.14 W
Spatial stream 1 EVM:
  Spatial expansion:    7.1% RMS, 29.9% max
  Transmit beamforming: 2.2% RMS, 7.4% max
Spatial stream 2 EVM:
  Spatial expansion:    4.7% RMS, 21.1% max
  Transmit beamforming: 8.4% RMS, 34.7% max
fx >>
```

CONCLUSION

- It is observed that there is an improved constellation using SVD-based transmit beamforming which has been backed up by EVM values.
- If a receiver is capable of being a beamformee,
    - the SNR can potentially be improved.
    - The increase in received power when using beamforming can lead to more reliable demodulation
    - potentially even a higher order modulation and coding scheme can be used for the transmission.
- From the simulation, it is apparent that to obtain a diversity gain, we need more number of Tx antennas than Rx antennas.

REFERENCES

1. Yong Soo Cho, Chung G. Kang, Jaekwon Kim, Wo˘n-yo˘ng Yang, MIMO-OFDM Wireless Communications With MATLAB,2010.
2. Aditya K.Jagannatham,Principles of Modern Wireless Communication Systems,3rd ed,2019.
3. El Ayach, Oma, et al. ”Spatially Sparse Precoding in Millimeter Wave MIMO Systems.” IEEE Transactions on Wireless Communications, Vol. 13, No. 3, March 2014, pp. 1499-1513
4. Mathew S. Ghast,802.11ac:A Survival Guide,2013
5. Emil Bjornson, Mats Bengtsson, and Bjorn Ottersten Optimal Multiuser Transmit Beamforming:A Difficult Problem with a Simple Solution Structure,2013.

THANK YOU!!!!