TEXAS INSTRUMENTS

Application Report

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AN-1566 Techniques for Thermal Analysis of Switching Power Supply Designs

ABSTRACT

This application note provides thermal power analysis techniques for analyzing the power IC.

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1 Introduction

To reduce time-to-market and component count, power management ICs with integrated power transistors such as Texas Instruments new SIMPLE SWITCHER® regulators (LM5576, LM25576, and others) are often preferred over controllers with external FETs. However, with the power transistor on-board, it's important to do careful thermal analysis of the power IC to make sure the silicon temperature does not exceed the maximum allowable junction temperature. Integrated circuits are rated up to a maximum 'die' temperature. Operation at higher temperatures will put the IC out of specification and possibly destroy it.

There are three main ways of thermally analyzing a given design. The following article explains the different approaches, and discusses the precision of each approach.

2 The Analytical Approach

The analytical approach is a good way to get a rough estimate of the die temperature of a given switching regulator. One approach is to calculate the losses the switching regulator IC generates. For step down regulators the following formulas can be used.

There are bias losses which are mainly the ground pin current times the input voltage:

$$P_{bias} = I_q \bullet V_{IN} \quad (1)$$

The power conduction losses are the losses of the built in transistors while fully turned on and a rough estimation is:

$$P_{cond} = \text{duty cycle} \bullet R_{dson} \bullet I_{OUT}2 \quad (2)$$

The switching losses are the losses that occur during the transition times of the internal transistor before and after the on time and can be estimated by:

$$P_{switch} = (I_{OUT} \bullet V_{IN})/2 \bullet F \bullet (t_{LH} + t_{HL}) \quad (3)$$

Where F is the switching frequency and tLH and tHL are the transition times from low to high or high to low.

All the individual losses are sometimes difficult to calculate due to incomplete information regarding parameters such as the exact rise time, exact Rdson during the on time and other parasitics which are not easily characterized. Sometimes it is easier to take the overall efficiency of a given power converter board and to subtract the losses of the external components such as the external Schottky diode, the inductor, current flowing through the external resistive divider, and possibly the capacitors depending on the ESR.

Once we know the losses of the switching regulator IC, the thermal analysis can be started. The individual data sheets give the thermal resistance from the junction of the IC to case (or PCB), which is referred to as θJC. The units are degrees centigrade per Watt, and knowing the ambient temperature as well as the dissipated power on the die gives the temperature of the die. The resistance value θJC has a lot to do with the package the silicon is housed in but it also includes the size of the die, the die attach material, and bond wire type and number. This is the reason why there is not one θJC per package type, and why the junction to resistance has to be thermally measured with each individual newly released IC product.

The junction to ambient thermal resistance, θJA, depends greatly on the design of the printed circuit board around the IC. Generally, data sheets give information about the PCB and layout situation in which the given thermal resistance is valid.

The precision of the analytical approach depends greatly on the complexity of the formulas as well as on the precision of data of components available to the designer. In many cases, it is more precise to use a practical approach with measurements in the lab rather than mathematical models which lack accuracy due to many unknowns.

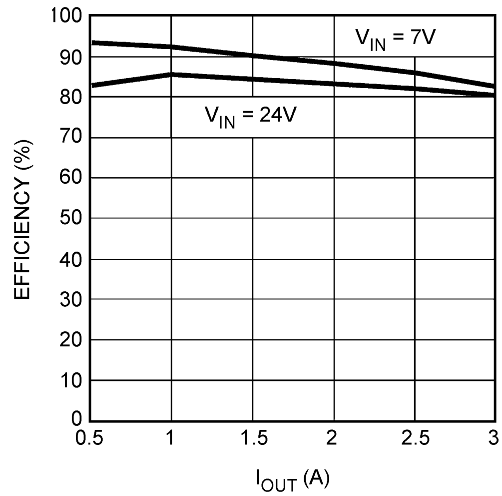

Figure 1. Typical Efficiency at 5V V_{OUT} vs I_{OUT} and V_{IN}

3 The Simulation Approach

To simplify thermal predictions, Texas Instruments WEBENCH® online simulation tool includes a module called WebTHERM™ which offers thermal modeling of many switching regulator ICs, including Texas Instruments new LM557x and LM2557x SIMPLE SWITCHER® regulators. The thermal simulation results are given in a colorful thermal graph where hotspots can easily be detected and the temperature of each point on the board can be found. Heat sinks can be added to improve thermal dissipation. Also, airflow can be adjusted using fans from different directions. Figure 2 shows a screenshot of a thermal simulation result with WebTHERM. This approach is very simple and gives a good idea of how heat dissipates across a board. It also helps to understand where hotspots exist in individual designs.

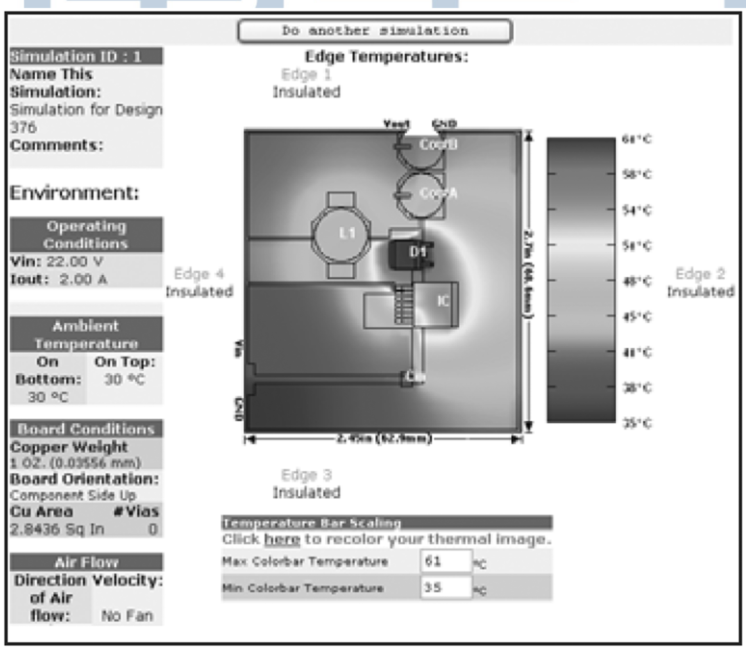

Figure 2. Thermal Simulation with WebTHERM

4 The Hands-On Approach

The most accurate approach in finding the true IC temperature in a design is to build the design with all the final components which will be on the board, but physically set up on a board with enough distance from component to component so that the heat dissipations of individual components do not influence the temperature of other components on the board. A clever way of achieving the same result without changing the layout is to mount components in the air on short wires. The board can then be set to run steady state and the temperature of the external components can be measured with an infrared thermometer.

In the next step, we try to heat up the external components to the exact same temperature by driving them individually. For example, we would drive the inductor with a DC current so that in steady state we would get the same infrared temperature measurement. The dissipated power needed to warm the device up to the same level as with the complete power design running can easily be calculated by multiplying the DC current by the DC voltage drop across the inductor.

Once this exercise is done for the external components, but mostly the external diode and the inductor, we can correctly measure the efficiency of the complete power design, subtract the losses of the individual external components from our measurements, and get to the power losses of the switching regulator IC.

This power loss can again be translated into die temperature using the θJC thermal resistances as given in the data sheet.

5 The Choice is Yours

There are many different methods for performing thermal analysis. Depending on the precision needed as well as the time and effort one is willing to put into it, there are different options as described above. If your design requires the switching regulator to work with a junction temperature up to 150ºC rather than the typical 125ºC maximum junction temperature, there are SIMPLE SWITCHER regulators that can help, such as TI's LM2590HV-AQ.

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Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265