博士論文（要約）

A Study on Measurement Method of PLL Frequency Characteristics through Digital Interface

(ディジタルインターフェースを用いた

PLL の周波数特性の測定手法に関する研究)

A Dissertation

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Abstract

This thesis proposes a measurement method of PLL frequency characteristics not through analog measurement but through digital interface in order to reduce the test cost.

Chapter 1 introduces the background and objective of this study. These days, much-higher frequency should be synthesized by a PLL in order to realize higher-speed communication systems or more efficient utilization of the frequency bands. On the supply chain, testing measurements should be carried out to confirm the correct operation of the PLL before shipping. We challenge to integrate the measurement macros on the chip in order to reduce the test cost. Furthermore, we aim at the realization of the measurement through only digital interface.

Chapter 2 forms the foundation of the PLL and its frequency characteristics. First of all, the closed loop transfer function and related characteristics are introduced with mathematical expressions. Then several analysis methods of the transfer function are discussed. Sinusoidal phase modulation is conventionally used in the frequency-domain analysis, we propose to use triangular phase modulation. We theoretically compare these analysis methods using MATLAB, and show that the triangular phase modulation is easy to implement and accurate after some mathematical operations. We also explain about the lock range of the PLL.

Chapter 3 describes the circuit components to realize our proposed method. The proposed method utilizes Digital-to-Time Converter (DTC) as an integrated stimulus generator, and its architecture, operation and design constraint of the DTC is explained. Then, the triangular phase modulation carried out by the DTC is described. At the same time our proposed method employs Time-to-Digital Converter (TDC) as an integrated response analyzer, and its architecture and operation of the Vernier TDC is described in addition to the flash TDC. Dynamic range of the TDC required for the proposed method is also explained. Finally, the Process, Voltage, and Temperature (PVT) effects on the DTC and TDC are discussed. Since

both the DTC and the TDC are composed of the same delay cells in our proposed method, the measurement result is robust against the PVT variations. The robustness of our proposed method is demonstrated by HSPICE simulations.

Chapter 4 introduces a flow of the proposed measurement method. Design of the circuit components suitable for our measurement method is also summarized in this chapter. The 2nd-order PLL is constructed by Simulink for MATLAB demonstration. Furthermore, a the 3rd-order PLL with the DTC and the TDC, which are manually designed, as well as the control circuit of the DTC and the Thermometer-to-Binary Converter (TBC), which are designed in standard digital circuit design flow in 180 nm CMOS process for HSPICE simulation. As a summary of this chapter, the circuit area is compared and the result shows that the circuit area occupied by the additional components for the measurement is less than quarter of the total area. Since the additional components have a high scalability, the overhead of the additional components will be reduced as the process scaling is advanced.

Chapter 5 demonstrates the proposed measurement method using MATLAB and HSPICE simulations. Since only the divisor of the reference frequency can be the modulation frequency in our method, we shift the reference frequency so as to increase the calculated frequency points on the transfer function and it is demonstrated by MATLAB simulation. Additionally, from the transfer function with increased frequency points, we discuss the error caused by the harmonic components of the triangular phase modulated stimulus. HSPICE simulations confirm that our proposed method can be applicable to real PLLs which are composed of non-linear circuits. Here, the time-domain method using an impulse response is also carried out on the same DTC and TDC, and the comparison results show that our proposed triangular modulation method has better accuracy than the time-domain method. The lock range measurement is also discussed in this chapter.

Chapter 6 introduces a PLL bandwidth control as an application of the proposed measurement method. Our method easily measures the magnitude of the transfer function at a specified modulation frequency. The bandwidth is feedback controlled by changing the charge pump current of the PLL such that the magnitude transfer function at the specified frequency becomes -3dB. The proposed bandwidth control is demonstrated by MATLAB.

Through the analysis and the demonstration of the PLL measurement method presented in this thesis, it is shown that the integration of the DTC which carries out the triangular phase modulation at the input and the TDC which digitalizes the output response effectively reduces the PLL measurement cost. Furthermore, the robustness against the PVT variations with the high process scalability, as well as the ease of use through the digital interface make our proposed method more attractive.