# THERMAL SENSOR AND TEST TECHNOLOGY IMPROVING FOR AUTOMOTIVE ICS

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## ABSTRACT

Analog ICs are widely used in automotive, industrial and consumer area. ICs working environment such as the temperature is the major fact which affect the performance of ICs. The top lead semiconductor companies all on research for developing integrated temperature sensor inside their ICs. This article investigates the method of thermal sensor structure and the test technology improving on automatic test equipment. The high accuracy testing method and system configuration are presented on Intelligent Distribution Controller (IDC) IC. The experiment result shows this method has higher accurate to measure the real chip temperature than the traditional method (achieve ±2℃ tolerance). The flash array is using for storing the temperature calibration data.

## INTRODUCTION

Semiconductor martial is undoubtedly one of the purest materials routinely available in automotive, industrial and consumer area. And it has special linearity feature with surrounding, especially for the temperature environment. This feature can be performed by electrical parameter. For example, the temperature diode's reverse current will be increased in index number when the environment temperature increasing [1]. If one silicon diode's temperature increased 8°C , the reverse current value can be doubled. The same volume current increasing will be happened on germanium diode also. In addition, with temperature increasing, the diode's positive voltage drop will be decreased. For example, one degree centigrade increasing, the positive voltage drop will decrease with number 2mV. This is called negative temperature coefficient [2]. This is the basic theory for IC's temperature measurement. With more and more ICs using in our life, the quality reliability of these devices become more and more important.

For automotive application area, refer to AEC (Automotive Electronics Council) qualification requirement, all the ICs must have stable electrical performance within at least minus 40℃ to over 125℃ [5][6]. Besides that, temperature monitor function needs to be integrated into the individual IC. With high accuracy temperature measuring, the ICs can work at correct condition and perform right excitation.

This article describes one of the key automotive product's internal temperature sensor structures from FREESCALE Semiconductor, presents the theory of using two matched diodes to eliminate temperature test offsets. Creatively put forward the usage of implementing formula to calculate the offset for each particular IC. Moreover, the temperature parameter can be saved into the flash memory for future failure analysis.

## IDC TEMPERATURE SENSOR STRUCTURE

IDC (Intelligent Distribution Controller) is a family of network enabled controllers for automotive applications that integrate an HCS12 microcontroller and a SMARTMOS analog control IC into a single package. The analog die combines system basis chip (SBC) functionality and application specific functions, which include a LIN (local interconnect network) transceiver, relay drivers, a dc motor current sense circuit, and a selection of high and low side digital I/O. Control of the analog die is via a new high performance internal die to die interface, which seamlessly integrates the analog IC registers into the MCU register map, to provide faster access than SPI based systems. Top features contain 16-Bit CPU which has 32 kByte flash, 2.0 kByte ram, background debug (BDM) & debug module (DBG).

This complex IC is used for vehicle's windows driving. According to AEC's specification, temperature measurement module is mandatory. To be able to measure the current die chip temperature, the temperature sensor feature is implemented. A constant temperature related gain of sensor can be routed to the internal analog digital converter.

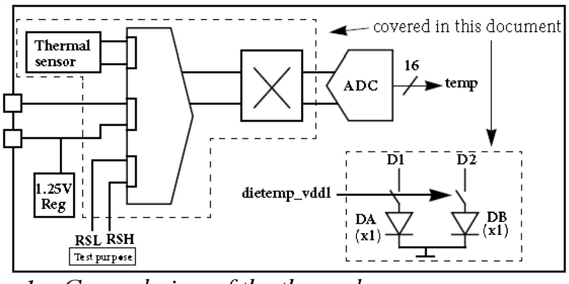


*Figure 1. General view of the thermal sensor*

Theory of operation of the internal sensor and die temperature determination is shown following.

Figure 1 shows the thermal sensor. It consists of four blocks (boxed with dashed lines): The internal thermal sensor which converters the temperature into an analog signal, a multiplexer to make the selection between the internal sensor and the external one, a mixer, and two identical diodes which allow to measure the junction temperature. The internal sensor needs to be calibrated to reach the ±2% accuracy. The calibration is performed at one temperature (125℃). The calibration relies on the precise knowledge of the die temperature.

It can measure the temperature from an internal built-in temperature sensor or from an external temperature sensor connected to pin "VTEMP". The external temperature sensor is supplied via the pin TSUP. The measurement channel is the same for the internal and external temperature sensor except the use of a different reference voltage. Which sensor shall be used is determined by the programming of the multiplexer. Whenever an external temperature sensor is enabled both temperature sensors are measured successively.

## HIGH ACCURACY TEMPERATURE MEASUREMENT CONCEPT

Based on the internal thermal sensor design, another way of measuring diode temperature method should be implemented also. This can help test engineers to double verify the sensor's tolerance [7]. From figure1, the die temperature is determined by means of two matched diodes: DA and DB. The measurement is done in following steps (as shown in Figure 2):

1). 20uA and 10uA are sourced into DB and DA respectively. V1 is the voltage difference.

2). 20uA and 10uA are sourced into DA and DB respectively. V2 is the voltage difference.

3). V1-V2 is used to determine the temperature.

The voltages across the diodes are given by the following relationships:

$$I(DA) = Isa \times e^{\frac{Vbe(DA)}{Vth}} \quad (1)$$

$$I(DB) = Isb \times e^{\frac{Vbe(DB)}{Vth}} \quad (2)$$

With $$Vth = \frac{kT}{q} \quad (3)$$

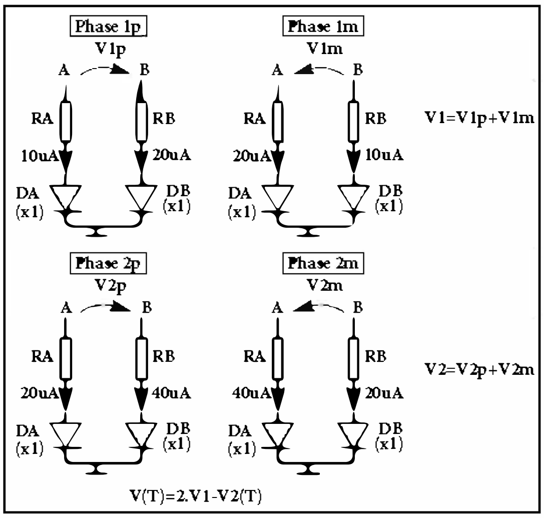


*Figure 2. Die temperature determination view*

The voltages on A and B can be written as follows:

$$V(A) = Vth \times ln(\frac{I(DA)}{Isa}) + RA \times I(DA) \quad (4)$$

$$V(B) = Vth \times ln(\frac{I(DB)}{Isb}) + RB \times I(DB) \quad (5)$$

Phase 1p and phase 1m lead to the following relationships with K being the ratio between the highest current (K x I = 20uA) and the lowest one (I = 10uA)

$$V1p = V(A) - V(B) \quad (6)$$

$$V1m = V(B) - V(A) \quad (7)$$

Summing both equations gives V1:

$$V1 = V1p + V1m \quad (8)$$

The same procedure is applied for phase 2p and phase 2m. It is exactly the same procedure with twice the current. V2 is then given by the following relationship:

$$V2 = V2p + V2m \quad (9)$$

The difference between 2 times V1 and V2, V(T), is given by:

$$V(T) = 2 \times V1 - V2 = 2 \times \frac{kT}{q} \times Ln(K) \quad (10)$$

This method is tolerant to diode mismatch V(T) is not a function of the diode parameters. It also cancels the effect of the parasitic resistors. The above relationship corresponds to a straight line which passes through the (0,0) point where the temperature is expressed in Kelvin. And at 125℃, V(T)=475.64mV. The K parameter must be controlled accurately. The relative error in temperature can be expressed as follows:

$$|\varepsilon_T(T)| = \frac{1}{Ln(K)} \times \varepsilon_T(K) \qquad (11)$$

The temperature to determine is about 125℃ which is equal to 398.15K. A tolerance of 0.5°C (or K) corresponds to a relative error of 0.12%. This gives the following constraint: relative error on K < 0.087%.

## TEMPERATURE CALIBRATION BY FLASH MEMORY

Perform the temperature calibration during three temperature modes: Make a reasonable linear equation (14) for temperature sense (TSENSE) readout calculation. This equation has to be matched with ±-2℃ tolerance during application within full temperature operation range. Using the idle flash address for storing calibration data. TSENSE equation:

$$TSENSE = Slope \times TSENSE(ADC) + Offset \qquad (12)$$

TSENSE(ADC) is the TSENSE temperature which read out through ADC module. After checking TSENSE from cold temperature with ±10℃ tolerance, store the diode's cold temperature value by "DiodeTemp". Then store the content into peculiar flash memory area. In the next, store the TSENSE(ADC). Based on this IDC IC's feature, the 10 bit content will be stored into a peculiar flash memory. Then in next hot flow, we measure the diode's temperature (around 130℃ to 150℃). Measure TSENSE(ADC) and then convert to voltage value. Read out former cold insertion's values from the peculiar flash memory. Calculate the slope by the ratio of the hot and cold temperature's variance. Save the slope value into peculiar flash memory [9]. For the offset compensation, it will be stored into another peculiar flash memory.

Figure 4 shows actual measurement result in hot temperature. ±-2℃ tolerance achieved successfully.

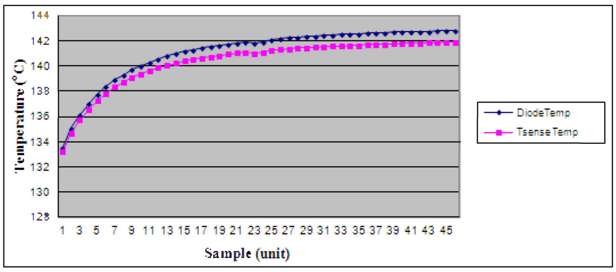


*Figure 4. Temperature Measurement Result*

This method uses the idle flash memory to store testing data. The data could be used for any kind of calibration adjustment for analog module even application modules.

## CONCLUSION

In this paper, a temperature accuracy improving method is proposed and verified by test. It is very important for test engineer to choose a critical test condition or a high accuracy test environment for IC, especially the automotive parts. Performing temperature calibration can help to custom-made themselves data to fit the different user mode.

This method is more effective to improve the whole device's performance. It can increase the test coverage and the test accuracy by two diodes implementation. This technology and measurement concept is verified successfully in mass production.

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