# QPSK Adaptive Equalization: System Identification and Signal Recovery Using LMS

**B.Tech (AIDS)**
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# Motivation / Problem Statement

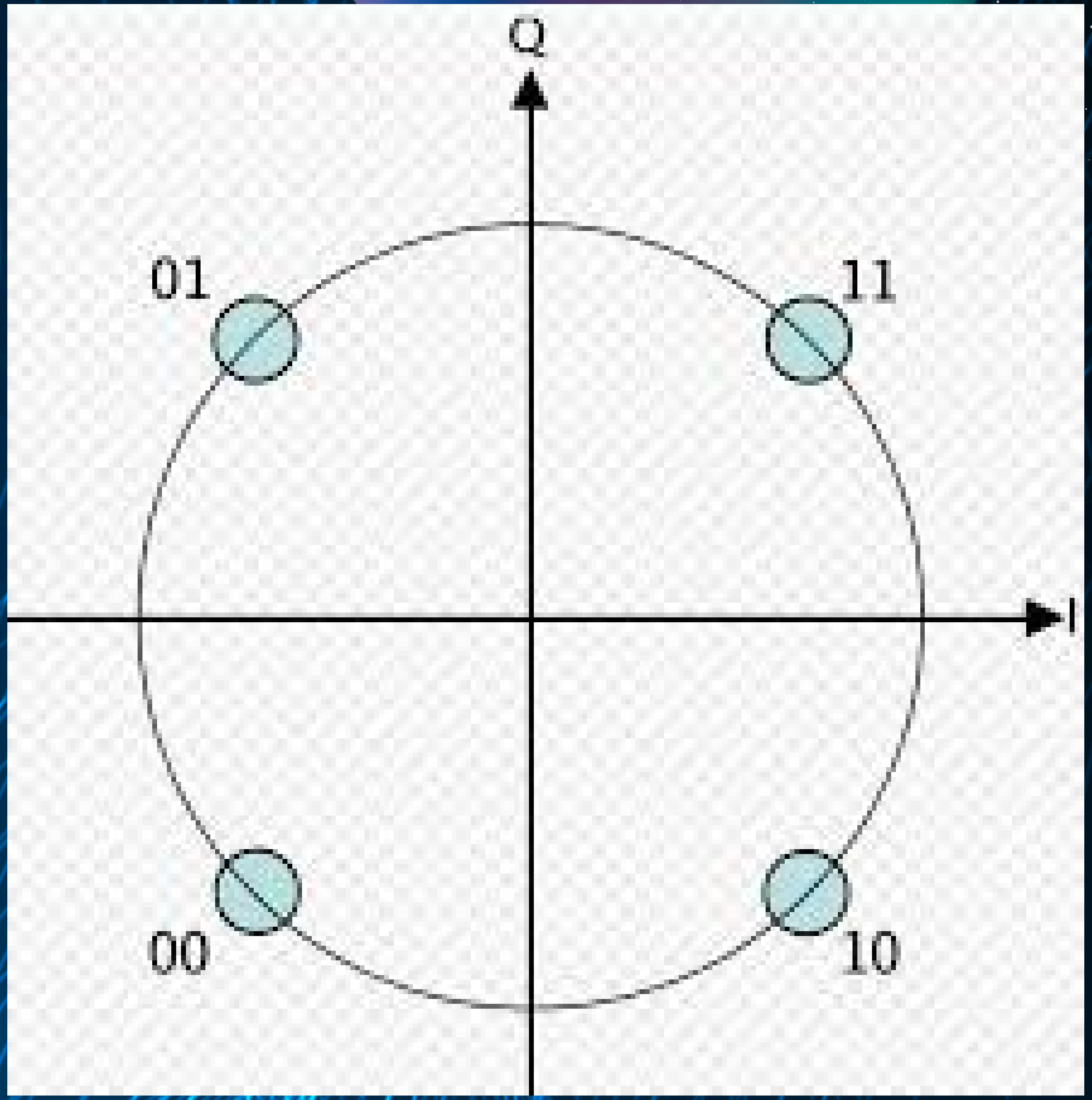
- Wireless channels suffer from multipath and noise
- Causes Inter-Symbol Interference (ISI)
- ISI distorts QPSK constellation
- Leads to high error rates

# OBJECTIVES

- To design and simulate a QPSK-based communication system.
- To model a multipath channel that introduces inter-symbol interference (ISI).
- To implement an LMS-based adaptive equalizer for signal recovery.
- To analyze LMS convergence using error magnitude plots.
- To validate system identification through constellation recovery.

# QPSK Overview

- Quadrature Phase Shift Keying (QPSK) is a digital modulation technique
- Transmits 2 bits per symbol by varying the carrier phase
- Uses four distinct phase states: $(\pm 1 \pm j)$
- Each phase represents a unique symbol in the constellation
- Provides higher spectral efficiency than BPSK
- Commonly used in wireless and satellite communication systems
- Performance degrades in multipath channels due to phase distortion and ISI



# System Design & Math Model

## Dynamic System Definition :

- Input/Output: Stochastic QPSK source $\longrightarrow$ Equalized symbol stream.
- System Type: Linear Time-Invariant (Channel) + Time-Varying (Equalizer).

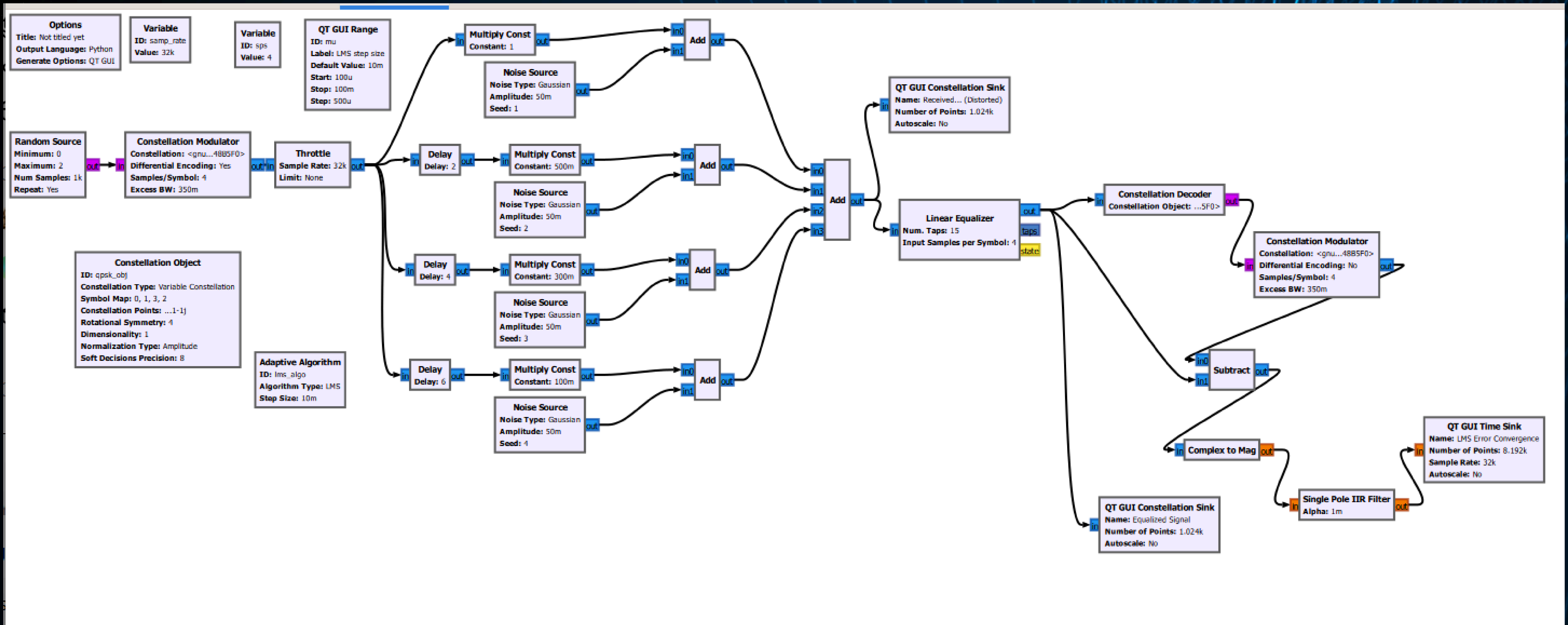
## Mathematical Formulation

**Channel Equation:** $$r(n) = \sum_{k=0}^{L-1} h(k)s(n-k) + w(n)$$

**LMS Weight Update Equation:** $$w(n+1) = w(n) + \mu e(n)u^*(n)$$

# GNU RADIO FLOWGRAPH

- Tx: Random Source → QPSK Modulator.
- Channel: Tapped Delay Line (Severe ISI) + AWGN.
- Rx: Linear Equalizer (LMS) → Decoder.



# Simulation Parameters & Analysis

## Key Parameters:

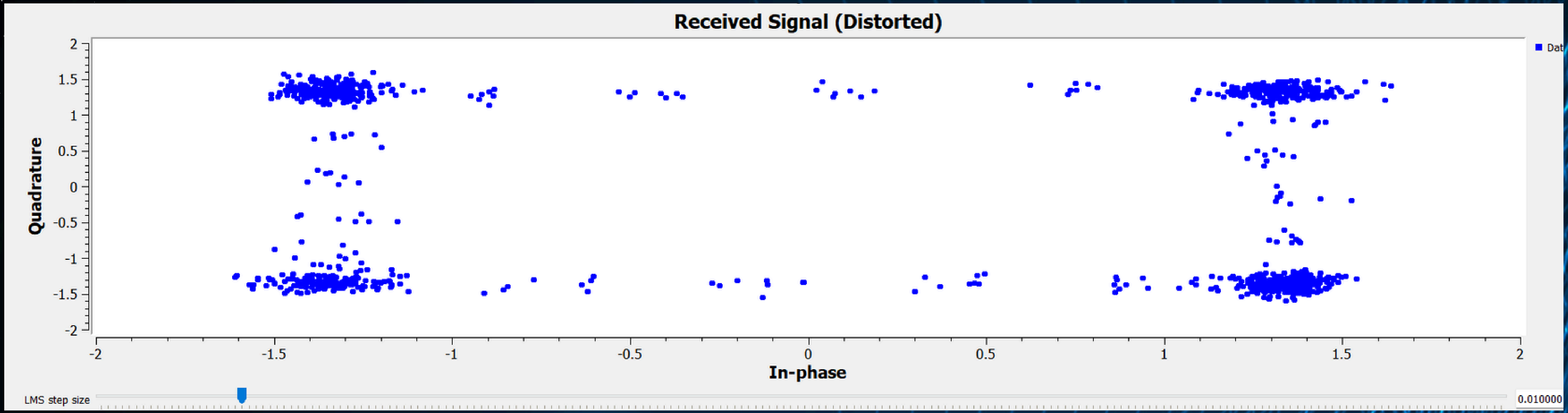
- Sample Rate: 32 kHz.
- Channel Taps: [1, 0.5, 0.3, 0.1] (Guarantees closed eye/ISI).
- LMS Step Size (mu): 0.01 (Stability criteria met).

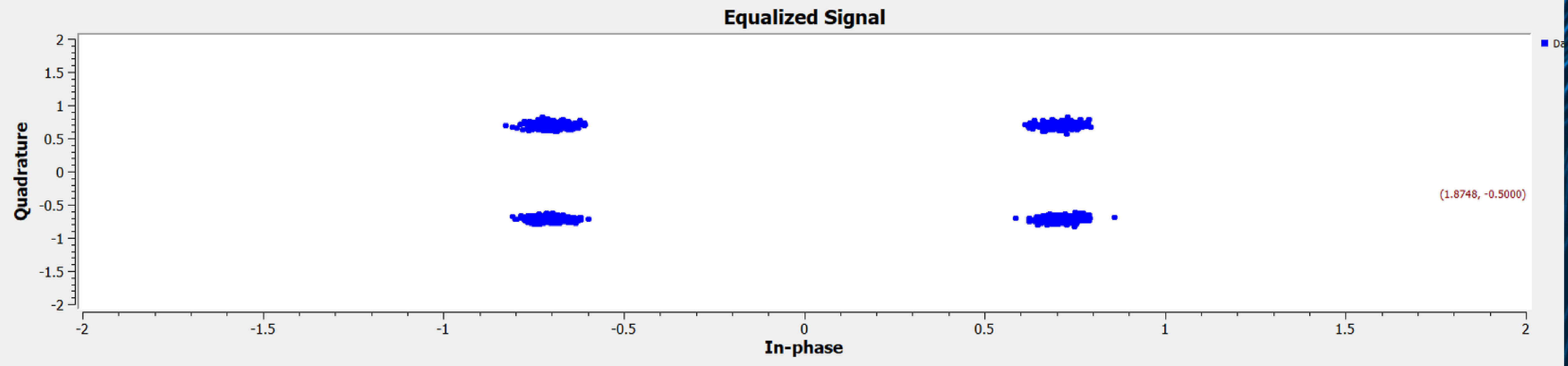
Table 3.1: Simulation Parameters and Theoretical Justification

| Parameter | Value | Justification (Theoretical Reference) |
|---|---|---|
| Sample Rate | 32 kHz | Sufficient to represent baseband signal (Nyquist). |
| Samples/Symbol | 4 | Provides resolution for pulse shaping. |
| Channel Taps | $[1, 0.5, 0.3, 0.1]$ | **Severe ISI:** Magnitudes of delayed paths guarantee a closed eye diagram. |
| LMS Step Size ($\mu$) | 0.01 | **Stability:** Satisfies $0 < \mu < 2/\lambda_{max}$ for stable convergence [2]. |
| Equalizer Taps | 15 | $> L$ (channel length) to allow inversion. |
| Noise Amp | 0.05 | Simulates moderate SNR. |

# Run Time & Frequency Domain Simulations

- "Received" plot showed scattered clouds (ISI).
- "Equalized" plot showed distinct QPSK clusters.



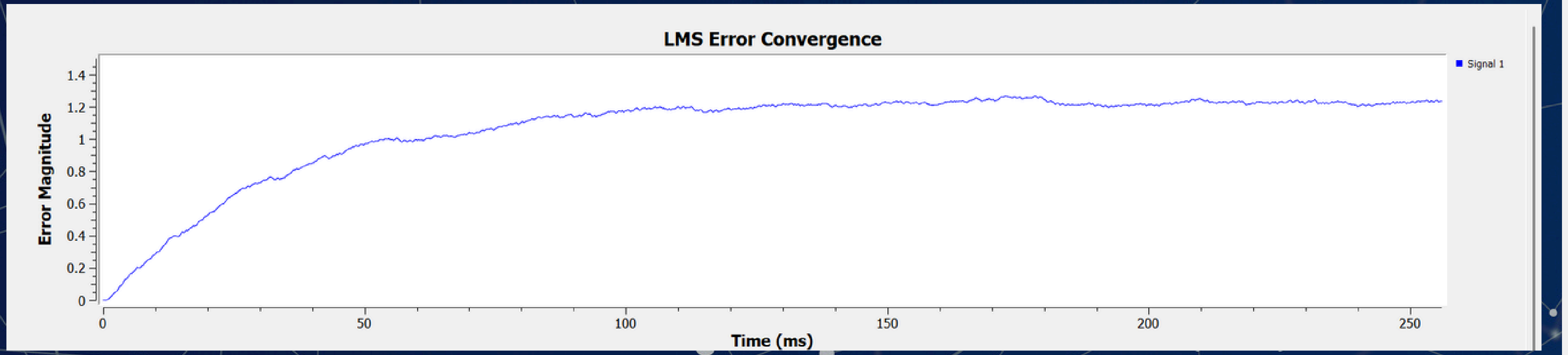



# Theoretical Validation

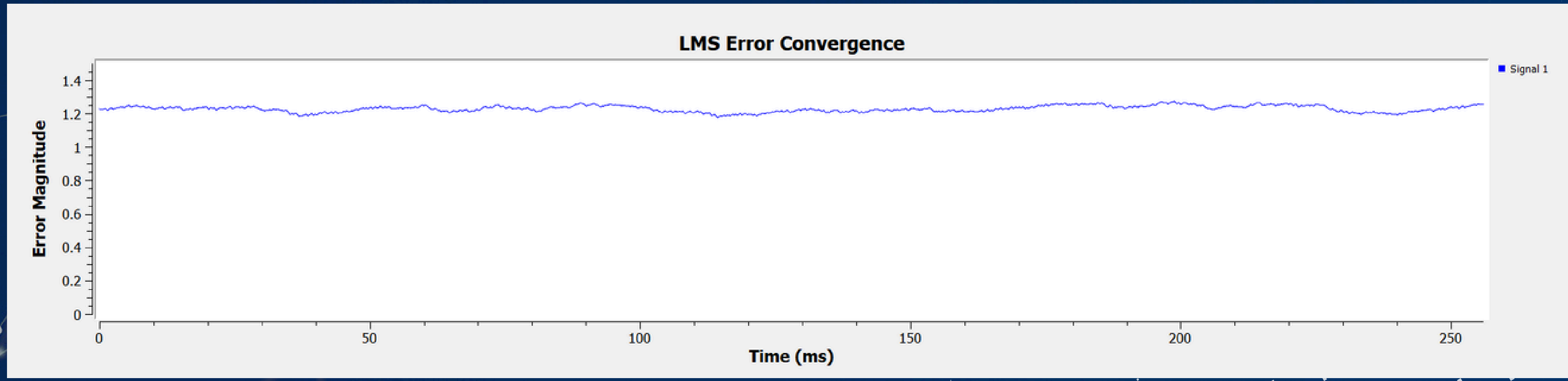
Expectation: Steady-state error approx Noise floor (0.05).

Observation: Simulation matches theoretical exponential decay.

# Analyze Dynamic & Performance Response




Transient Phase (0-100ms): Rapid learning.

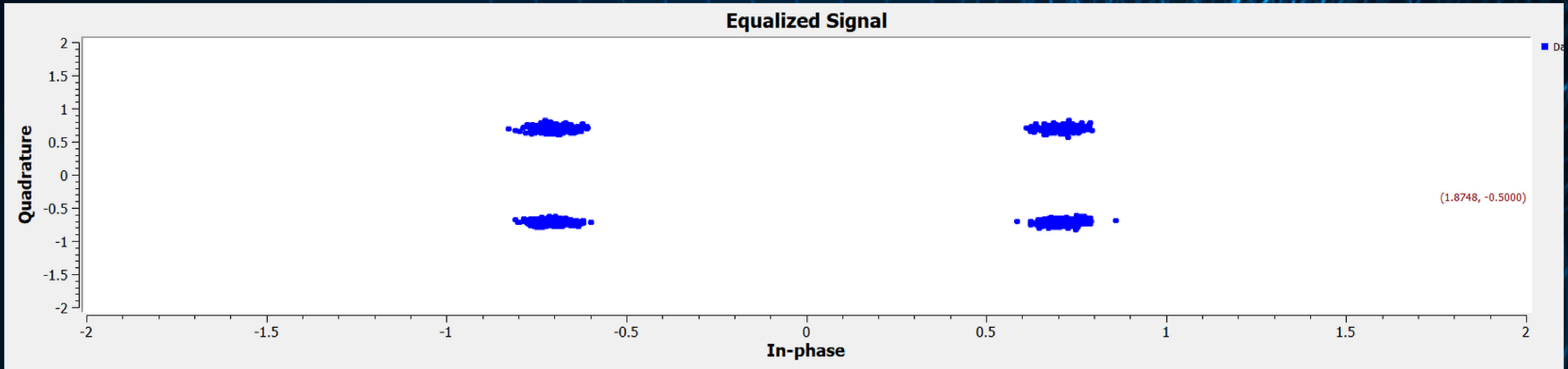



Steady-State: Noise floor oscillation.

# Validate & Optimize the Model

## Validation:

Constellation "opening" confirmed the Linear Equalizer effectively inverted the Linear Channel.




## Model Optimization:

- mu = 0.002 (Overdamped/Slow).
- mu = 0.08 (Underdamped/Unstable).
- mu = 0.01(Optimal): Achieved best convergence speed vs. stability.

# FINDINGS

- **Trend 1: Higher step size mu = faster convergence but higher noise.**
- **Trend 2: Multipath distortion acts as a linear filter that is reversible by an adaptive FIR filter.**
- **Discrepancy: Real-time error signal is noisy due to the  gradient approximation in LMS.**

# Errors Encountered & Debugging

- Constellation distortion even after equalizer.

  **FIX:** Constellation object & LMS parameters corrected.
- No direct error port .

  **FIX:** Manual error calculation circuit built.
- Large step size caused instability.

  **FIX:** Tuned by changing the parameter

# Conclusion

- Effective Mitigation: The LMS equalizer successfully removed severe multipath distortion and Inter-Symbol Interference (ISI).
- Blind Adaptation: The system recovered the signal without any prior knowledge of the channel characteristics.
- Validated Results: Clear QPSK clusters and stable error plots confirmed the accuracy of the model.
- Modeling Success: GNU Radio proved to be an effective tool for simulating dynamic communication systems.

# Thank You!