International Rectifier

Application Note AN-1030

Applying *i*POWIR™ products in your thermal environment

by Steve Brown, International Rectifier

Background

iPOWIR™ technology products represent a new class of power solutions which have their own unique application process. They provide a higher level of functionality than a MOSFET, or an IC, but are not a complete power supply.

Thermal design is a simple process

iPOWIR products also employ a unique approach to rating and characterization. From a thermal standpoint, the *iPOWIR* products are much more similar to a power supply than a discrete component.

Thermal design is simplified because the power supply designer no longer has to estimate losses of the component by combining a complex set of MOSFET and driver parameters. Each *iPOWIR* product is fully characterized for power loss under expected operating conditions.

Applying *iPOWIR* Technology

Overview

A go, no-go check of your basic thermal design can be broken into four simple steps:

1- Identify the operating conditions of your application
2- Determine the maximum expected power loss of the *iPOWIR* block
3- Calculate the expected PCB temperature
4- Verify the safe operating area (SOA) of the *iPOWIR* block

Alternatively, you can pick a point on the SOA curve, then work back from there to find your required thermal environment:

1- Pick the desired operating current and other conditions
2- Determine the maximum PCB temperature from the SOA graph
3- Find the power loss at the application current from the power loss graph
4- Calculate the required thermal environment for the application

In both cases, the power loss graph (Figure 1) and the SOA graph (Figure 2) are required for the solution. When determining current for multi-phase applications, be sure to allow for worst-case phase imbalance.

Operating conditions

Input voltage, output current, and operating frequency are the main electrical factors. Output voltage has an effect, but is second order compared to input voltage.

System ambient temperature (T_A) and printed circuit board (PCB) thermal resistance are the important thermal factors. System ambient temperature should be known, but PCB-to-ambient thermal resistance (R_{THBA}) is sometimes unknown. Refer to the section at the end of this application note for a method to determine PCB thermal resistance.

Power loss graph

Every *iPOWIR* product data sheet includes a graph of maximum power loss versus current, for the appropriate family of input voltages and operating frequencies. Be sure to use the curve that most closely corresponds to the application.

Typical power blocks will have power loss well below the graph limit. All *iPOWIR* products are 100% tested for power loss at final test so they are guaranteed to be within the graph limit.

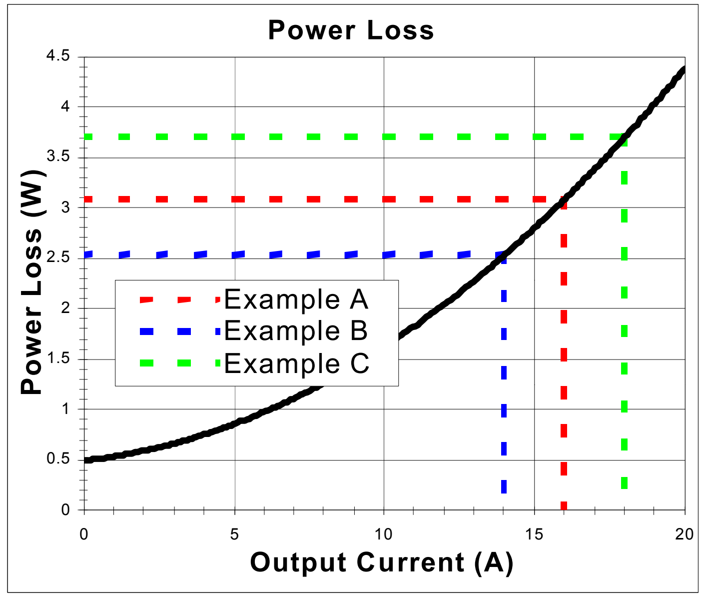

Figure 1

Calculate PCB temperature

Given the power loss of the power block (P_{BLK}) and the thermal resistance of the PCB, expected PCB temperature during operation can be calculated as in Equation 1:

$$T_{PCB} = T_A + P_{BLK} \times R_{THBA}$$

Equation 1

Every circuit board is different, so the best way to determine the R_{THBA} is to measure the actual board that will be used. By knowing *iPOWIR* block power dissipation, the required thermal environment can easily be calculated:

$$R_{THBA} = \left(T_{PCB} - T_A\right) \div P_{BLK}$$

Equation 2

$$T_A = T_{PCB} - R_{THBA} \times P_{BLK}$$

Equation 3

SOA graph

Every *iPOWIR* product data sheet also has an SOA graph which defines the maximum safe operating area of the device in terms of PCB[1] temperature and output current. This graph also has multiple curves corresponding to various input voltages and operating frequencies. Use the curve closest to the intended application.

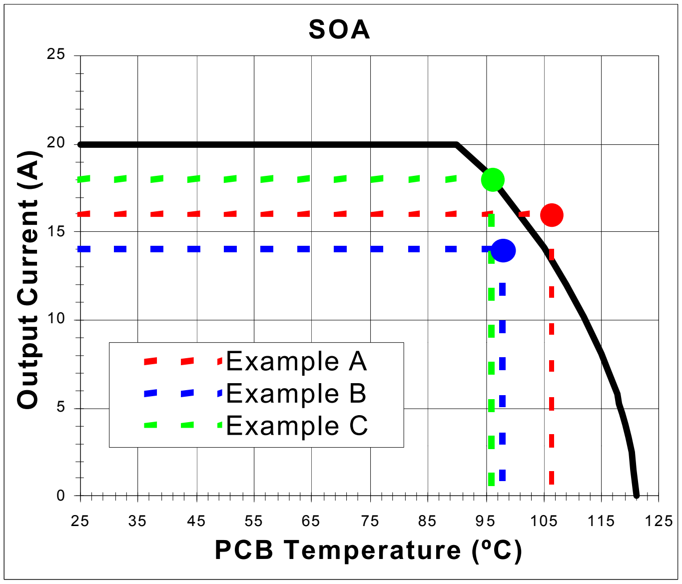

Figure 2

Like the power loss graph, the SOA graph is guaranteed for each device. In the case of this graph, however, the rating is a maximum rating and must not be exceeded.

Design verification (Examples A & B)

This procedure verifies the operation of the *iPOWIR* device in conjunction with your application environment. Two examples will be used to convey the method.

Identify operating conditions

Both examples assume that the graphs relating to the correct input voltage and operating frequency have been chosen.

Example A

- Output current = 16A
- T_A = 60°C
- R_{THBA} = 15°C/W

Example B

- Output current = 14A
- T_A = 60°C
- R_{THBA} = 15°C/W

Determine maximum power loss

Referring to Figure 1, find the power loss for both examples.

- Power loss Example A: 3.1 watts @ 16A
- Power loss Example B: 2.5 watts @ 14A

Calculate PCB temperature

Making substitutions into Equation 1:

$$T_{PCB\ "A"} = 60°C + 3.1W \times (15°C\ per\ W) = 106.5°C$$

Equation 4

$$T_{PCB\ "B"} = 60°C + 2.5W \times (15°C\ per\ W) = 97.5°C$$

Equation 5

Verify SOA of the *iPOWIR* block

Now that PCB temperature has been determined, the SOA graph of the *iPOWIR* device can be checked for compliance.

Example A: 16A @ 106.5°C T_{PCB} (Equation 4)

By examination of Figure 2, it is evident that this example falls outside the SOA of the device and is therefore an unacceptable operating point.

Example B: 14A @ 97.5°C T_{PCB} (Equation 5)

Also referring to Figure 2, it is clear that example B falls well within the SOA of the device and is therefore an acceptable operating point.

Back calculation method (Example C)

In this case the design is targeted for a specific output current. Example C will be used to derive two examples (C1 & C2).

Pick the desired operating conditions

Example C1

- Output current = 18A
- T_A = 60°C
- R_{THBA} = TBD

Example C2

- Output current = 18A
- T_A = TBD
- R_{THBA} = 15°C/W

Determine the maximum PCB temperature

Referring to Figure 2, at 18A output current the maximum PCB temperature for Example C1 & C2:

- T_{PCB}: 96°C

Find power loss at the application current

Referring to Figure 1, at 18A output current the maximum power loss for Example C1 & C2:

- P_{BLK}: 3.7W

Calculate the required thermal environment

Substitute into Equation 2 and Equation 3 to solve for the missing thermal parameters for Example C1 & C2 as required for operation within the device SOA.

Example C1

$$R_{THBA\ "C1"} = (96°C - 60°C) \div 3.7W = 9.73°C/W$$

Equation 6

Example C2

$$T_{A\ "C2"} = 96°C - (15°C\ per\ W) \times 3.7W = 40.5°C$$

Equation 7

Characterizing the PCB

Although this step is often overlooked or misunderstood, when using any component that dissipates power through the PCB it is always necessary to know or control the R_{THBA} of the application.

Procedure

In order to measure the R_{THBA} of your application it is necessary to apply a known power dissipation in place of the *iPOWIR* block, then measure the temperature difference between the PCB adjacent to the power source, and the ambient temperature. A thermocouple, IR camera, or other measurement technique can be used. T_{PCB} is defined as 1mm from the *iPOWIR* block at the hottest point on the PCB. Once the values of T_A, T_{PCB}, and P_{BLK} are known they can be substituted into Equation 2 in order to compute R_{THBA}.

T_A should be measured about 1 foot from the test board. It should be assumed that the hottest point on the PCB will be where the switch node (V_{SW}) is routed away from the *iPOWIR* block on the top layer unless you're PCB design is somehow unique.

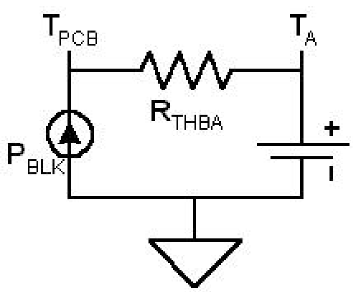

Figure 3

If the board is designed for a multi-phase solution, all phases should be populated with heat sources so that thermal coupling can be accounted for.

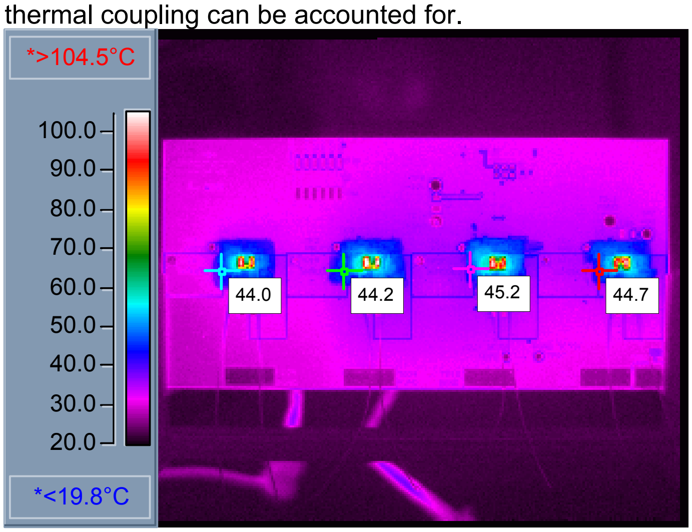

Figure 4

In the example that follows, four 0.68Ω surface mounted power resistors[2] were used to populate a 4 phase demo board in place of the *iPOWIR* blocks. These resistors were chosen because of their large solder pads for transferring heat to the PCB. They were soldered down, making good contact with the V_{IN} and V_{SW} pads. These pads are the primary heat egress points of the *iPOWIR* block.

All four resistors were placed in parallel because the V_{IN} pads are in parallel. Current was set to 1.643A and the voltage drop across the resistor was 1.124 volts for a power dissipation of approximately 1.847 Watts.

The thermograph of Figure 4 reveals some non-uniformity in board temperature. Zooming in on the hottest part in Figure 5 confirms that the temperature about 1mm from the part body is 46.4°C[3].

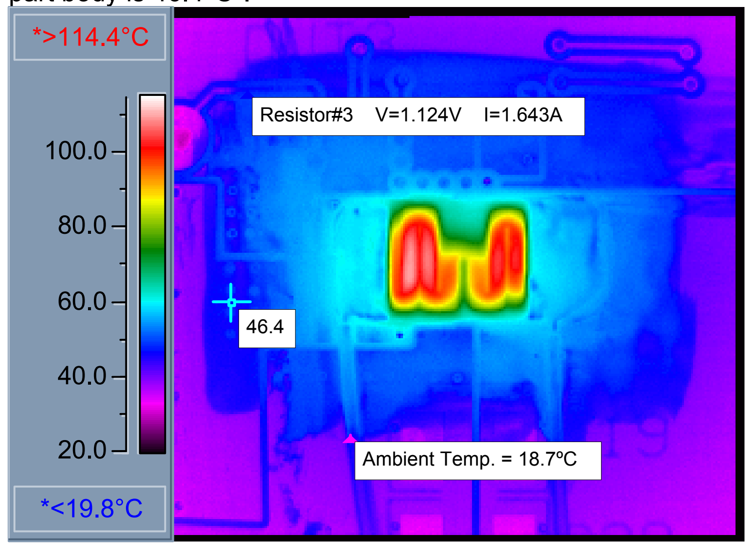

Figure 5

Substituting the known values back into Equation 2:

$$R_{THBA} = (46.4°C - 18.7°C) \div 1.847W \approx 15°C/W$$

Equation 8

Post verification of this number using actual iPOWIR blocks indicated a R_{THBA} of about 14.5°C/W. This is well within the expected margin of error for this type of measurements.

Be careful about adding excessive design margin to the thermal resistance. Generally, if you're using the top layer to carry most of the heat from the device, there should be little unit-to-unit variation. If you're using inner layers primarily, there will be some variation because of via alignment, but even this will be minimal[4]. Primarily you should allow for error in your measurement. Although in this case the error was much smaller, I usually allow about 10%-to-15% margin for thermal measurements. Once you have your final board to verify, you can expect repeatability to be very good if the board quality is good.

Since the *iPOWIR* specifications already incorporate manufacturing variability, indiscriminately adding additional margin may result in an over conservative design.

When making the measurement, use airflow consistent with worst-case design conditions. Most of the power block dissipation is out through the circuit board connections. Very little is dissipated off the top of the device.

One other thing that may become evident is that if the power sources are set to the worst case expected *iPOWIR* block dissipation, then you only need to verify that the board temperature is within the SOA limit. Board to ambient thermal resistance becomes a non-issue.

Summary

Power Loss

For multi-phase applications, be sure to allow for imbalance between phases when using the power loss graph. Remember that the curves are already worst case so there is no reason to add design margin.

SOA

IPOWIR SOA curves are maximum boundaries that must not be exceeded under worst case operating conditions. They account for variability of the *iPOWIR* block, but not for variability of your thermal environment or circuit conditions.

R_{THBA}

Understanding the R_{THBA} of the application circuit board is a necessary part of design when using *iPOWIR* products, or any other surface mounted power components.

Measuring R_{THBA} is straightforward but remember to allow 10%-to-15% for error in the measurement.

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[1] Ratings assume that 1oz or thicker copper traces. For thinner copper contact the factory for technical advice.

[2] ISOTEK: SMT-R680-1.0

[3] PCB temperature should be measured on the V_{SW} trace, 1mm from the expected edge of the package.

[4] See AN-1029: Optimizing A PCB Layout For An *i*POWIR™ Technology Design