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A Novel Thermal Shut Down circuit

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ABSTRACT

A Novel way to support typical Thermal Shut Down(TSD) circuit is proposed. In power ICs, on-time or on-duration is the key factor to anticipate an abrupt increase of internal temperature. Such an abrupt raise of the temperature can cause TSD circuit cannot protect on proper time due to the temperature detection delay come from the physical distance or the imperfect coupling between heat sources and detector. The proposed circuit checks the duty ratio touched their maximum or not in every cycle. Once duty ratio touches the maximum duty, new circuit generates the warning signal to the TSD circuit and lowers pre-determined temperature for shut down to compensate the detection delay. The novel circuit will be analyzed to the transistor level and checked the validity by simulation.

1. Introduction

Typically the power consumptions of power ICs like switching loss, conduction loss and so on are converted to heat. Therefore IC makers use TSD circuit to protect IC before the internal or junction temperature reaches to its maximum which semiconductor material lose their characteristics. That's why the normal power ICs are shut down around 150~160 °C.

But the precise detection of temperature is not easy due to the physical distance or the imperfect coupling between heat source and detector. In case of power system is made by discrete switch and controller, the situation becomes worse due to the wide distance between heat source that is discrete switch and temperature detector inside the control IC.

The other cases like monolithic or multi-chip in one package are still not positive. Even though physical length is much less than prior one it is not negligible especially when temperature increases very rapidly. This can cause IC breakdown or malfunction. To overcome this, there were various approaches like using multiple temperature detectors in various positions, combining detector and power switch in one process, using new lead frame which is the metal body of IC package for quick temperature detection and so on.

This paper proposes a novel way to support normal TSD circuit by additional and simple circuit. With the proposed circuit, predict the rapid increase of heat and protect IC from breakdown more quickly than conventional TSD circuit.

We will begin with the conventional TSD circuit of power ICs and describe operation first and then show the validity of the novel TSD circuit by timing chart and simulation result.

2. Novel TSD circuit

2.1 Conventional TSD circuit

The most common way to check the internal temperature of IC for TSD circuit is using forward voltage drop between base-emitter junction. The base-emitter voltage to sustain a given collector current can be expressed as[2]

$$V_{BE} = V_T \times \ln\left(\frac{I_C}{I_{CO}}\right)$$

where, $V_T = \frac{kT}{q} \approx 26mV@25\,^{\circ}C$, $I_{CO} = \frac{qD_n n_i^2}{Q_B} A$

k = Boltzmann's constant

q = electronic charge

T = temperature(in °K)

D_n = diffusion constant of electrons in the base

n_i = intrinsic carrier concentration in silicon

Q_B = total number of dopant atoms in the base region per unit area of the emitter

A = area of the base-emitter junction

I_C = given a collector current

As can be seen in the equation, forward voltage of base-emitter junction is affected by temperature and physical characteristics of semiconductor material. Once a transistor made down by IC process and a collector current

is fixed by additional circuit, V_{BE} shows a strong but highly predictable dependence upon temperature. The temperature coefficient falls within the narrow range of -1.8 to -2.2 mV per °C.

Using transistor as temperature detector, conventional TSD circuit is shown in the Fig. 1.

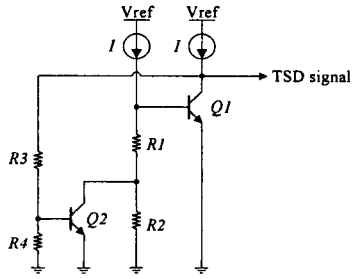

Fig. 1 Conventional TSD circuit

In the circuit, Q1 is temperature detector, Q2 makes hysteresis, resistors with current sources make set point and the TSD signal becomes low when the TSD enabled. When the internal temperature makes base-emitter voltage sufficiently lower than pre-determined voltage, which is multiplied by current source and R1, TSD signal goes to low. Once TSD is triggered, set point by current source and R1+R2 is higher than prior one, TSD will release on less temperature than enable one. This hysteresis operation is shown on Fig. 2. Like this, multiple set point is easily possible by the combination of resistor and switch.

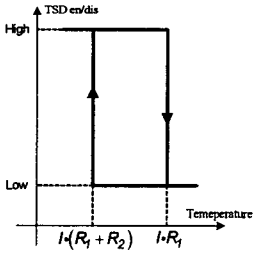

Fig. 2 Hysteresis operation of TSD circuit

2.2 The problems of the conventional TSD circuit

The problems are come from the characteristics of thermal transfer not come from the circuit itself. In case of the system is build up by discrete power switch and controller TSD circuit is placed inside the controller but main heat source is the external power switch. This condition is duplicated similarly on 2 chip in 1 packaged IC which discrete power switch and controller are combined together in 1 package.

This condition is getting worse when the temperature increases very rapidly which occurs many times in transient status. It is inevitable that temperature gap exists between source and detector in these conditions and results to IC breakdown or abnormal operation of function due to the parasitic elements could be activated.

2.3 Novel TSD circuit

Additional or structural changes are not allowed or not recommended in mass producing ICs because of time to market, limited resources and price etc. To complement the existing imperfect TSD circuit we propose new circuit using another information as predictor of rapid increase of temperature like Fig. 3.

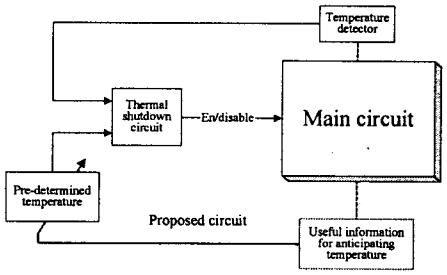

Fig. 3 Conceptual block diagram of proposed circuit

Typically the duty ratio of power switch is the main factor to raise the internal temperature of IC or system. After some switching cycles of the maximum duty ratio power consumption of power switch increases very rapidly and the abrupt increase of internal temperature will follow. At the same time, because during transient or startup of system duty ratio can touch its maximum we must handle the maximum duty as normal operation. We use the rate of the maximum duty ratio as temperature predictor not to affect the other circuit. Futhermore in many cases the maximum duty ratio is already programmed inside IC or system circuit to limit or protect abnormal operation, using maximum duty in the novel TSD circuit is easy and cost effective way compared to other approaches.

FPS™, stands for Fairchild Power Switch, is specifically designed for high performance off-line Switch Mode Power Supplies with minimal external components, design size while increasing efficiency, productivity and so on. Our new TSD circuit can be adopted in the FPS™ like Fig. 4.

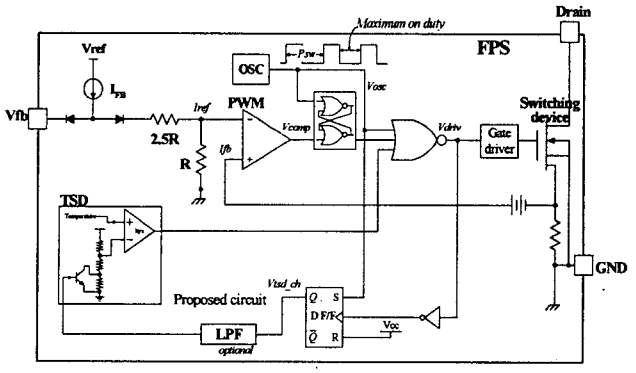

Fig. 4 Novel TSD circuit

The feedback voltage comes from external voltage regulator like TL431 and controls the drain current. The maximum duty is generated by internal oscillator and

combined together with comparator output of real drain current and the reference drain current. When the comparator output triggers within the maximum duty the gate signal is same to the comparator output, but when the comparator signal exceeds the maximum duty the gate signal is limited by the maximum duty.

If we check the maximum duty signal on every falling edge of gate signal we can acknowledge the current cycle is triggered by comparator or maximum duty ratio. The gate signal is triggered by the maximum duty ratio means that the temperature will increase very rapidly sooner or later. The time gap between the maximum duty warning signal and real action is programmable by additional low pass filer or counter. Fig. 5 shows the operational sequence and Fig. 6 shows SABER® simulation result. As stated above paragraph, the maximum duty warning signal doesn't affect the other circuit.

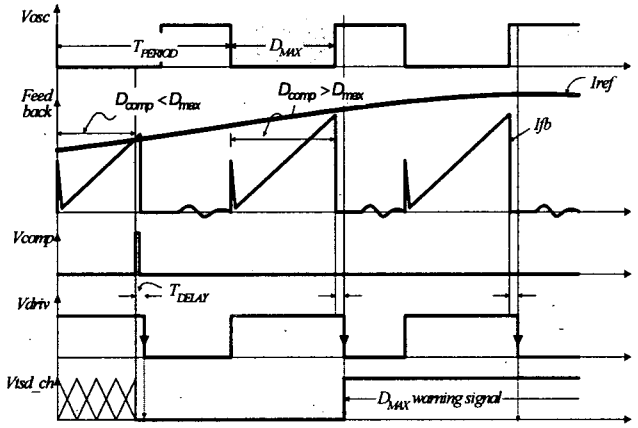

Fig. 5 Operation of novel TSD circuit

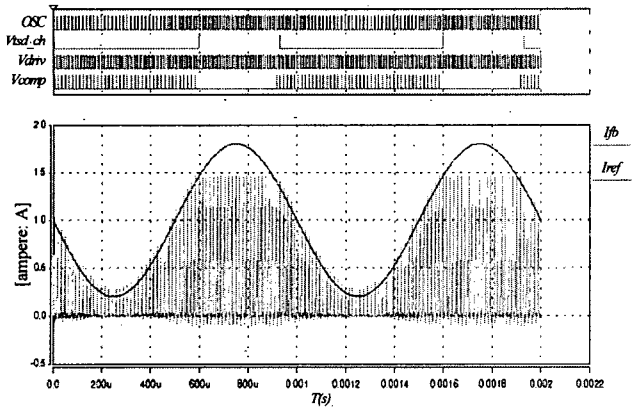

Fig. 6 Simulation waveform of novel TSD circuit

Once abstract well prepared warning signal from D-F/F and maximum duty ratio, we need to consider how to use warning signal. The main purpose of a TSD circuit is to protect IC or power component from breakdown, so it will not do much harm when a TSD circuit is enabled on lower temperature only in case of emergency not to affect transient or startup.

To change pre-determined temperature of TSD circuit it needs additional 1 transistor Q1 and 1 resistor R5 from the circuit of Fig. 1. Except the maximum duty warning signal the operation is same to previous one but the setting point. When the maximum duty warning signal is enabled, R5 is added to R1 and R2 results to lower pre-determined setting point of temperature like Fig. 7.

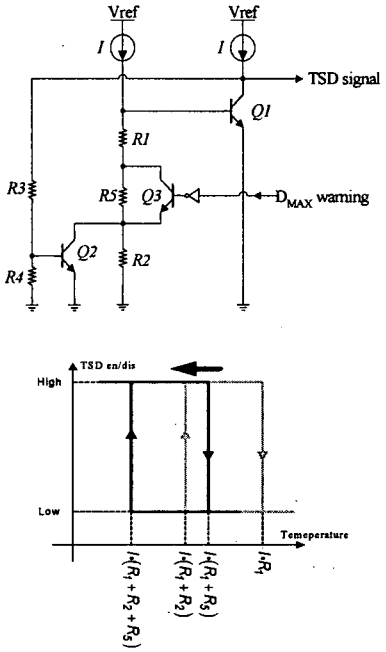

Fig. 7 Change of pre-determined temperature

3. Conclusion

The TSD circuit is the last protection function for power systems and ICs from breakdown. But when the system is made up by discrete power switches and controller or 2 chips in 1 packaged power ICs it is not easy to protect system absolutely because the temperature detection is delayed or inaccurate. The proposed novel TSD circuit support conventional TSD operation by monitoring key factor to raise temperature. The operation of proposed method was analyzed to the transistor level and checked by SABER® simulation.

References

[1] FPS™ application note, "Troubleshooting and Design Tips for Fairchild Power Switch(FPS™) Flyback Applications".

[2] Alan B. Grebene, Bipolar and MOS Analog Integrated Circuit Design, John Wiley & Sons. 1984.