SICE Annual Conference 2012
August 20-23, 2012, Akita University, Akita, Japan

Monolithic Fan Speed Control IC for Monitoring Temperature and Improving Power Efficiency

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Abstract: Heat sinks and cooling fans are currently the most common tools for regulating temperature within the application-specific integrated circuits of electronic products. Unfortunately, fans consume additional power; therefore, effectively monitoring ASIC temperatures and reducing the power consumption of fans are crucial. This study employed built-in thermal sensors to monitor the temperature within the ASIC and a boost DC-DC converter to drive cooling fans and improve power efficiency.

Keywords: DC-DC, fan speed control, PWM.

1. INTRODUCTION

In recent years, a number of advances have been made in low power processes and circuitry; however, the operating speed of application-specific integrated circuits (ASICs) has increased considerably, resulting in the production of excess heat. As a result, heat dissipation has become a critical issue in electronics applications. The most common heat dispersing approach is the inclusion of brushless DC fans in conjunction heat sinks [1] – [4]. However, this raises the issue of power consumed by the fans themselves and reduces the efficiency of the system. Therefore, fan speed control (FSC) ICs must ideally place equal consideration on controlling the temperature within the ASIC and reducing the power consumption of the fans.

Fig. 1 shows a schematic of a conventional method used for fan speed control; a built-in thermal sensor (TS) in the ASIC converts detected temperatures into a corresponding voltage signal, which is propagated to the FSC IC. By adjusting voltage at node V_B, the FSC IC regulates the current flowing through the fan to control its speed. Another method involves providing a PWM signal at node V_B to adjust fan speed. Both of these methods have a common requirement of at least two power sources. This is because the operating voltage of most ASICs and FSC ICs is less than 5 V whereas fans generally require a driving voltage of at least 12 V. Furthermore, the application of PWM signals to control fan speed in CMOS applications necessitates additional oscillators, large external capacitors, or large ASIC chip area, due to the extremely low frequencies of PWM signals.

Fig. 2 shows the fan current and speed corresponding to fan voltages as derived in [5]. From these results, we can see that operating voltage of the fan has a linear relationship with the speed of the fan and the current flowing through the fan. Consequently, an increase in fan speed can be achieved by increasing the voltage across the fan or increasing the current flowing through the fan, and vice versa [6]. This study proposed the use of a boost DC-DC converter to regulate fan current, thereby controlling fan speed. Moreover, ASICs

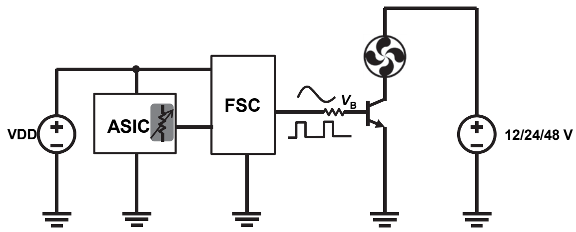

Fig. 1. Schematic of conventional FSC circuit.

comprise various types of circuits, each of which produces differing amounts of heat depending on their functions and operating frequencies (Fig. 3). This study monitored the distribution of heat throughout the ASIC and regulated fan speeds according to the temperature of the hottest areas to achieve heat dissipation.

2. CIRCUIT DESIGN AND IMPLEMENTATION

Fig. 4 presents the circuit of the proposed monolithic fan speed control IC for monitoring temperature and improving power efficiency. The ASIC is integrated

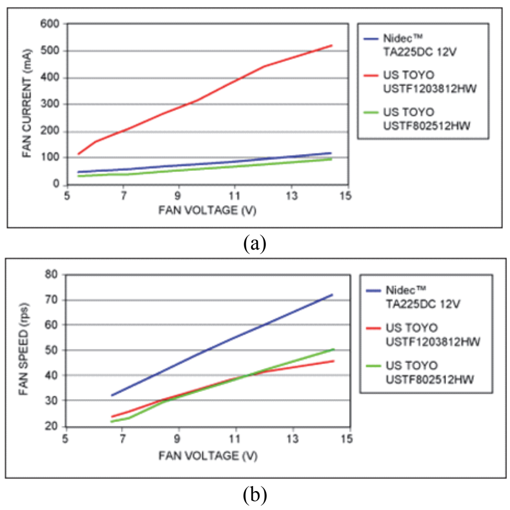

Fig. 2. Experiment results of [5]: (a) relationship between fan current and fan voltage; (b) relationship between fan speed and fan voltage.

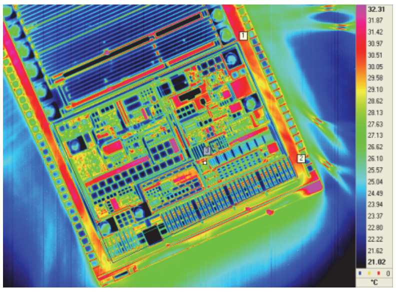

Fig. 3. Distribution of heat within an ASIC.

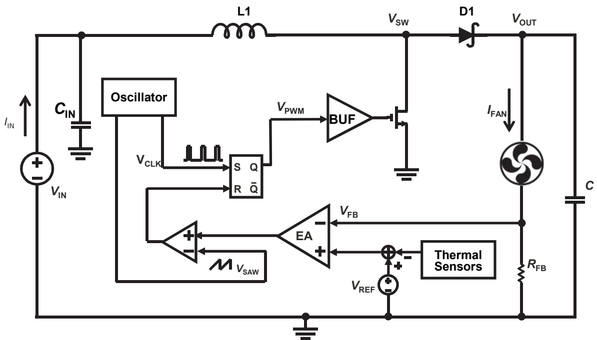

Fig. 4. Schematic of the monolithic fan speed control IC.

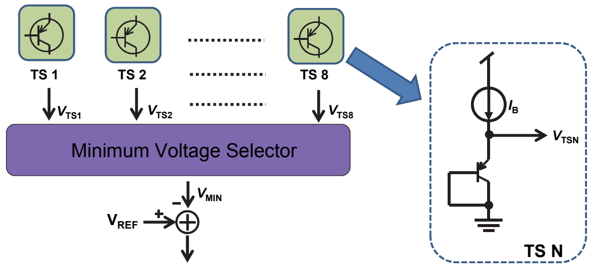

Fig. 5. Schematic of thermal sensors.

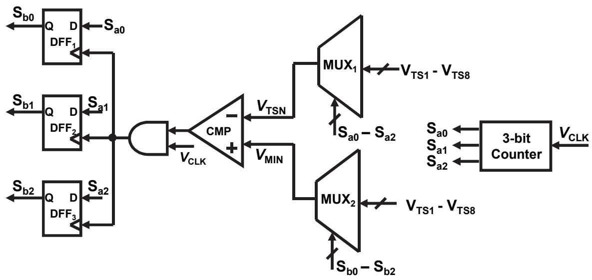

Fig. 6. Minimum voltage selector circuit.

with a boost DC-DC converter to drive the cooling fan, while the fan speed is controlled by the reference voltage provided by built-in TSs. Because the driving voltage of the fan can be generated by the original the boost DC-DC converter, the fan can be driven without dual power sources. Moreover, fan speed is controlled by adjusting the fan current, which eliminates the need for a PWM signal. Finally, the actual temperatures within the ASIC can be monitored directly by the built-in TSs, thereby enabling an immediate response to any changes in temperature within the IC by adjusting fan speeds.

As aforementioned, internal circuits may be designed for ASICs according to the specific functions required. For this reason, the distribution of heat within ASICs is often uneven, and the use of single TS to measure temperature may be insufficient to identify the hottest area in the ASIC. We therefore distributed eight TSs in the ASIC to detect and identify the area with the highest temperature. Fan speed is regulated according to the highest temperature, ensuring that the temperatures within the entire ASIC remain within the accepted range.

Temperature detection and the circuit for identifying the highest temperature are exhibited in Fig. 5. The TSs comprise BJTs, the base-emitter voltage of which demonstrates the characteristics of negative temperature coefficients. Under the same bias voltage current, TSs in areas with higher temperature output a V_{TS} of lower voltage; the minimum voltage selector derives the minimum voltage V_{MIN}. The original reference voltage V_{REF} minus V_{MIN} equals the final reference voltage of the boost DC-DC converter; therefore, when the temperature in any area within the ASIC rises, V_{MIN} drops, thereby increasing the reference voltage of the boost DC-DC converter. Fan speed increases as well, achieving the objective of heat dissipation.

Fig. 6 shows the circuit of the minimum voltage selector circuit (MVSC) used to detect the area with the highest temperature. The eight TSs convert the measured temperatures into voltages (V_{TS1} - V_{TS8}) and then send them to two multiplexers (MUX_1 and MUX_2). Using the selection signals provided by a 3-bit counter, MUX_1 propagates the voltages (V_{TS1} - V_{TS8}) in sequence to the negative input of the comparator (CMP) whereas MUX_2 sends the minimum voltage derived through comparison to the positive input of the CMP. For example, initially, "$S_{a0}S_{a1}S_{a2}$" = "$S_{b0}S_{b1}S_{b2}$" = "000", and V_{TS1} is regarded as the minimum voltage, and therefore $V_{TSN} = V_{TS1} = V_{MIN}$. If only V_{TS8} is lower than V_{TS1}, then before "$S_{a0}S_{a1}S_{a2}$" becomes "111", none of the three D-flip flops (DFF_1 - DFF_3) are triggered and "$S_{b0}S_{b1}S_{b2}$" remains "000" because the output of the CMP is always "0". When "$S_{a0}S_{a1}S_{a2}$" becomes "111", then $V_{TSN} = V_{TS8}$. This is because $V_{MIN} = V_{TS1} > V_{TS8}$, and the output of the CMP becomes "1"; the DFFs are triggered, which means that "$S_{a0}S_{a1}S_{a2}$" = "$S_{b0}S_{b1}S_{b2}$" = "111". At this moment, MUX_2 selects V_{TS8} as the

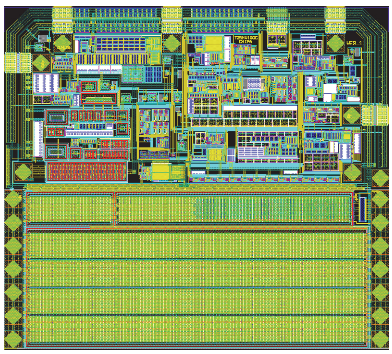

Fig. 7. Layout view of the proposed FSC driver IC.

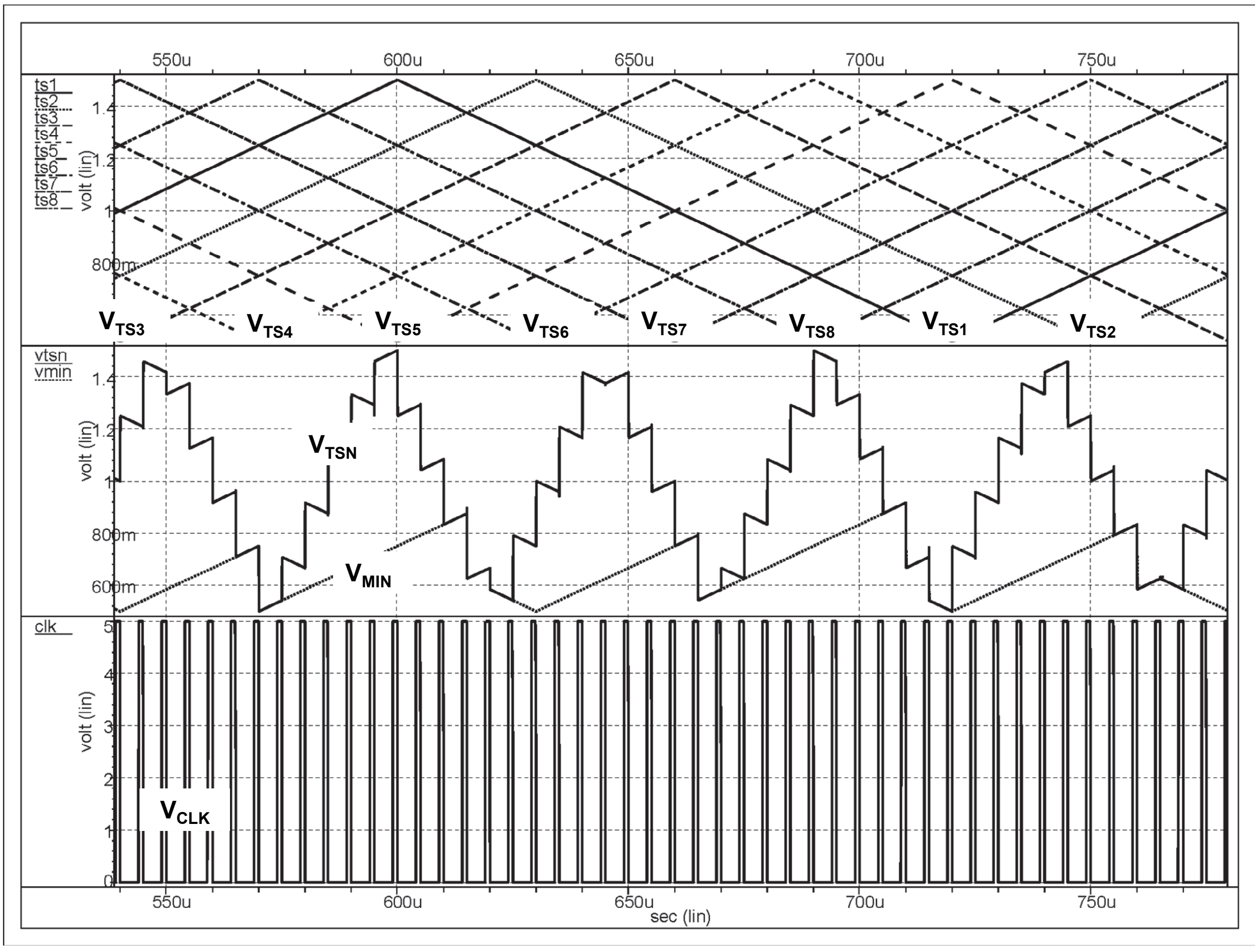

Fig. 8. Simulation results comparing eight triangular signals using the proposed MVSC.

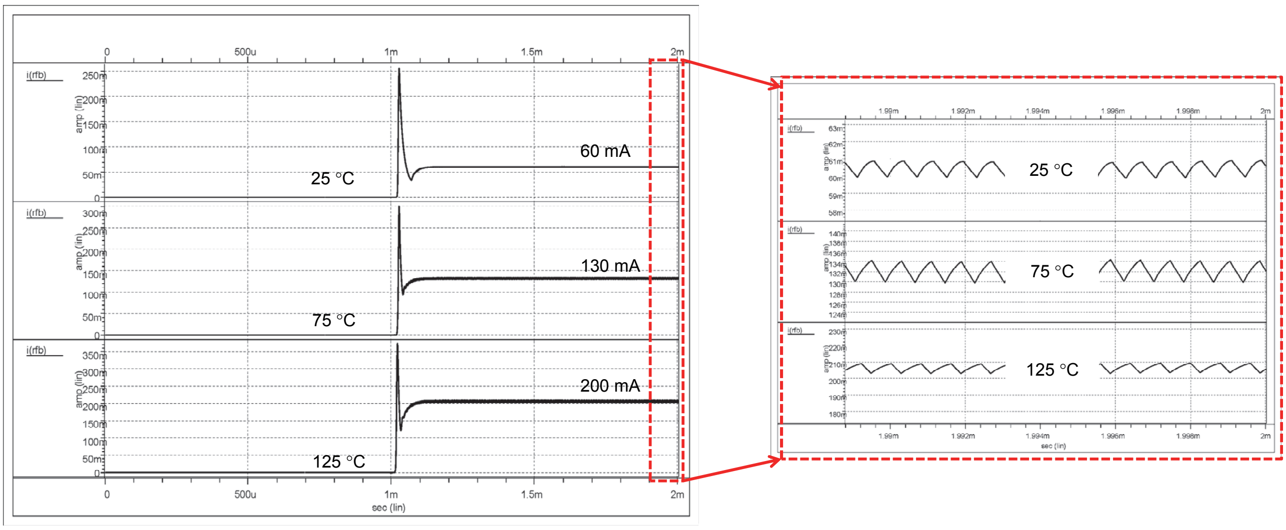

Fig. 9 Fan currents corresponding to various temperatures: 60, 130, and 200 mA for 25, 75, and 125 °C, respectively.

minimum voltage, thereby completing the selection of minimum voltage (i.e., $V_{MIN} = V_{TS8}$). Because the selection signals of MUX_1 are controlled by a 3-bit counter, the minimum voltage selector periodically detects the voltages provided by all of the TSs, enabling the system to continually respond with fan speeds required appropriate to the areas with the highest temperature.

3. SIMULATION RESULTS AND DISCUSSIONS

The proposed monolithic fan speed control IC for monitoring temperature and improving power efficiency was manufactured in the TSMC 0.25 μm 60 V bipolar-CMOS-DMOS process. The layout of the chip is shown in Fig. 7. The total area of the chip is 1400 μm × 1570 μm.

Fig. 8 shows the simulation results of the minimum voltage selector. As can be seen, the triangular waveforms of the eight voltages that are input (V_{TS1} - V_{TS8}) are compared to derive the minimum value. In pace with the signal of V_{CLK}, V_{TSN} gradually relays the input voltages from V_{TS1} to V_{TS8}; V_{MIN} remains equal to or less than V_{TSN}, ensuring that following eight clock cycles, a minimum voltage will be selected from among V_{TS1} - V_{TS8}. Fan speed is then adjusted according to the highest temperature in the ASIC.

Fig. 9 shows the simulation results of the FSC IC at various temperatures. When the temperature within the ASIC is 25 °C, 75 °C, and 125 °C, the current flow through the fan is regulated at 60 mA, 130 mA, and 200 mA, respectively. The current and speed of the fan are proportional to the operating temperature, thereby facilitating the effective dissipation of heat.

4. CONCLUSION

The proposed monolithic fan speed control IC for monitoring temperature and improving power efficiency provides an alternative to direct voltage control or PWM signal control in conventional FSC ICs. The proposed method detects the area with the highest temperature in the ASIC and subsequently controls the speed of the cooling fan. Direct adjustment of fan current renders low-frequency PWM control signals unnecessary. Furthermore, the proposed design only requires a single low voltage power source to drive cooling fans over 12V, which could reduce the design complexity of the power source.

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