

# Implementation Of Psam Fading Estimator for Wireless Communication

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**Abstract**—Channel estimation is necessary in wireless communication systems that are affected by noise as well as multipath fading. In this project, a Pilot Symbol Assisted Modulation (PSAM) method of channel estimation is designed using VHDL and simulated using Vivado software. The input signal is changed, and different channel conditions are analyzed by observing the spikes in the output. The changes in the input signal are used to mimic the noise conditions, similar to the AWGN channel in actual communication systems. Small spikes indicate low noise conditions, while large changes indicate high channel disturbance. The interpolation method is used to smooth the output, as shown by the spikes, which makes the channel estimation process stable.

**Index Terms**—Channel Estimation, PSAM, VHDL, Vivado, Pilot Symbols, Multipath Fading, Interpolation

## I. INTRODUCTION

Wireless communication systems are everywhere these days, powering things like cell phones, internet connections, and data transfers. But transmitting signals isn't always smooth—there's noise, interference, and multipath fading to deal with. All these problems mess up the signal and make it tough for the receiver to recover the original information. That's where channel estimation comes in. It's basically the process of figuring out how the signal gets changed by the transmission path, so the receiver can adjust for distortions and pull out the cleanest possible signal. If channel estimation is accurate, the system sees fewer errors, gets better signal quality, and runs more reliably. People have developed a bunch of techniques to estimate the channel—like Least Squares (LS), Minimum Mean Square Error (MMSE),

and Pilot Symbol Assisted Modulation (PSAM). PSAM is especially popular because it's straightforward and easy to set up. The idea is to regularly insert known pilot symbols into the transmitted signal. When the receiver picks them up, it uses these as reference points to estimate how the channel's behaving, then fixes the incoming data accordingly. For this project, I built a channel estimation system based on PSAM using VHDL and simulated it using the Vivado tool. The system grabs the input signals, processes them through different blocks—things like buffers, multipliers, and interpolation modules—and spits out an estimated channel signal. To see how well the estimator works, I tested it under various channel conditions by changing the input signal values. When the inputs barely change, the output stays fairly stable, showing small spikes. Make the input more variable, and the output shows bigger spikes—signaling more disruption in the channel. Interpolation techniques also play a part here. For example, since interpolation helps smooth out the estimated output, cutting down on wild fluctuations and making the results more stable. Even with large changes in the input, the output stays relatively steady. Those spikes and fluctuations in the output actually mimic how noise shows up in real wireless systems. I didn't stick a direct noise model into the system, but by varying the input, I could see how the estimator responded to different kinds of disturbance. Looking at the simulation results, it's clear the system delivers stable and reliable channel estimation. It handles input variations well and keeps the output under control, making it a solid candidate for real-time communication systems.

### 1.1. Research Objectives

The primary objective of this work is to design and implement a channel estimation system based on Pilot Symbol Assisted Modulation (PSAM) using VHDL. In modern wireless communication systems, channel estimation plays a critical role in ensuring reliable data transmission, as the transmitted signal is affected by noise, fading, and interference. Therefore, this work aims to develop a hardware-efficient estimation technique that can accurately identify the channel characteristics and assist in recovering the transmitted signal with minimal distortion. Another important objective of this project is to analyze the behavior of the channel estimator under varying signal conditions. In order to achieve this, different input patterns and amplitudes are introduced into the system to simulate realistic channel environments. These variations represent different types of noise conditions, including low noise, moderate noise, and high noise scenarios. The effect of these variations is observed through output waveforms, where the estimator response is represented in the form of flat regions and spikes. A flat output indicates a stable channel with minimal noise, while small spikes correspond to low noise conditions such as additive white Gaussian noise (AWGN). Larger spikes represent severe channel variations caused by multipath fading. By analyzing these patterns, the system behavior under different channel conditions can be clearly understood. The work also focuses on evaluating the stability and robustness of the proposed PSAM-based estimator. In practical communication systems, sudden fluctuations in the estimated channel can lead to incorrect data recovery. To address this issue, interpolation techniques are incorporated into the design to smooth the estimated values and reduce abrupt variations. The objective is to ensure that even when the input signal undergoes significant changes, the output remains controlled and stable. Another key objective is to implement the complete channel estimation system using VHDL and verify its functionality using the Vivado simulation environment. The design is constructed using multiple hardware modules such as buffers, delay elements, multipliers, and estimation blocks. Each module contributes to the overall functionality of the system, demonstrating how theoretical concepts of channel estimation can be translated into practical hardware implementation. The FPGA-based implementation further ensures that

the design is suitable for real-time applications. The work also aims to compare the performance of the proposed PSAM-based estimator with conventional estimation techniques such as Least Squares (LS) and Minimum Mean Square Error (MMSE), and to demonstrate that the proposed method provides an effective balance between estimation accuracy, robustness, and hardware implementation complexity. The comparison is carried out based on waveform behaviour and estimation accuracy, where LS shows large irregular spikes due to high noise sensitivity, MMSE shows moderate variations with improved stability, and the proposed method produces smoother and more controlled output. This confirms that the proposed system adapts effectively to varying channel conditions while maintaining stable performance, making it suitable for practical wireless communication applications.

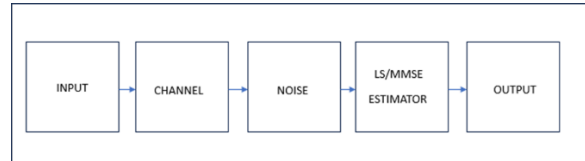


Fig:1 Block diagram of existing channel estimation method using ls/mmse

## II. EXISTING METHOD

In wireless communication systems, several channel estimation techniques have been developed to reduce the effect of noise and improve signal recovery. Among these

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However, each method has certain limitations in terms of complexity, accuracy, and hardware implementation. The Minimum Mean Square Error (MMSE) method improves the performance of LS by considering noise statistics and minimizing the overall estimation error. This method provides better accuracy compared to LS, especially in noisy environments. However, MMSE requires complex matrix calculations and inversion operations, which increase the computational complexity. Due to this high complexity, MMSE is difficult to implement efficiently in hardware-based systems such as FPGA. The improvement of MMSE over LS can be observed in the waveform results, where the output variations are more controlled. The values change gradually, for example from -2000 to -2500, -3000, -2200, -2700, and -3100, showing moderate fluctuations instead of large abrupt spikes. This indicates that MMSE reduces noise impact to some extent, but still does not completely eliminate estimation variations. Due to the limitations of these existing methods, there is a need for a technique that provides a balance between accuracy and implementation complexity. In practical systems, especially hardware-based implementations, it is important to use methods that are not only accurate but also simple to implement. This motivates the use of Pilot Symbol Assisted Modulation (PSAM), which provides a reliable and efficient way to estimate the channel using known pilot symbols while maintaining manageable complexity.



Fig:2 Waveform of conventional LS channel estimation showing large irregular spikes due to high sensitivity to noise



Fig.3 Waveform of MMSE channel estimation showing moderate variations with improved stability compared to LS

### III. PROPOSED SOLUTION

The proposed system implements a Pilot Symbol Assisted Modulation (PSAM) based channel estimation technique using VHDL, with the objective of accurately estimating the channel response under different noise and fading conditions while maintaining stable output behaviour. In practical wireless communication systems, the transmitted signal is affected by various impairments such as Additive White Gaussian Noise (AWGN) and multipath fading. Therefore, the proposed method is designed to analyse and respond to these channel conditions effectively by using pilot-assisted estimation and interpolation techniques.

The overall flow of the proposed system begins with the generation of known pilot symbols, which are inserted into the transmitted signal. These pilot symbols act as reference points that enable the estimator to identify the characteristics of the channel. The signal is then passed through a channel model, where variations are introduced to represent realistic communication conditions. These variations include both small random disturbances corresponding to AWGN and larger fluctuations corresponding to multipath fading. The received signal, which contains these distortions, is then processed by the PSAM estimator block to obtain the estimated channel response.

The estimation process follows a systematic computational flow. Initially, the received signal corresponding to pilot symbols is compared with the known transmitted pilot values. Based on this comparison, an estimated channel value is obtained. The estimation error is then calculated as the difference between the true channel value and the

estimated value. This error is further processed by computing its magnitude squared. Similarly, the magnitude squared of the true channel is calculated. The Normalized Mean Square Error (NMSE) is then obtained by taking the ratio of the error magnitude squared to the true channel magnitude squared. This step-by-step process effectively represents the flow of NMSE computation, which is used as the primary performance metric in the proposed system.

The NMSE values provide a clear understanding of estimation accuracy under different conditions. When the channel is ideal and no noise is present, the NMSE value approaches zero, indicating perfect estimation. Under low noise conditions, the NMSE value is approximately 0.05, which corresponds to small estimation error. For moderate noise conditions, the NMSE ranges between 0.1 and 0.2, indicating noticeable but acceptable deviation. In cases of high noise or severe distortion, the NMSE exceeds 1, which indicates poor estimation performance. Thus, NMSE serves as a quantitative measure to classify channel conditions as excellent, good, average, or poor.

The proposed system considers two major types of noise effects. The first is Additive White Gaussian Noise, which introduces small random variations in the signal. For example, a transmitted signal of the form  $(1 + j1)$  may be slightly altered to values such as  $(1.02 + j0.02)$  or  $(0.95 + j0.05)$ . These small deviations represent low noise conditions and are considered favourable for estimation, as the estimator is capable of accurately tracking such minor variations. The second type is multipath fading, which includes Rayleigh and Rician fading effects. In this case, the signal undergoes larger fluctuations over time, such as transitioning from  $(1 + j1)$  to  $(0.5 + j0.5)$  and further to  $(0.3 - j0.8)$ . These variations indicate strong fading conditions and lead to higher estimation errors.

The behaviour of the estimator is analysed through waveform outputs obtained from Vivado simulations. Under stable channel conditions, where the input signal remains constant, the output waveform appears flat with only minimal variation. For example, the observed output values remain within a narrow range such as  $-6026$  to  $-6094$ , indicating stable estimation with very low NMSE. When small variations are introduced in the input signal, corresponding to AWGN conditions, the output waveform exhibits small spikes. The observed values, such as  $-2018$ ,  $-2026$ ,  $-2034$ ,  $-2038$ , and  $-2040$ , show controlled

fluctuations, which confirm that the estimator is accurately tracking minor channel changes while maintaining stability.

In contrast, when large variations are applied to simulate multipath fading conditions, the output waveform shows significant spikes. The observed values, such as  $-240000$ ,  $-245014$ ,  $-244086$ ,  $-243066$ , and  $-248512$ , indicate large fluctuations in the estimated channel. These spikes correspond to high noise conditions and increased NMSE values. However, it is important to note that these variations are not errors but represent the correct response of the estimator to severe channel conditions. The estimator continues to track the channel variations rather than producing random or unstable outputs.

The overall behaviour of the estimator clearly demonstrates that the output variation is directly related to the input channel condition. A stable channel produces a flat output, low noise conditions result in small spikes, and high noise conditions lead to larger spikes. This confirms that the estimator is adaptive and responds correctly to changes in the channel. Additionally, certain failure conditions were identified, such as corrupted pilot symbols and empty pilot buffers, which lead to increased NMSE and unstable outputs. These conditions further validate that the estimator performance depends on the availability and quality of pilot information.

Compared to conventional estimation techniques such as Least Squares (LS) and Minimum Mean Square Error (MMSE), the proposed PSAM method provides improved stability and reliability. The use of pilot symbols ensures accurate channel tracking, while the interpolation process reduces abrupt variations in the output. As a result, the proposed system produces smoother and more controlled output waveforms, even under varying noise conditions. This demonstrates that the proposed PSAM-based channel estimation technique is more robust and suitable for practical wireless communication systems.

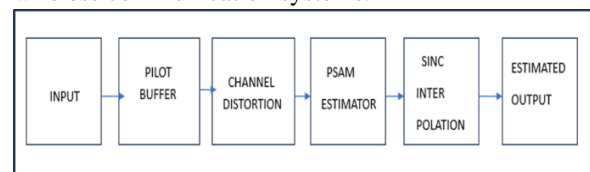


Fig:4 Block diagram of proposed channel estimation method

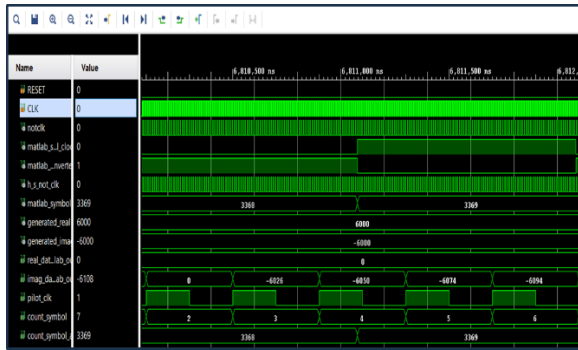


Fig.5 Output waveform of the proposed PSAM estimator under stable channel conditions showing minimal variation (flat response).

The flat output indicates that the channel is stable and the estimator produces consistent values with very low NMSE.

The small spikes represent minor channel variations caused by AWGN, where the estimator accurately tracks the changes.

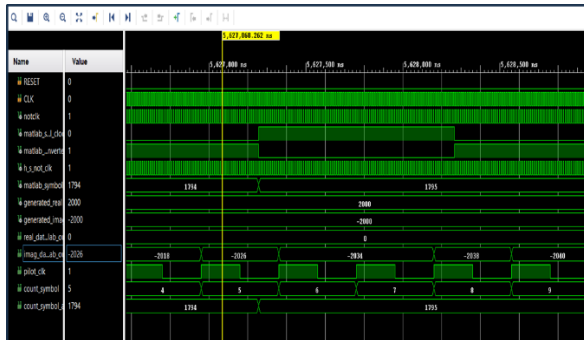


Fig.6 Output waveform of the proposed PSAM estimator under low noise (AWGN) conditions showing small controlled variations

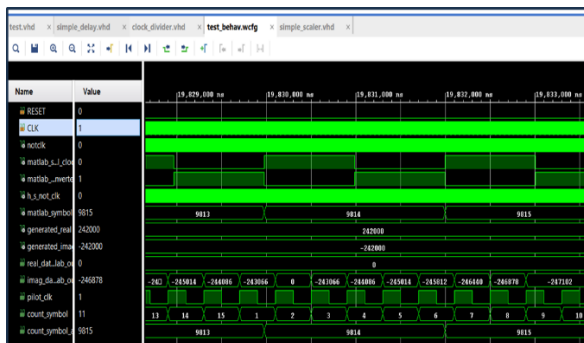


Fig.7 Output waveform of the proposed PSAM estimator under high noise/multipath conditions showing significant variations

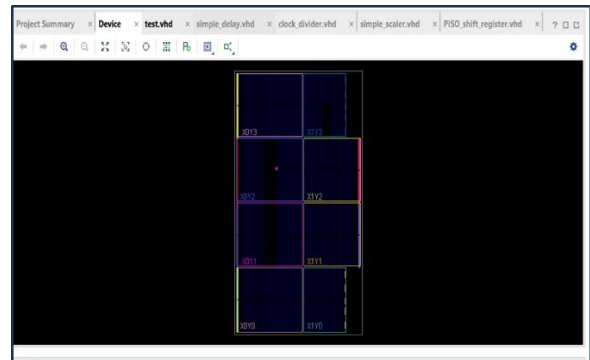


Fig.8 FPGA implementation layout of the proposed PSAM channel estimation system.

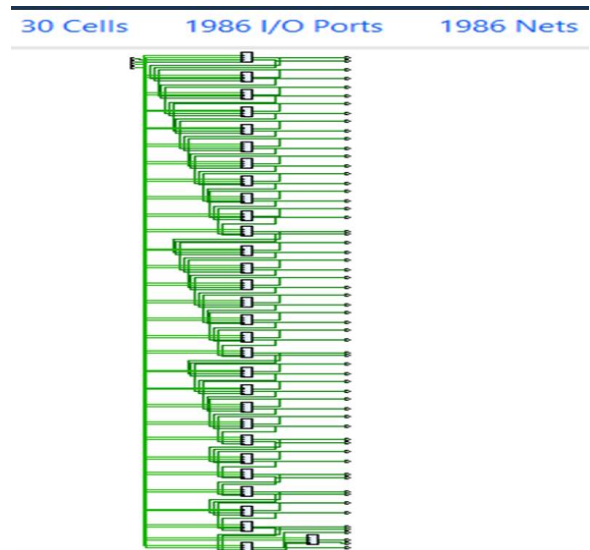


Fig.9 Schematic diagram of the proposed PSAM-based channel estimation system implemented in Vivado.

#### IV. REFERENCE IMAGES

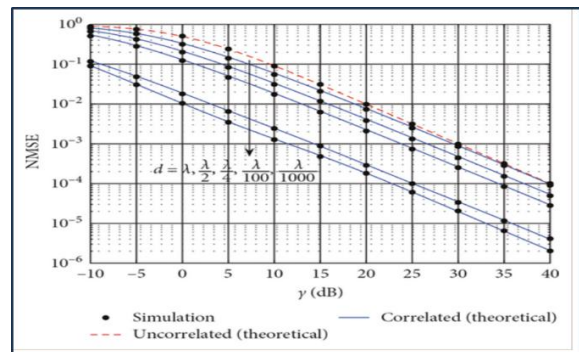


Fig.10 NMSE for MMSE channel estimation in an M-MIMO system as a function of the SNR and parameterized by different values of ULA interelement spacing, given in terms of  $\lambda$ ,

considering  $M = 100$  antennas and a correlated Rayleigh fading channel.

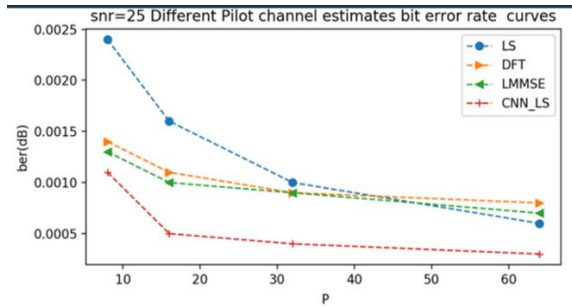


Fig.11 CNN\_LS Algorithm BER vs. No. of pilots for different channel estimation methods

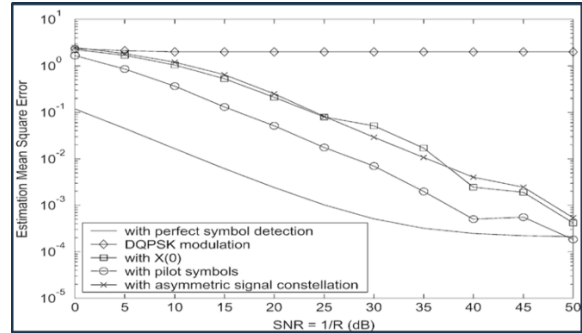


Fig.15 Channel estimation MSE of various solutions to isometry for DQPSK modulation at  $f T = 0:006 37$ .

V. COMPARISON TABLE

PARAMETER	EXISTED	PROPOSED
NMSE RANGE (clean channel)	~0 – 0.1	~0 – 0.05
NMSE RANGE (low noise)	~0.1 – 0.3	~0.05 – 0.15
NMSE RANGE (High noise)	~0.3 – 1.0+	~0.3 – 1.0+
OUTPUT BEHAVIOR	Mostly unstable or fluctuating	Controlled spikes
CHANNEL TYPE	Assumes static or mildly varying channel	Handles dynamic and rapidly varying channels

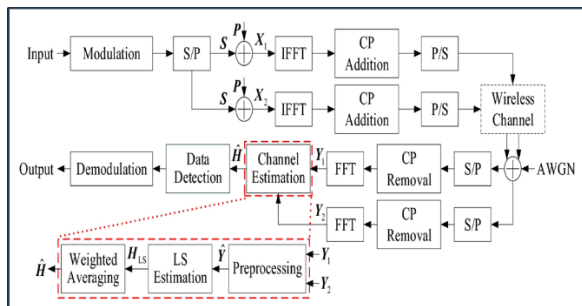


Fig.12 Channel estimation based on superimposed pilot and weighted averaging

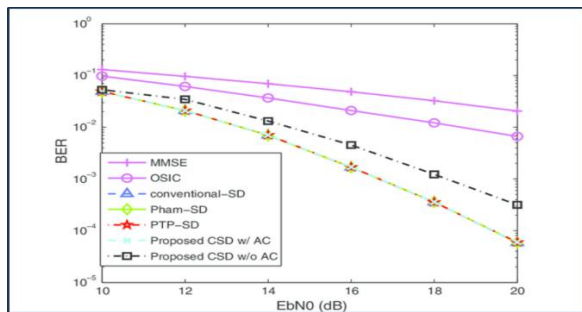


Fig.13 BER performance with LS channel estimation.

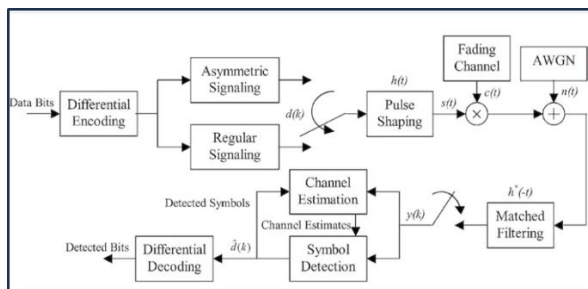


Fig.14 CE/DD system in a multiplicative fading channel with additive noise for an AM/PM modulation scheme.

VI. CONCLUSION

The proposed PSAM-based channel estimation system has been successfully designed and implemented using VHDL and verified through FPGA simulation in Vivado. The system effectively captures different channel conditions by representing them as distinct output patterns. A flat output indicates a stable channel, small spikes correspond to low noise conditions similar to AWGN, and large spikes represent severe multipath fading. Compared to conventional LS and MMSE estimators, the proposed method demonstrates improved robustness and reduced error under varying noise conditions. Existing methods often suffer from increased NMSE and instability as noise increases, whereas the proposed system maintains controlled variation and better adaptability. The FPGA implementation further confirms efficient hardware utilization and real-time capability. Overall, the

proposed PSAM-based estimator provides a practical, reliable, and hardware-efficient solution for channel estimation in wireless communication systems.

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