2004 IEEE Asia-Pacific Conference on Advanced System Integrated Circuits(AP-ASIC2004) / Aug. 4-5, 2004

Design and Measurement of On-chip di/dt Detector Circuit for Power Supply Line

Toru Nakura, Makoto Ikeda*, and Kunihiro Asada*

Dept. of Electronic Engineering, *VLSI Design and Education Center (VDEC),

Univ. of Tokyo, Tokyo 113-8656, Japan

{nakura, ikeda, asada}@silicon.t.u-tokyo.ac.jp

Abstract — This paper demostrates design and measurement of an on-chip di/dt detector circuit for power supply line. The di/dt detector circuit consists of a spiral inductor under the power supply line which induces a di/dt proportional voltage, and an amplifier which amplifies and outputs the value. The di/dt detector is mounted on Cu board, and the measurement results show that the di/dt detector output and the voltage difference between a resistor have good agreement.

Introduction

As the process technology advances, the number of the transistors on a LSI chip has been increasing and their high speed operations generate more power supply noise while the low supply voltage reduces the noise margin. Thus, the power supply noise becomes a serious issue for the reliability of the LSI operations.

Recently, a di/dt noise is becoming one of the dominant source of the power supply noise along with an IR drop. An EMI noise also becomes a serious problem for high speed operating LSIs. Therefore, a current measurement technique, especially a high frequency di/dt measurement techniques, is necessary in order to estimate the di/dt noise.

Many techniques have been proposed to measure the power supply voltage bounce[1]. On the other hand, only few techniques have been developed for the power supply current measurement. One technique uses a resistor connected in series to a power supply line on a PCB board and measures the voltage difference of the both terminals using electron-beam probing[2]. This technique needs numerical calculation to obtain the current and di/dt waveforms. Another technique picks up the magnetic field and measure the spectrum[3]. It is unable to reproduce the original current nor di/dt waveforms from the spectrum because the phase information is lost.

This paper demonstrates an design and measurement of an on-chip detector circuit[4][5]. This technique can be applicable to control the LSI system operations dynamically according to the observed di/dt, such as operating frequency and power supply voltage, because the detector is realized on-chip and outputs the di/dt value in real time.

Circuit Design

A. Overview

Figure 1 shows the overview of the di/dt detector circuit. The internal current goes out from *vdd_i* to the internal circuit through the the series resistor R_s, and the inductor L_1. The internal circuit switching causes the di/dt. A pickup inductance L_2 coupled to L_1 with a coupling coefficient K induces the di/dt proportional voltage. The amplifier amplifies and outputs the voltage to *didtOut*. The both terminals of the series resistor R_s are connected to the oscilloscope as the $s1$, $s2$ signals, and the internal current and di/dt can be obtained by calculating the voltage difference and its numerical-time-differentiation. Then we can compare the waveform of the di/dt detector output with the calculated di/dt waveform numerically-obtained from the series resistor.

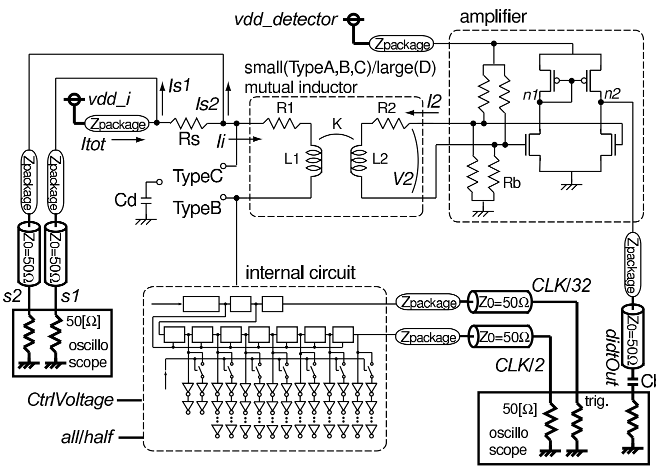

Fig. 1. Over-all circuit with the measurement setup.

B. Mutual Inductor

The mutual inductor consists of a spiral inductor under the power supply line. The power supply line is composed of the top metal layer, ML3, with 1 turn, 20μm width. The spiral inductor has 10 turns with 2μm width and 2μm spacing using ML1. The outside diameter of the both inductors are 140μm × 140μm. This structure is called small mutual inductor. Another type of inductors, called large mutual inductor, has 200μm diameter, and 24 turns, as shown in Fig.2. The equivalent circuit is included in Fig.1.

C. Amplifier

The amplifier schematic is also shown in Fig.1. The resistors R_b are used to keep the DC bias voltage as half-vdd where the amplifier has the biggest gain. The resistance is big enough to be considered open for AC signal. The output is connected to a transmission line whose characteristic impedance is 50Ω. The blocking capacitor C_b is inserted to keep the bias voltage of node $n2$ as the same as $n1$, where the amplifier realizes the widest linearity.

0-7803-8637-X/04/$20.00

D. Power Supply Line Structures

The power supply line has a resistor R_s in series and the both terminals are connected to output pins, which enables the current measurement by calculating the voltage difference.

Four types of circuits were designed, as shown in Fig.1. TypeA: no decoupling capacitor with the small mutual inductor, TypeB: the decoupling capacitor C_d between the detector and the internal circuit with the small mutual inductor, TypeC: the decoupling capacitor C_d between the resistor and the detector with the small mutual inductor, TypeD: no decoupling capacitor with the large mutual inductor.

Measurement Results

A. Process Technology

The chip was designed and fabricated using 0.35μm 2-Poly 3-ML standard CMOS technology. The chip size is 4.9mm×4.9mm and the chip photograph is shown in Fig.2.

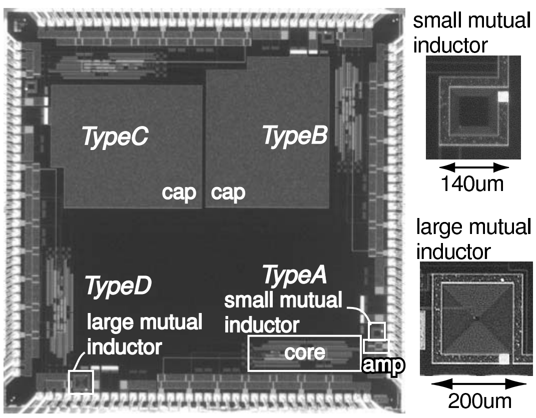

Fig. 2. Chip photograph. The chip size is 4.9mm×4.9mm.

B. Feasibility of the di/dt detector

Figure 3 shows the waveforms of (a) $CLK/2$, (b) $s1$ and $s2$, (c) $V_{s1} - (1 + R_s/R_t)V_{s2}$ signal and the numerical-time-integral of the di/dt detector output multiplied by R_sA_{v2didt}, (d) the di/dt detector output and the numerical-time-differential of $V_{s1} - (1 + R_s/R_t)V_{s2}$ signal divided by R_sA_{v2didt}, of TypeA circuit, where R_sA_{v2didt} is the fitted parameter to convert the di/dt value to the di/dt detector output voltage. Since the $V_{s1} - (1+R_s/R_t)V_{s2}$ waveform is noisy, we applied a smoothing before the numerical differentiation.

These graphs show that the currents measured by the series resistor voltage difference and the di/dt detector output have good agreement, and our di/dt detector circuit works well.

Conclusion

The design and measurement of an on-chip di/dt detector circuit for power supply line has been demonstrated. The di/dt detector circuit consists of a spiral inductor under the power supply line which induces a di/dt proportional voltage, and an amplifier which amplifies and outputs the value. The di/dt detector is mounted on Cu board, and the measurement results show that the di/dt detector output and the voltage difference between a resistor have good agreement.

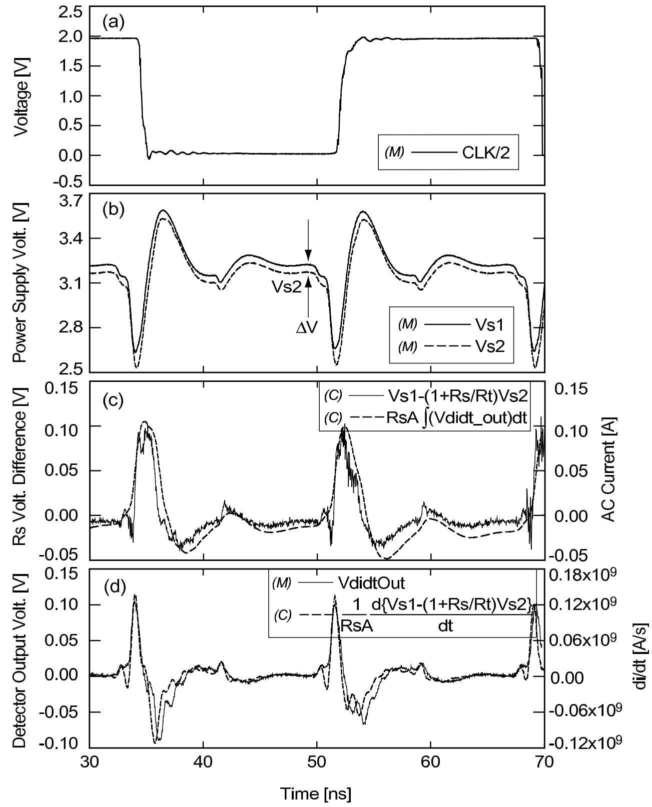

Fig. 3. Waveforms of (a) $CLK/2$, (b) Power supply voltage, $s1$ and $s2$, (c) Calculated internal current, (d) the di/dt detector output and the calculated di/dt obtained from the series resistor voltage.

Acknowledgement

The VLSI chip in this study has been fabricated in the chip fabrication program of VLSI Design and Education Center(VDEC), the University of Tokyo in collaboration with Rohm Corporation and Toppan Printing Corporation. This study was supported by Grant-in-Aid for JSPS Fellows of the Ministry of Education, Culture, Science and Technology.

References

[1] Makoto Takamiya, Masayuki Mizuno, Kazuyuki Nakamura, "An on-chip 100GHz-sampling rate 8-channel sampling oscilloscope with embedded sampling clock generator," in *Int. Solid-State Circuit Conf. Dig. Tech. Papers*, Feb. 2002, pp.182–183.

[2] Keith A. Jenkins, Robert L. Franch, "Measurement of VLSI Power Supply Current by Electron-Beam Probing," *IEEE J. Solid-State Circuits*, vol. 27, pp.948–950, June 1992.

[3] H. Wabuka, N. Masuda, N. Tamaki, H. Tohya, T. Watanabe, M. Yamaguchi, K. Arai, "Estimation of the RF current at IC power terminal by magnetic probe with multi-layer structure," *IEICE Technical Report*, EMCJ98-6, pp.39–43, May 1998.

[4] Toru Nakura, Makoto Ikeda, Kunihiro Asada, "On-chip di/dt Detector Circuit for Power Supply Line," in *Proc. IEEE International Conf. on Microelectronic Test Structures (ICMTS)*, pp.19-22, March 2004.

[5] Toru Nakura, Makoto Ikeda, Kunihiro Asada, "Power Supply di/dt Measurement using On-chip di/dt Detector Circuit," in *IEEE/JSAP Symposium on VLSI Circuits*, to be published, June 2004.