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A novel under-voltage and over-voltage detection circuit with voltage detector using one transistor

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Abstract: This letter presents a novel under-voltage and over-voltage (UVOV) detection circuit which detects whether the supply voltage is within the operating range or not, with a simple configuration. The proposed circuit exploits only a transistor for detecting both under and over supply voltages and hence, it provides smaller area and better robustness to offset and mismatch compared to the previous ones. The prototype is implemented in 5 um BCDMOS process with an active area of 0.0625 mm^2. The measurement results show that the prototype detects under and over voltages at 3.85 V with 650 mV of hysteresis and 48.45 V with 700 mV of hysteresis, respectively, while dissipating 18.7 uA at 12 V in simulation.

Keywords: high-side switch, smart switch, under-voltage and over-voltage detection circuit
Classification: Integrated circuits

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1 Introduction

An intelligent high-side switch has been widely used in many fields of applications such as industry, automotive, home appliances, etc [1]. Typically, a control part in the intelligent high-side switch offers self-diagnostic func-

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tions like over-current detection and open-load detection to prevent damages caused by malfunction [2, 3]. One of the major diagnostic functions provided by the control part is under-voltage and over-voltage (UVOV) detection which shuts the high-side switch down when the supply voltage is out of its operating range and hence, it avoids the breakdown induced by temporal supply voltage drop or overshoot. In the previous UVOV detection circuits, two comparators with two constant reference signals for the lower and upper supply limits are generally exploited for UVOV detection [4]. However, they typically suffer from large silicon area, large power consumption and high complexity due to the use of two comparators [5]. In this letter, we propose a novel UVOV detection circuit using only a voltage detector instead of two comparators providing easier portability to different processes and lower overall cost compared to previous ones.

2 The proposed UVOV detection circuit

The proposed UVOV detection circuit is composed of a level shifter, a voltage clamper, a voltage regulator and a voltage detector, as shown in Fig. 1. The level shifter shifts the supply voltage, V_{BB}, to a predetermined level, V_{shift}, and the voltage clamper limits the maximum voltage of node A, V_A, at a predetermined clamping voltage, V_{clamp}. Meanwhile, the voltage regulator generates a constantly dropped voltage from V_{BB}, V_{reg}, and the voltage detector generates UVOV signal for shutting the high-side switch down by comparing V_B and V_{reg}. Note that a hysteresis buffer between node A and B is exploited to change the UVOV detection level according to the status of UVOV signal for the robust operation. Fig. 2 (a) shows the change of V_A and V_{reg} according to V_{BB}, describing the simple operation principle of the proposed UVOV detection circuit. It can be seen that V_A has constantly dropped voltage from V_{BB} and it is clamped at V_{clamp}. Meanwhile, V_{reg} maintains a constant voltage in low V_{BB}, while it has constantly dropped voltage from V_{BB} in high V_{BB}. Hence, V_A is always higher than V_{reg} if the constant voltage drop by the level shifter is lower than that by the voltage regulator, when V_{BB} is within the operating range. On the other hand, the

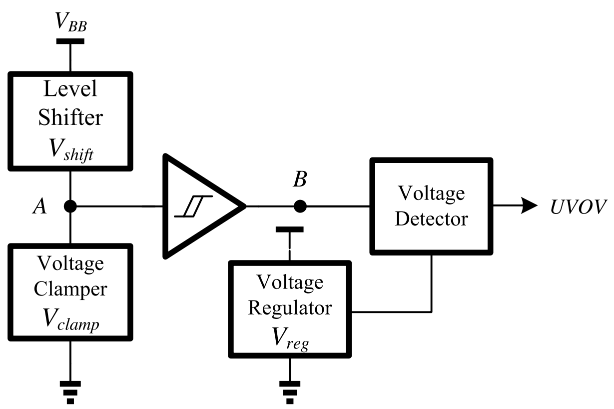

Fig. 1. Simplified model of the proposed UVOV detection circuit.

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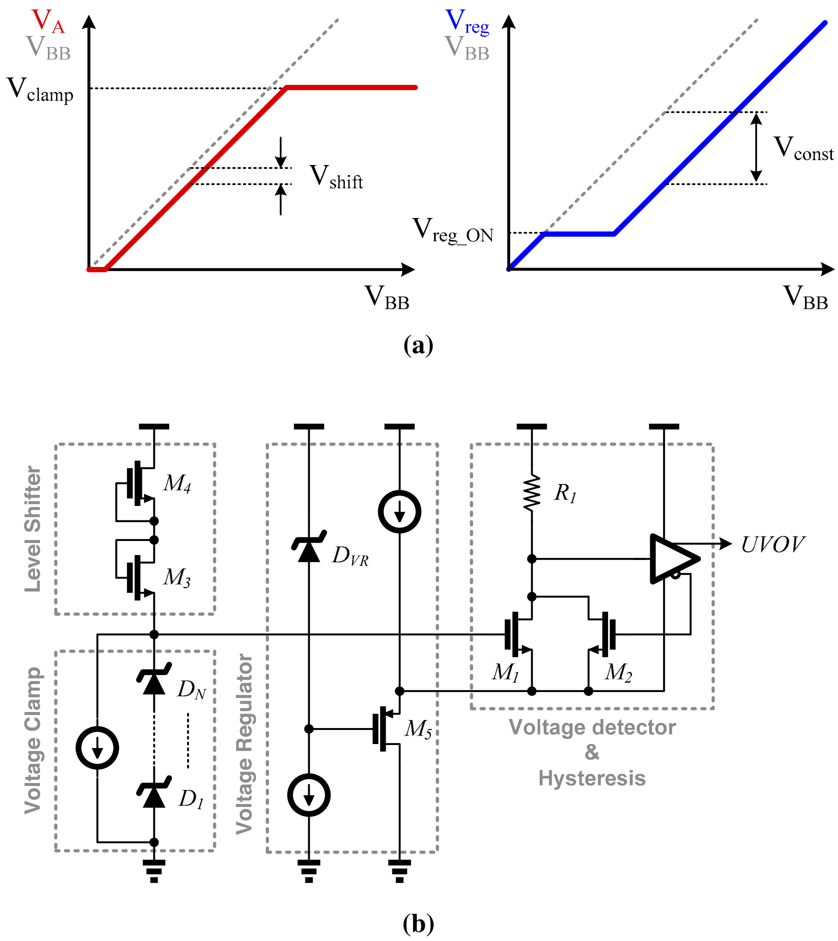

Fig. 2. Proposed UVOV configuration. (a) V_A *and* V_{reg} *versus* V_{BB}. (b) detail schematic.

proposed circuit has lower V_A than V_{reg}, when V_{BB} is out of the operating range. As V_{BB} decreases from the normal operation level to GND, V_A decreases to GND continuously while V_{reg} decreases to V_{reg_ON}, the initial voltage of the voltage regulator, and maintains that level despite of further decrease of V_{BB}. Hence, V_A is lower than V_{reg} and the voltage detector triggers UVOV signal in low V_{BB}. In case of high V_{BB}, V_A is limited at V_{clamp} by the voltage clamper while V_{reg} increases continuously according to the increase of V_{BB} and hence, V_A is lower than V_{reg} and UVOV signal is triggered, too. Note that UVOV detection level can be controlled by changing V_{shift} and V_{clamp}, not V_{reg}, since the voltage regulator is typically exploited to generate the source voltage of the other circuits in the high-side switch.

The detail schematic of the proposed UVOV detection circuit is shown in Fig. 2 (b). The voltage detector is implemented as only a transistor, M_1, whose gate and source are connected to V_A and V_{reg}, respectively. Thus, the voltage detector triggers UVOV signal, when V_A is lower than V_{reg} at under voltage or over voltage. In addition, M_2 is connected in parallel with M_1 for hysteresis and hence, UVOV detection thresholds are changed according to the status of UVOV signal. The level shifter is simply designed as a source follower with a current source implemented as a depletion transistor, M_4,

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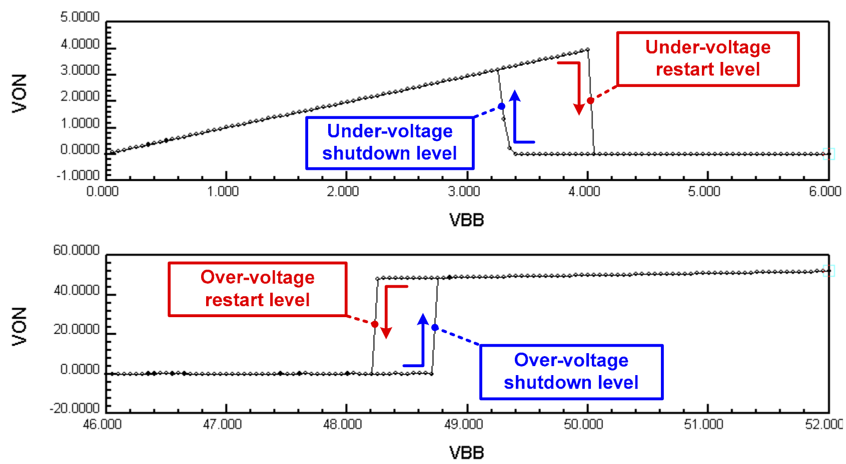
and its amount of a constant voltage drop is determined by its operating current. The voltage clamper consists of a current source having extremely small current and an array of zener diodes, $D_1 \ldots D_N$, connected in series and hence, V_A is clamped when V_A is high enough to turn all the zener diodes on. Meanwhile, the voltage regulator is designed operating as described in Fig. 2 (a). Before D_{VR} is turned on due to the insufficient V_{BB}, the output of the voltage regulator maintains the constant voltage level, $|V_{TH}|$ of M_5, while providing the constantly dropped voltage from V_{BB} after D_{VR} is turned on. Note that all the current sources described in Fig. 2 (b) are implemented as a depletion transistor whose gate and source are shorted and the last buffer consists of the inverter chain.

3 Measurement results

The prototype of the intelligent high-side switch is fabricated in 5 um BCDMOS process and its micrograph is shown in Fig. 3 (c). The proposed UVOV detection circuit is implemented with an active area of 0.0625 mm^2 and its output signal is exploited to shut the high-side switch down, when V_{BB} is out of its operating range. Fig. 3 (a) shows the measured V_{ON}, voltage difference between the high-side switch's drain and source, according to the change of V_{BB}. V_{ON} is close to zero when the high-side switch is turned on, while it is close to V_{BB} when it is turned off due to under or over V_{BB}. Note that V_{ON} cannot be a zero due to the finite resistance of the high-side switch, typically tens of mΩ. It can be seen that under voltage is detected and the high-side switch is shut down at 3.85 V with 650 mV of hysteresis, and over voltage is detected at 48.45 V with 700 mV of hysteresis. In addition, 2000 different samples are tested to verify the robustness of the proposed circuit and their measured UVOV detection levels are summarized in Fig. 3 (b). It can be seen that the prototype has well distributed UVOV detection levels, about 0.04 of standard deviation for under-voltage detection and about 0.42 of standard deviation for over-voltage detection, despite of sample-to-sample variation. Note that over-voltage restart level is always larger than shutdown level in a sample, although the over-voltage detection level's distribution has



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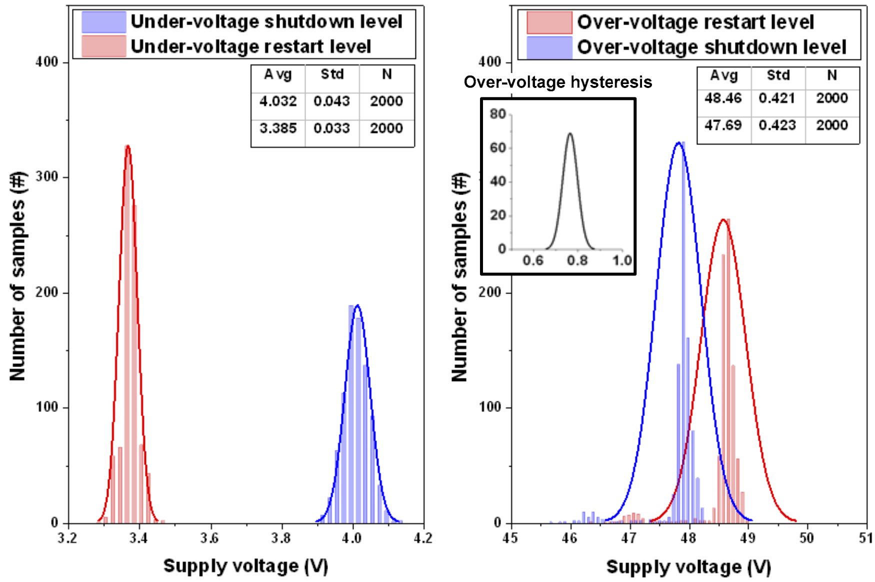

(b)

(c)

Fig. 3. Measurement results and chip photo. (a) measured V_{ON} of the high-side switch vs V_{BB}. (b) measured UVOV detection level. (c) chip micrograph.

an overlap, and over-voltage hysteresis has always positive value, around 0.75 V, as shown in Fig. 3 (b). The simulated current consumption the proposed circuit is negligible, 18.7 uA at 12 V, 18.8 uA at 24 V and 22.4 uA at 60 V, since only a transistor is used as the voltage detector.

4 Conclusion

In this letter, a novel UVOV detection circuit that exploits only a transistor as the voltage detector is proposed. The prototype has 3.85 V of under-voltage detection level with 650 mV of hysteresis and 48.45 V of over-voltage detection with 700 mV of hysteresis, while having 18.7 uA of current consumption at 12 V, estimated from the simulation result.

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