Analysis of 256-QAM Performance

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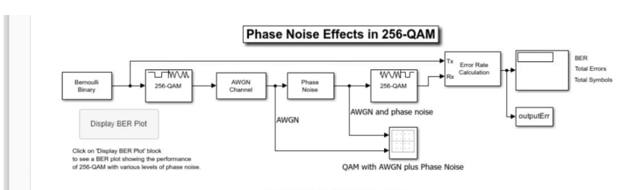
***Abstract*—This study focuses on modeling and analyzing the performance of a 256-QAM communication system using MATLAB and Simulink. The evaluation was conducted under various noise conditions, such as additive white Gaussian noise (AWGN) and phase noise. Key components of the simulation included QAM modulation and demodulation blocks, noise channels, and measurements of the bit error rate (BER). The analysis employed constellation diagrams and BER calculations to evaluate the system's behavior. Furthermore, the study explored the effects of incorporating an OFDM block and substituting 256-QAM with other modulation schemes like M-PSK. The results indicated that an increase in the signal-to-noise ratio (SNR) leads to a decrease in BER, while phase noise causes significant signal distortion. OFDM showed enhanced noise tolerance, while M-PSK demonstrated better resistance to phase noise, albeit with a reduction in spectral efficiency. These findings underscore the essential trade-offs involved in designing effective and resilient communication systems.**

***Index Terms*—**

I. Introduction

THE basic principle of OFDM involves division of the available bandwidth into several narrow subcarriers,each with different frequency and orthogonal to each other. Amplitude Modulation (QAM) is a popular digital modulation technique recognized for its capability to deliver high data rates while making efficient use of bandwidth. It conveys information by altering the amplitudes of the in-phase and quadrature components of the carrier signal. This study focused on a 256-QAM system to evaluate its performance in the presence of Additive White Gaussian Noise (AWGN) and phase noise. Simulations were performed using MATLAB and Simulink, which included essential system elements such as modulation and demodulation blocks, noise channels, and bit error rate (BER) analysis. Furthermore, the study examined the effects of incorporating Orthogonal Frequency Division Multiplexing (OFDM) and substituting 256-QAM with other modulation techniques like M-PSK to assess the system's robustness and noise resilience.



Phase noise effect in 256-QAM

Bernoulli Binary Generator block creates a random sequence of 8-bit binary values that range from 0 to 255.The Rectangular QAM Modulator Baseband block carries out baseband modulation using 256-ary QAM. AWGN Channel block simulates a noisy transmission medium by adding additive white Gaussian noise. The Phase Noise block alters the phase of the complex input signal, reflecting real-world imperfections. The Rectangular QAM Demodulator Baseband block retrieves the transmitted signal through demodulation.

These simulation blocks play a vital role in thoroughly analyzing the system's performance in noisy conditions.

- The Constellation Diagram block displays the signal's constellation points after the introduction of AWGN and phase noise.
- The Error Rate Calculation block counts bits that differ between the received signal and transmitted signal. To Workspace block, named `outputErr`, saves simulation results for additional analysis and visualization.
- A Callback Button labeled `Display BER Plot` opens a plot showing the Eb/N0 performance curves for 256-QAM transmission and reception at various levels of phase noise.

QAM is a modulation technique that works on a single carrier by making efficient use of two orthogonal signal components. This is done through the application of a Hilbert transform, which creates a 90° phase shift between the original carrier and a secondary signal. Consequently, the two components stay orthogonal to one another, allowing for precise demodulation and signal reconstruction.

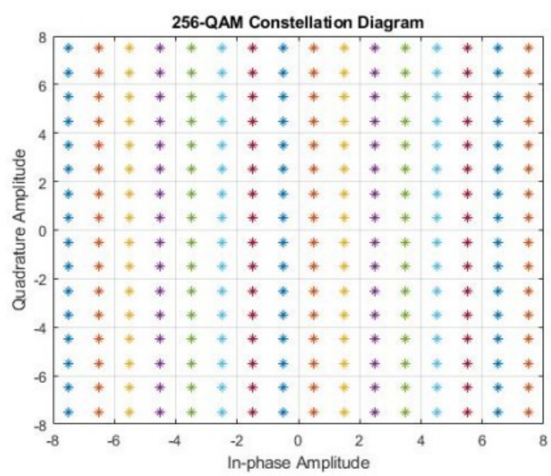


Fig. 1. 256-QAM constellation diagram diagram

II. MATERIALS AND METHOD

Simulation Procedure Using MATLAB and Simulink 1.Initialize the Simulation Environment - Start by opening MATLAB and launching Simulink to create a new blank model.

2. Insert Essential Blocks - Add the required components from the Communication Toolbox, such as the Bernoulli Binary Generator, 256-QAM Modulator and Demodulator, AWGN Channel, Phase Noise block, Display block, and Error Rate Calculator.

3. Configure and Connect Blocks - Organize the blocks in a systematic manner, ensuring a clear signal flow from the generator through the modulator, AWGN channel, phase noise, demodulator, and error calculation unit.

4. Monitor Signal Behavior - Connect scope blocks to visualize constellation diagrams, eye diagrams, and bit error rate (BER) plots for a thorough analysis.

5. Set Simulation Parameters and Run - Adjust the necessary parameters and start the simulation by clicking ”Run.” - Observe and document the resulting constellation diagrams, eye diagrams, and BER values.

6. BER Plot Analysis - Utilize the BER Plot block to generate and evaluate BER performance across different Eb/No values.

7. OFDM Implementation - Swap the 256-QAM Modulator and Demodulator with OFDM Modulator and Demodulator blocks. - Integrate these into the signal path and rerun the simulation. - Capture new constellation and eye diagrams and compare the BER results with those from the 256-QAM setup.

8.M-PSK Evaluation - Replace the 256-QAM blocks with M-PSK Modulator and Demodulator, choosing an appropriate modulation order like 16-PSK. - Simulate and assess system performance in terms of BER, eye diagrams, and clarity of the constellation. - Compare these results with earlier configurations to evaluate the effectiveness of the modulation scheme.

III. Results

The constellation diagram displayed by the first scatter plot in Fig. 3 is a constellation diagram of 256-QAM for Eb/No=100 dB and without the presence of phase noise.

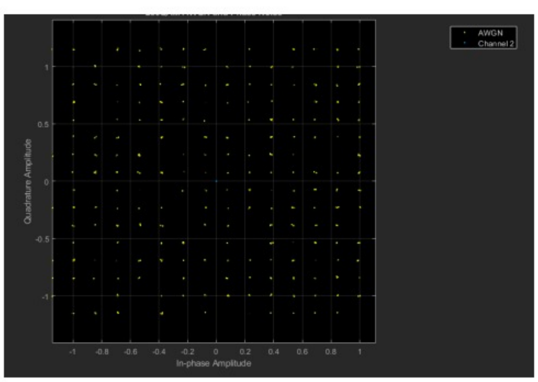


Fig. 3. 256-QAM constellation diagram without phase noise

Fig. 2. 256-QAM constellation diagram without phase noise

The Scatter Plot Scope, located after the Phase Noise block, yields different outcomes based on the Phase Noise Level Density (PNLD). The constellation diagrams for PNLD = -30 dBc/Hz and PNLD = -80 dBc/Hz are displayed in Fig. 4 and Fig. 5, respectively, highlighting how phase noise affects signal integrity.

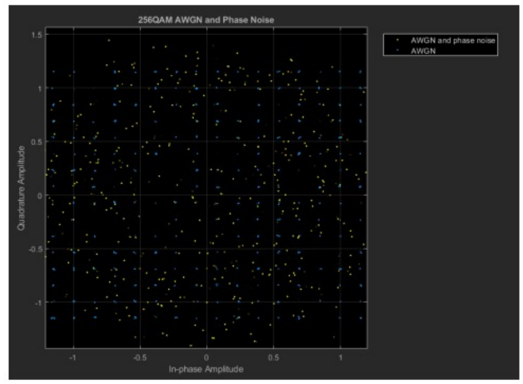


Fig. 4. Constellation diagram of 256-QAM for Eb/No=100 dB and PNLD=-30 dBc/Hz

Fig. 3. Constellation diagram of 256-QAM for Eb/No=100 dB and PNLD=-30 dBc/Hz

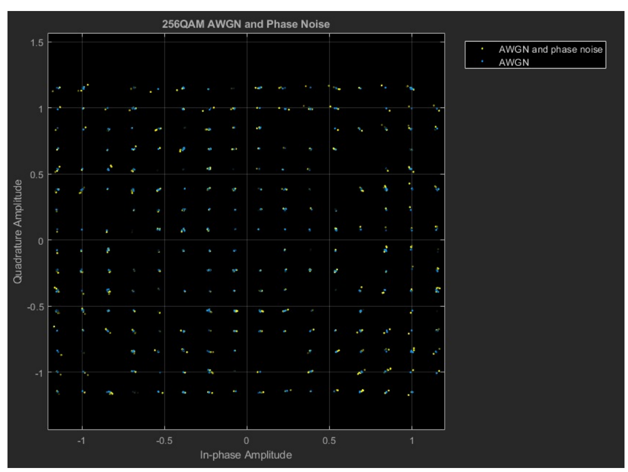


Fig. 4. Constellation diagram of 256-QAM for Eb/No=100 dB and PNLD=-80 dBc/Hz

To investigate how phase noise impacts the BER performance of the 256-QAM modulation technique, we varied the phase noise level density. We simulated the BER curve for each of the values [-88, -85, -82, -79, -76] dBc/Hz of the PNLD, and the results are presented in Fig. 6.

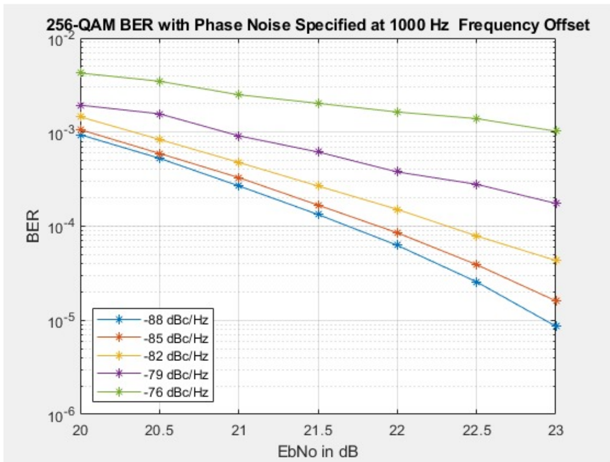


Fig. 5. BER vs. Eb/No for 256-QAM at different phase noise level densities

After incorporating the OFDM Modulator and Demodulator into the system, as illustrated in the block diagram in Fig. 7, the constellation diagram in Fig. 8 shows scattered points, highlighting the effect of OFDM on the signal.

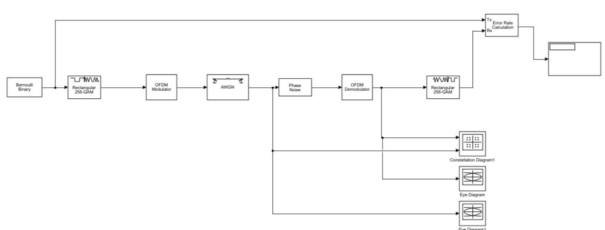


Fig. 6. OFDM block diagram

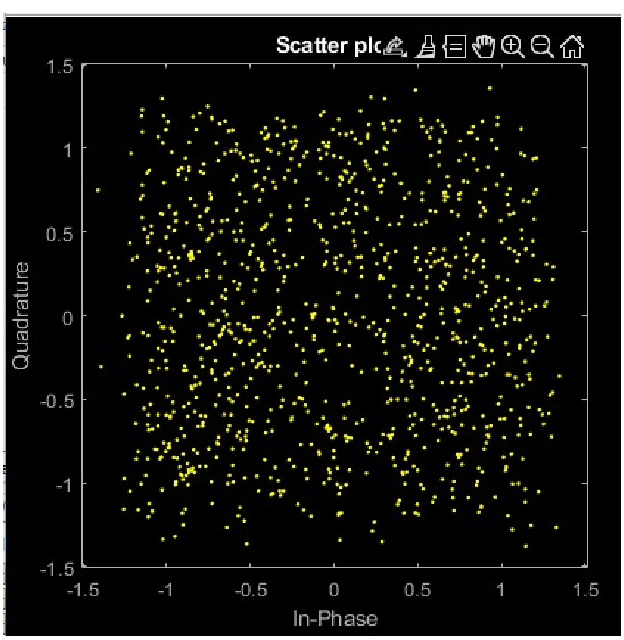


Fig. 7. OFDM scatter plot

To assess the performance of 256-QAM in comparison to other modulation schemes, the 256-QAM block was replaced with an M-PSK modulator and demodulator, as shown in the block diagram in Fig. 9.

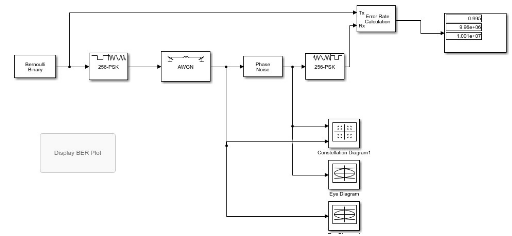


Fig. 8. M-PSK block diagram

The constellation diagram of the M-PSK modeling scheme was ring-shaped with the contellation clusters forming ring as depicted in Fig.10

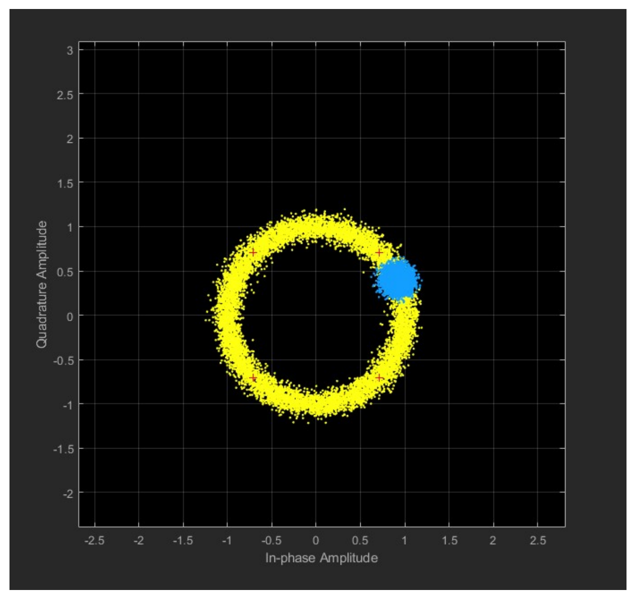


Fig. 9. M-PSK contellation diagram

IV. Discussion and Summary

The constellation diagram of 256-QAM in an AWGN channel, without the effects of phase noise (Fig. 3), shows distinct clusters that represent the modulation states. In this ideal situation, the signal points are accurately positioned with minimal spread, indicating a high signal-to-noise ratio (SNR). The clear separation of states highlights the strength of 256-QAM in an AWGN environment, confirming its effectiveness for high-data-rate transmission.

However, when phase noise is introduced, as illustrated in the scatter plots in Fig. 4 and Fig. 5, a significant shift occurs. The angular displacement of the constellation points increases, disrupting their optimal arrangement. A comparison of phase noise levels at -30 dBc/Hz and -80 dBc/Hz shows that reducing phase noise enhances signal stability, minimizing distortion and better preserving the modulation states.

Further insights are provided by the BER vs. Eb/No plot in Fig. 6, which emphasizes the effect of phase noise on system performance. The findings indicate that as phase noise decreases, the bit error rate (BER) also declines. This is due to phase noise causing random fluctuations in the signal's phase, leading to a spread of constellation points and a higher chance of errors. Lower levels of phase noise keep points closer to their intended locations, thereby improving reliability.

The introduction of OFDM, as depicted in Fig. 7, alters system behavior by splitting data into multiple orthogonal subcarriers, each carrying a 256-QAM symbol. The cumulative impact of phase noise across these subcarriers leads to additional distortion, with random rotations or jitter affecting each individual subcarrier. This is evident in the scatter plot (Fig. 8), where the constellation points are more spread out compared to a standard 256-QAM system, although OFDM does enhance spectral efficiency.

ACKNOWLEDGMENT

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[9](https://github.com/ctimmins96/256-QAM-Research-Paper GitHub)- ctimmins96/256-QAM-Research-Paper: Code Repository for my 256-QAM Research Paper that included discussion of Viterbi and error detection codes