

EE 504 Software Defined Radio Final Project



CAL POLY

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Transmitting File Over the Air



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Intra-Transcieve

Objective:

Learn how to operate and understand transceiving between Pluto radio and the LimeSDR (unsuccessful, went with Pluto to Pluto)

Equipment:

MATLAB, Pluto Radio, USB cable, Antennas, Loopback Cable

Background:

A sentence will be typed into a text file and transmitted to the LimeSDR where it will be decoded using 2.4GHz (ISM band) frequencies due to Pluto's detection capabilities. The frequencies used must ensure that there is minimal interference on the wavelength. If the bunny ears do not function properly, a wire antenna will be used that is the wavelength over four to ensure proper transmission.

Later, a scaled down image will be sent from one Pluto to another over the ISM band. The limits of the Pluto's range, the power decreases by a fourth for $1/(R)^2$, and the SNR limits for different modulation methods will be explored.

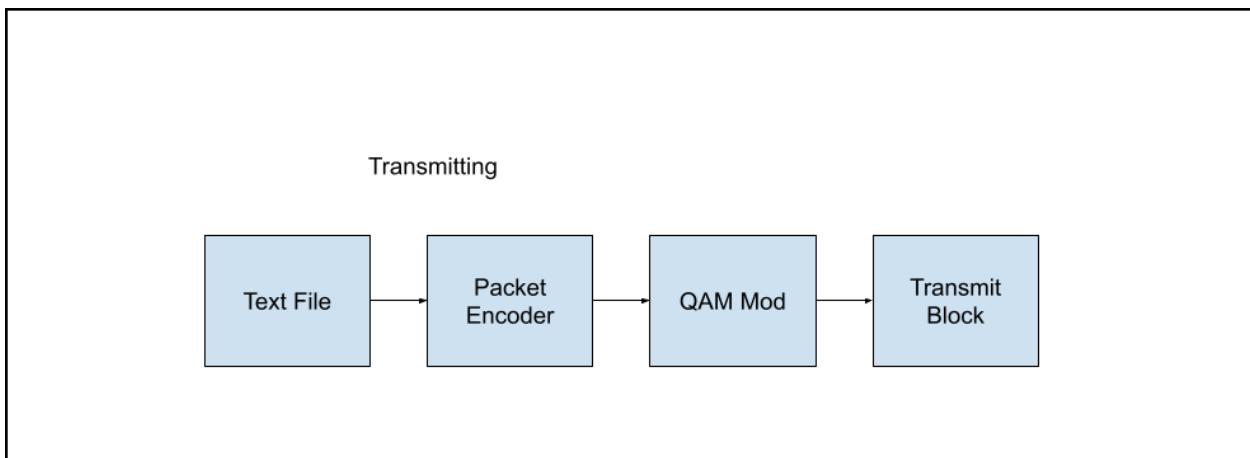
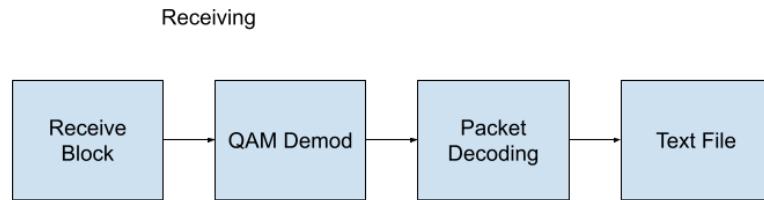


Figure 1: Transmission flowchart

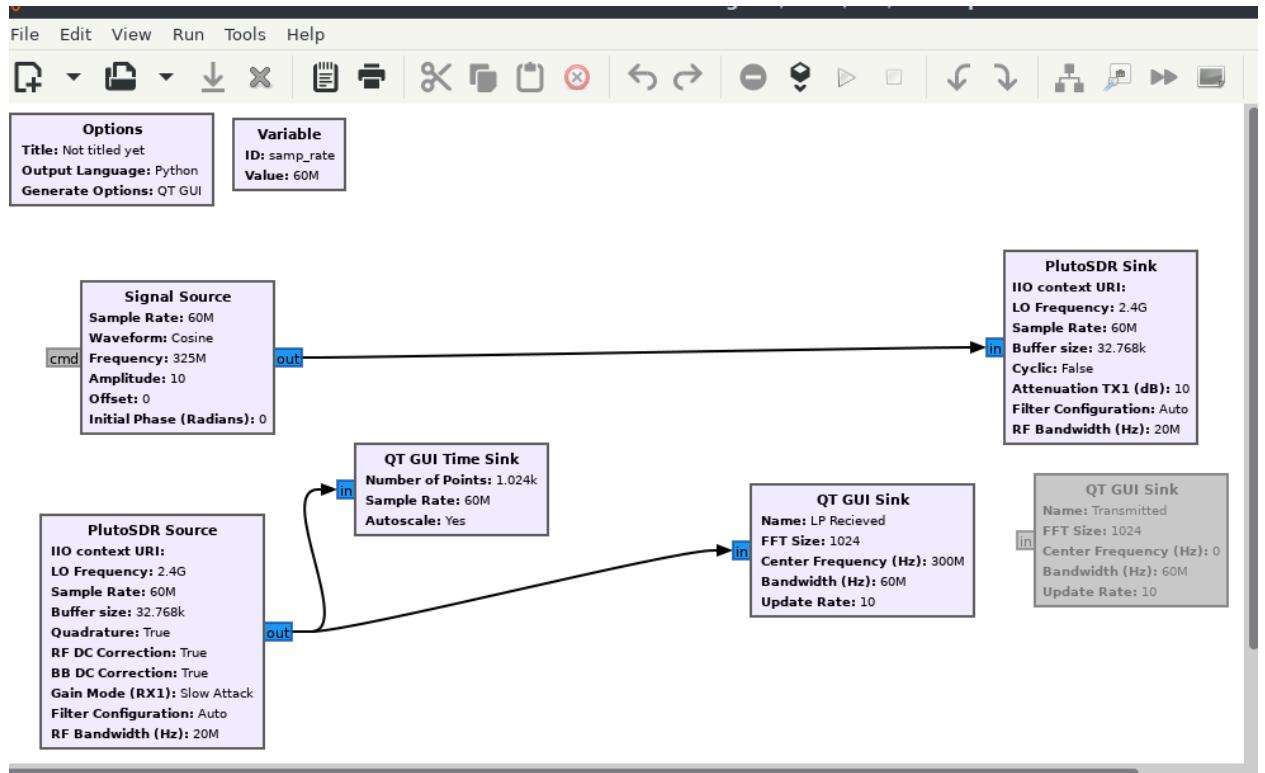
The text field will be encoded where the symbols from the text file will be able to be modulated using QAM. Then, they will be transmitted by the Pluto radio.



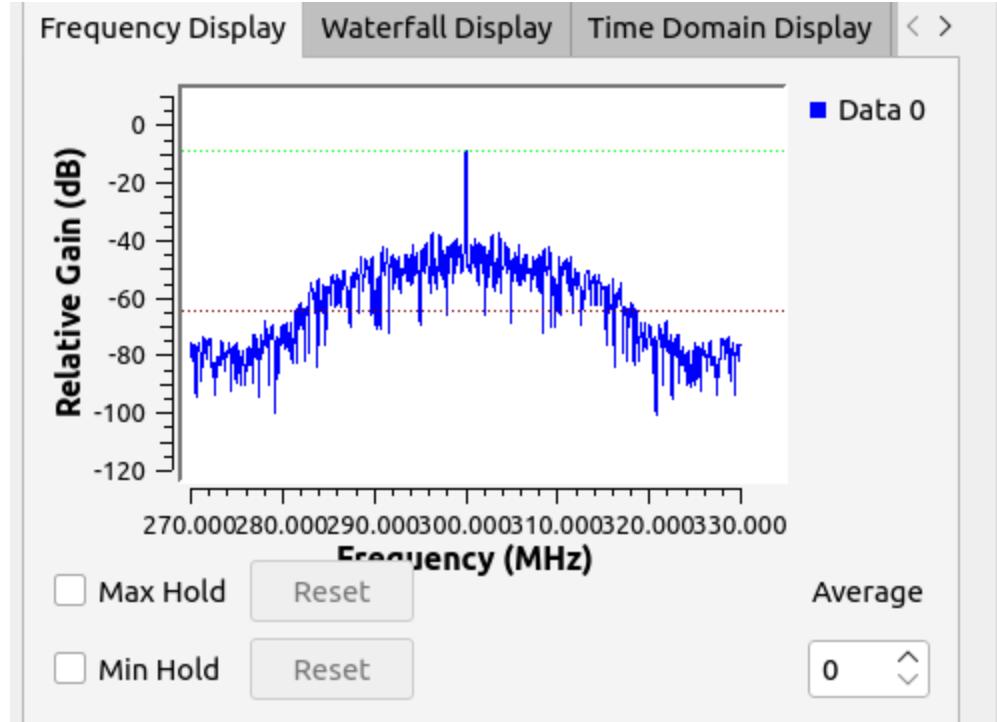
Results:

The original plan was to use GNU radio, but MATLAB had better libraries for packet encoding as GNU radio decommissioned their packet encoder. The results were not ideal so MATLAB was used instead.

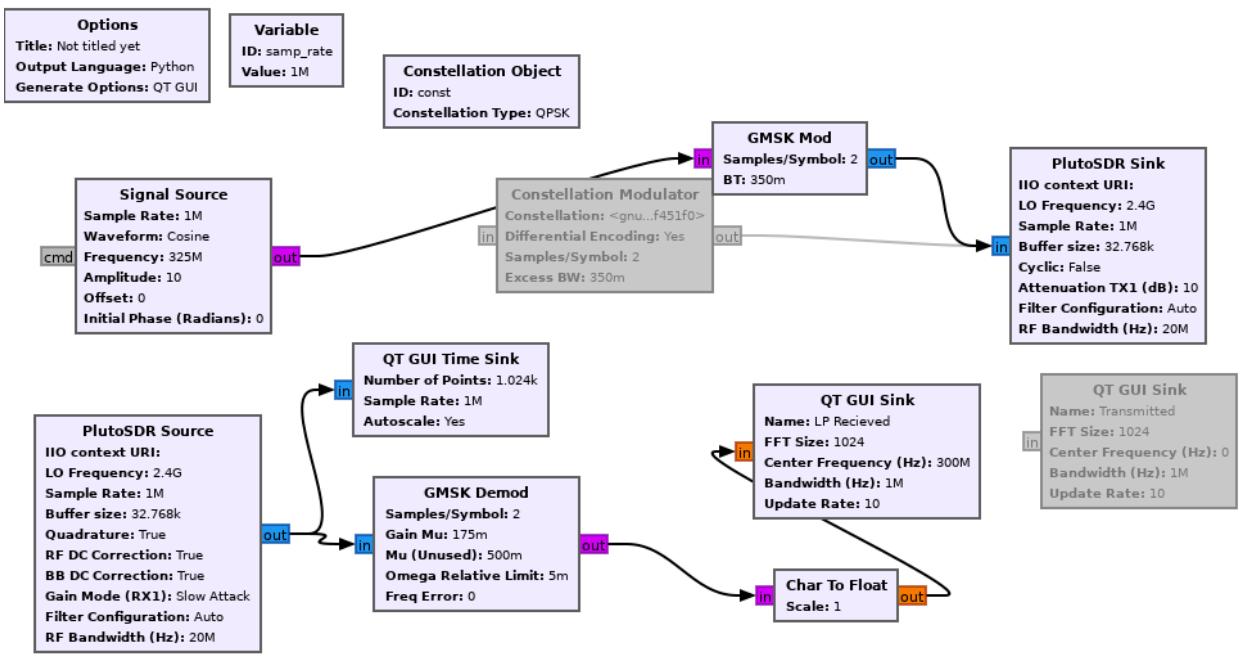
GNU Radio Pluto Testing:



Testing pluto sending and receiving sine wave without modulation



325 MHz received on the pluto



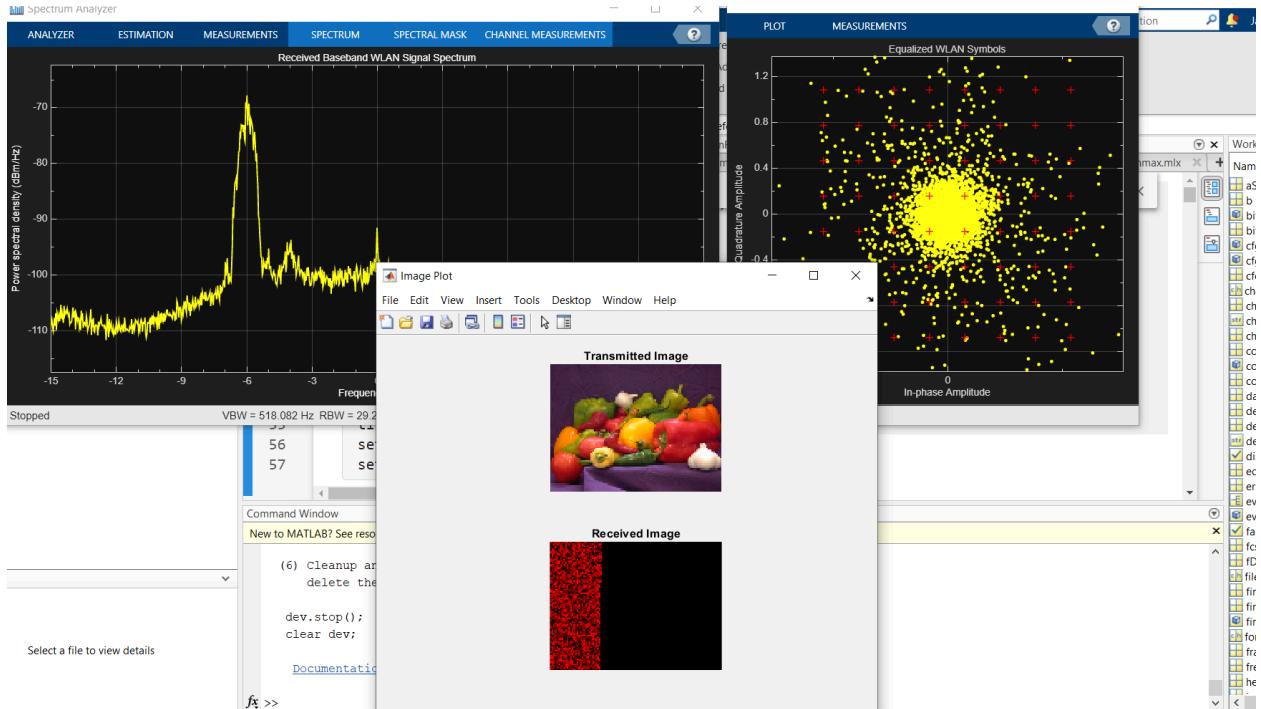
Using GMSK Demod

Virtual Sink Simulation

Refer to the code in the Appendix on page 45. While transmitting files, set up two plutos. Place an SMA loopback on the TX of one pluto and one on the RX of the other. Cap the unused ports to prevent interference. Create a text file on the TX pluto. Put anything you would like. Specify the channel as “Over the air”, this will ensure the pluto is ready to transmit and receive from another pluto. Set the channel number to 5 and the frequency to 2.4GHz. Then transmit by pressing the run button on both computers around the same time. The code works by detecting the preamble and stopping when the packet transmission stops. A text file that was inputted into the transmitter should be displayed as the output on the receiver.

Change the receiver and the transmitter gain to optimize the best results. Below are some results to gauge troubleshooting issues. Try different modulation techniques such as QPSK, 16QAM, etc and change the MCS value according to the $\frac{3}{4}$ data rate. The data will be recorded. Add antennas when the SMA transmission has no error.

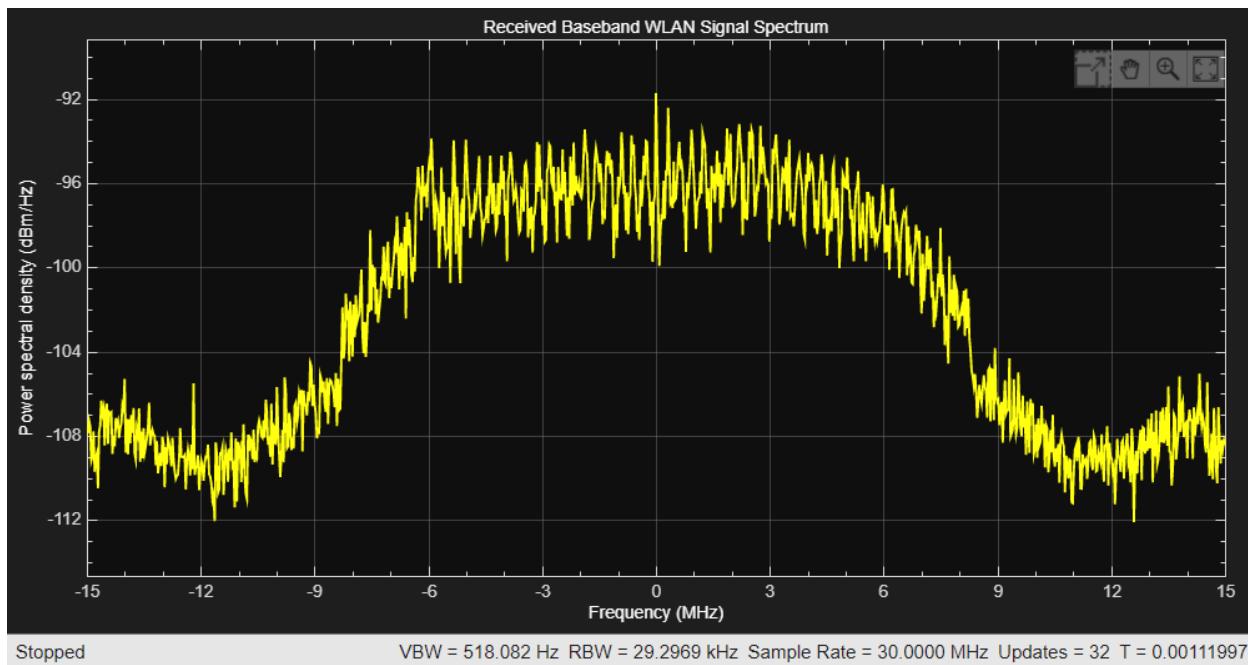
When no file is transmitted:

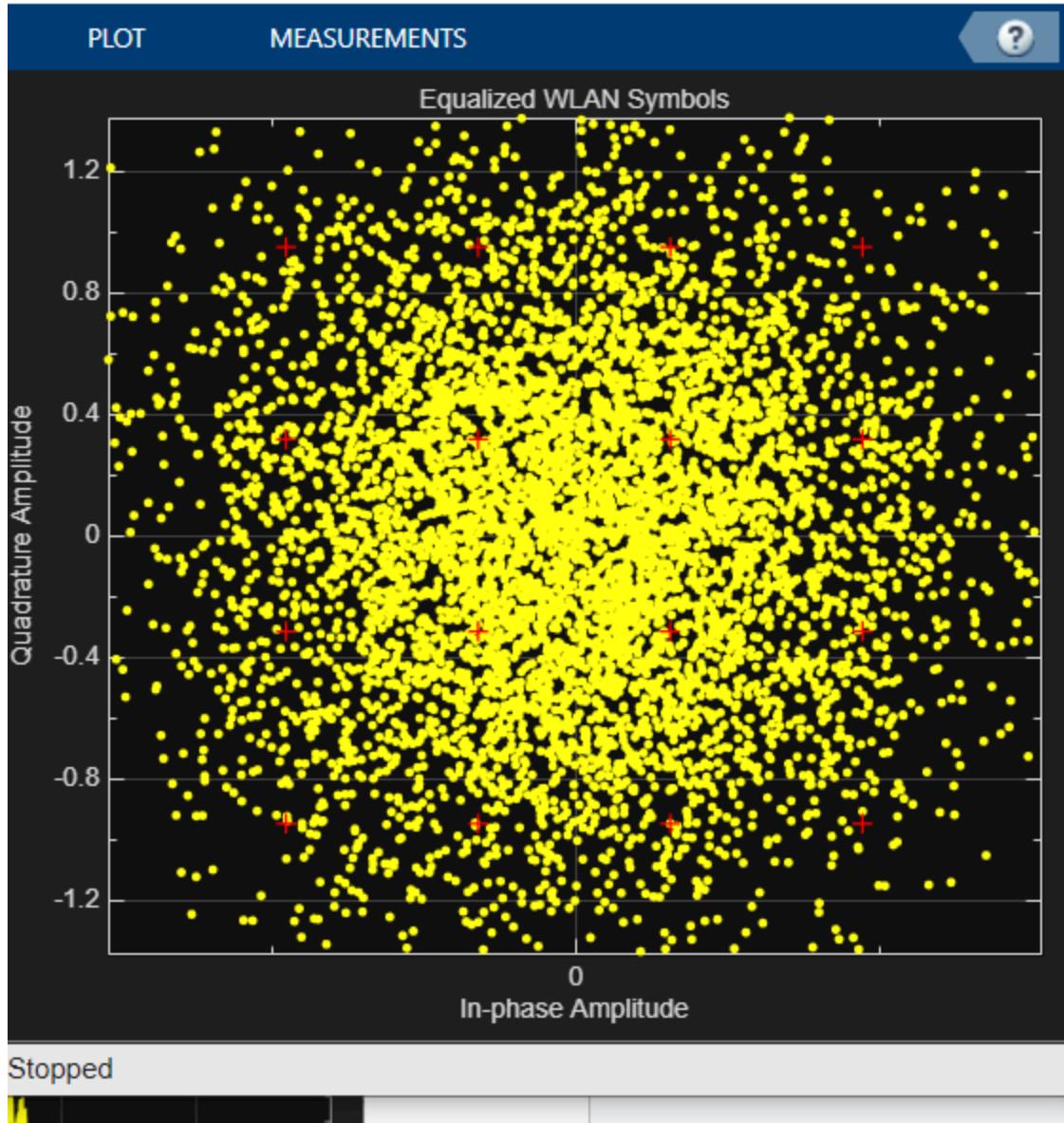


Signal with one antenna on TX and only sma on RX.

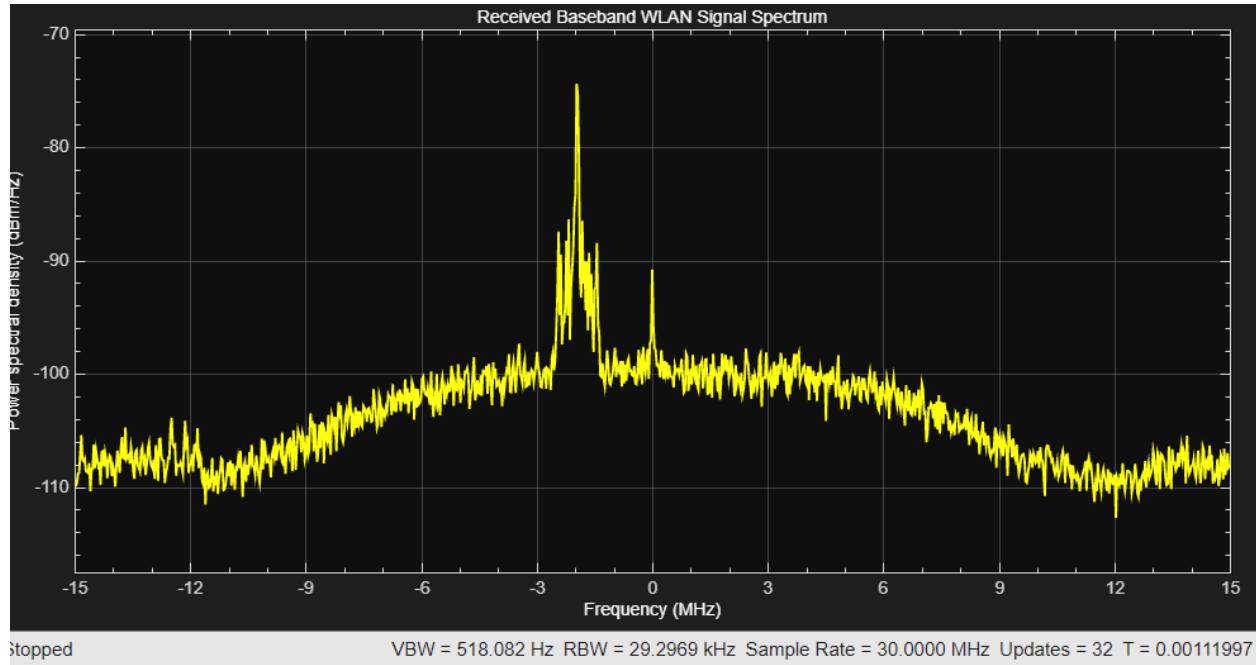
16QAM No Antenna on RX but antenna on TX

File received





16QAM Receiver with antenna and TX with SMA



Not enough packets detected, empty receiver file

L-SIG check fail

Packet-1 detected at index 19454

HT-GF format detected

A format other than Non-HT has been detected

Packet-1 detected at index 19638

Non-HT format detected

L-SIG check pass

** Not enough samples to decode packet **

Brace indexing is not supported for variables of this type.

Error received.

MATLAB Single Pluto Testing for Text File Transmission

File type	Gain dB	Channel Type	Modulation Type	SNR	BER	Pass/Fail
Text	-10/10	Over the Air	BPSK	50	0	Pass
Text	-10/10	Over the Air	QPSK	50	0	Pass
Text	-10/10	Over the Air	16QAM	50	0	Pass
Text	-10/10	Over the Air	64QAM	50	0	Pass
Text	-10/10	Gaussian Noise	BPSK	4	0	Pass
Text	-10/10			8	0	Pass
Text	-10/10			12	0	Pass
Text	-10/10			16	0	Pass
Text	-10/10			20	0	Pass
Text	-10/10	Gaussian Noise	QPSK	4	.01389	Pass w/e's
Text	-10/10			8	0	Pass
Text	-10/10			12	0	Pass
Text	-10/10			16	0	Pass
Text	-10/10			20	0	Pass
Text	-10/10	Gaussian Noise	16QAM	4	.49691	Fail
Text	-10/10			8	.22114	Fail
Text	-10/10			12	0	Pass
Text	-10/10			16	0	Pass
Text	-10/10			20	0	Pass
Text	-10/10	Gaussian Noise	64QAM	4	.50201	Fail
Text	-10/10			8	.50575	Fail
Text	-10/10			12	.30984	Fail
Text	-10/10			16	.00521	Pass
Text	-10/10			20	0	Pass

MATLAB Single Pluto Testing for Image Transmission

File type	Gain dB	Channel Type	Modulation Type	SNR	BER	Pass/Fail
	TX/RX					
Image	-10/10	Over the Air	BPSK	45	0	Pass
Image	-10/10	Over the Air	QPSK	50	0	Pass
Image	-10/10	Over the Air	16QAM	50	0	Pass
Image	-10/10	Over the Air	64QAM	50	0	Pass
Image	-10/10	Gaussian Noise	BPSK	4	0	Pass
Image	-10/10			8	0	Pass
Image	-10/10			12	0	Pass
Image	-10/10			16	0	Pass
Image	-10/10			20	0	Pass
Image	-10/10	Gaussian Noise	QPSK	4	.03190	Fail
Image	-10/10			8	0	Pass
Image	-10/10			12	0	Pass
Image	-10/10			16	0	Pass
Image	-10/10			20	0	Pass
Image	-10/10	Gaussian Noise	16QAM	4	.50040	Fail
Image	-10/10			8	.49712	Fail
Image	-10/10			12	.00069	Fail
Image	-10/10			16	0	Pass
Image	-10/10			20	0	Pass
Image	-10/10	Gaussian Noise	64QAM	4	.50010	Fail
Image	-10/10			8	.49915	Fail
Image	-10/10			12	.38363	Fail
Image	-10/10			16	.00125	Fail
Image	-10/10			20	0	Pass

Calculations:

According to the image transmission results, 16QAM can transfer a lot of data, but it will be used but an SNR of at least 16 must be used. This correlates to the results below where 15 or above must be achieved.

For 16QAM Optimal transmission:

$$C = \text{Blog}_2(1 + S/N)$$

$$4 = \text{Blog}_2(1 + S/N)$$

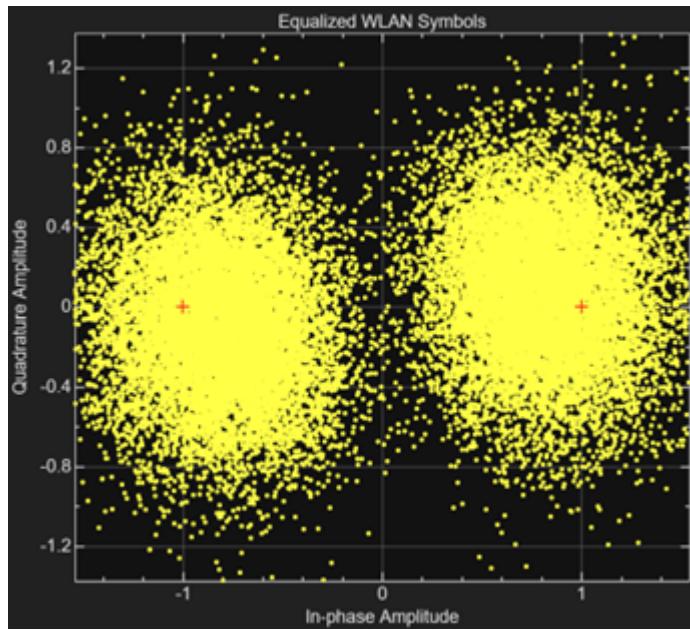
$$16 = 1 + S/N$$

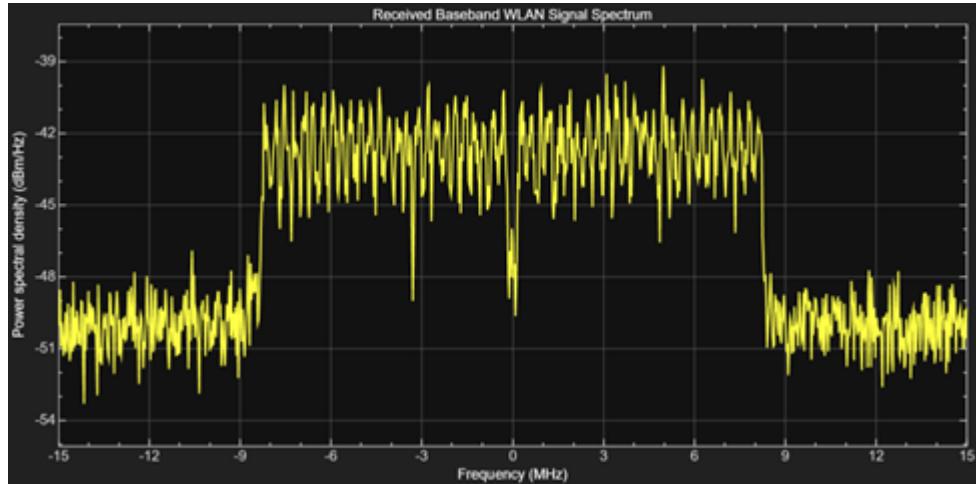
$$15 = S/N \rightarrow 10\log(15) = 12\text{dB}$$

Text File Transmission captures

Refer to the code in the Appendix on page 45. While transmitting files, set up two plutos. Place an antenna on the TX of one pluto and one on the RX of the other. Cap the unused ports to prevent interference. Create a text file on the TX pluto. Put anything you would like. Specify the channel as “Over the air”, this will ensure the pluto is ready to transmit and receive from another pluto. Set the channel number to 5 and the frequency to 2.4GHz. Then transmit by pressing the run button on both computers around the same time. The code works by detecting the preamble and stopping when the packet transmission stops. A text file that was inputted into the transmitter should be displayed as the output on the receiver.

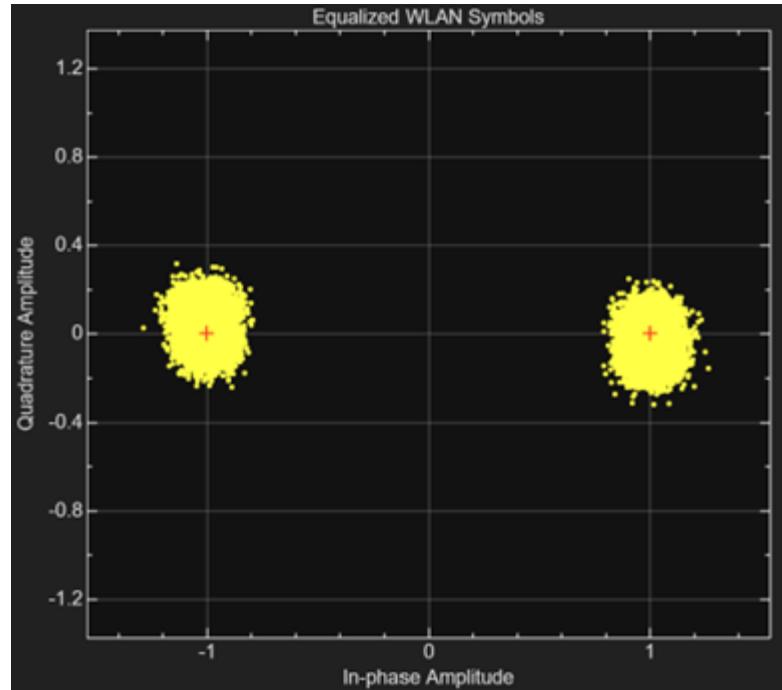
BPSK



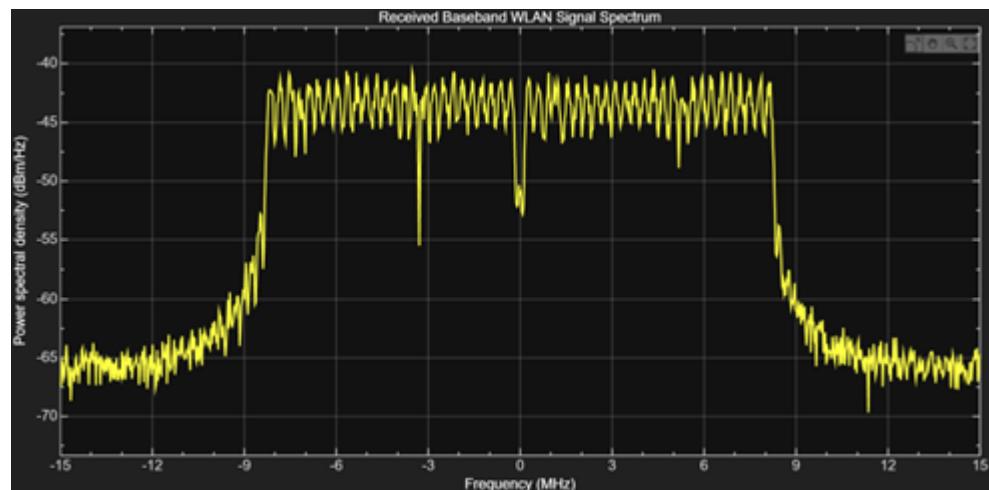
SNR = 4 Constellation Diagram**SNR = 4 Signal Spectrum**

1 Hey kid! It's not that kind of movie!

SNR = 4 Output

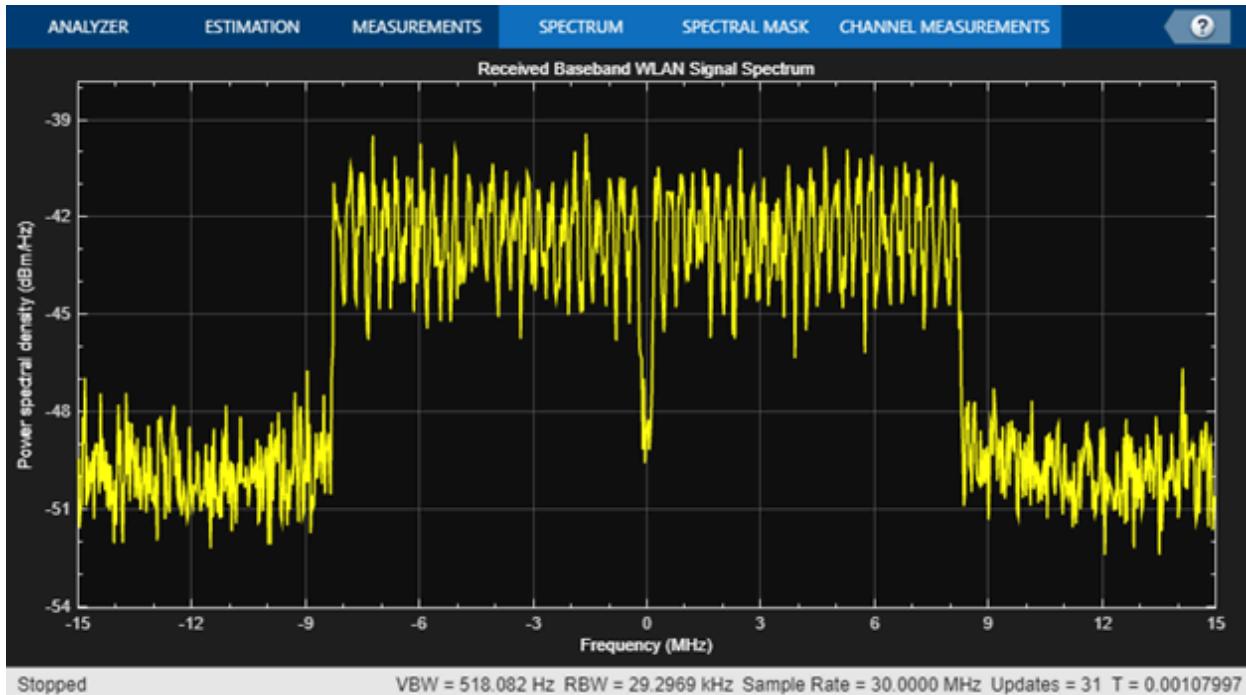


SNR = 20 Constellation Diagram

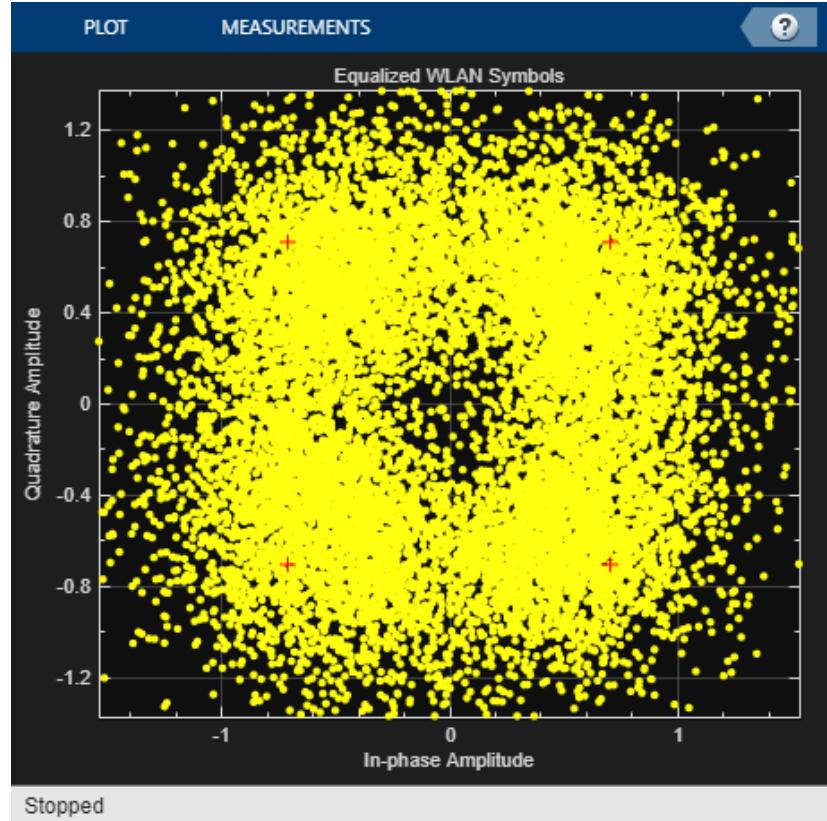


SNR = 20 Signal Spectrum

QPSK



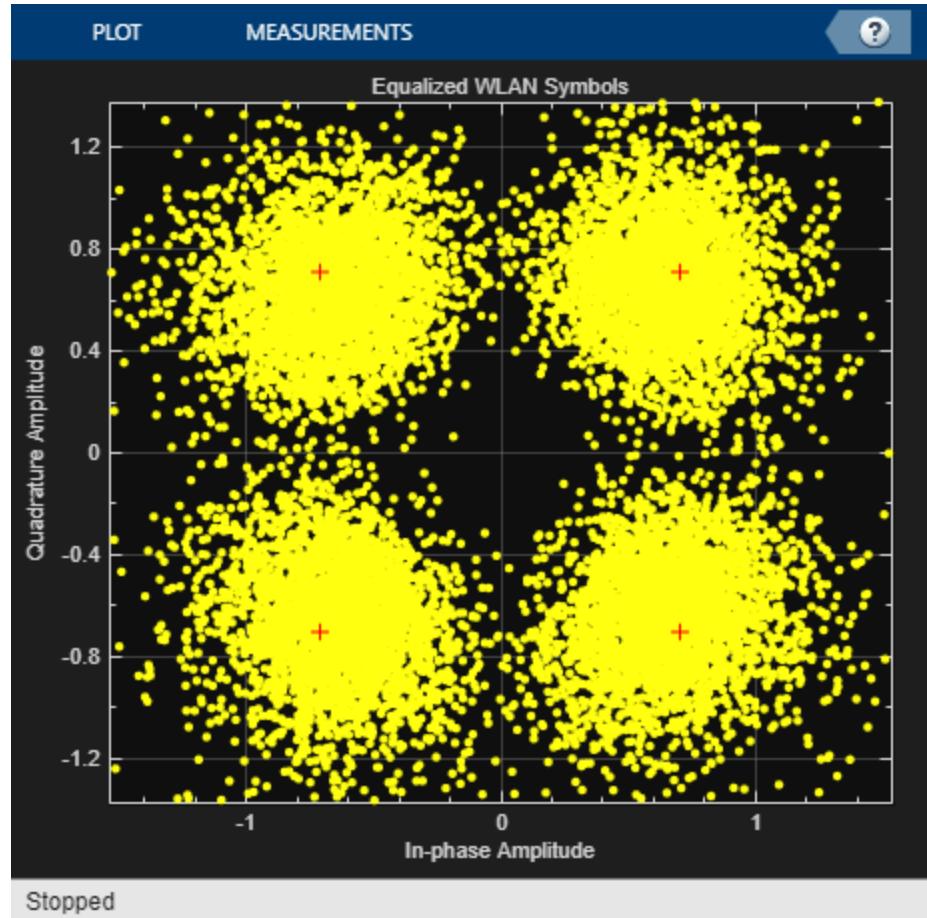
SNR = 4 Signal Spectrum



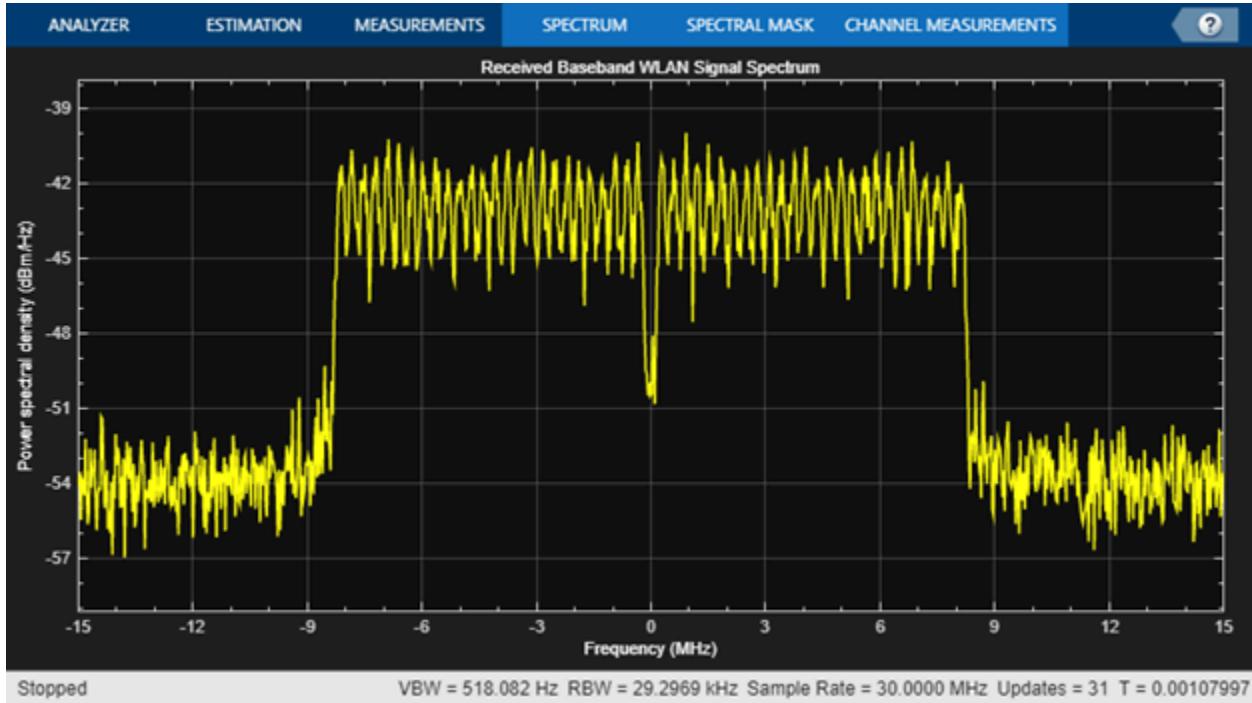
SNR = 4 Constellation Diagram

```
Received data saved to Received.txt.  
Received Text Data:  
Hey pkyd! It's not that kind of movie!  
FikaFika  
ÜwiÜ]<1Gë  
-TRE
```

SNR = 4 Output



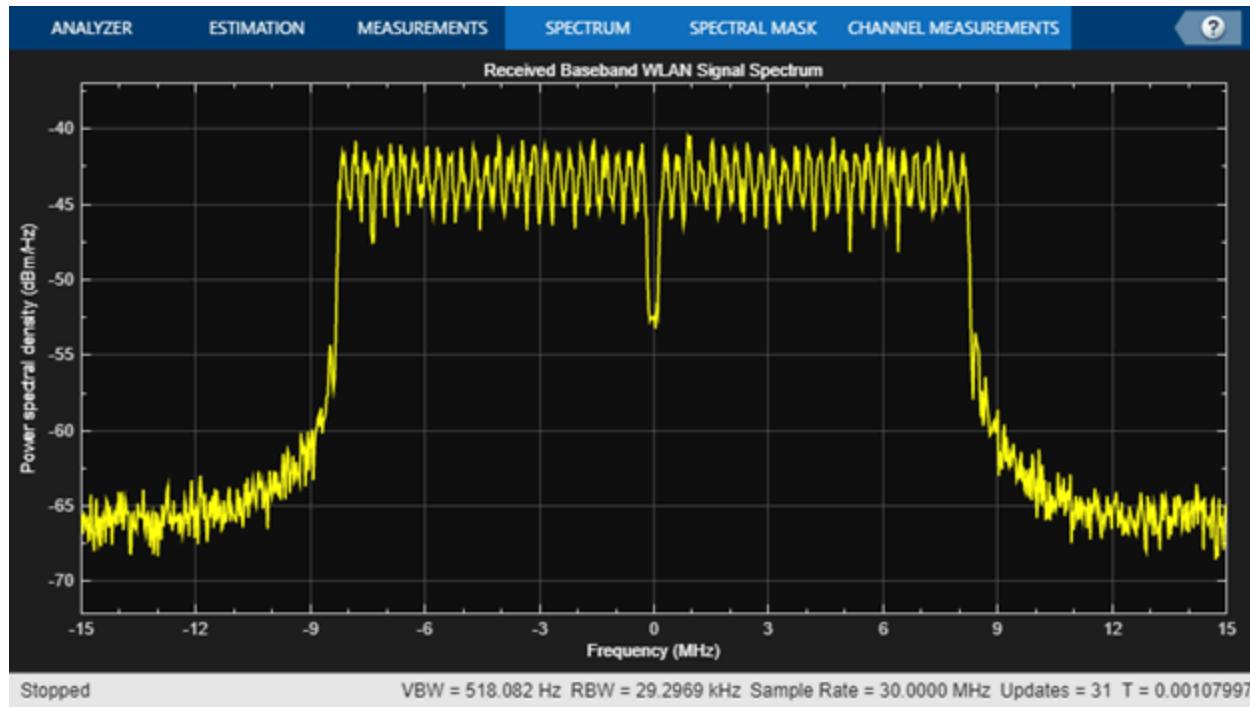
SNR = 8 Constellation Diagram



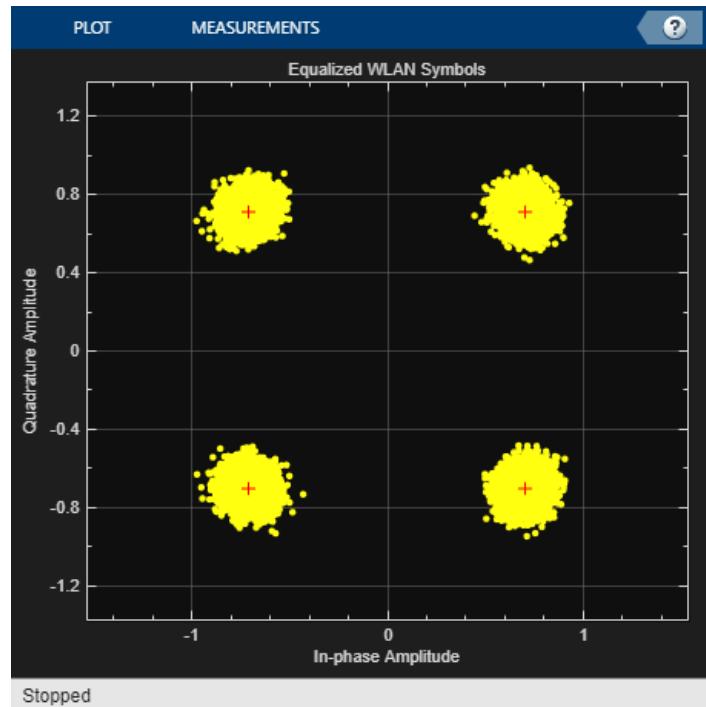
SNR = 8 Signal Spectrum

```
Received data saved to Received.txt.
Received Text Data:
Hey kid! It's not that kind of movie!
```

SNR = 8 Output



SNR = 20 Signal Spectrum

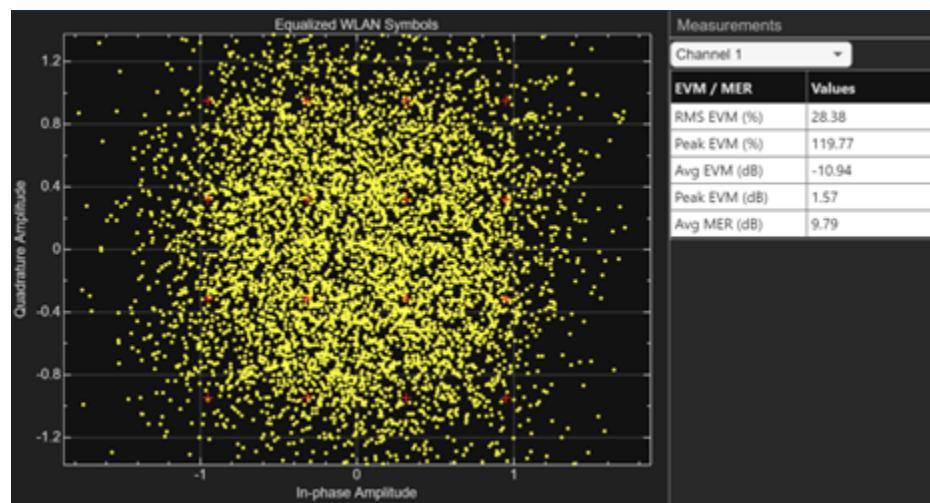


SNR = 20 Constellation Diagram

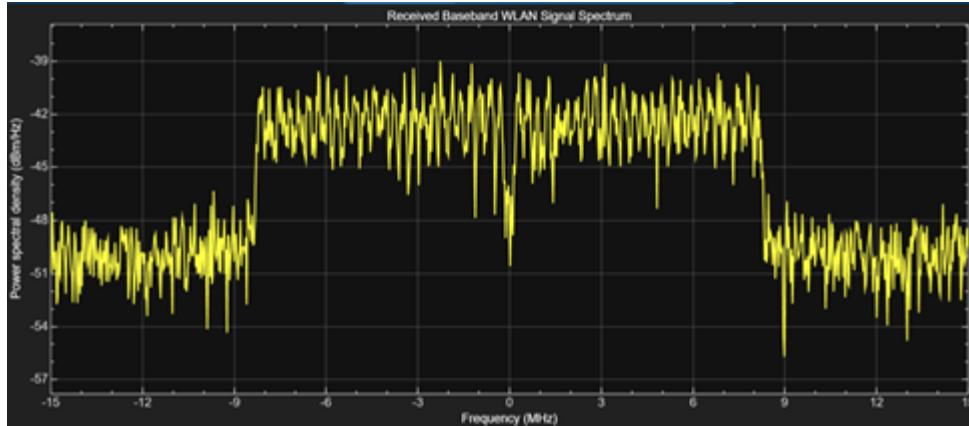
```
Received data saved to Received.txt.  
Received Text Data:  
Hey kid! It's not that kind of movie!
```

SNR = 20 Output

16QAM

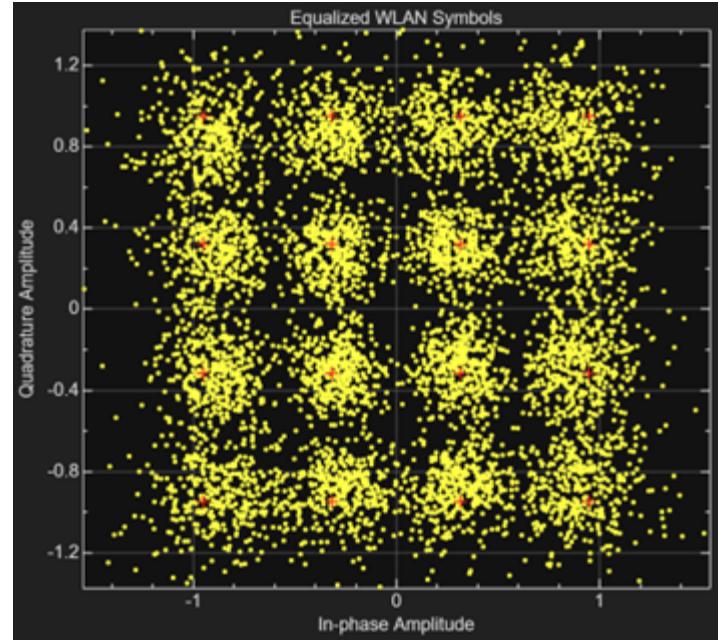


SNR = 4 Constellation Diagram

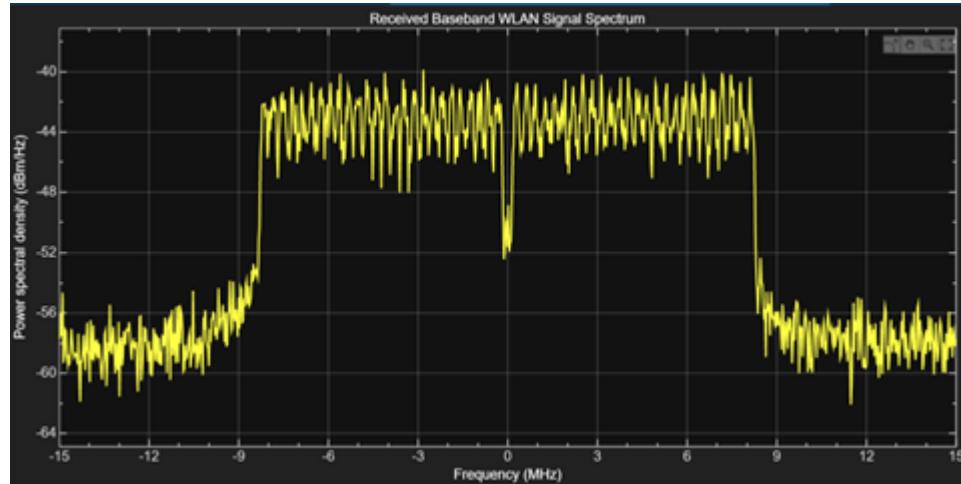


SNR = 4 Signal Spectrum

SNR = 4 Output



SNR = 12 Constellation Diagram

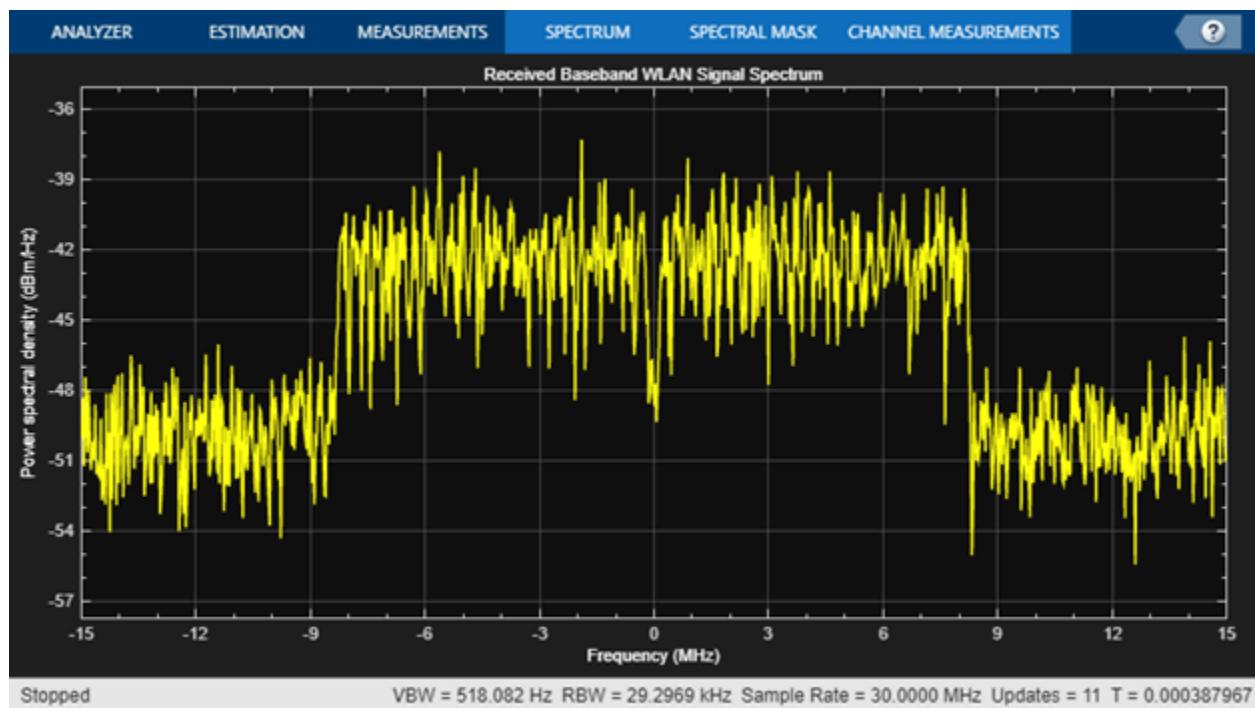


SNR = 12 Signal Spectrum

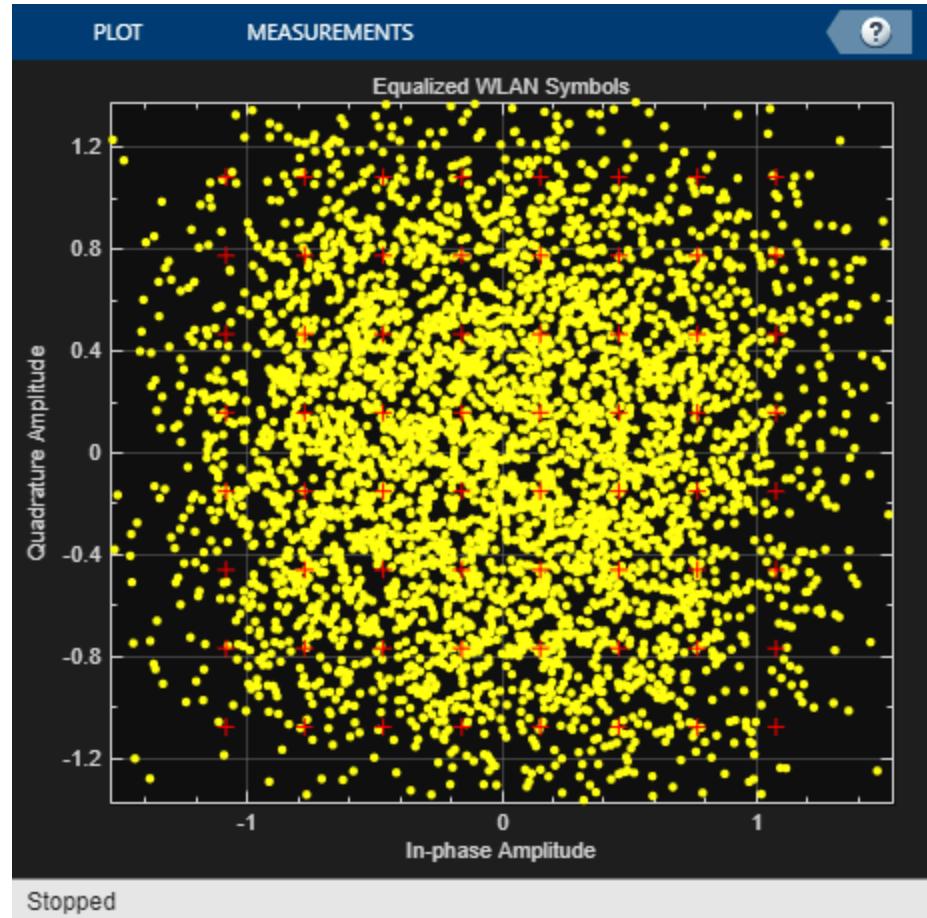
1 Hey kid! It's not that kind of movie!

SNR = 12 Output

64QAM



SNR = 4 Signal Spectrum

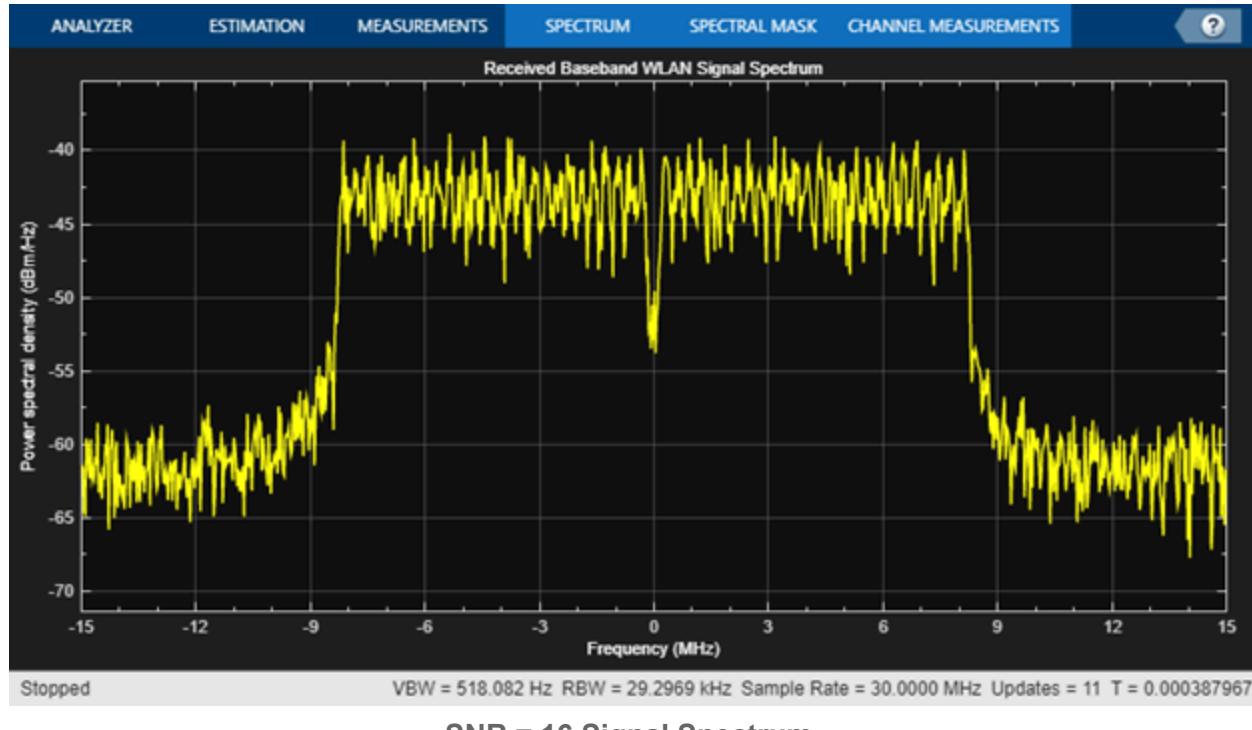


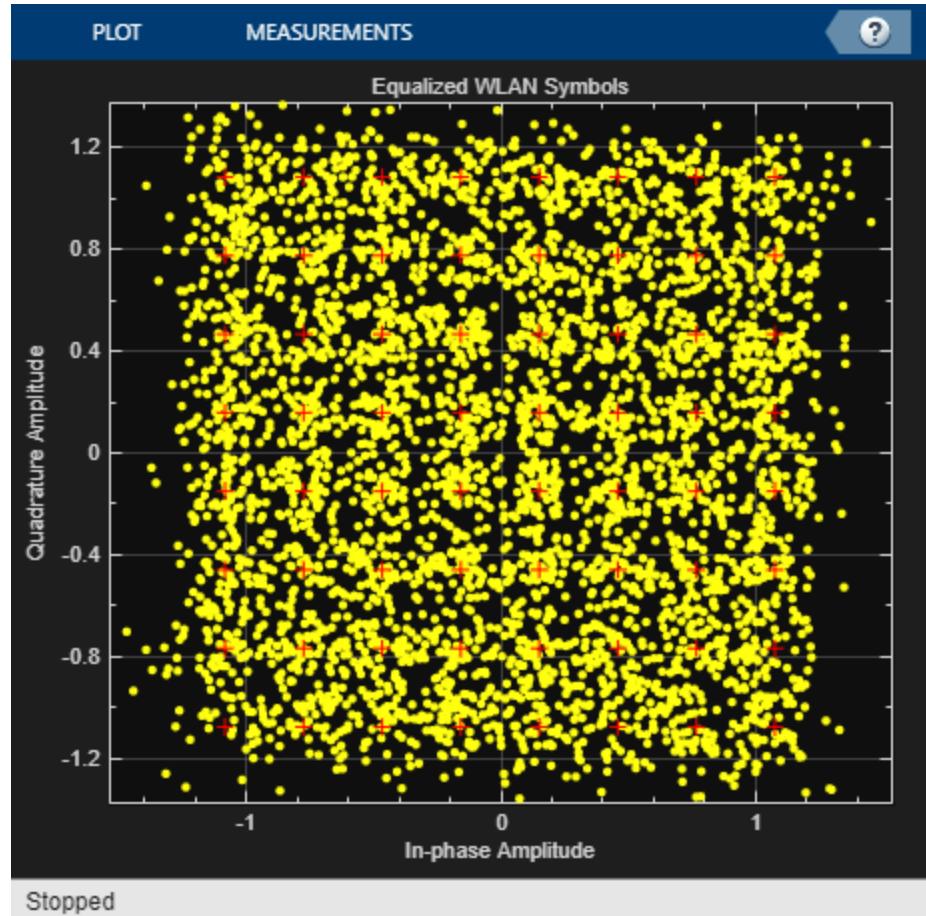
SNR = 4 Constellation Diagram

Received data saved to Received.txt.

Received Text Data:

SNR = 4 Output





SNR = 16 Constellation Diagram

```
Received data saved to Received.txt.
```

```
Received Text Data:
```

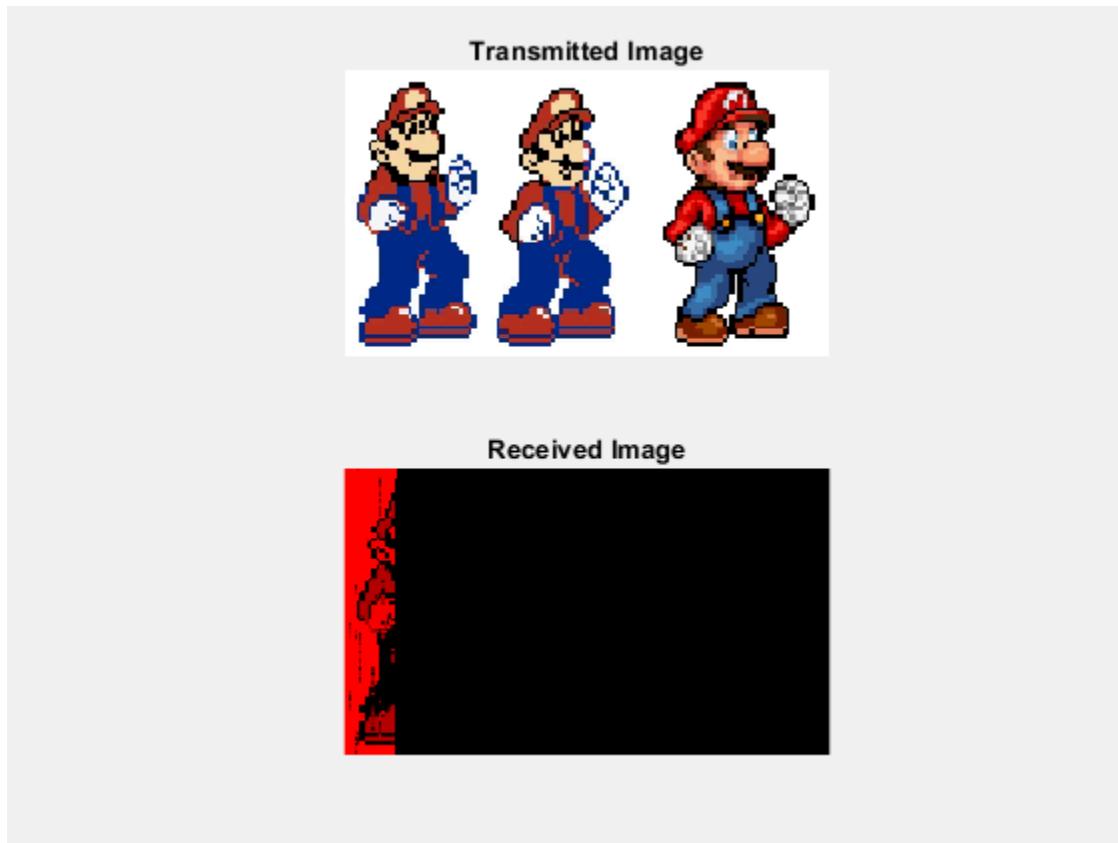
```
Hey kid! It's not that kind of movie!
```

SNR = 16 Output

The higher the modulation, the higher the SNR needs to be to ensure the data doesn't overlap on the constellation diagram, causing errors.

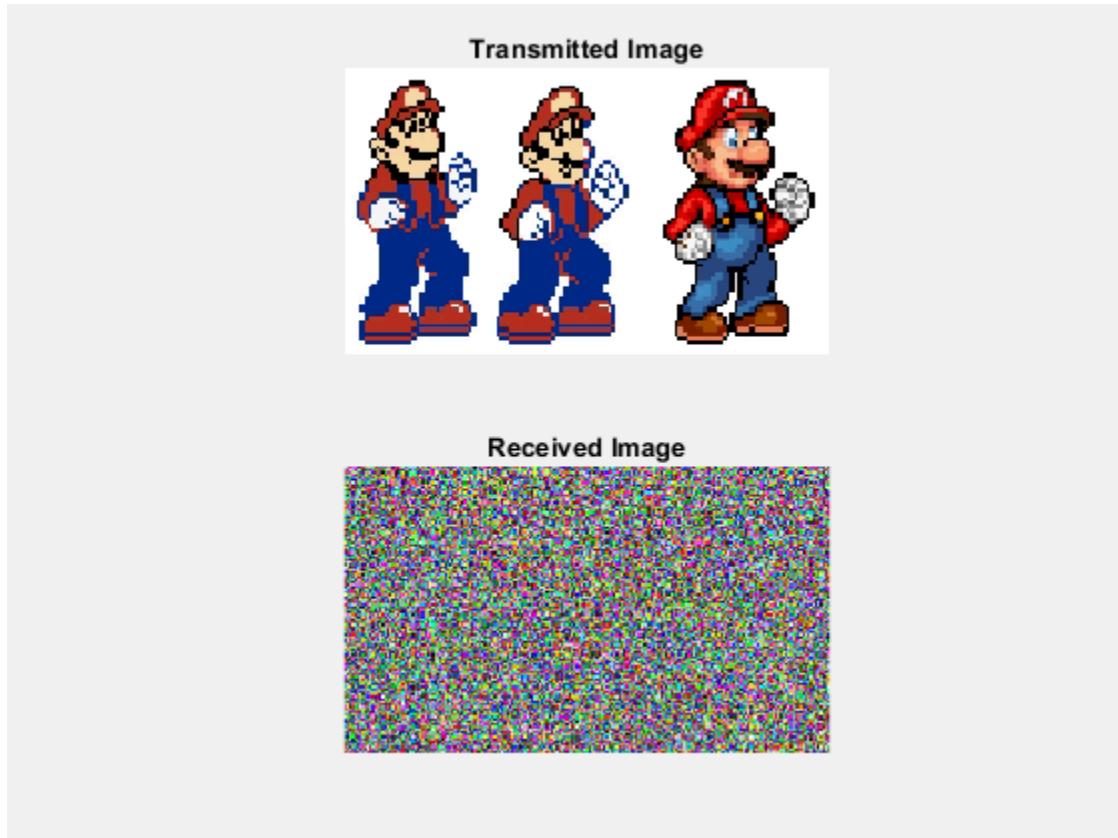
Image Transmission & Reception Captures

QPSK

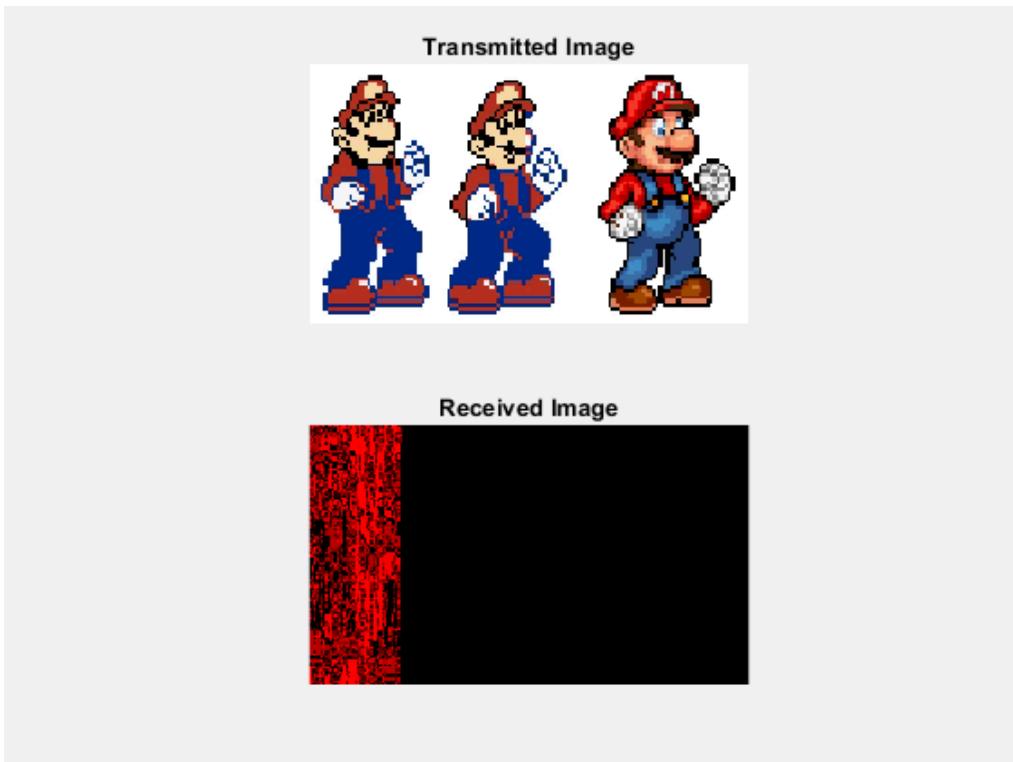


SNR = 4 Image Sent & Received

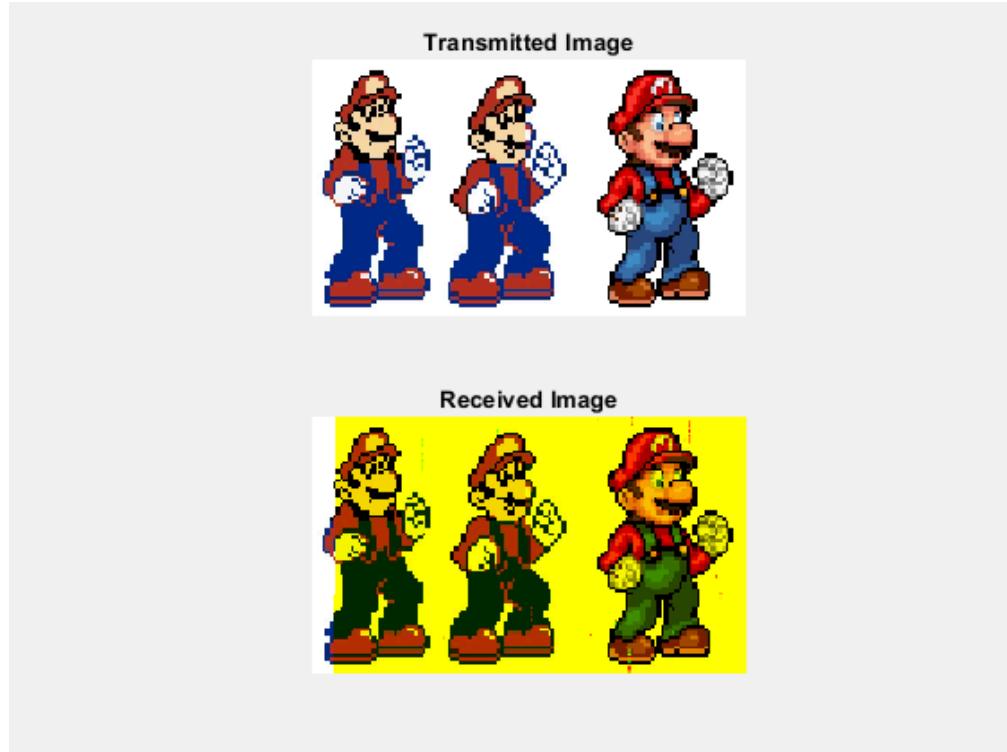
16QAM



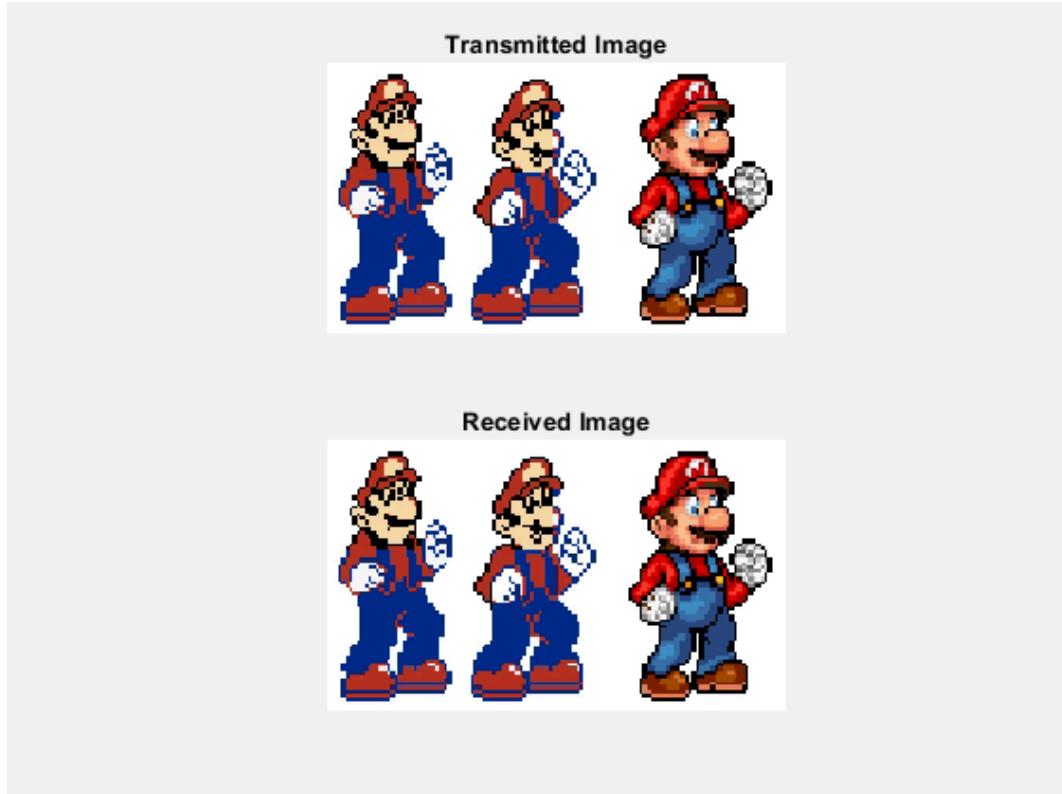
SNR = 4 Image Sent & Received



SNR = 8 Image Sent & Received

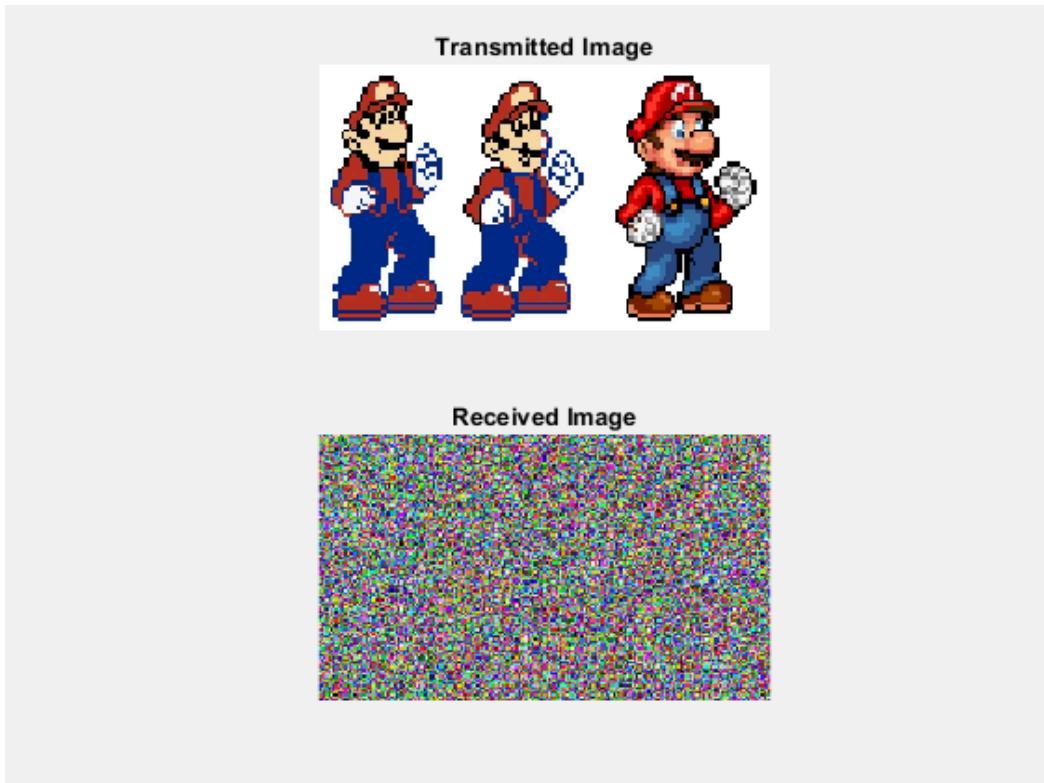


SNR = 12 Image Sent & Received

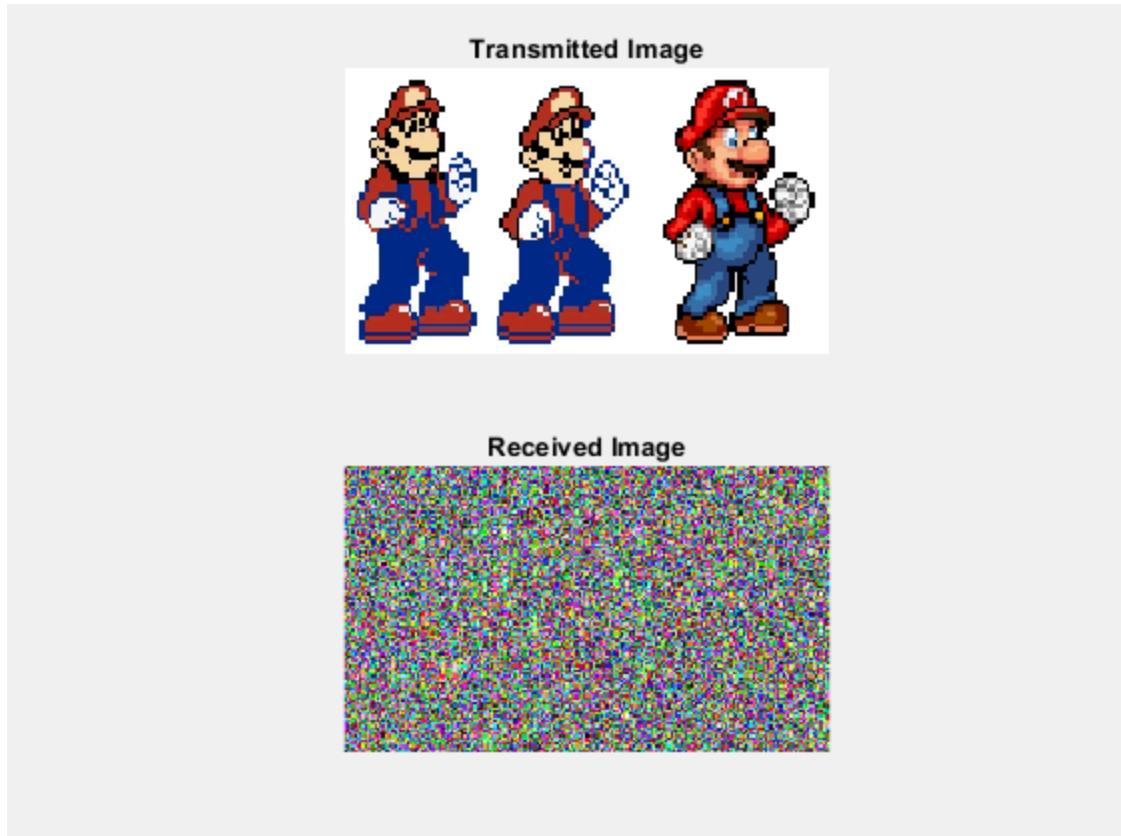


SNR = 16 Image Sent & Received

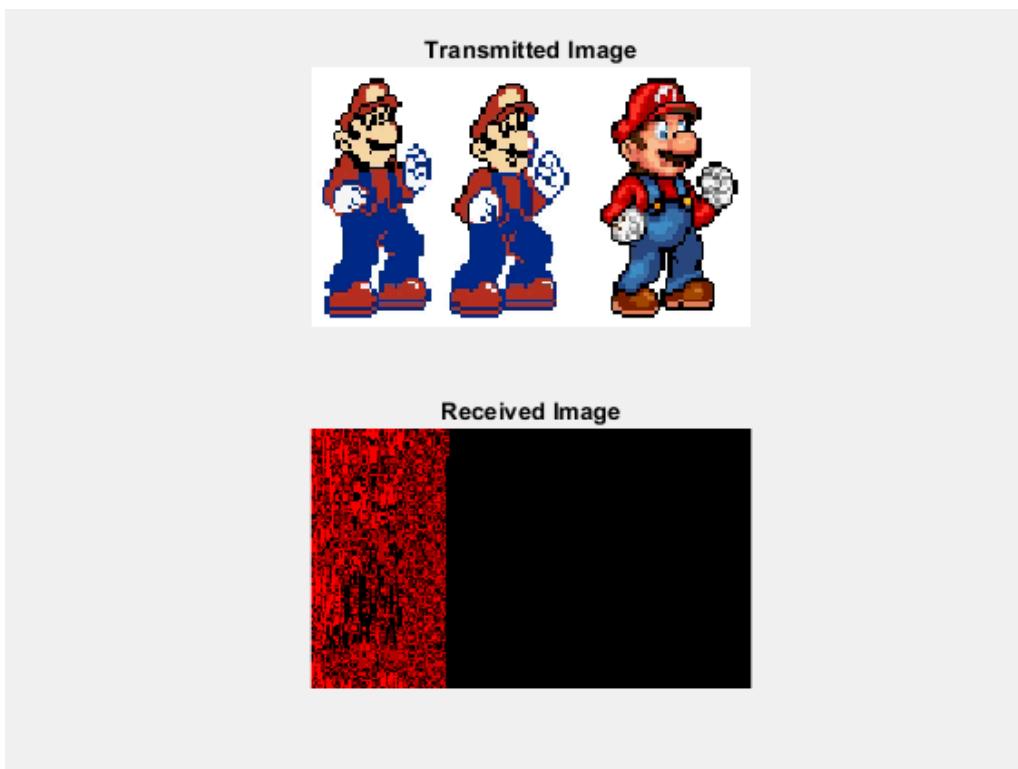
64QAM



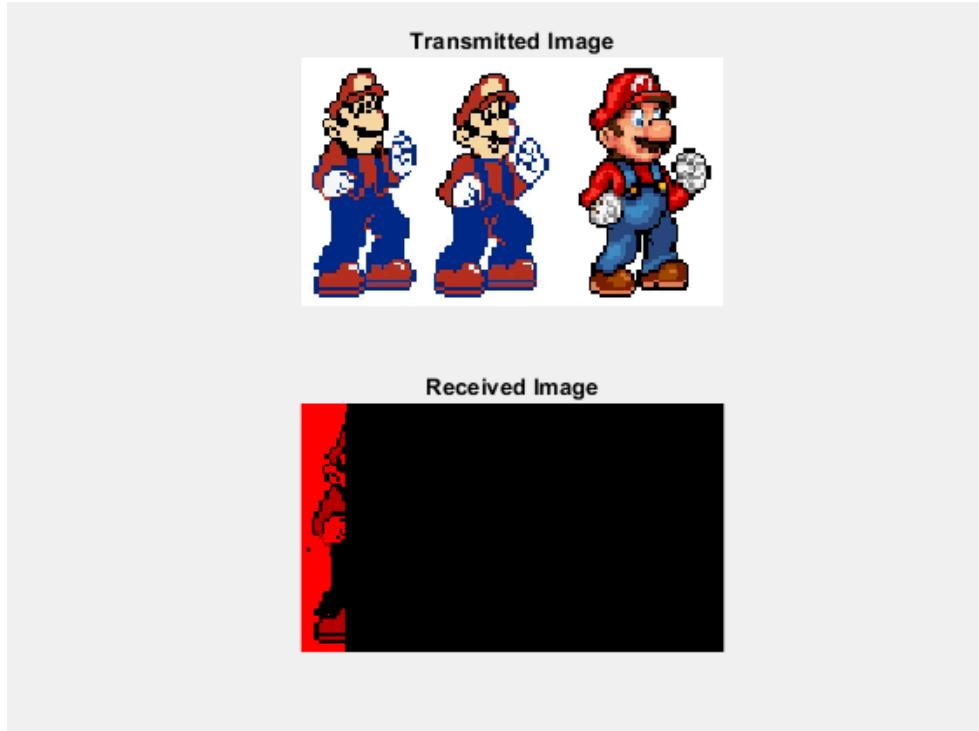
SNR = 4 Image Sent & Received



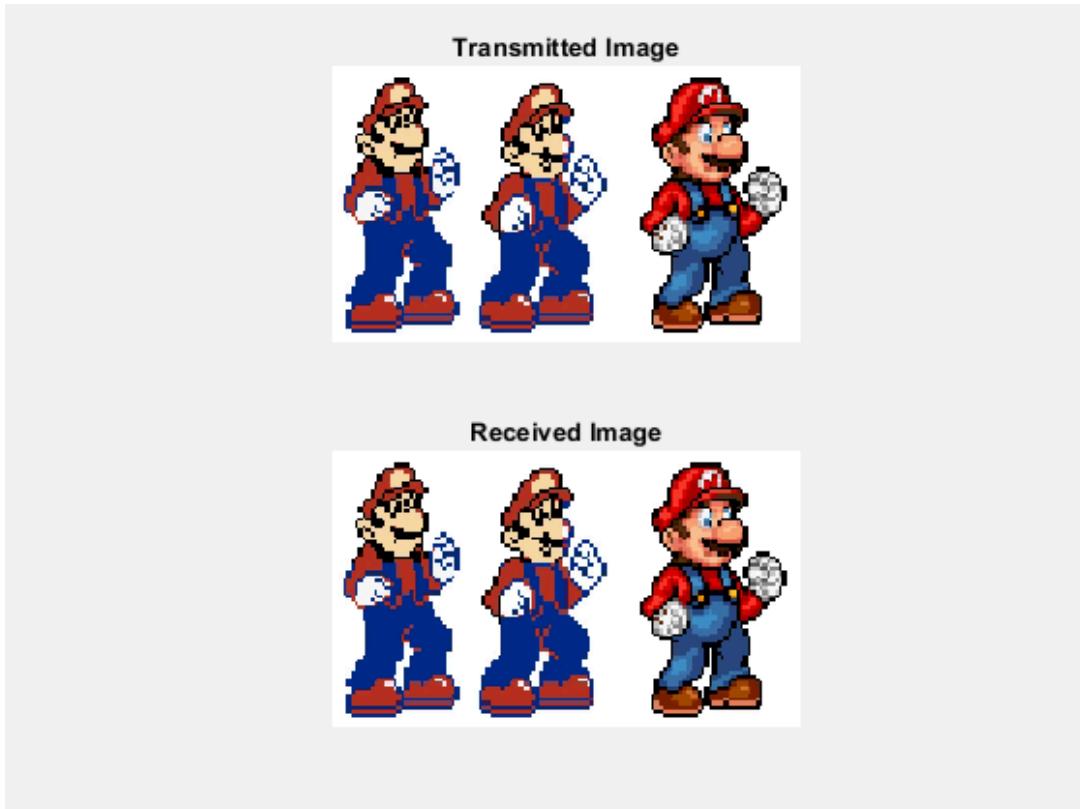
SNR = 8 Image Sent & Received



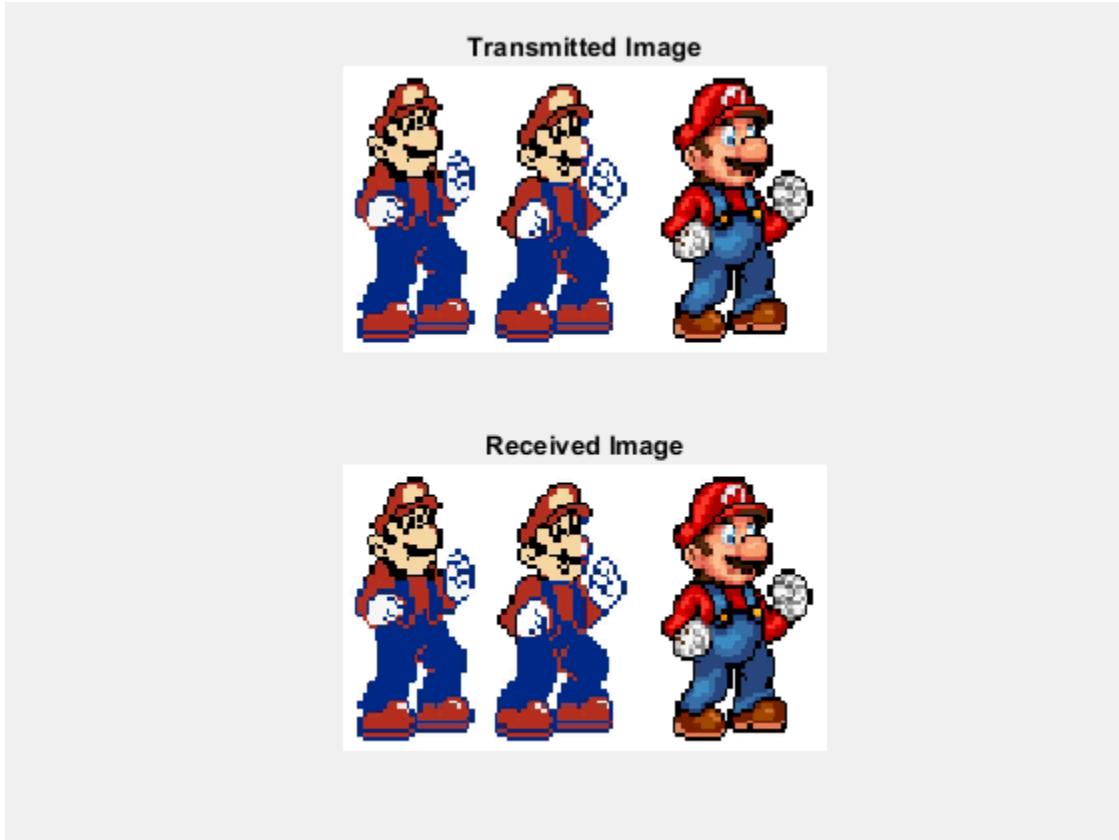
SNR = 12 Image Sent & Received



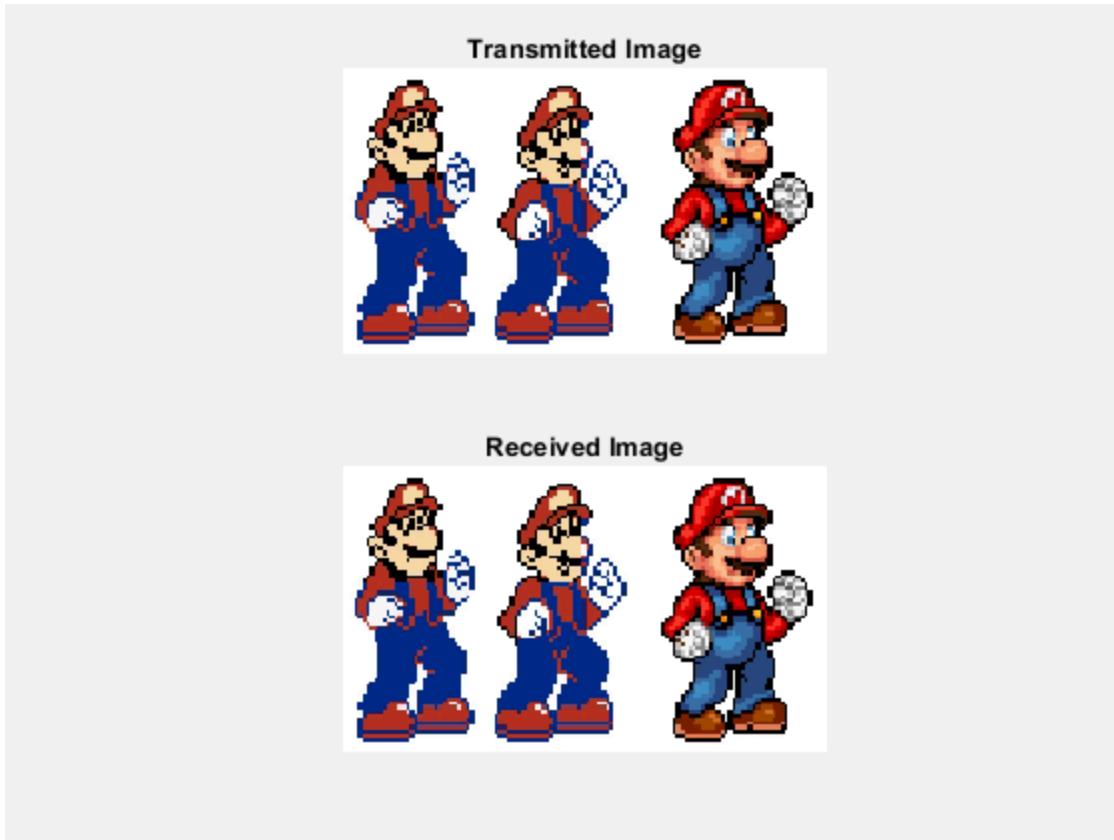
SNR = 16 Image Sent & Received



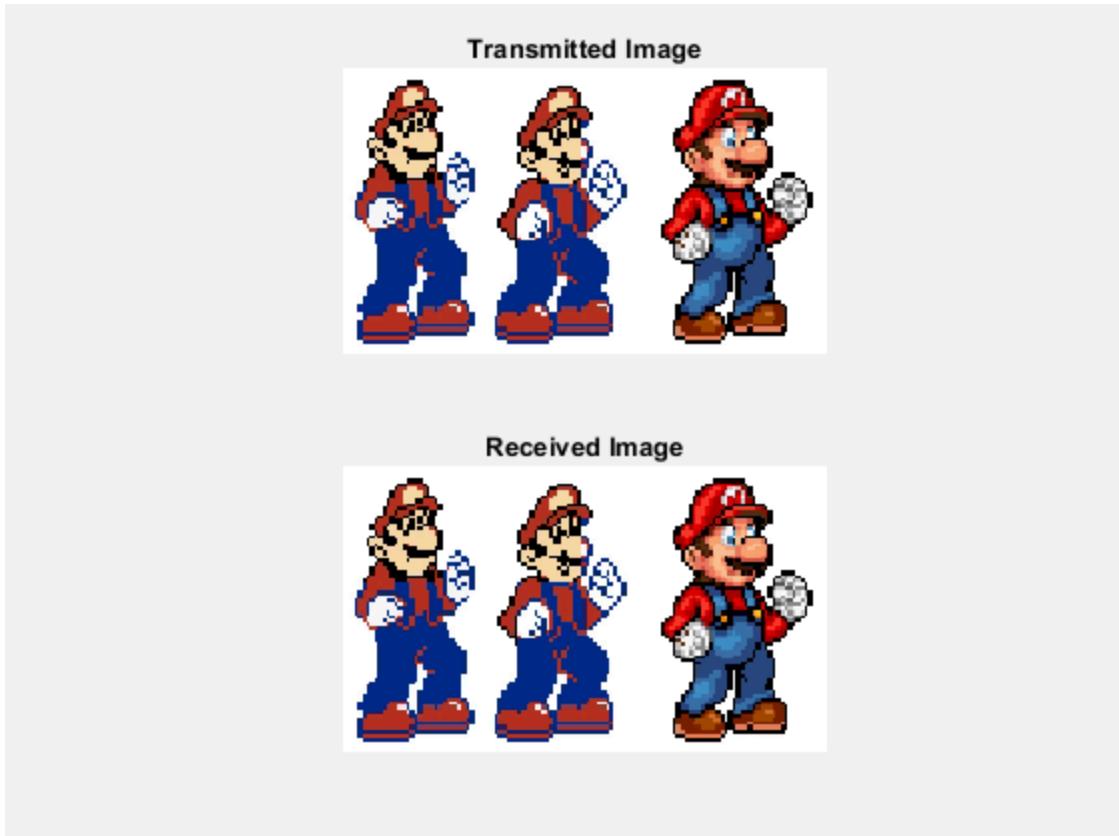
SNR = 20 Image Sent & Received



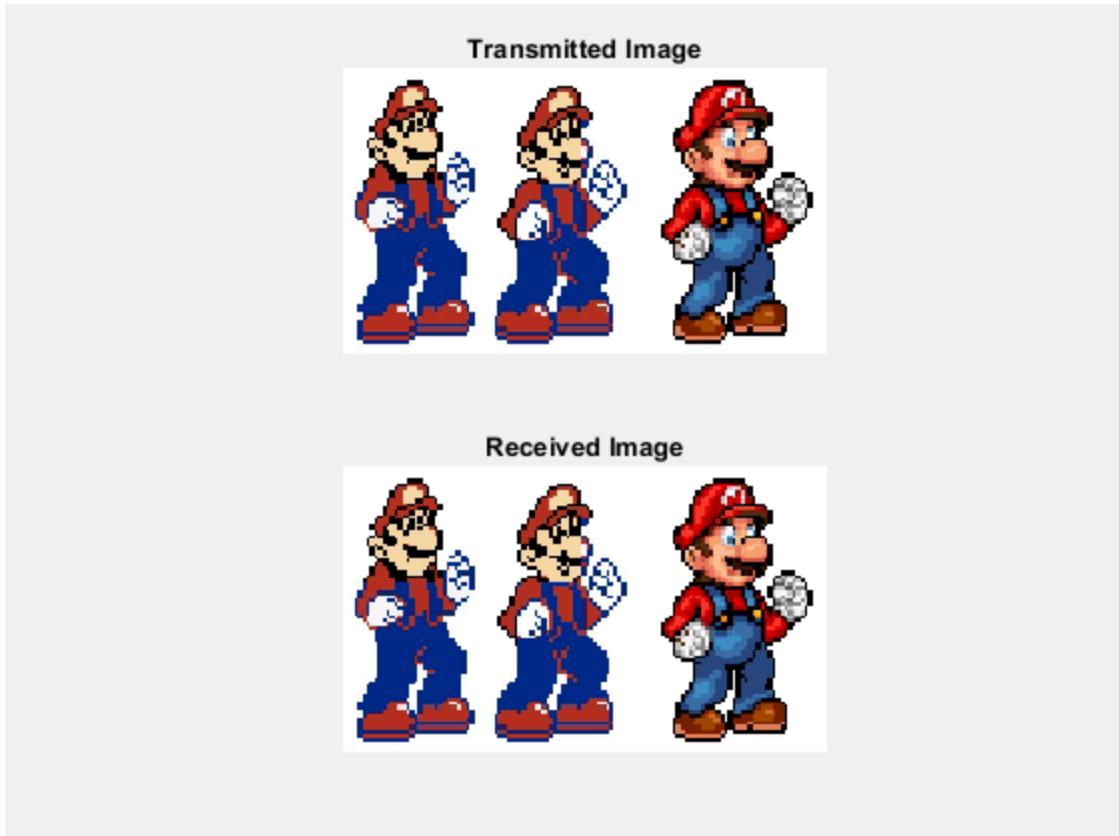
Over the Air BPSK Image (Single Pluto)



Over the Air QPSK Image Transfer (Single Pluto)

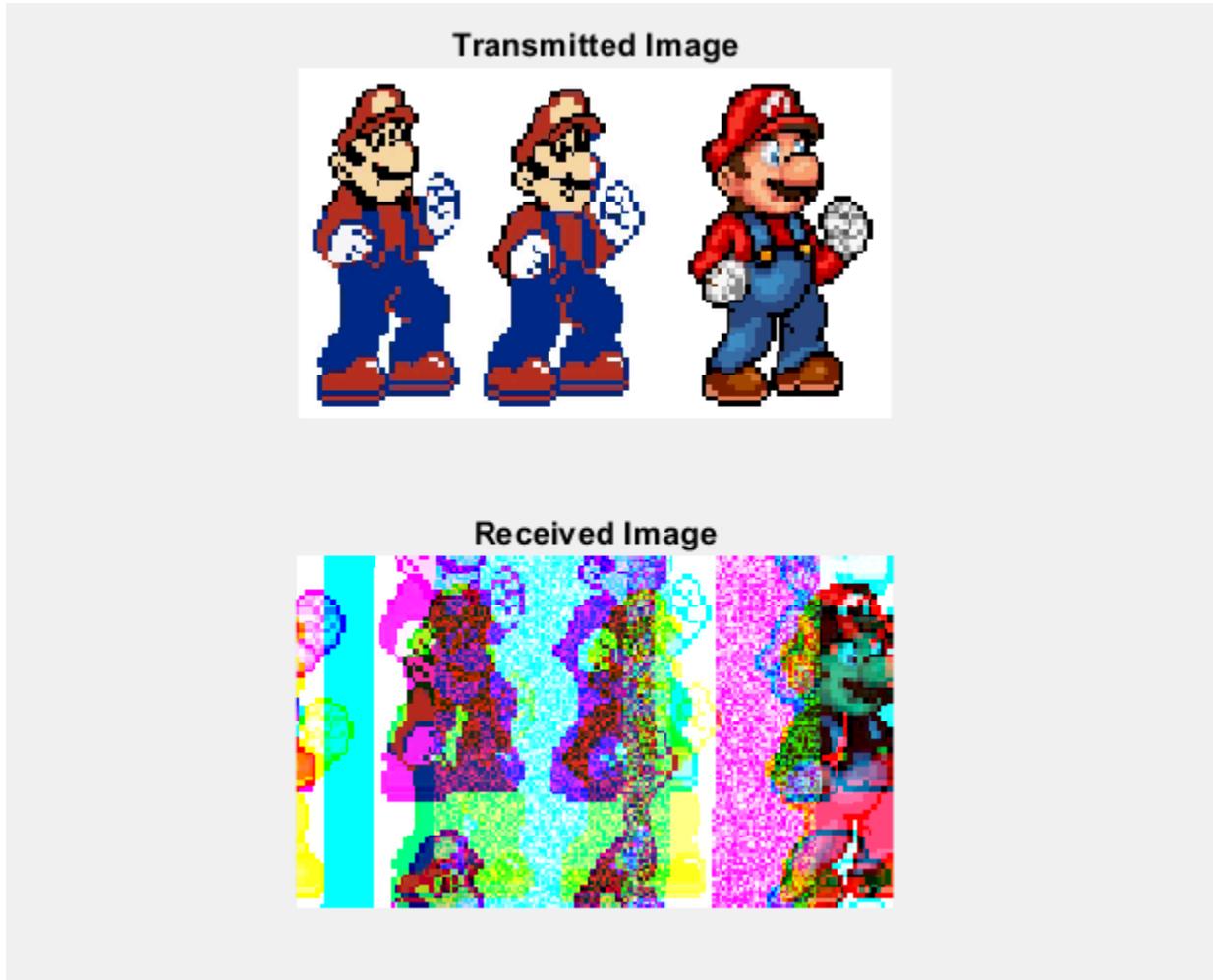


Over the Air 16QAM Image Transfer (Single Pluto)

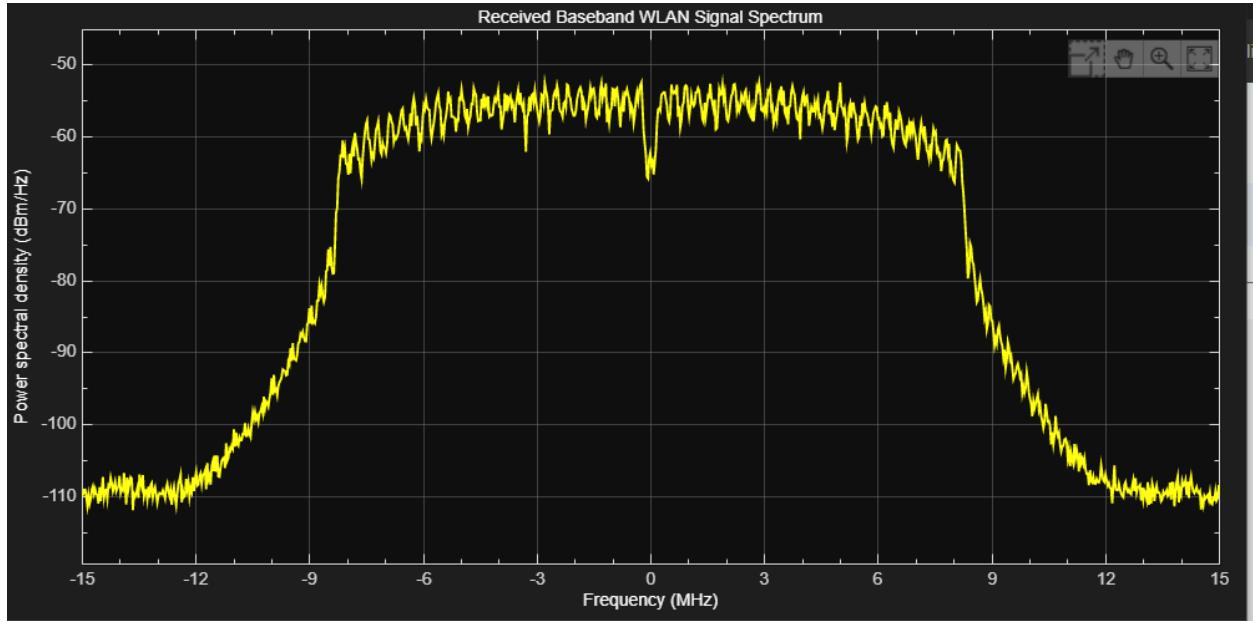


Over the Air 64QAM Image Transfer (Single Pluto)

Two Plutos BPSK Using SMA

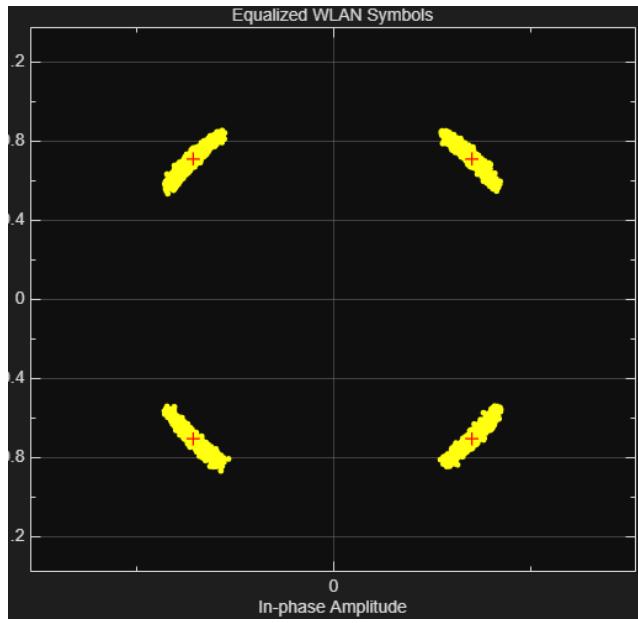


BPSK Image received using SNR = 20

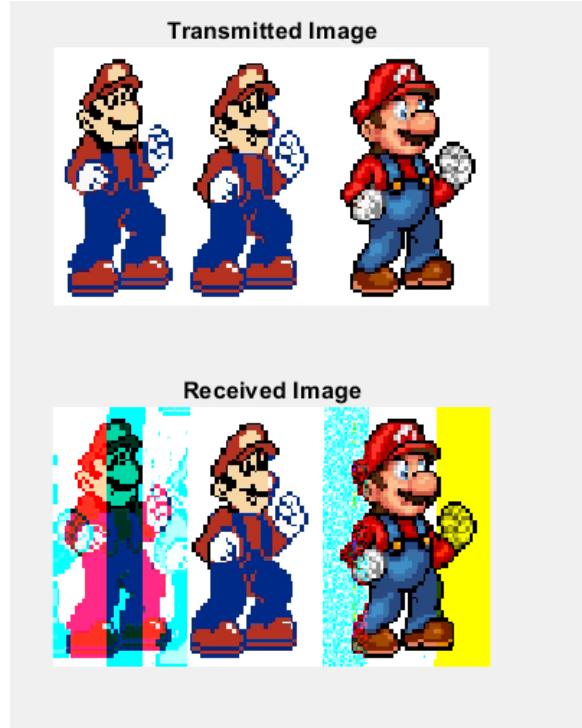


Received image Baseband

Two Plutos QPSK Using SMA

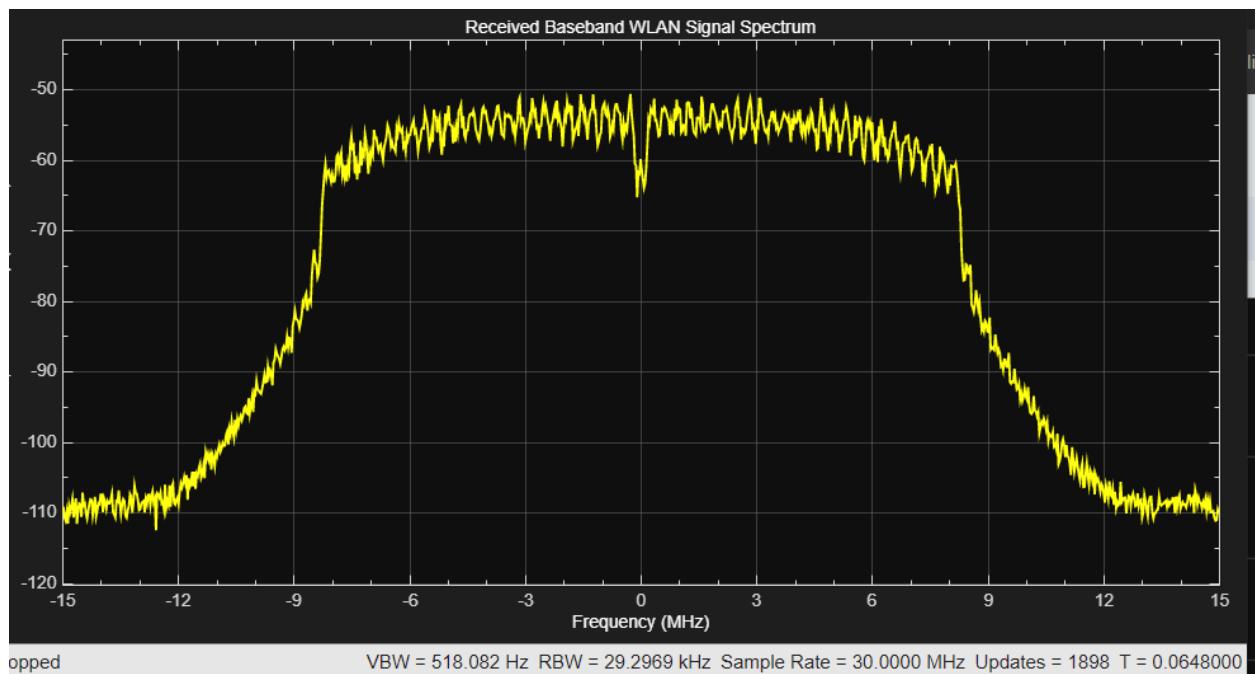


Two Plutos Using QPSK over SMA Constellation Diagram

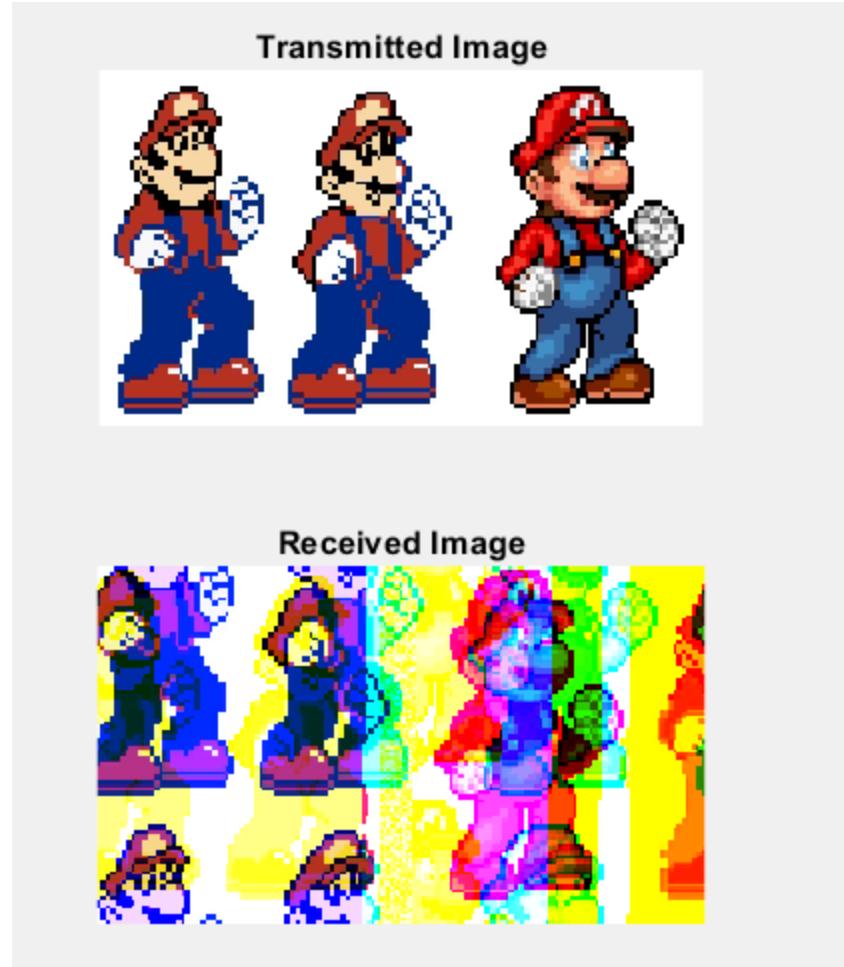


Two Plutos Using QPSK over SMA Sent and Recieved Image

Two Plutos Using 16QAM Using an Image over the Air

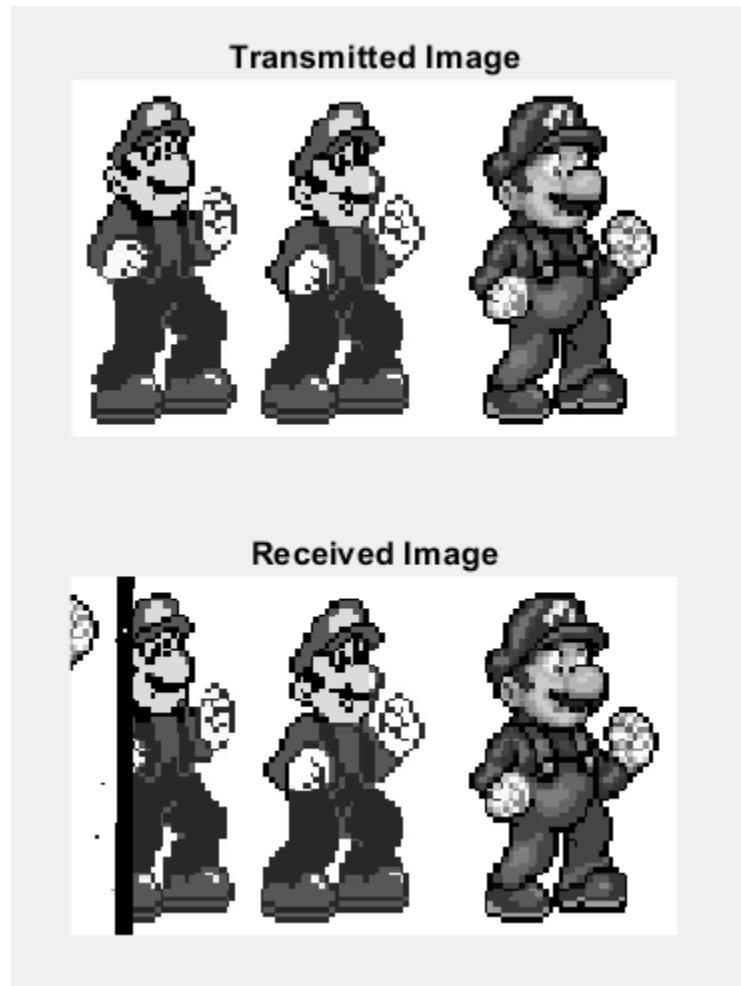


Two Plutos using 16QAM Over the Air Baseband



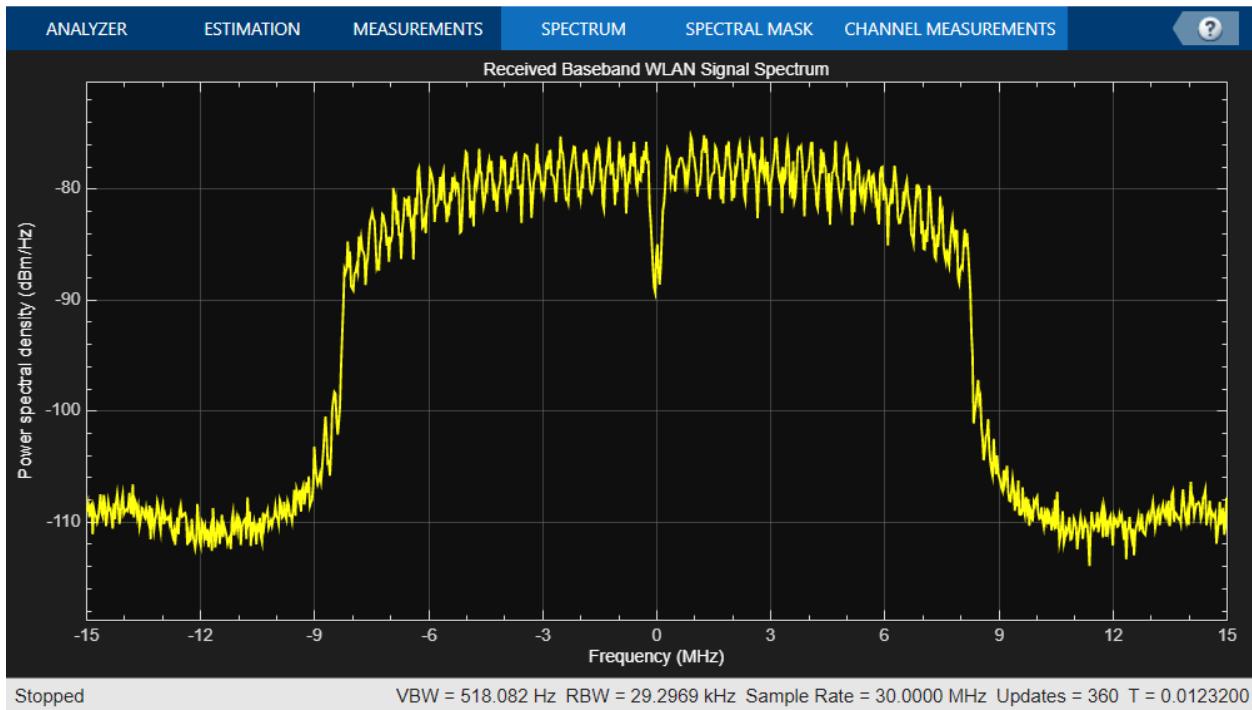
Two Plutos using 16QAM Over the Air Image Received

Using im2gray 16QAM 2 Plutos over the air



Using im2gray 16QAM 2 Plutos over the air

16QAM 2 Plutos Over the Air



16QAM 2 Plutos over the air Baseband

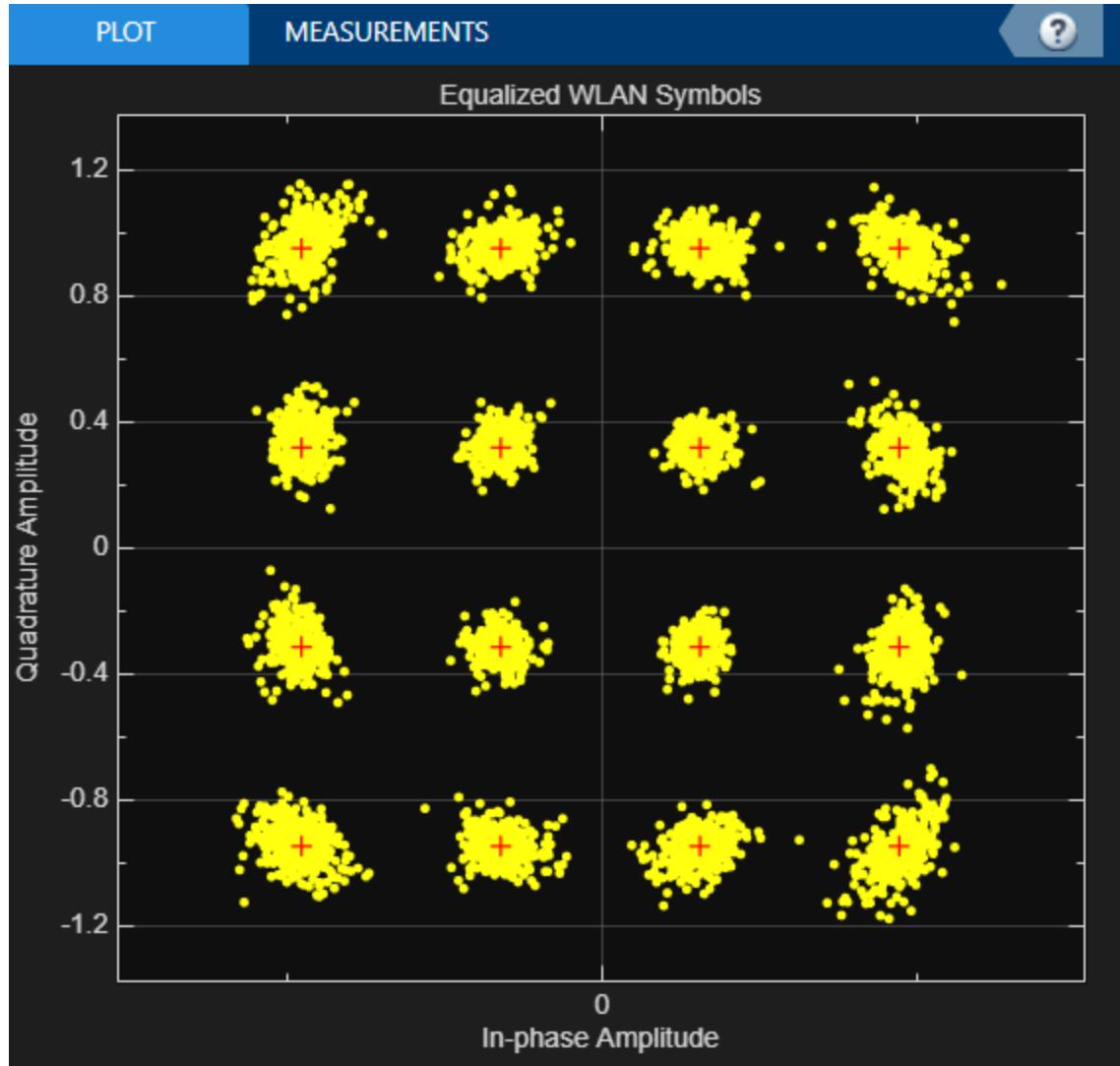
Transmitted Image



Received Image

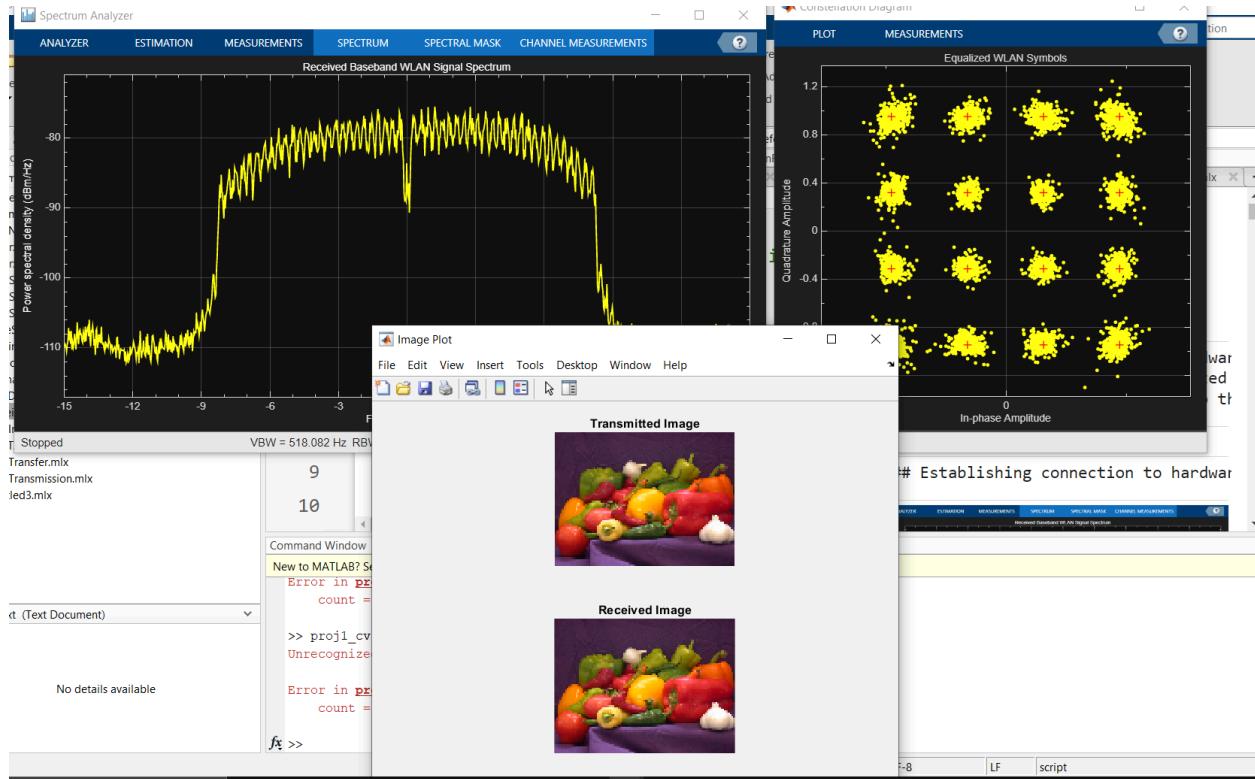


Image received over the air baseband



The 16QAM image transfer works perfectly over the air with no errors, the plutos are about 6 cm apart using 2.4 GHz.

12 cm apart 16QAM



12cm

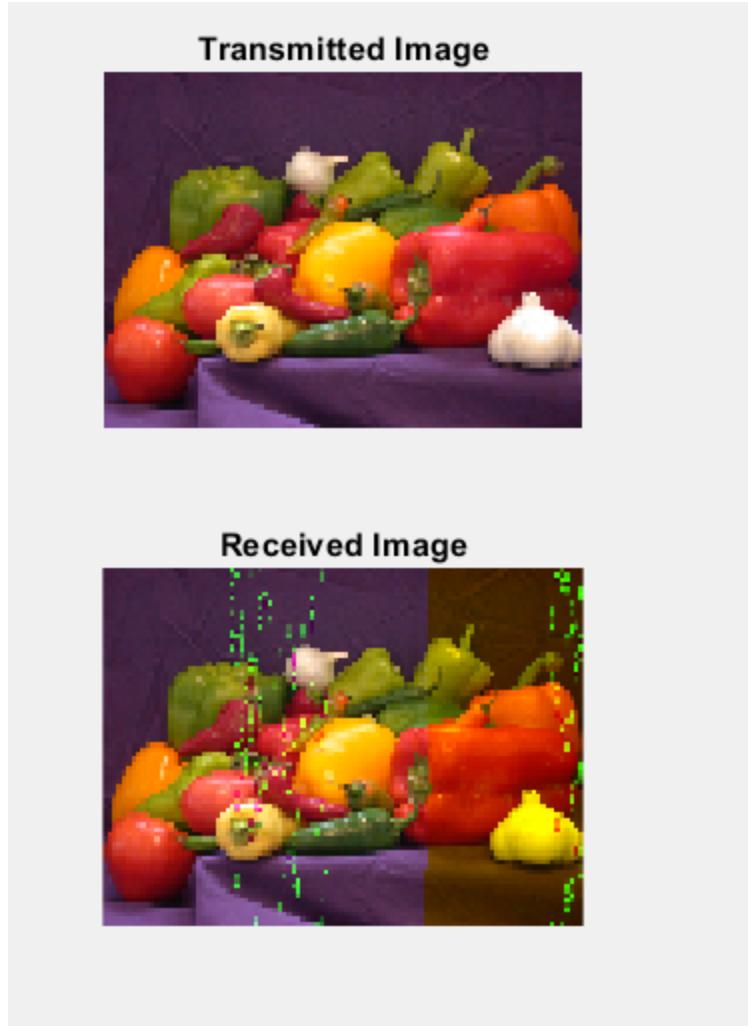
67cm 16QAM 2 Pluto Transmission

Bit Error Rate (BER):

Bit Error Rate (BER) = 0.00845

Number of bit errors = 1401

Number of transmitted bits = 202752



The SNR here is slightly below 15 which results in the errored bits because they overlap on the constellation diagram.

Appendix

Research

Pluto Transmission using AM:

<https://ez.analog.com/adieducation/university-program/f/q-a/550960/am-transmitter-with-adalm-pluto-sdr-using-gnu-radio>

MATLAB Image Transmission & Reception

<https://www.mathworks.com/help/wlan/ug/image-transmission-reception-using-802-11-waveform-sdr.html>

Pluto File Transmission Prior Projects:

<https://patel999jay.github.io/ADALM-Pluto-File-Transfer/>

Building our own packet encoder:

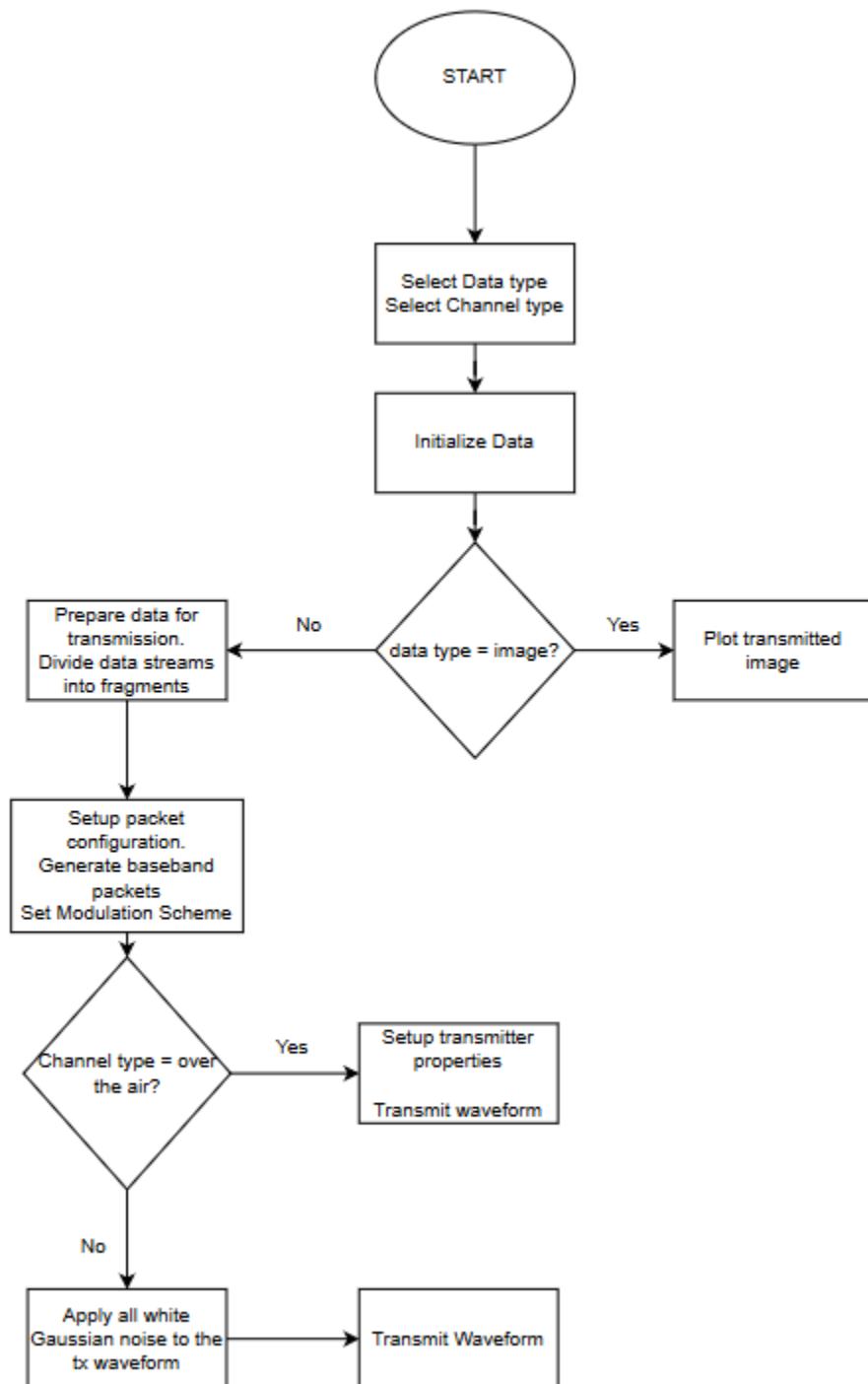
<https://github.com/handiko/gr-HDLC-AFSK/blob/master/module/epb.py>

FileTransmission MATLAB Code Github link

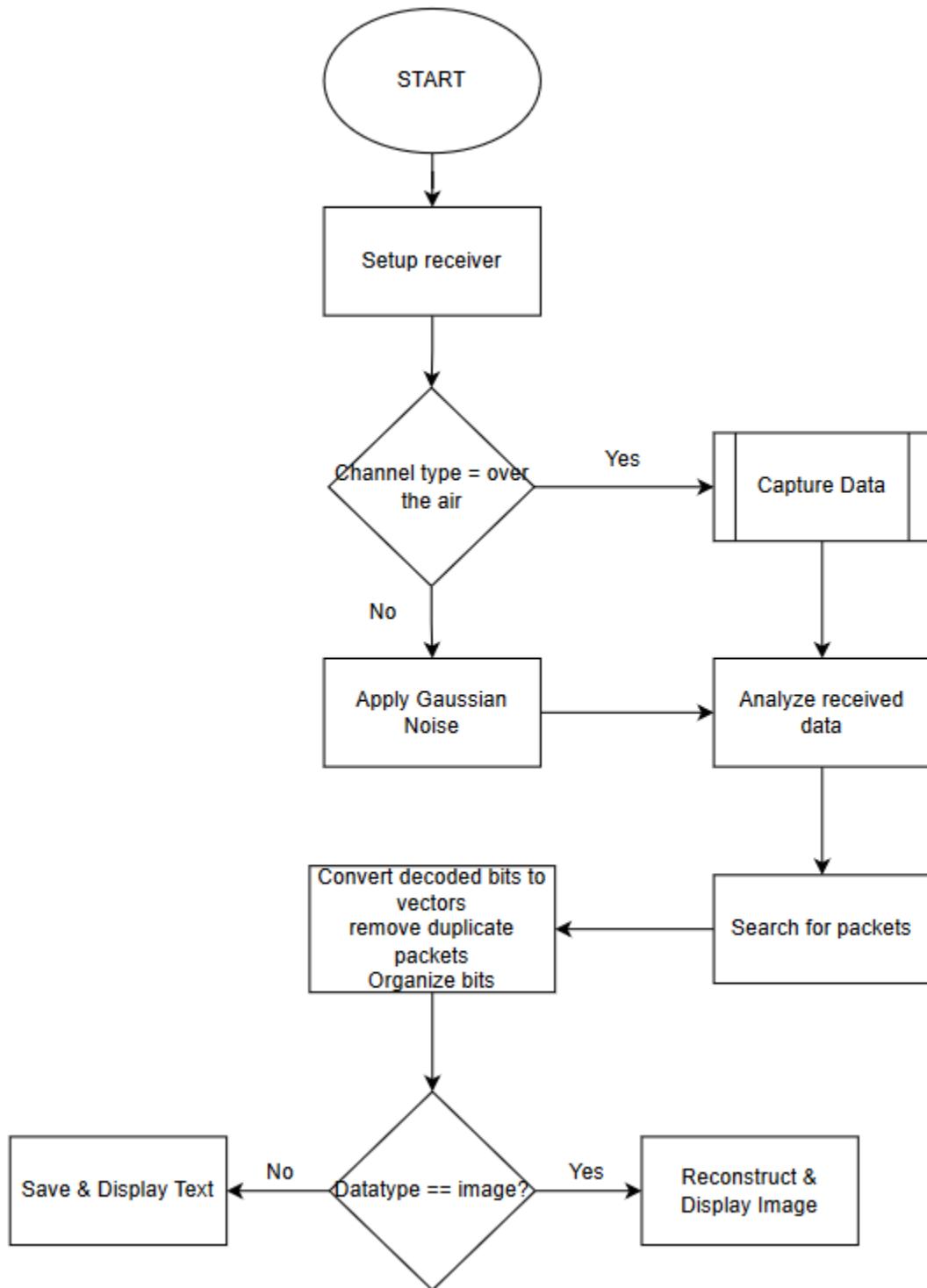
<https://github.com/BenDuval/504Project/blob/32a523815e7161cc5ae7f972262383268c803007/FileTransmission>

Value of MCS	Modulation	Coding Rate	Coded Bits Per Subcarrier	Coded Bits Per OFDM Symbol	Data Bits Per OFDM Symbol	Data Rate in Mbps		
						5-MHz Channel Bandwidth	10-MHz Channel Bandwidth	20-MHz Channel Bandwidth
0	Binary phase-shift keying (BPSK)	1/2	1	48	24	1.5	3	6
1	BPSK	3/4	1	48	36	2.25	4.5	9
2	quadrature phase-shift keying (QPSK)	1/2	2	96	48	3	6	12
3	QPSK	3/4	2	96	72	4.5	9	18
4	16-point quadrature amplitude modulation (16-QAM)	1/2	4	192	96	6	12	24
5	16-QAM	3/4	4	192	144	9	18	36
6	64-QAM	2/3	6	288	192	12	24	48
7	64-QAM	3/4	6	288	216	13.5	27	54

MCS Reference MATLAB Modulation Chart



MATLAB Transmit Flowchart



MATLAB Receive Flowchart