Investigation of Phase Noise Effects on 256-QAM, OFDM, and M-PSK Schemes

Denzel Ninga ENG-219-042/2022

Department of Electrical and Communication Engineering

Multimedia University of Kenya

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***Abstract*—This laboratory report aims to study the performance of digital modulation techniques under channel impairments, specifically Additive White Gaussian Noise (AWGN) and Phase Noise. Using MATLAB/Simulink, a baseline 256-QAM system is analyzed to establish a reference Bit Error Rate (BER). Later , Orthogonal Frequency Division Multiplexing (OFDM) is introduced into the model to evaluate multi-carrier performance. Finally, the system is modified to use 8-PSK to demonstrate the trade-off between spectral efficiency and noise resilience. The results show the sensitivity of 256-QAM to phase noise and the robustness of lower-order PSK schemes.**

***Index Terms*—256-QAM, OFDM, Phase Noise, 8-PSK, BER, Simulink.**

I. Introduction

Digital communication systems must balance data rate (spectral efficiency) against robustness to channel errors. High-order modulation schemes like 256-Quadrature Amplitude Modulation (QAM) offer high throughput by transmitting 8 bits per symbol [1]. However, the dense constellation makes them highly susceptible to impairments such as Phase Noise [3], which causes random angular rotation of the received symbols. The objectives were to accomplish:

1) **Baseline Analysis:** Performance of the single-carrier 256-QAM.
2) **OFDM Integration:** Implementation of a multi-carrier system to mitigate channel distortion to evaluate multi-carrier performance [2].
3) **Modulation Comparison:** Replace QAM with 8-PSK to analyze robustness.

II. Methodology and System Model

The simulation was conducted using MATLAB/Simulink. The main channel impairments modeled were:

- **AWGN:** Thermal noise added to the signal.
- **Phase Noise:** Random fluctuations in the carrier phase, simulated at various levels (measured in dBc/Hz).

The Bit Error Rate (BER) was calculated using the `bertool` interface and Monte Carlo simulations.

III. Part 1: Baseline 256-QAM Performance

A. System Configuration

The initial system consisted of a Bernoulli Binary Generator driving a Rectangular 256-QAM Modulator. The signal passed through an AWGN channel and a Phase Noise block before demodulation.

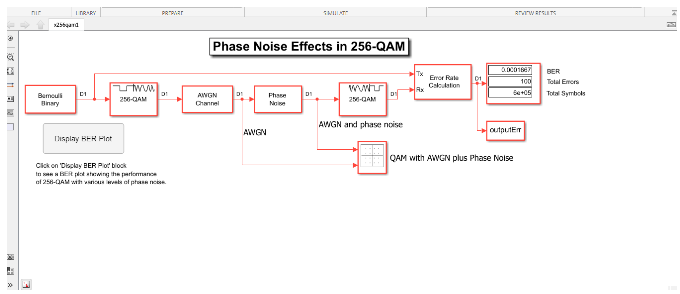

Fig. 1. Baseline Simulink Model. Single-carrier 256-QAM transmission chain.

B. Results Analysis

The constellation diagram for the baseline system is shown in Fig. 2.

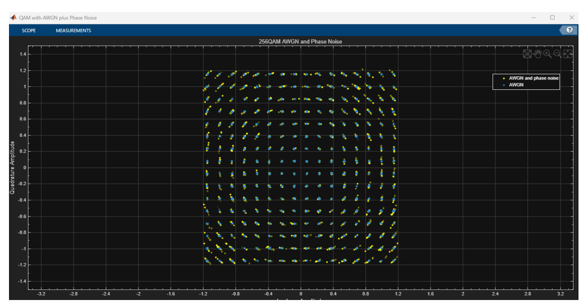

Fig. 2. Baseline 256-QAM Constellation. Note the radial displacement (rotation) of the outer points.

Observation: The characteristic signature of phase noise is visible as a concentric rotation of the constellation points. Because 256-QAM relies on both amplitude and phase, this rotation moves the symbols dangerously close to the decision boundaries. The outer symbols (highest amplitude) suffer the largest displacement, making them the most prone to error.

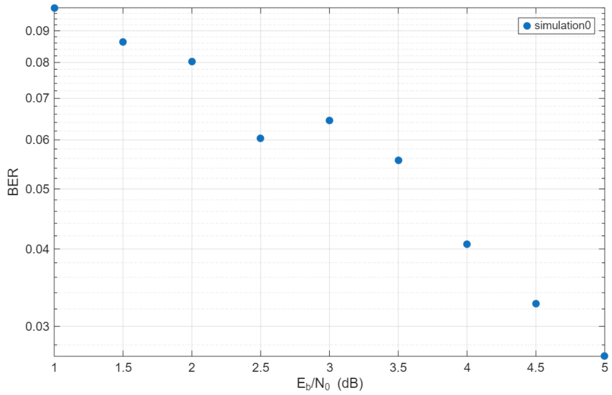

Fig. 3. Baseline BER vs E_b/N_0. High error rates persist even at high SNR due to the phase noise floor.

IV. Part 2: OFDM Integration

A. OFDM Implementation

As instructed by the lab, an OFDM Modulator and Demodulator pair was inserted into the signal chain. OFDM splits the high-rate serial data into multiple parallel lower-rate subcarriers [1].

- **FFT Length:** 64
- **Cyclic Prefix (CP):** 16 samples

To ensure that the Simulink model ran correctly, the input frame size was adjusted to align with the number of active subcarriers.

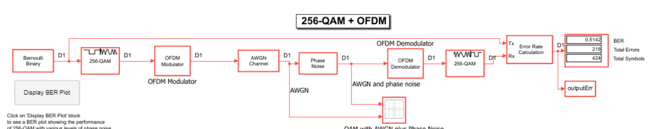

Fig. 4. Simulink Model with OFDM Integration. The OFDM blocks are placed between the QAM modulation and the channel.

B. Analysis of OFDM Output

The constellation diagram after OFDM demodulation (Fig. 5) differs significantly from the single-carrier case.

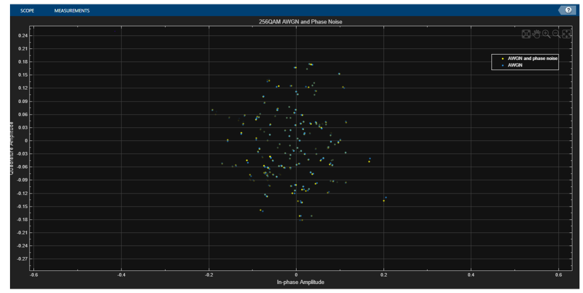

Fig. 5. 256-QAM Constellation over OFDM. The distinct rotation seen in Fig. 2 is replaced by a scattered cloud.

Technical Insights: In OFDM, phase noise destroys the orthogonality between subcarriers. This leads to Inter-Carrier Interference (ICI) [2]. Unlike the clean rotation seen in single-carrier QAM, ICI behaves like additive Gaussian noise, scattering the points randomly around their centers. This creates an irreducible error floor, as seen in the BER plot (Fig. 6), where increasing power (E_b/N_0) yields diminishing returns.

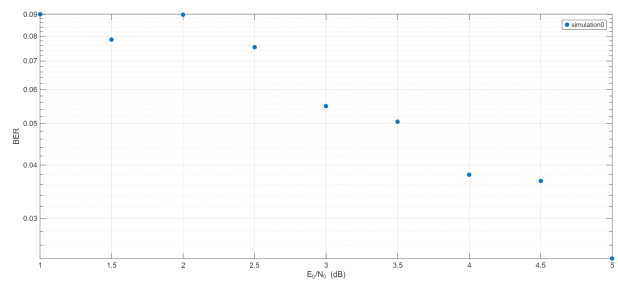

Fig. 6. BER Performance with OFDM. The curve flattens (floors) due to ICI.

V. Part 3: Comparative Study with 8-PSK

A. 8-PSK Implementation

To evaluate the balance between speed and reliability, the 256-QAM scheme was replaced with 8-Phase Shift Keying (8-PSK).

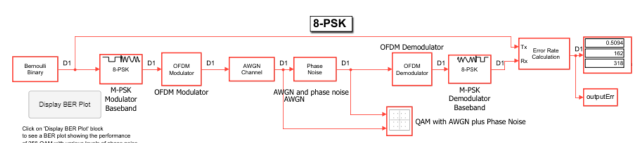

Fig. 7. Modified System Model using 8-PSK Modulation.

B. Performance Comparison

The 8-PSK constellation (Fig. 8) shows 8 points spaced 45° apart on a circle.

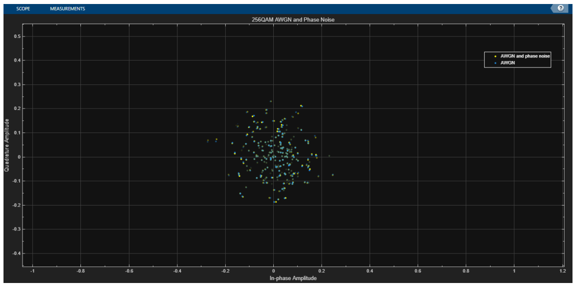

Fig. 8. 8-PSK Constellation. The points have a constant amplitude and large angular separation.

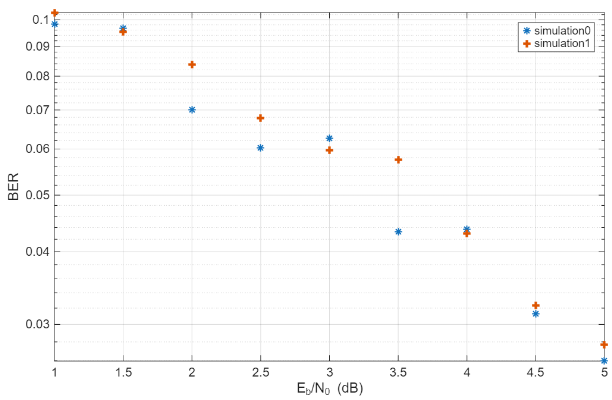

Fig. 9. BER Performance of 8-PSK. Excellent performance is achieved even at moderate SNR.

Discussion:

1) **Noise Resilience:** 8-PSK is significantly more robust than 256-QAM. The Euclidean distance between symbols in 8-PSK is much larger [3] than the tiny gaps in the 256-point grid. As a result, phase noise rotation that would cause an error in 256-QAM does not cross the decision boundary in 8-PSK.
2) **Trade-off:** This robustness comes at a cost. 8-PSK transmits only 3 bits per symbol, whereas 256-QAM transmits 8 bits. Thus, 256-QAM is $\approx 2.6\times$ more spectrally efficient but requires a much cleaner channel to operate.

VI. Conclusion

This lab successfully demonstrated the effects of channel impairments on digital modulation. The original 256-QAM system showed high sensitivity to phase noise. The integration of OFDM transformed the phase error into Inter-Carrier Interference (ICI), changing the error characteristics. Finally, the 8-PSK experiment confirmed that lower-order modulation schemes offer superior robustness against phase noise, though at the expense of data rate. For practical systems, 256-QAM is suitable only for high-SNR environments, while 8-PSK is preferable for noisy channels.

Appendix: Simulation Files

The MATLAB/Simulink models (.slx) used to generate these results are available at:
`https://github.com/plochoidysis-ojwege/Digital-com`

References

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