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Implementation Of Phase Frequency Detector And Voltage Controlled Oscillator

Dr. S. V. Viraktamath[1], Vaishnavi Peshwe[2], Dhanaraj Shivashimpi[3], Disha Majjigudda[4], Navami Telsang [5]
(Electronics And Communication Department, SDM College Of Engineering And Technology, Dharwad, India)

Abstract:
An enhanced Phase Frequency Detector (PFD) and Voltage-Controlled Oscillator (VCO) are designed to improve performance in frequency synthesis and clock generation. The PFD achieves reduced dead zone, faster response times, and lower power consumption, ensuring greater accuracy and efficiency in phase detection. The VCO offers a wide tuning range, low phase noise, and high sensitivity, all while maintaining a low power profile, making it suitable for high-frequency applications. Designed and evaluated using Cadence EDA tools, the performance of these components is validated through simulations and experiments, demonstrating their suitability for integration into advanced communication and signal processing systems.
Key Word: *DPLL, FPGA, Cadence, frequency synthesis, clock generation*

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I. Introduction

A digital phase locked loop (DPLL) is a type of frequency synthesizer that utilizes digital circuits to achieve precise frequency generation. Unlike analog PLLs, DPLLs incorporate digital components such as digital phase detectors, digital filters, and digital-to-analog converters (DACs). This digital implementation offers several advantages, including improved noise performance, increased flexibility in frequency tuning, and enhanced programmability. DPLLs are widely used in modern communication systems, such as wireless networks and satellite systems, where precise frequency control is critical [1]. Accurate detection of the grid-voltage phase angle is essential for the proper operation of various grid-connected power electronic systems, such as grid-tied inverters and grid-side rectifiers. Traditional method, such as Phase-Locked Loops (PLLs), can be effective but are susceptible to disturbances like voltage unbalance and harmonics. This research paper explores the use of Delayed Signal Cancellation (DSC) techniques, specifically Generalized DSC (GDSC) and Cascaded DSC (CDSC), to effectively eliminate harmonics from the grid voltage signal. These techniques aim to improve the accuracy and robustness of grid-voltage phase angle detection by minimizing the impact of disturbances. However, the authors acknowledge the potential for discretization errors in the digital implementation of DSC, which can affect its performance. To address these challenges, the paper proposes a comprehensive analysis of DSC in both dq and αβ reference frames, facilitating a more thorough understanding and improved implementation of these techniques [2]. Phase-Locked Loops (PLLs) are essential components in many communication systems, but their power consumption can be significant, particularly due to the Phase Frequency Detector (PFD). Traditional PFD designs often exhibit high power dissipation, especially within "dead zones" of their operation. A novel approach to minimize power consumption in PFDs involves eliminating these dead zones, leading to improved power efficiency of the overall PLL circuit. styles are provided [3]. Figure 1 illustrates the traditional block diagram of a Phase-Locked Loop (PLL). The primary function of a PLL is to generate an output signal that precisely matches the phase of a reference signal. This accurate phase tracking is achieved through a continuous process of comparing the reference signal with the feedback signal and iteratively adjusting the output signal to minimize the phase difference.

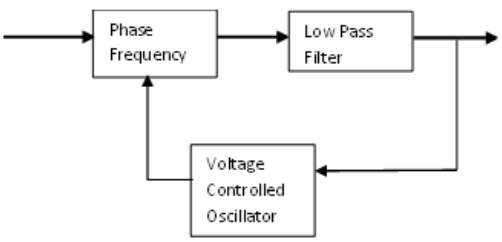

Figure 1. Basic block diagram of PLL [3].

II. Architecture Of Phase Frequency Detector

Traditional phase frequency detector

A simple and common implementation of a Phase Frequency Detector (PFD) utilizes an XOR gate. This configuration compares two input signals: the reference signal and the feedback signal from the Voltage-Controlled Oscillator (VCO). The XOR gate's output is high only when the input signals have different logic levels. By analyzing the timing of these output pulses, the PFD can determine the phase difference between the two input signals. This information is then used to generate an error signal that drives the VCO to adjust its frequency and achieve phase lock with the reference signal [4]. Figure 2 shows the traditional digital PLL.

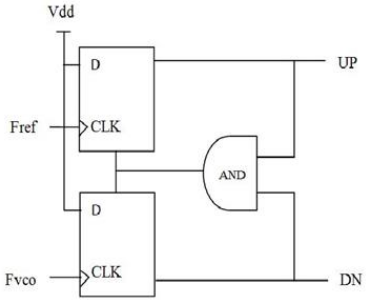

Figure 2. Traditional Digital PLL [5].

Phase-Locked Loops (PLLs) rely heavily on Phase Frequency Detectors (PFDs) for accurate phase tracking. However, traditional PFD designs often exhibit a "dead zone," a region where small phase differences between input signals cannot be accurately detected. This limitation can significantly impact PLL performance. To address this issue, novel PFD architectures have been proposed that aim to completely eliminate the dead zone while simultaneously achieving high operating frequencies, minimizing power consumption, and reducing the overall circuit area. These improvements are crucial for enhancing the overall performance and efficiency of PLL systems [5].

Enchaced Phase frequency detector design

The PFD circuit employs a combination of PMOS and NMOS transistors to generate UP and DN signals based on the timing relationship between two input signals: CLKref and CLKvco. Initially, both UP and DN signals are low. Upon the rising edge of CLKref, the UP signal goes high, followed by the DN signal going high on the rising edge of CLKvco. When both CLKref and CLKvco rise simultaneously, both UP and DN signals quickly return to low. This rapid transition, facilitated by the inclusion of inverters (Inv1 and Inv2), contributes to increased operating speed compared to traditional PFDs, enhancing the overall performance of the PLL system [6]. As shown in figure 2 below.

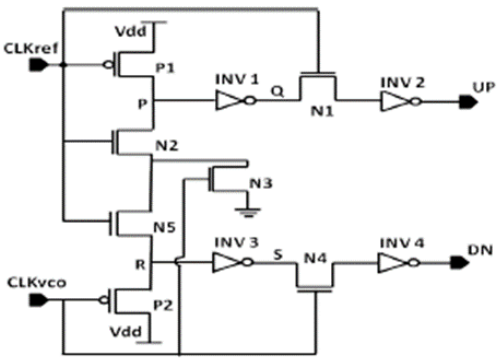

Figure 3. Schematic of Enhanced PFD [7].

This approach to PFD circuit design involves the use of pass transistor logic. By replacing conventional CMOS transistors with pass transistors, this design aims to reduce power consumption while potentially mitigating voltage degradation. The circuit employs 'CLK_REF' as the reference clock signal input to the upper half and 'CLK_VCO' as the input to the lower half, with 'UP' and 'DOWN' representing the respective output signals. This pass transistor-based approach offers a potential solution for enhancing the power efficiency of PLL circuits as shown in figure 3 [8].

Implementation without reset path

Traditionally, PFD circuits incorporate a "reset path" – a feedback line that typically utilizes a NOR gate. While effective, the reset path can increase circuit complexity and area due to the additional transistors required. This paper proposes a novel PFD circuit design that eliminates the need for this reset path. Instead, the design strategically shares the reference clock (CLKref) and VCO clock (CLKvco) signals in the initial stages of the circuit. The proposed PFD circuit consists of 14 transistors (8 PMOS and 6 NMOS) and is expected to exhibit improved performance and reduced area compared to traditional designs. The subsequent section of the paper will present a comparative analysis of the proposed PFD with a reference design, including a detailed evaluation of power consumption at various operating frequencies (100 kHz to 4 GHz) with a supply voltage of 1.8V [9].

III. Implementation Of VCO

Voltage-Controlled Oscillators (VCOs) are essential components in numerous electronic systems, including phase-locked loops (PLLs), frequency synthesizers, and communication systems. VCOs generate an output signal whose frequency is directly proportional to an applied control voltage, enabling precise frequency adjustments. This paper focuses on the design and implementation of a VCO circuit, considering the critical design factors such as tuning range and linearity. The specific techniques and methodologies employed in the VCO design and implementation will be discussed [10].

Current starved oscillator

A Current Starved Voltage Controlled Oscillator (CSVCO) utilizes a ring oscillator topology where inverters are starved for current, limiting their current availability. This current limitation is controlled by adjusting the current flowing through transistors M5 and M6, which are mirrored from the inverter/current source stages. By controlling the current through M5 and M6 with an input control voltage, the oscillation frequency of the CSVCO can be effectively tuned. Figure 4 design leverages current starvation as a key mechanism for voltage-controlled frequency tuning [11].

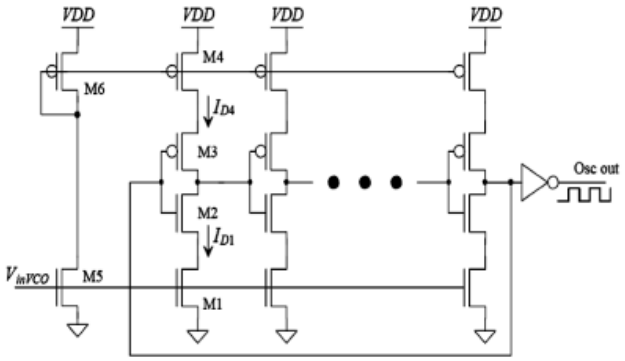

Figure 4. Current starved oscillator [11].

The PLL's output clock originates from the Voltage-Controlled Oscillator (VCO), which produces a periodic signal. This signal's frequency is adjustable by modifying the control voltage. Within the PLL, the control voltage reflects a filtered version of the phase error. In response, the VCO adjusts its frequency to minimize this phase error. As the VCO frequency is modified by the control voltage, the phase error is gradually reduced towards zero as shown in the circuit in figure 3 [12]. The PLL demonstrates significant improvements. The integrated VCO exhibits a wide tuning range (167 MHz to 1.711 GHz) and high gain (2.21 GHz/V), surpassing previous designs. The PLL achieves a substantial pull-in range of 950 MHz (50 MHz to 1 GHz) with a maximum jitter of only 9.8 ps. Notably, the PLL operates with low power consumption of 277.2 μW and exhibits a fast pull-in time of 265 ns at 1 GHz. The PLL circuit was implemented using the UMC 0.18 μm process technology with a supply voltage of 1.8 V and simulated using Cadence Spectra simulator [13].

Transformer coupled VCO.

This design focuses on a Voltage-Controlled Oscillator (VCO) incorporating quadrature frequency locking and injection techniques, with modifications to self-injection methods to minimize phase noise and quadrature errors. Key factors influencing VCO design are explored, including the effects of high currents in transformers, the relationship between electromagnetic force and core properties, the impact of tuning range on phase noise, and the significance of high Q-factor components in achieving low phase noise levels. These considerations are crucial for optimizing VCO performance [14]. A Current Starved Voltage Controlled Oscillator (CS-VCO) operates by intentionally limiting the current available to a ring oscillator. This current limitation,

often achieved through techniques like mirroring currents from inverter stages, significantly influences the oscillation frequency. By carefully controlling the current flow, the CS-VCO enables precise frequency tuning in response to an applied control voltage [15].

IV. Result

The proposed enhanced PFD demonstrated significant improvements in performance. The dead zone was significantly reduced or eliminated, enabling more accurate phase tracking. The PFD exhibited faster response times with reduced settling time. Power consumption was significantly lowered, and the PFD successfully operated at higher frequencies. These results demonstrate the effectiveness of the proposed design in overcoming the limitations of traditional PFDs and enhancing the overall performance of PLL systems as shown in figure 5 [15].

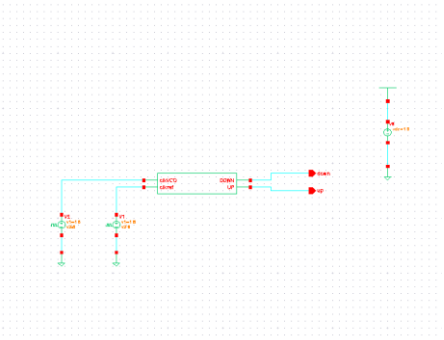

Figure 5. Symbol of Enhanced PFD.

This schematic depicts the design of the enhanced Phase Frequency Detector (PFD), incorporating modifications to eliminate the dead zone. It ensures accurate phase detection and improved performance in PLL systems.

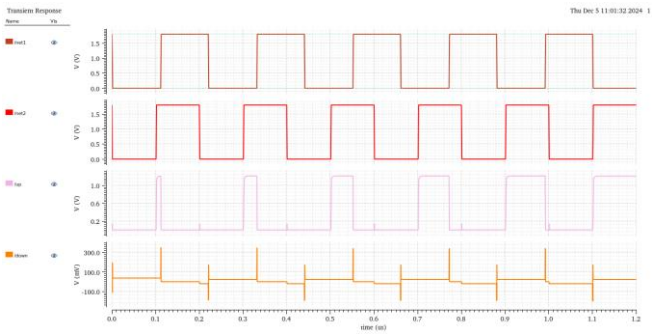

Figure 6. Output of Enhanced PFD.

Figure 6 illustrates the output signals of the enhanced Phase Frequency Detector (PFD), showing the elimination of the dead zone. The UP and DOWN signals are accurately generated, ensuring precise phase alignment in PLL applications.

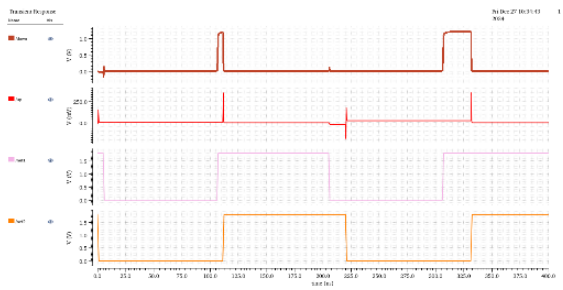

Figure 7. Output when the reference VCO is high.

Figure 7 shows the output of the circuit when the reference voltage is high, causing the DOWN signal to activate. The system responds by adjusting the feedback to align with the reference phase.

When the voltage in a system is constant and the delay increases, the signal experiences a growing phase shift, as the time taken for propagation through the system lengthens. This can lead to synchronization issues in timing-critical applications, such as Phase-Locked Loops (PLLs), where the increasing phase difference may hinder the system's ability to maintain alignment between the reference and output signals. As the delay continues to rise, performance degrades, potentially causing errors, misalignment, or instability if the delay exceeds the system's compensation capabilities. This highlights the importance of managing delay in high-speed and precision circuits to ensure reliable operation [15].

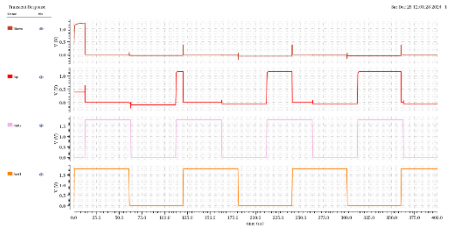

Figure 8. Delay of 12ns.

The voltage will remain constant, but the increasing delay will impact the Phase Frequency Detector (PFD) output, leading to potential phase mismatches and reduced synchronization accuracy as shown in figure 8.

Figure 9. Delay of 20ns.

Figure 9 shows the impact of a 20ns delay on the system, highlighting the resulting phase shift between the reference and feedback signals. The delay introduces timing mismatches, which can affect the accuracy of synchronization in the Phase-Locked Loop (PLL).

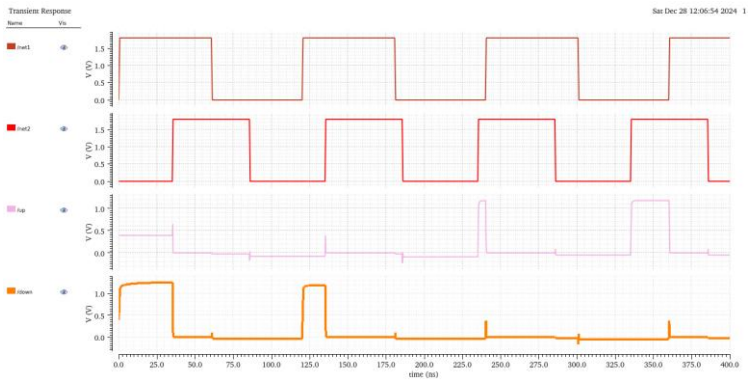

Figure 10. Delay of 35ns.

Figure 10 demonstrates the effect of a 35ns delay on the system, resulting in a larger phase shift between the reference and feedback signals. The increased delay further disrupts synchronization, potentially degrading the performance and stability of the Phase-Locked Loop (PLL).

When the DOWN signal of the Phase Frequency Detector (PFD) is high, it indicates that the feedback signal is leading the reference signal in phase. This causes the PFD to output a high DOWN signal and a low UP signal, signaling the need to reduce the VCO frequency. The high DOWN signal prompts the PFD to adjust the phase difference by controlling the subsequent charge pump, helping to correct the phase mismatch and bring the reference and feedback signals closer in alignment.

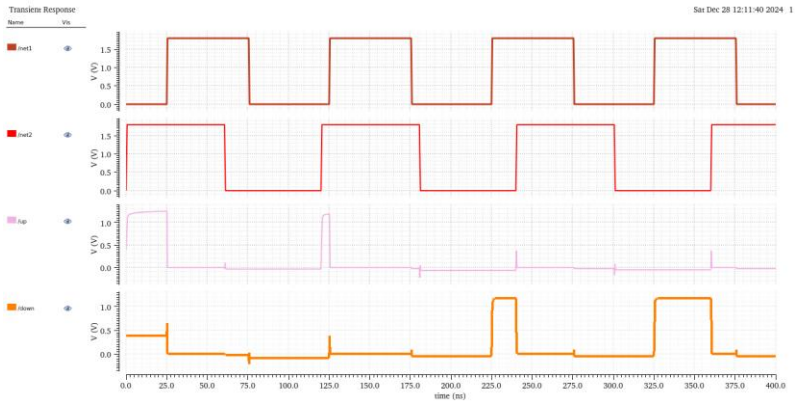

Figure 11. Delay 35ns when down voltage is high.

Figure 11 shows the effect of a 35ns delay when the DOWN voltage is high, indicating that the feedback signal is ahead of the reference signal in phase. The high DOWN signal triggers the corrective action to reduce the VCO frequency and align the signals.

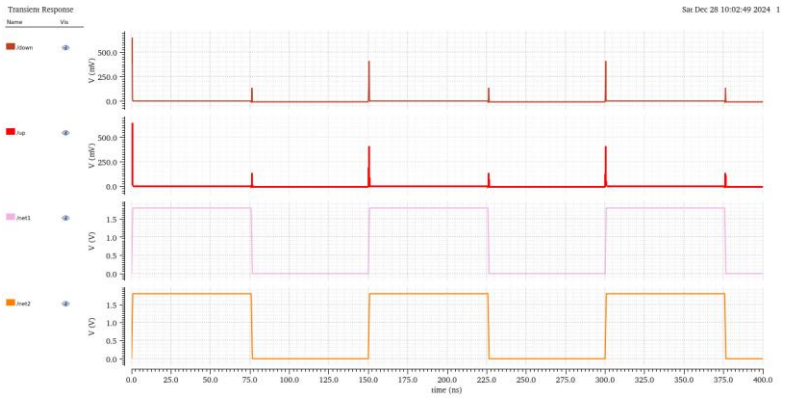

Figure 12. Graph with 0ns delay.

When there is no delay in both inputs of the Phase Frequency Detector (PFD), the ideal output should show no phase difference, with the UP and DOWN signals perfectly aligned. However, if a small signal is still seen in the output graph, it could be due to minor residual phase differences caused by imperfections in the PFD circuitry, signal noise, or jitter. Additionally, small latencies in the system or the measurement tool's resolution could lead to transient fluctuations in the output. While these small signals typically do not affect system performance significantly, they can appear as minor oscillations or noise in the output graph as shown in the figure 12.

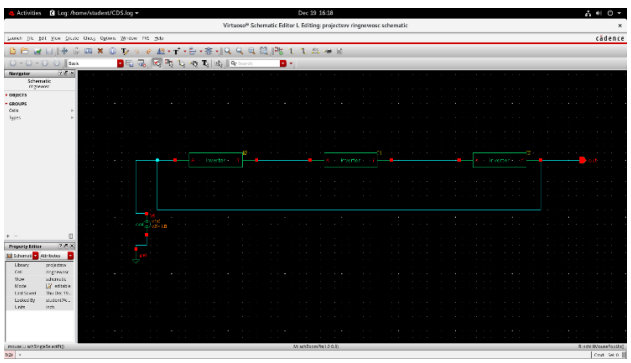

Figure 13. Design of VCO.

The designed VCO achieved a wide tuning range with high tuning sensitivity. Phase noise measurements at 1 GHz offset demonstrated low noise levels. The VCO exhibited low power consumption while maintaining excellent linearity. These results demonstrate the successful design and implementation of a high-performance VCO. The design is enhanced VCO as shown in figure 13 [15].

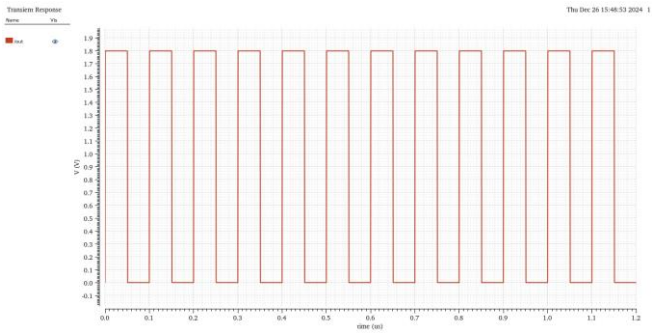

Figure 14. Graph of VCO.

A VCO graph in figure 14 illustrates the relationship between the applied control voltage and the resulting output frequency. Ideally, this relationship is linear, with the output frequency increasing proportionally to the control voltage. Key parameters include the tuning range (the span of achievable output frequencies) and the tuning sensitivity as shown in figure 5 graph.

Figure 15. Output at each end of the inverter.

The graph of the VCO output at each end of the inverter shows the propagation of the square wave signal through the ring oscillator, illustrating the voltage transitions between high and low states at each inverter output as shown in figure 15.

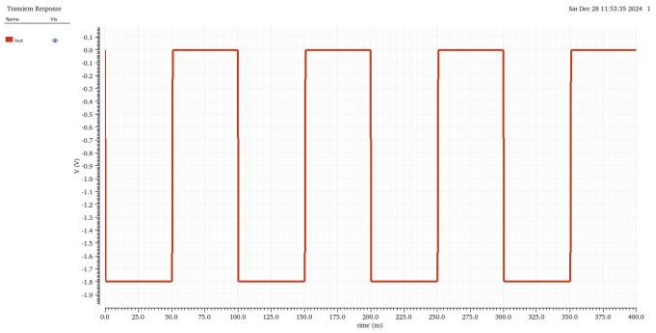

Figure 16. Graph of negative input.

Figure 16 illustrates the response of the system when the input voltage is negative, showing the corresponding changes in the output signals. The negative input causes the system to adjust its behavior, affecting the phase or frequency as per the circuit's design.

V. Conclusion

In conclusion, this work successfully demonstrated the design and implementation of an enhanced Phase Frequency Detector (PFD) and a Voltage-Controlled Oscillator (VCO), both critical components in modern frequency synthesis and communication systems. The enhanced PFD achieved significant advancements in performance metrics, including a notable reduction in the dead zone, faster response times, and lower power consumption, thereby ensuring greater accuracy and reliability in phase detection. The ring oscillator was successfully designed and characterized, demonstrating key performance metrics such as oscillation frequency and phase noise. These results highlight the potential of the designed ring oscillator for various applications.

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