OFDM and Multipath Effect

Course: Telecommunication Subsystems

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Agenda

- Context of OFDM
- Design and Experiment with OFDM and AWGN
- Context of Multipath effects
- Design and Experiment with OFDM with Multipath effects
- Conclusion and Demo

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- **Context of OFDM**
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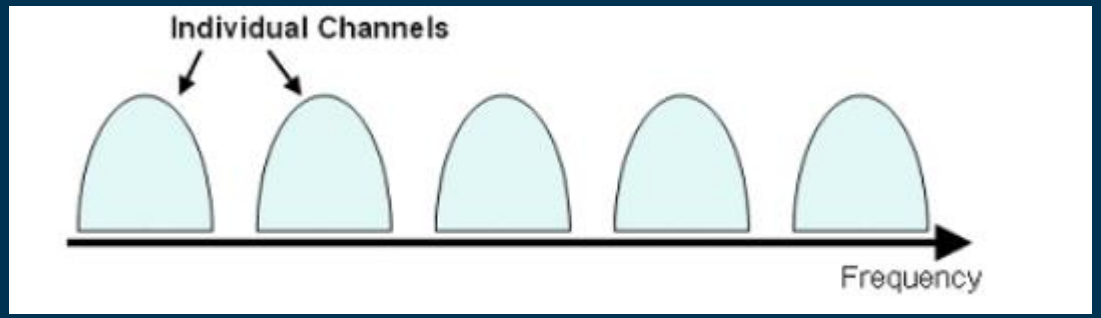
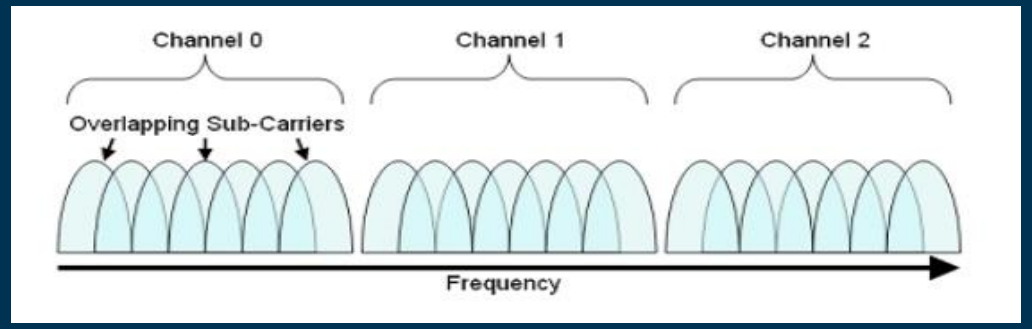
Context of OFDM (1)

- OFDM: Orthogonal Frequency Division Multiplexing
- FDM vs ODFM: Single Carrier vs Multiple subcarriers
- Subcarriers are orthogonal (overlap without interfering)
- Increases Spectral Efficiency bits/s/Hz



FDM: NEED OF GUARD BAND ☹



Context of OFDM (2)

- Each subcarrier performs digital modulation (e.g. QAM-16)
- The frequency of each subcarrier is
  - $f = \frac{k * fs}{N}$
  - f_s = sampling frequency = equivalent to bandwidth if spectrum analyzer contains negative frequencies
  - N = Number of subcarriers = FFT/IFFT Length
  - k = 0, ±1, ±2, ±N/2
- Fundamental subcarrier = f_s/N (smallest frequency of all)
- Subcarrier spacing = $\Delta f = f_s/N$ = OFDM symbol rate
- Period of OFDM signal (without CP) = $1/\Delta f$

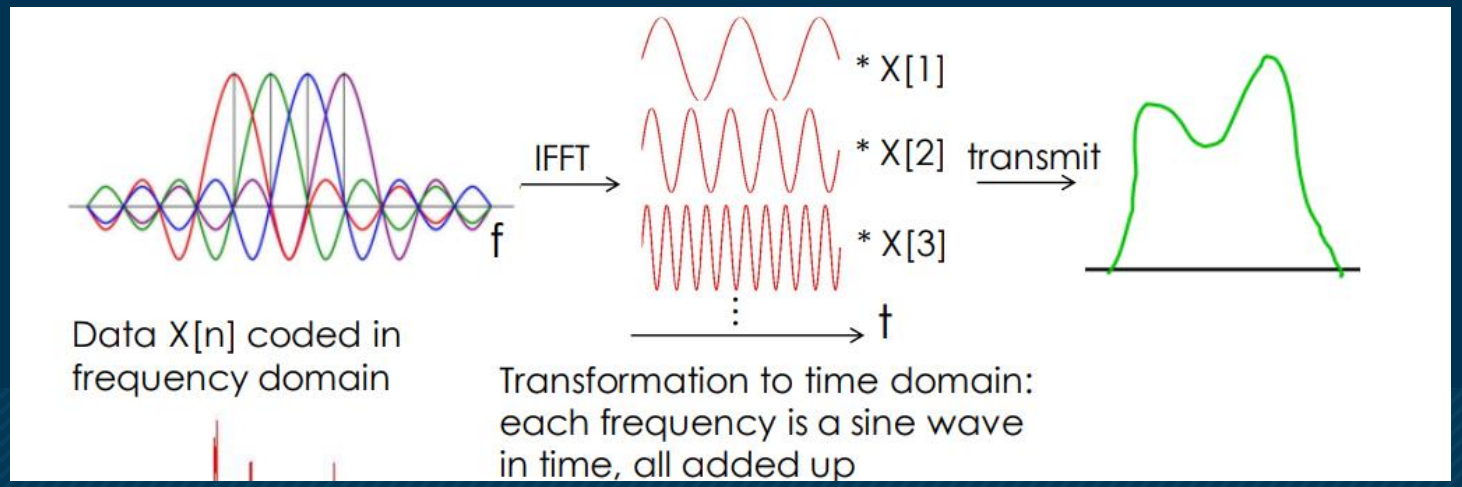
Context of OFDM (3)

- Types of Subcarriers:
  - Data (contain data information/bits)
  - Pilot (contain channel information, TX-RX Synchronization)
  - Guard NULL (contain nothing, to avoid interference)
  - DC (DC Carrier)
- Subcarriers = FFT length = Generally power of 2

Context of OFDM (4)

Process flow:

- Divide the band into set of subcarriers (Each contain fixed bits of data)
- For 16-QAM, Each subcarrier takes 4 bits. For 48 subcarriers = 192 bits
- Hence 1 OFDM signal contains 192 bits.
- Generate input data stream
- Convert into 48 parallel streams for 48 QAM-16 modulations
- Take IFFT to convert 48 Frequency bins to 48 time domain samples



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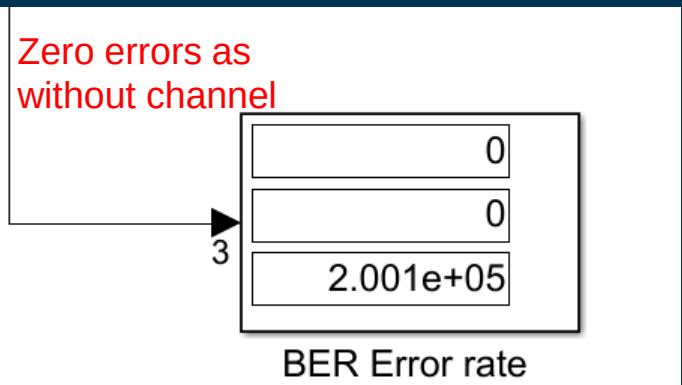
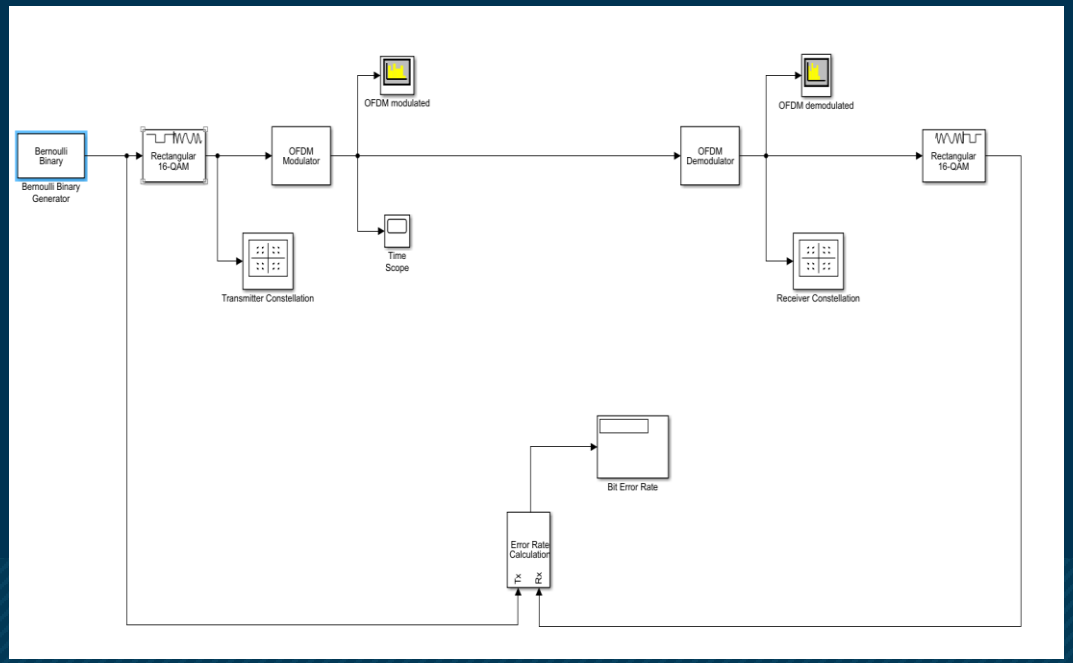
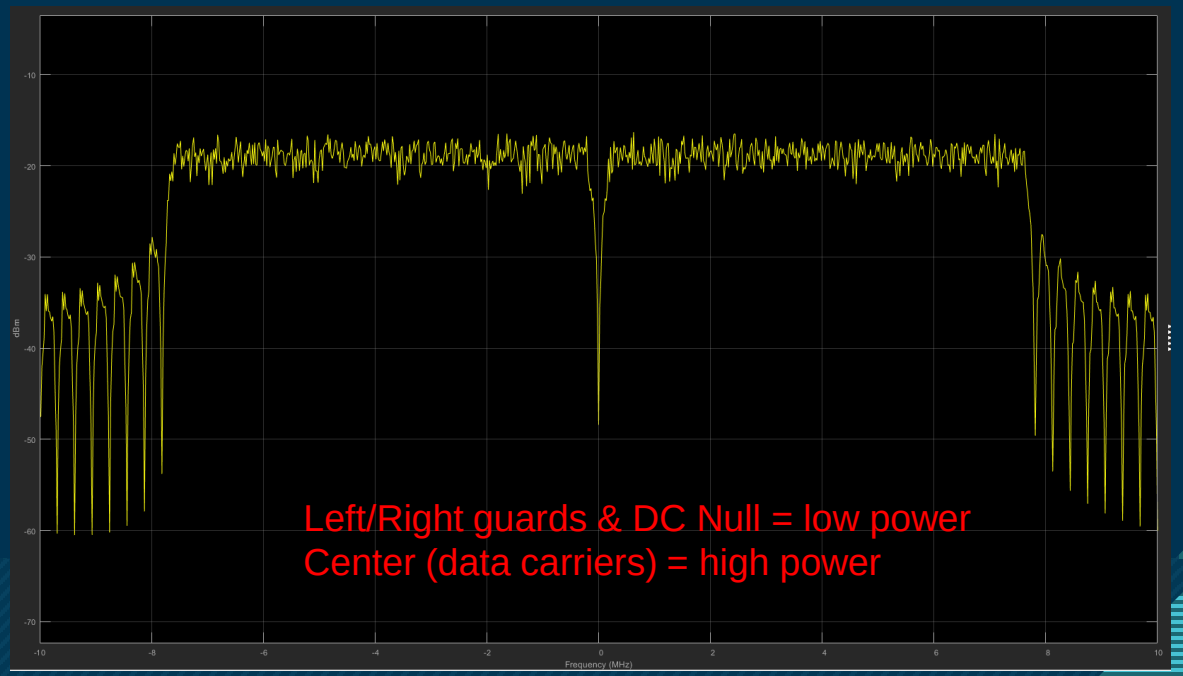
OFDM and AWGN (1)

Experiment 1: without AWGN channel:

- WIFI 802.11 SPECIFICATIONS
- Number of Subcarriers (FFT length) = 64
- Data Subcarriers = 48
- Bits/OFDM symbol = 192
- Sampling Frequency = 20 MHz
- Subcarrier spacing = 312.5 kHz
- OFDM symbol time = 3.2μs (without cyclic prefix)



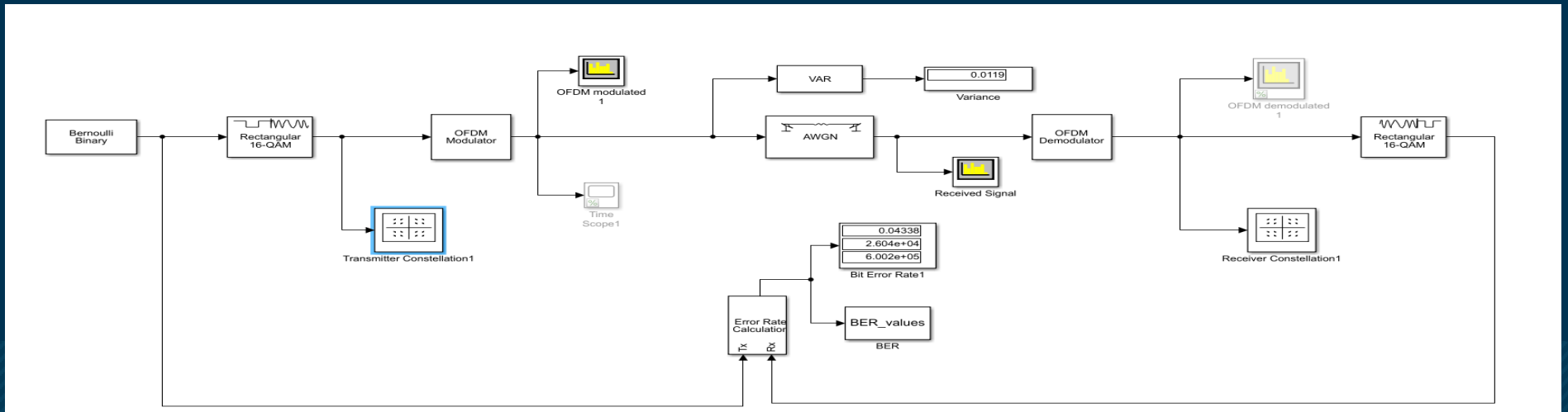




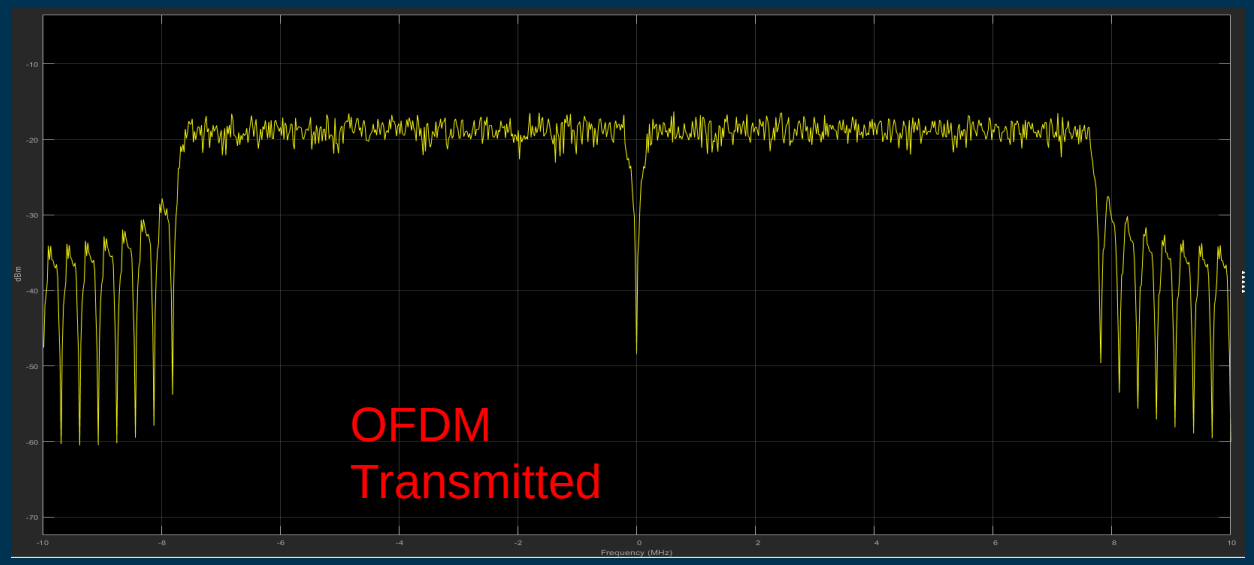
OFDM with AWGN (2)

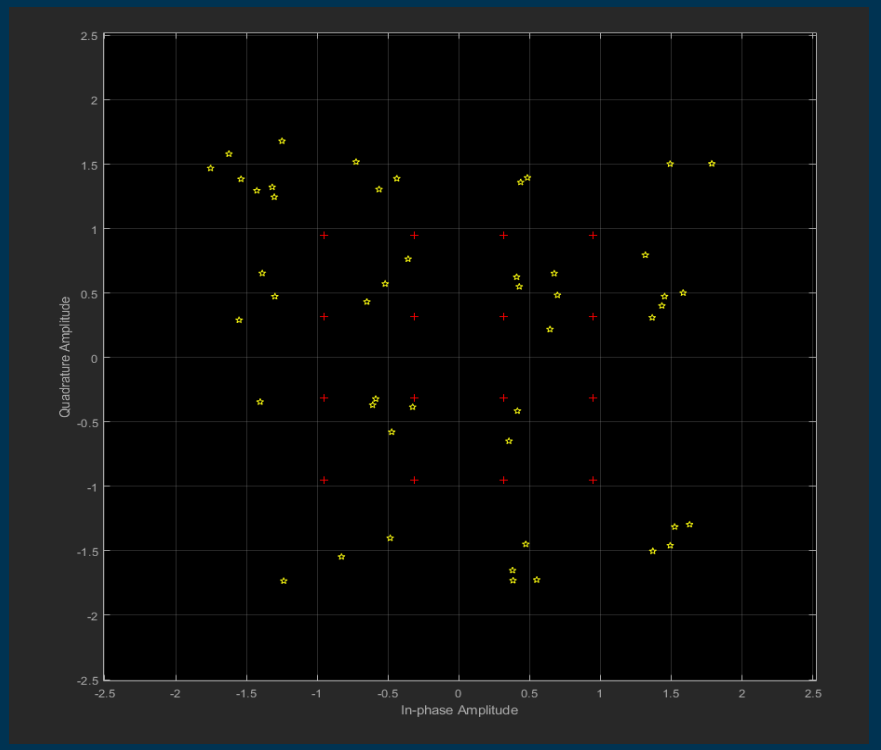
Experiment 2: with AWGN channel:

- WIFI 802.11 SPECIFICATIONS
- Number of Subcarriers (FFT length) = 64
- Data Subcarriers = 48
- Bits/OFDM symbol = 192
- Sampling Frequency = 20 MHz
- Subcarrier spacing = 312.5 kHz
- OFDM symbol time = 3.2 μs (without cyclic prefix)
- AWGN EbNo = 0-15 dB (Step size 3dB)
- Input Signal Power: Calculated from variance of OFDM signal ~33 mW



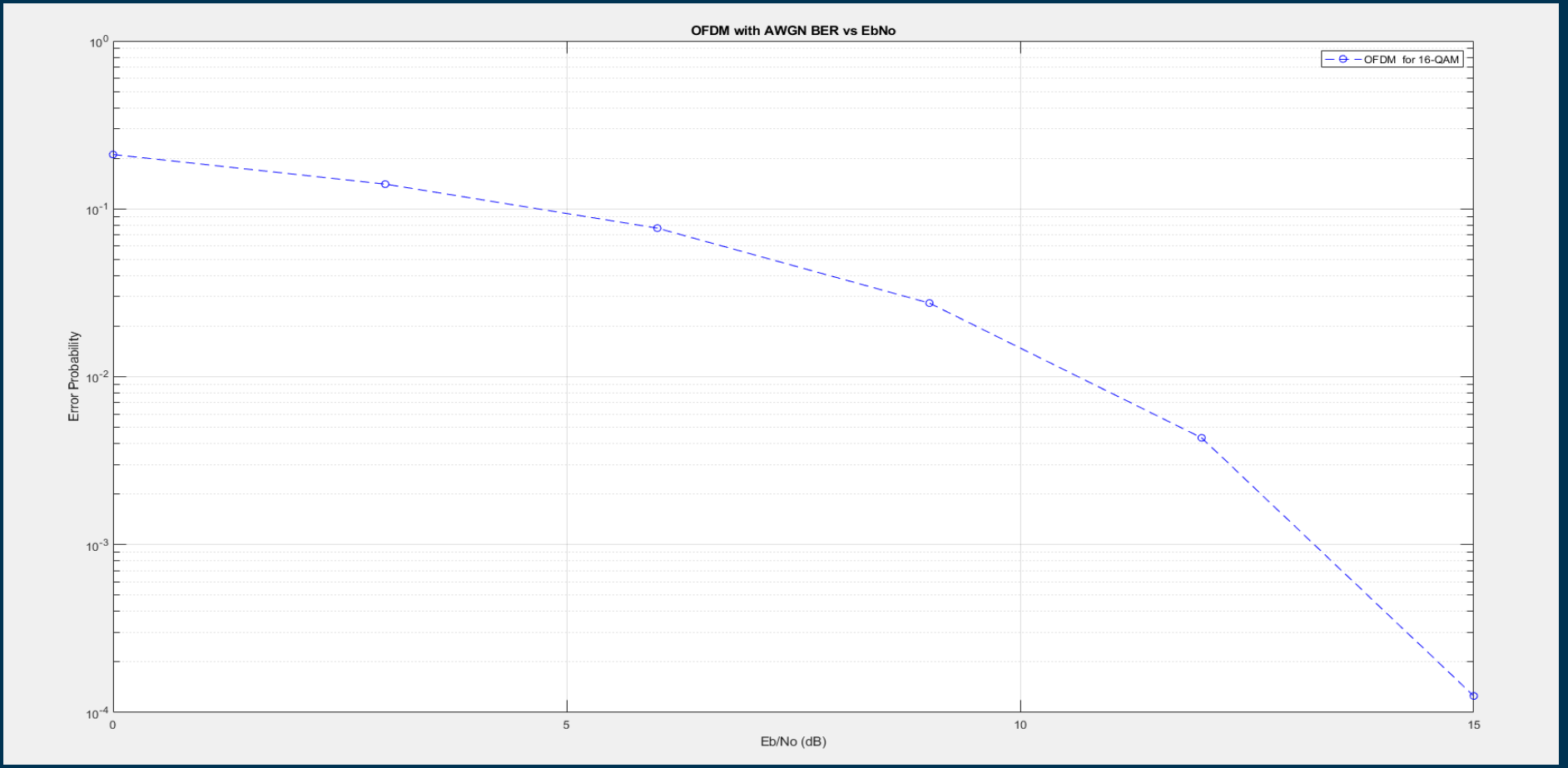
OFDM with AWGN (3)





Demodulated QAM symbols with AWGN channel

OFDM with AWGN (4)

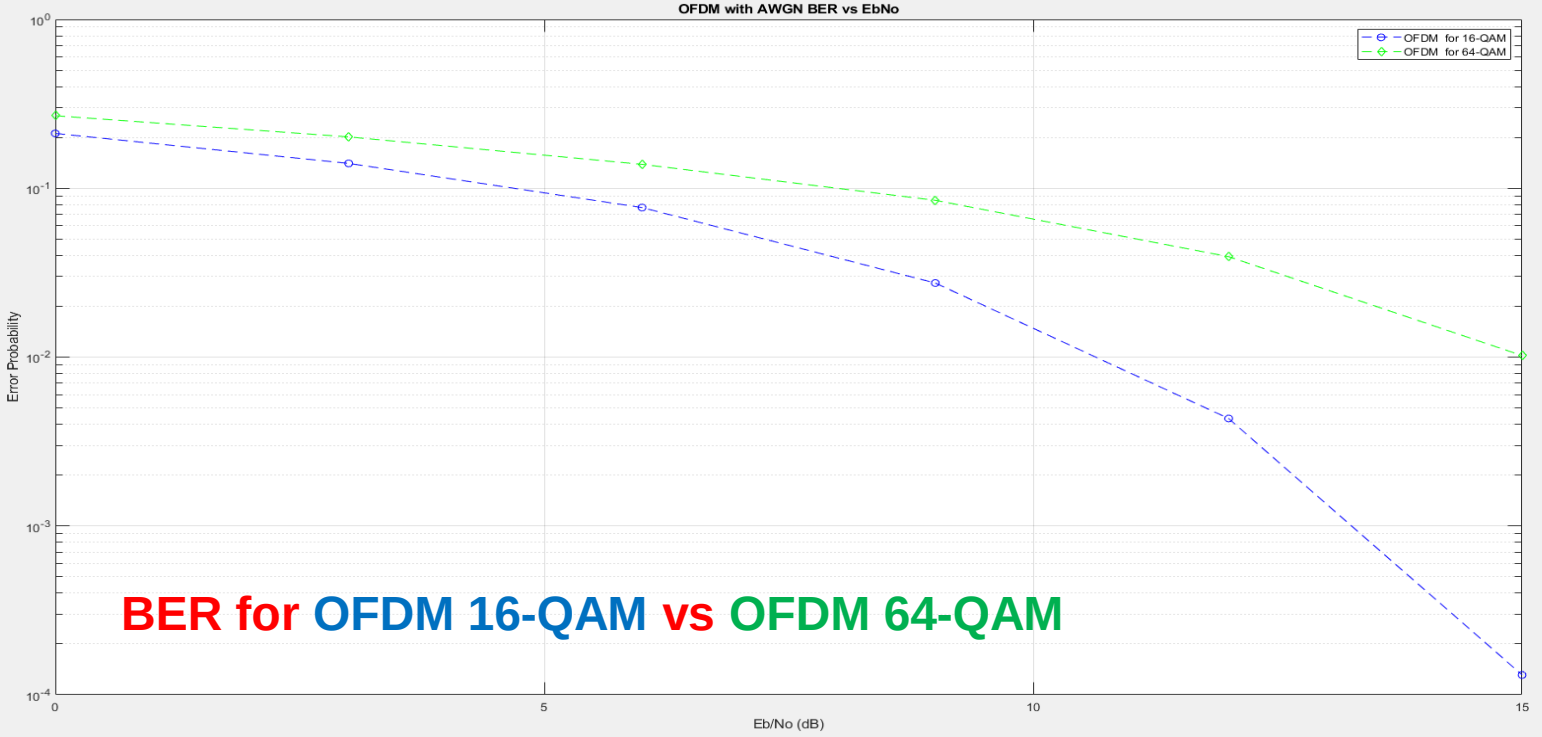


BER vs Eb/No for OFDM with AWGN.
Eb/No varies from 0 to 15 dB in step size of 3 dB

OFDM with AWGN (5)

Experiment 3: with AWGN channel and 64-QAM:

- Number of Subcarriers (FFT length) = 64
- Data Subcarriers = 32
- OFDM symbol time = 3.2 μs (without cyclic prefix)
- AWGN EbNo = 0-15 dB (Step size 3dB)



The error rate for a given SNR is much higher for 64-QAM than 16-QAM.

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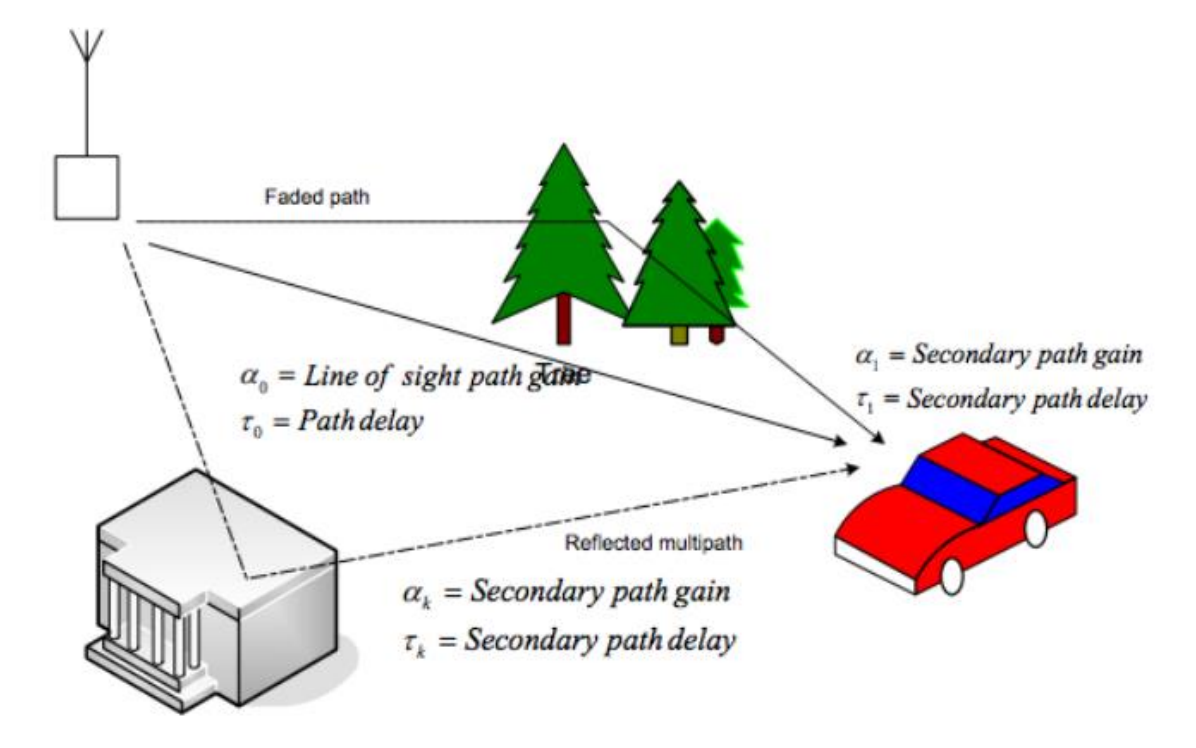
Context of Multipath (1)



$$y(t) = h(0)x(t) + h(1)x(t-1) + h(2)x(t-2) + \cdots$$
$$= \sum_{\triangle} h(\triangle)x(t-\triangle) = h(t) \otimes x(t)$$

time-domain convolution

Multipath Reasons:

Reflection
Scattering
Diffraction

The delayed version of a symbol overlaps with the adjacent symbol ☹

Solution: Cyclic Prefix.
Make the symbol period longer by copying the tail and glue it in the front

Context of Multipath (2)

Fading

- Large-scale Fading
  - Attenuation with distance
- Small-scale Fading
  - Time spreading of signal in time domain (Multipath)
    - Frequency flat fading
    - Frequency selective fading
  - Time variance of channel (Doppler shift)
    - Slow Fading
    - Fast Fading

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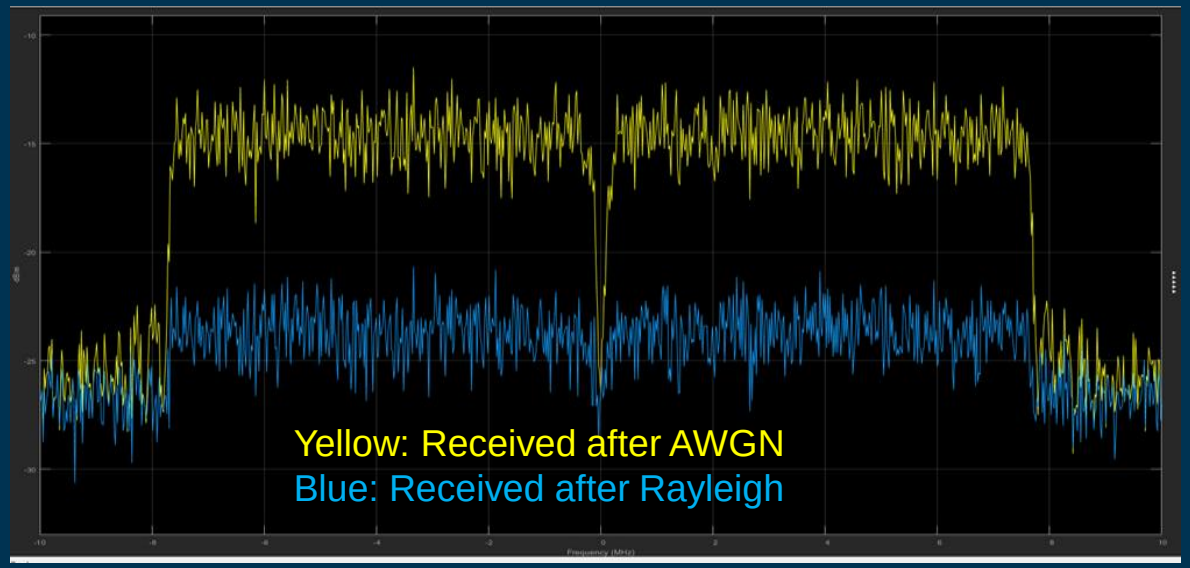
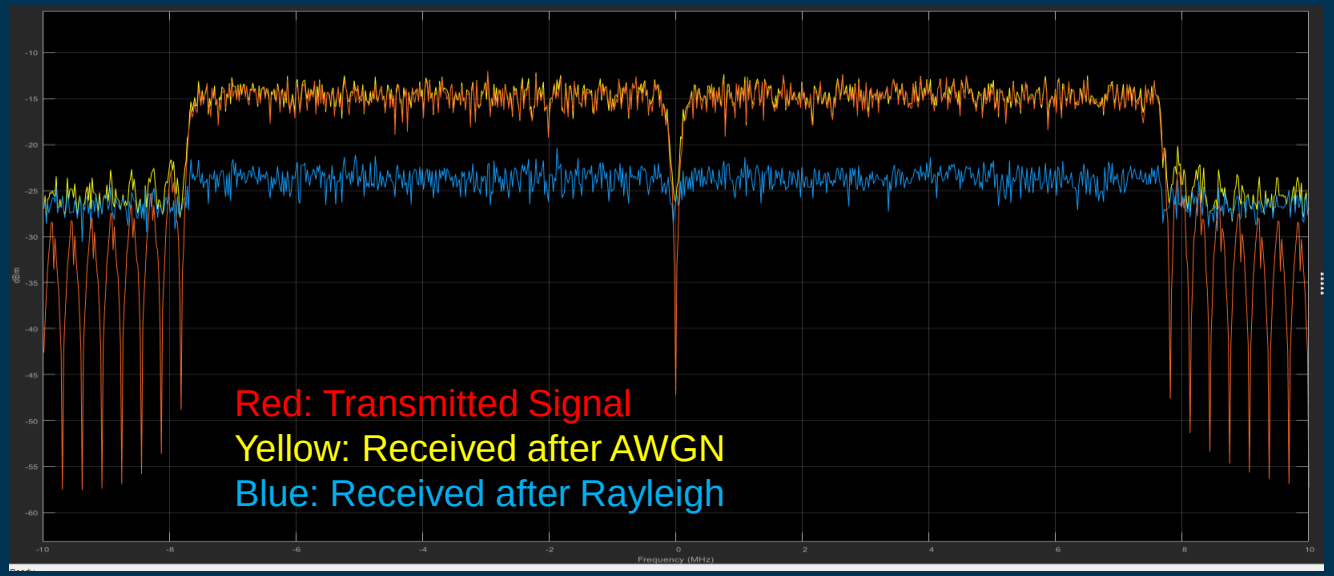
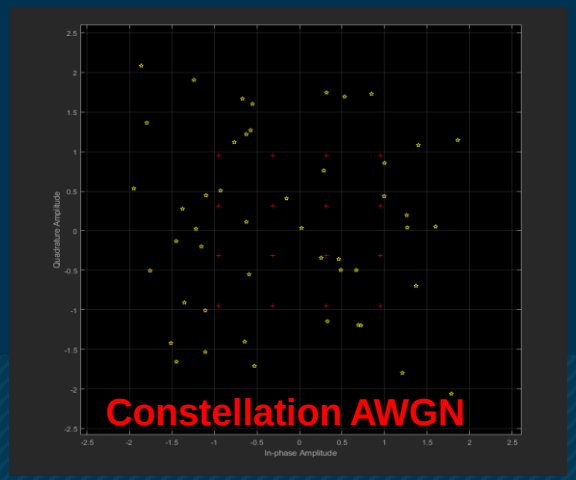
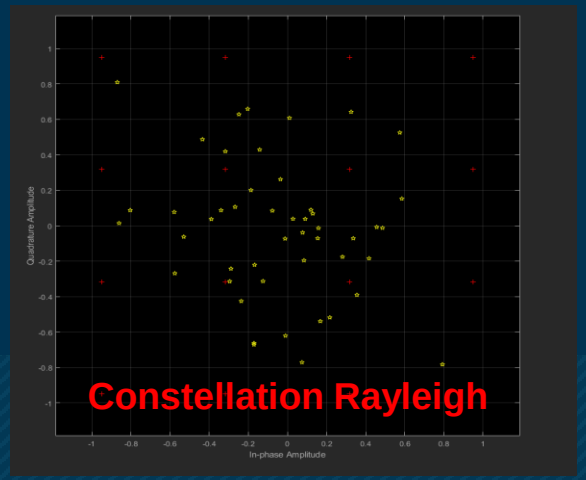
Design and Experiment with OFDM with Multipath effects (1)

- **Experiment 1:** Rayleigh Fading with just one path (no delay)





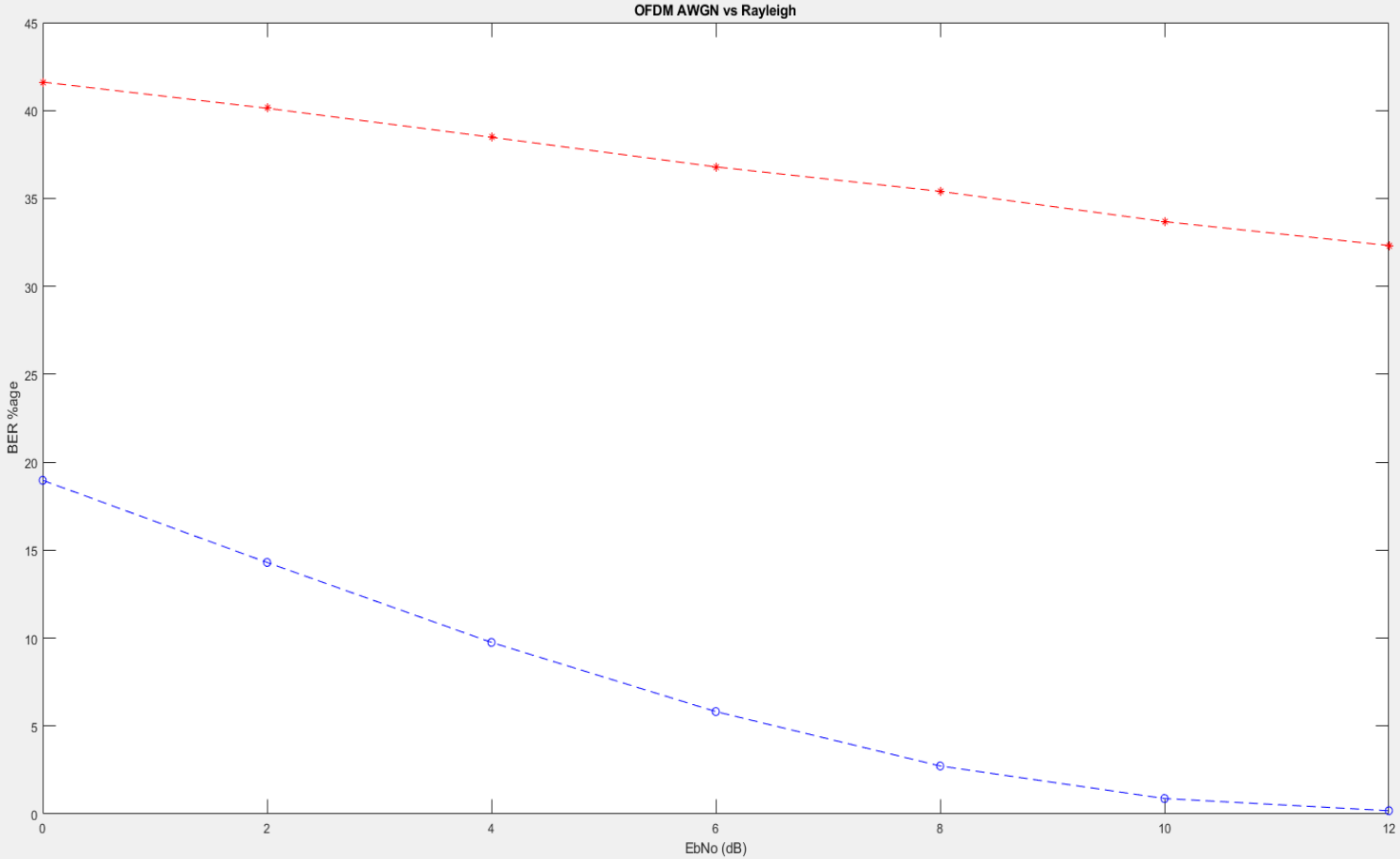




CONCLUSION:

Equalizer needed at receiver.
Equalizer has impulse response inverse of channel impulse response

Design and Experiment with OFDM with Multipath effects (2)



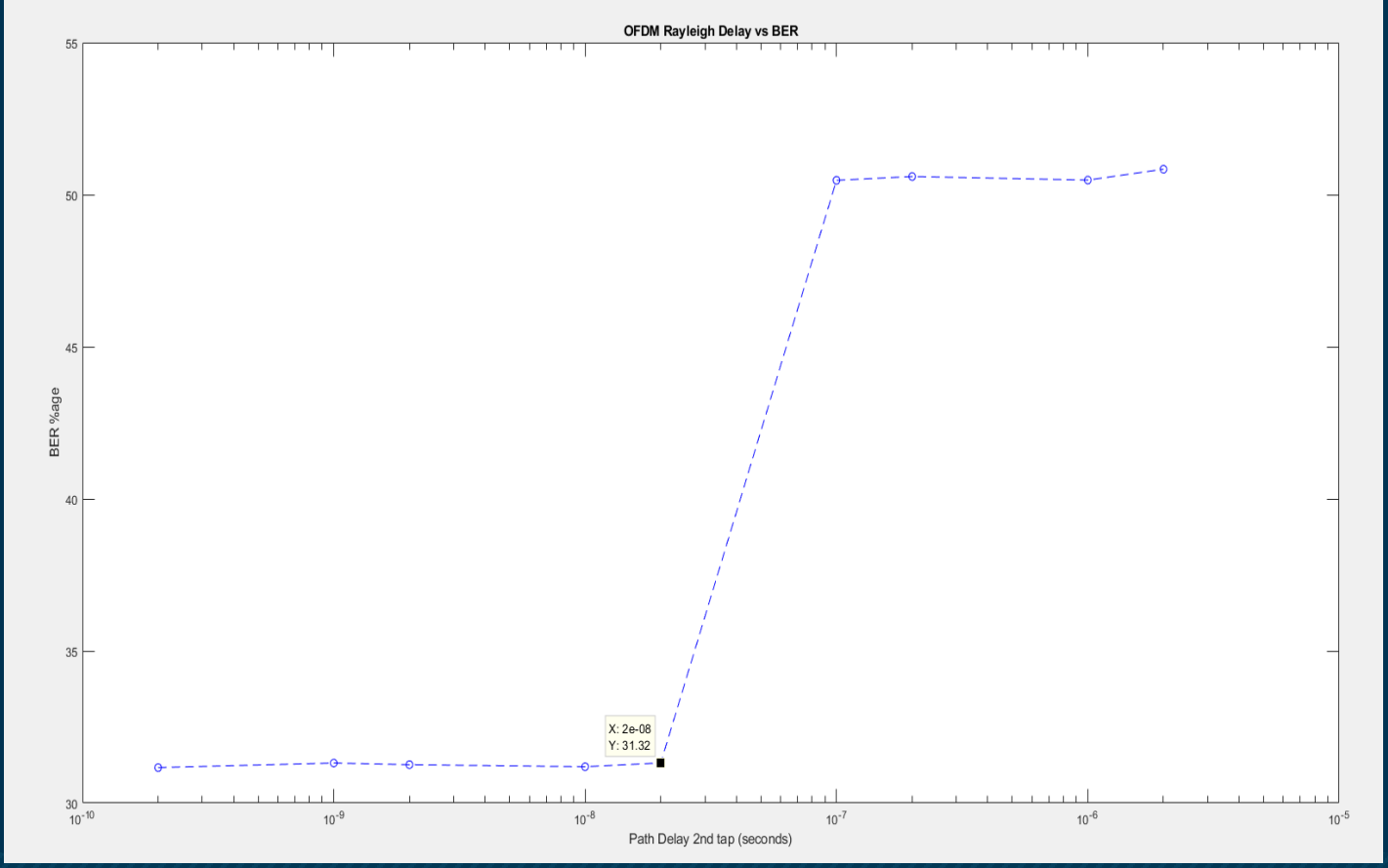
Experiment 2:
BER vs SNR

Blue: AWGN
Red: Rayleigh

AWGN is better in performance than Rayleigh in terms of BER for all types of Modulations

Note: Here y axis isn't logarithmic but linear scale with %age bit error value

Design and Experiment with OFDM with Multipath effects (3)



Experiment 3:
Multipath Max Delay vs BER

For a delay spread that is longer than the effective guard period, the BER (Bit Error Rate) rises rapidly due to the inter-symbol interference. From baseline 32%BER to 53%BER.

Design and Experiment with OFDM with Multipath effects (4)

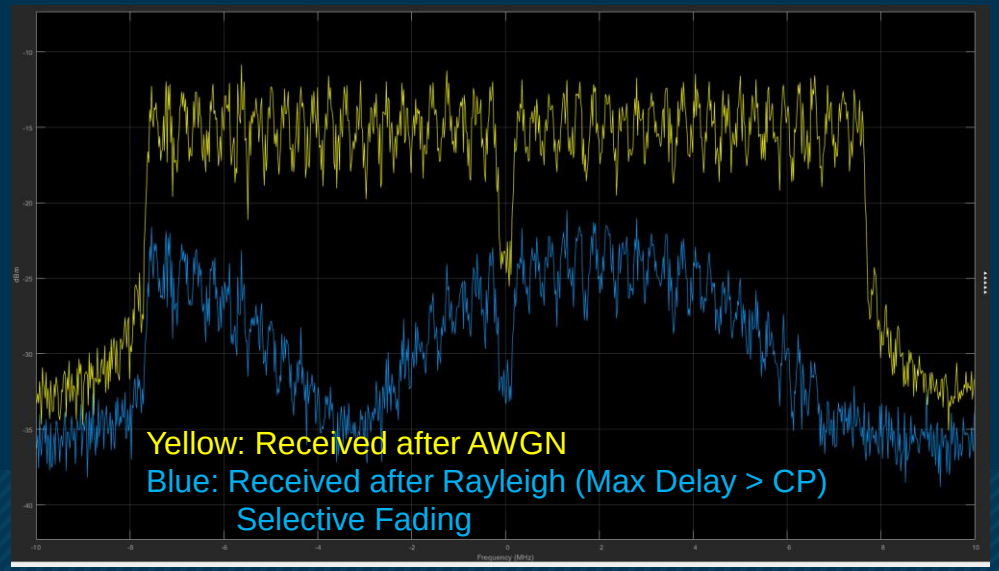
Experiment 4:

- 3 Paths: all less than cyclic prefix (0, 1ns, 10ns)
- BER = 29.4% (baseline)

Experiment 5:

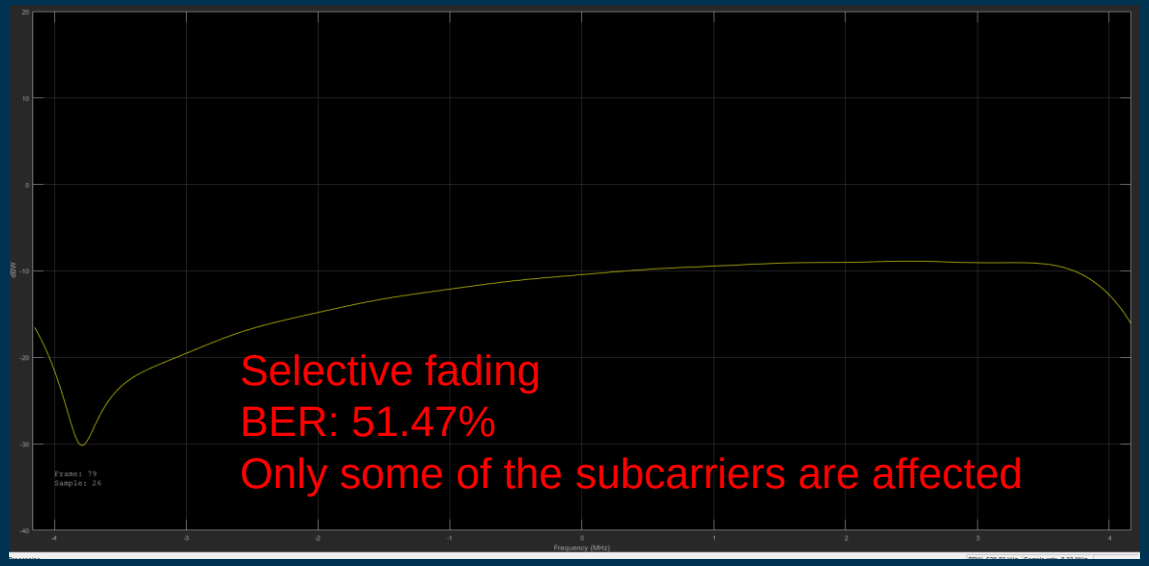
- 4 paths: 4th path greater than cyclic prefix
- BER = 46.02% (shoots due to ISI)

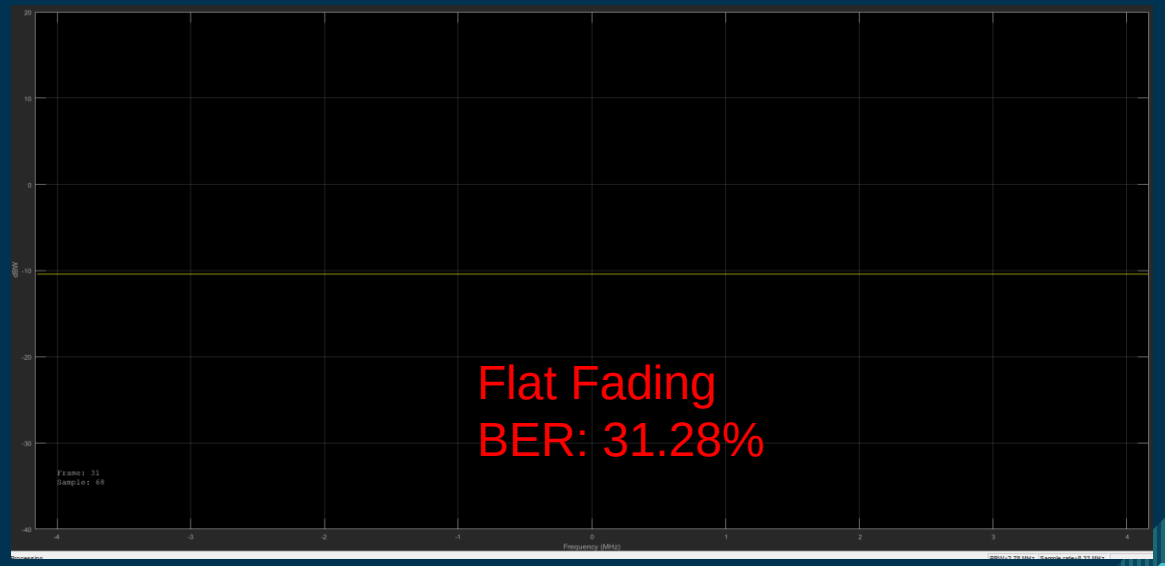
Rayleigh with max delay greater than cyclic Prefix causing ISI and higher BER



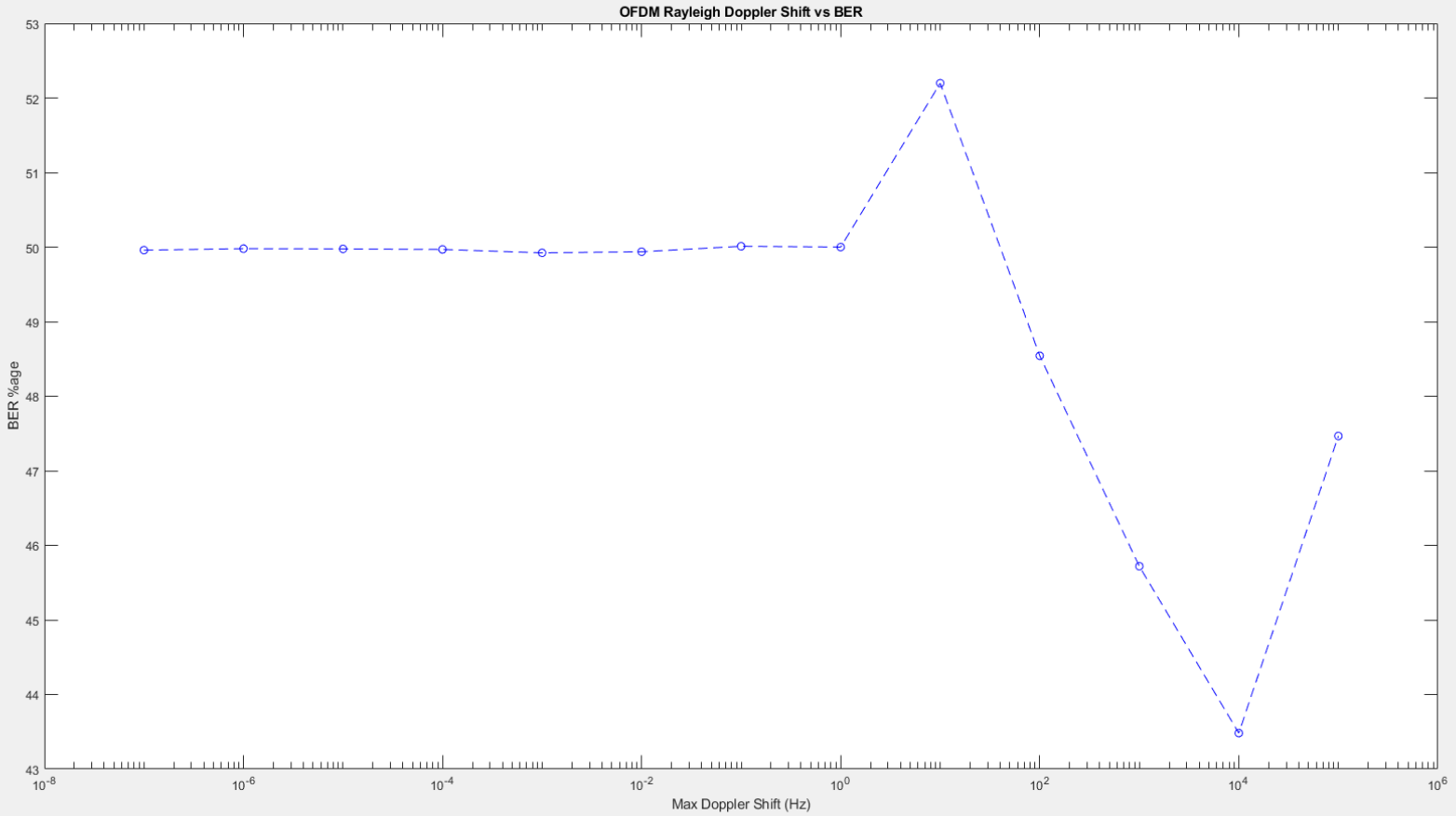
Design and Experiment with OFDM with Multipath effects (5)

- **Experiment 6:**
- Small scale fading + max delay higher than symbol period →Selective Fading
- Small scale fading + max delay lower than symbol period →Flat Fading





Design and Experiment with OFDM with Multipath effects (6)



Experiment 7:
Max Doppler Shift vs BER

BER is high and constant at low Doppler shift. At Shift= 10Hz, BER rate decrease a bit

Conclusion

- OFDM Concepts and Simulation Parameters
- OFDM with AWGN Experiments
- Multipath Concepts in Wireless Communication
- OFDM with Multipath Experiments

References

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Thank you ☺