Application Note 103
August 2005

LTM4600 DC/DC µModule™ Thermal Performance Application Note

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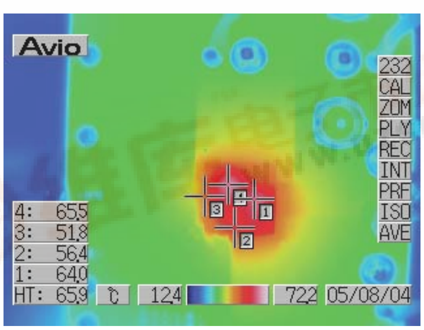
Introduction

The µModule power technology enables very dense power design for 14A peak, and 10A continuous loads in the LTM4600 device. The µModule has two voltage options: 20V maximum for the LTM4600EV and 28V maximum for the LTM4600HVEV. The small 15mm × 15mm × 2.8mm LGA surface mount package has specific load current de-rating curves in the datasheet for input voltage, output voltage, and ambient temperature with air flow. These de-rating curves provide guidelines for using the LTM4600 in ambient environments with regard to safe-operating-area (SOA). Also there are efficiency curves in the datasheet that are used to extrapolate the power loss curves used in this thermal application note. The purpose of this thermal application note is to provide a guideline for using the µModule in ambient environments with and without air flow. The goal is to be able to take measured temperature data on a design and derive the junction-to-ambient thermal resistance (θ_{JA}) in units of °C/W with and without a heatsink under air flow conditions. The required data includes power loss curves, safe operating curves (SOA), thermal camera images, current de-rating curves verses ambient temperature with and without a heatsink. Also air flow will be included in the de-rating curves. The 24V designs are analyzed for a worse case temperature rise due to the lower efficiency exhibited in these higher input voltage designs. The 12V designs are characterized for this common input voltage.

Thermal Imaging of a Design

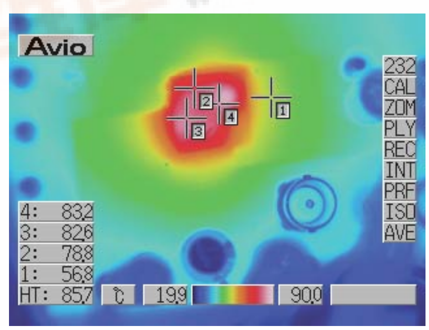
A 12V to 3.3V at 10A design and a 24V to 3.3V at 10A design are characterized for 33W operation at about 91% and 87% conversion efficiency respectively. This corresponds to a power loss of about 3W and 4.25W dissipated in the µModule and the PCB. The extra 4% loss on the 24V design is attributed to the extra power dissipation in the controller, and increased transition losses in the internal top MOSFET. This loss can be reduced by about 2%, or an efficiency of 89% from the 24V design, by connecting the $EXTV_{CC}$ pin to a 5V bias supply with a 50mA capability. The $EXTV_{CC}$ must be sequenced after the main input supply. Thermal imaging was performed on the two designs with and without a heatsink. Figure 1 shows a thermal image of the 12V to 3.3V design with several thermal image data points, and Figure 2 shows the 24V to 3.3V design with several thermal image data points. The maximum temperature in Figure 1 is equal to 66°C on the µModule with 3W of dissipation in the design, and Figure 2 has a maximum temperature of 82°C on the µModule with



AN103 F01

CONDITIONS: 25°C, NO AIR FLOW,
NO HEATSINK, NO $EXTV_{CC}$

Figure 1. LTM4600 12V to 3.3V at 10A, Top view



AN103 F02

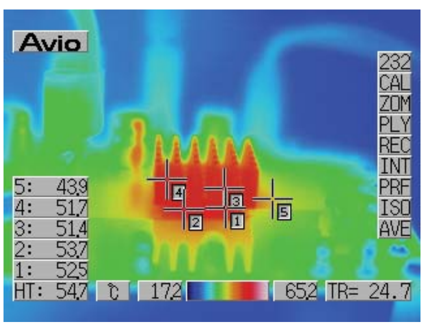
CONDITIONS: 25°C, NO AIR FLOW,
NO HEATSINK, NO $EXTV_{CC}$

Figure 2. LTM4600 24V to 3.3V at 10A, Top view

4.25W of dissipation. Total µModule PCB temperature T_{PCB} is defined as: $T_{PCB} = T_A + T_{RISE}$. Where T_A is the ambient temperature and T_{RISE} is the temperature rise due to the power dissipation in the µModule. The goal is find the θ_{JA}, which is defined as the junction-to-ambient thermal resistance. T_{RISE} can be defined as: $T_{RISE} = \theta_{JA} \bullet$ Power Loss. The T_{RISE} can be solved for as: $T_{PCB} - T_A = T_{RISE}$. The T_{RISE} can then be divided by the Power Loss to solve for θ_{JA} in units of °C/W. So taking our example of Figure 1, $T_{PCB} = 66°C$, $T_A = 25°C$, and Power Loss = 3W we can solve for a θ_{JA} of 13.5°C/W. Figure 2 shows a T_{PCB} of 83°C, T_A = 25°C, and Power Loss = 4.25W. This also equals a θ_{JA} of 13.5°C/W. So the µModule represents a θ_{JA} of approximately 13.5°C/W on a multilayer PCB.

Figures 3 and 4 show thermal images with a surface mount BGA heatsink on top of the µModule. The T_{PCB} temperature is about 54°C on the 12V to 3.3V design and about 67°C on the 24V to 3.3V design. Using the above equations we can solve for a θ_{JA} of 9.5°C/W.This is an improvement of 4°C/W with the BGA heatsink. Figure 5 shows a side view of the LTM4600 µModule with the surface mount BGA heatsink. Data point 2 indicates the heatsink temperature, and data point 4 indicates the junction point of the BGA heatsink and power µModule. The topside of the LTM4600 µModule is very effective at transferring heat into an external heatsink. There is only a 4°C delta between the device and the heatsink with 4.25W of dissipation. So the heatsink temperature and device temperature are approximated to be equal to one another in this analysis. The output current de-rating curves section will be discussed later with and without heatsinks under ambient conditions. A correlation will be made to see if the heatsink temperature and device temperature can be made approximately equal to one another.

Figure 6 shows the back side PCB view of a LTM4600 design that is mounted to a metal plate. This thermal test



AN103 F03

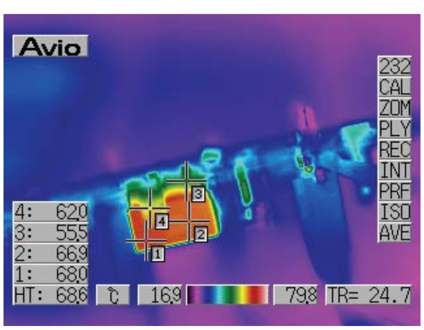
CONDITIONS: 25°C, NO AIR FLOW,
WAKEFIELD ENGINEERING PN# CIS20069,
15mm × 15mm × 9mm HEATSINK, NO $EXTV_{CC}$

Figure 3. LTM4600 24V to 3.3V at 10A, Side view

AN103 F04

CONDITIONS: 25°C, NO AIR FLOW,
WAKEFIELD ENGINEERING PN# CIS20069,
15mm × 15mm × 9mm HEATSINK, NO $EXTV_{CC}$

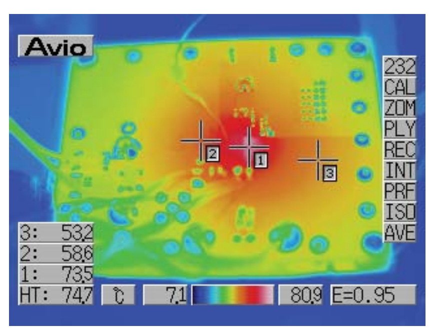
Figure 4. LTM4600 24V to 3.3V at 10A, Side view



AN103 F05

CONDITIONS: 25°C, NO AIR FLOW,
WAKEFIELD ENGINEERING PN# CIS20069,
15mm × 15mm × 9mm HEATSINK, NO $EXTV_{CC}$

Figure 5. LTM4600 24V to 3.3V at 10A, Side View

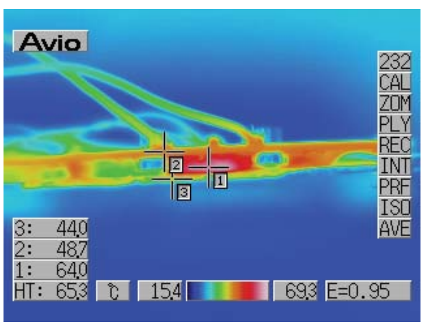


AN103 F06

CONDITIONS: 24V TO 3.3V AT 10A, 25°C, NO AIR FLOW.
A BERGQUIST "GAP PAD 1000" IS USED BETWEEN THE
µMODULE AND THE METAL PLATE. 0.04 THICKNESS
2°C/W. (METAL PLATE = 100mm × 75mm × 1.5mm)

Figure 6. LTM4600 24V to 3.3V at 10A, Back Side of the PCB

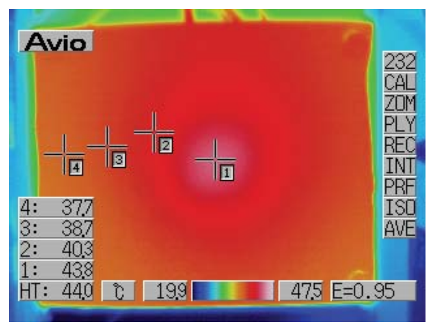
case is analyzed for consideration of use in systems that desire back side PCB mounting of the power µModule. The power µModule can then be mounted to a metal carrier either directly or through a thermal conductive pad for heatsinking. This test case uses a Bergquist "Gap Pad" for the thermal connection between the power µModule and metal carrier. The conditions are so noted below Figure 6. Figure 6 shows the T_{PCB} temperature at data point 1 of 73.5°C. So again, T_{RISE} can be solved for by taking the difference of 73.5°C minus 25°C to get 48.5°C. This 48.5°C is divided by 4.25W to derive an approximate θ_{JA} of 11.5°C/W. Figure 7 shows a side view of the device mounted to a metal plate. This opening between the PCB and the metal plate can offer some opportunity for air flow to further reduce this θ_{JA}. Figure 8 shows the metal plate view of the 33W design with the conditions noted below in the photo. The metal plate transfers heat pretty effectively, and would provide an even better result under air flow. There is a thermal resistance drop from the top of the µModule to the metal carrier. This thermal resistance drop is approximately derived from the temperature drop from the PCB under the µModule to the metal plate on top of the µModule. The metal plate temperature of 43.8°C noted as data point 1 in Figure 8 is subtracted from the 73.5°C PCB temperature under the µModule in Figure 6. This difference of 30°C is now divided by the power loss of 4.25W to get a thermal resistance drop of 7°C/W. The Bergquist "Gap Pad" that is used between the µModule and the metal plate has a θ_{JA} of 2°C/W, so this could be improved with the removal of the "Gap Pad". The other 5°C/W thermal resistance drop is developed by the interface of the µModule and metal plate to the "Gap Pad". This total thermal resistance drop can be reduced by an improved thermal interface from the µModule to the metal plate.



AN103 F07

CONDITIONS: 24V TO 3.3V AT 10A, 25°C, NO AIR FLOW. A BERGQUIST "GAP PAD 1000" IS USED BETWEEN THE µMODULE AND THE METAL PLATE. 0.04 THICKNESS 2°C/W. (METAL PLATE = 100mm × 75mm × 1.5mm)

Figure 7. LTM4600 24V to 3.3V at 10A, Side View



AN103 F08

CONDITIONS: 24V TO 3.3V AT 10A, 25°C, NO AIR FLOW. A BERGQUIST "GAP PAD 1000" IS USED BETWEEN THE µMODULE AND THE METAL PLATE. 0.04 THICKNESS 2°C/W. (METAL PLATE = 100mm × 75mm × 1.5mm)

Figure 8. LTM4600 24V to 3.3V at 10A, Metal Plate View

De-rating Curves Verses Ambient Temperature and Air Flow

Several de-rating curves are shown below to provide a guideline for the maximum load current that can be achieved at certain ambient temperatures. These curves are characterized with 0LFM, 200LFM, and 400LFM. Also the curves are provided with heatsinks and no heatsinks. The power loss curves are provided to help establish an approximate θ_{JA} for the characterized operating conditions that will ultimately be correlated to the thermal images above. The power loss curves and de-rating curves will be used to build a table to correlate our approximate θ_{JA} and a reduced θ_{JA} with increased air flow. We have chosen 5V, 12V, and 24V as the input operating conditions for this analysis. The two output voltages are 1.5V and 3.3V.

Figures 9 and 10 show the 1.5V and 3.3V power loss curves with load current and input voltages.

Figures 11, 12, and 13 are the three de-rating curves for 5V to 1.5V verses load current, air flow, and with and without heatsinks. Figures 14, 15, and 16 are the same de-rating curves for 12V to 1.5V. Figures 17, 18, and 19 are the de-rating curves for 24V to 1.5V. All of the curves are put into columns to designate the type of heatsink used in the test conditions.

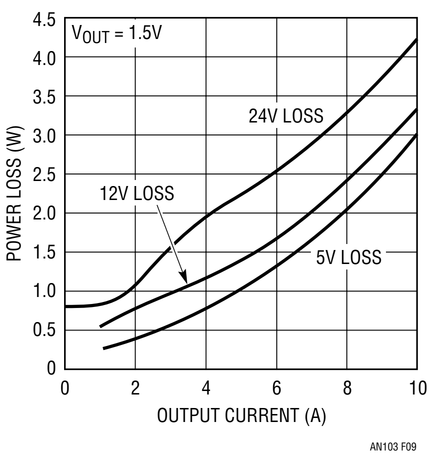


Figure 9. Power Loss vs Load Current

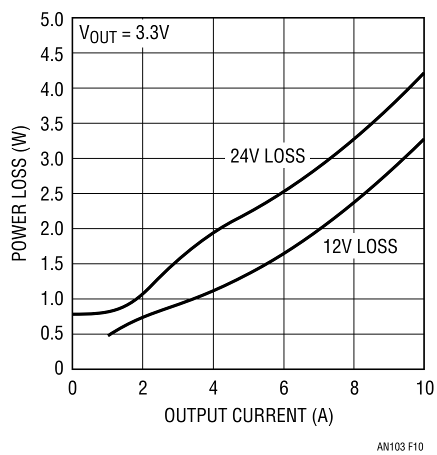


Figure 10. Power Loss vs Load Current

No Heatsink Column

BGA Heatsink Column

Metal Plate with Gap Pad Column

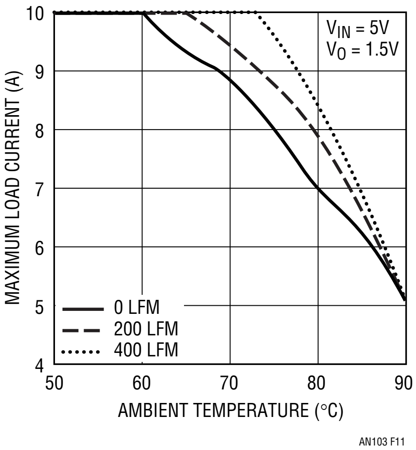


Figure 11

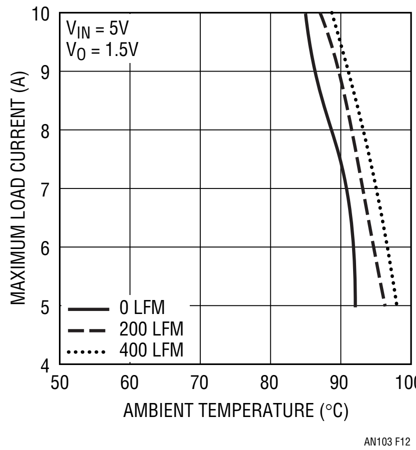


Figure 12

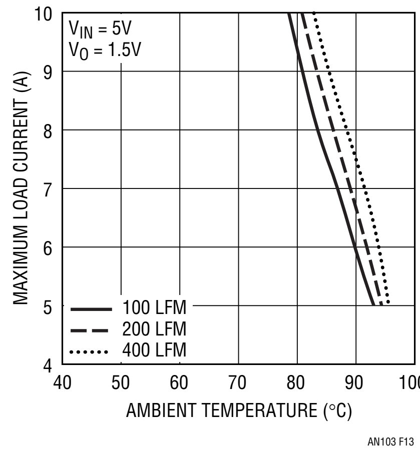


Figure 13

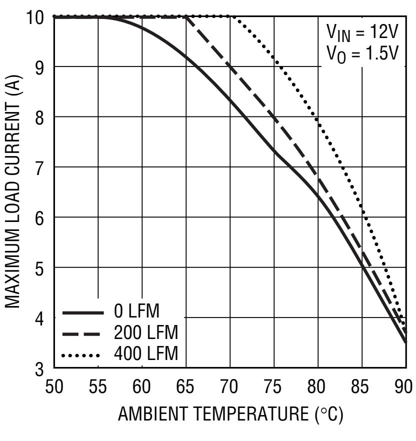


Figure 14

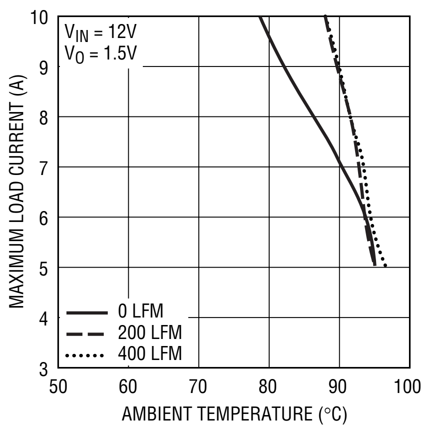


Figure 15

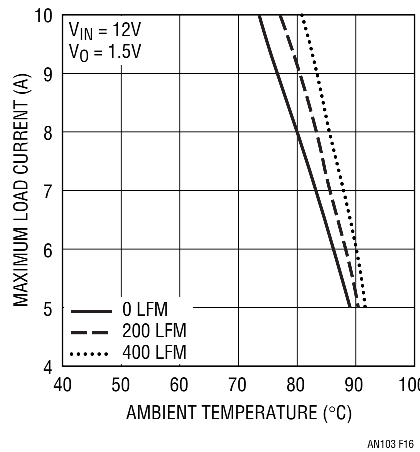


Figure 16

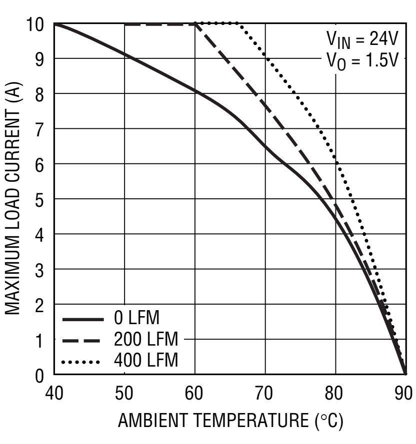


Figure 17

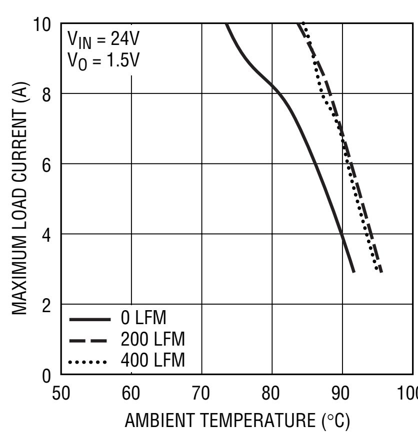


Figure 18

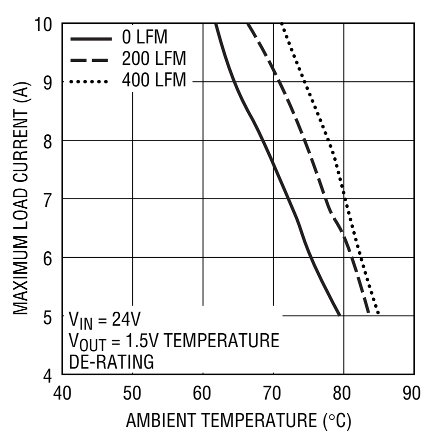


Figure 19

Figures 20, 21 and 22 are the three de-rating curves for 12V to 3.3V at the different load currents, different air flow, and different heatsinks. Figures 23, 24, and 25 are the three de-rating curves for 24V to 3.3V. All of these curves are put into columns to designate the type of heatsink used in the test conditions.

No Heatsink Column

BGA Heatsink Column

Metal Plate with Gap Pad Column

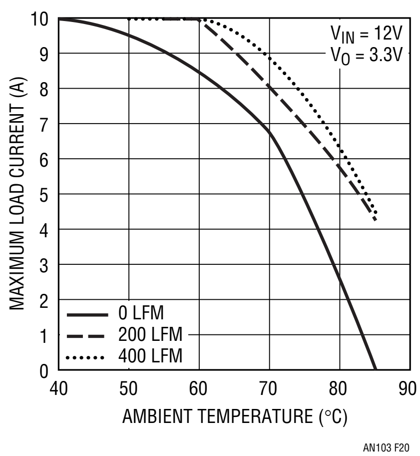


Figure 20

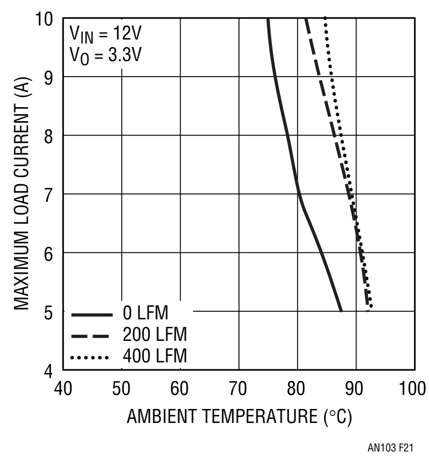


Figure 21

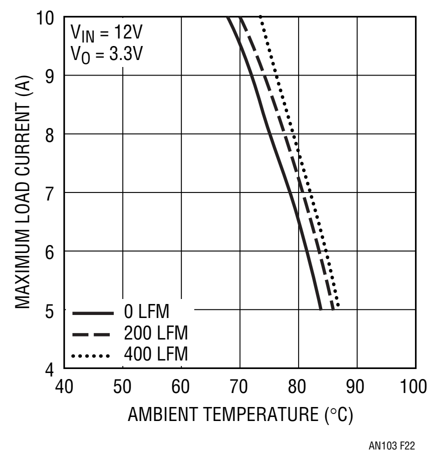


Figure 22

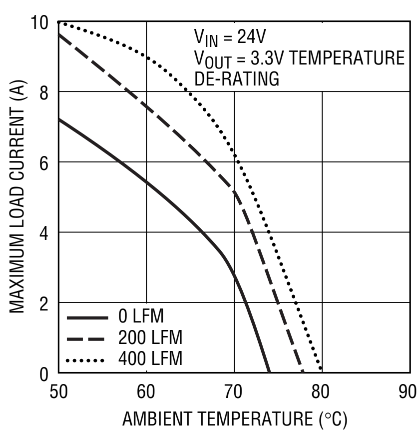


Figure 23

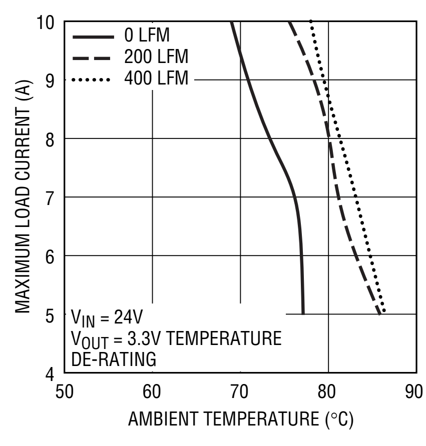


Figure 24

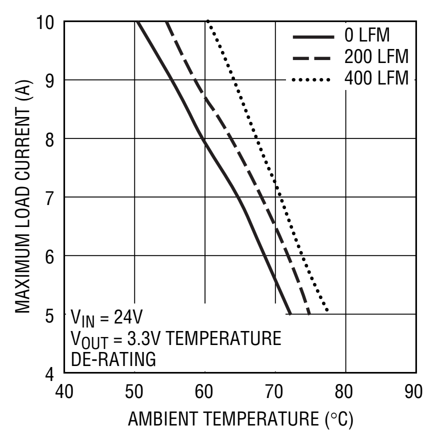


Figure 25

The power loss curves in Figures 9 and 10 will now be used in conjunction with the load current de-rating curves in Figures 11 through 25 to calculate an approximate θ_{JA}. Each of the load current de-rating curves will lower the maximum load current as a function of the increased ambient temperature to keep the junction temperature of the power µModule at 100°C maximum. This 100°C maximum is to allow for an increased rise of about 15°C to 20°C inside the µModule. This will maintain the maximum operating temperature below 125°C. Each of the de-rating curves and the power loss curve that corresponds to the correct output voltage can be used to solve for the approximate θ_{JA} of the condition. For example in figure 11, the 10A load current can be achieved up to 60°C ambient temperature with no air flow. If this 60°C is subtracted from the maximum µModule temperature of 100°C, then 40°C is the maximum temperature rise. Now Figure 9 records the power loss for this 5V to 1.5V at the 10A output. If we take the 40°C rise and divided it by the 3 watts of loss, then we get an approximate θ_{JA} of 13.5°C/W with no heatsink. If we take the next curve in Figure 11 at 200LFM of air flow, then the maximum ambient temperature allowed at 10A load current is 65°C. This calculates to a 35°C rise, and an approximate θ_{JA} of 11.6°C/W with no heatsink. At 400LFM in figure 11, the maximum ambient temperature allowed at 10A load current is 73°C. This calculates to a 27°C rise, and an approximate θ_{JA} of 9°C/W with no heatsink. Each of the de-rating curves that follow figure 11 can be used with the appropriate power loss curve in either Figure 9 or Figure 10 to derive an approximate θ_{JA}. The following tables show these different θ_{JA} values taken from the de-rating curves.

Conclusion

The approximate θ_{JA} was empirically solved for in the thermal image section of this application note. The data was taken with no air flow. The values for θ_{JA} that were derived from the thermal image section are 13.5°C/W, 9.5°C/W, and 11.5°C/W with no heatsink, a BGA heatsink, and a metal plate respectively. This data correlates very well with the zero air flow θ_{JA} in Table 1 and Table 2.

Table 1. 1.5V Output

DE-RATING CURVE	V_{IN} (V)	POWER LOSS CURVE	AIR FLOW (LFM)	HEATSINK	θ_{JA} (°C/W)
Figures 11, 14, 17	5, 12, 24	Figure 9	0	None	13.5
Figures 11, 14, 17	5, 12, 24	Figure 9	200	None	11
Figures 11, 14, 17	5, 12, 24	Figure 9	400	None	9
Figures 12, 15, 18	5, 12, 24	Figure 9	0	BGA Heatsink	9.5
Figures 12, 15, 18	5, 12, 24	Figure 9	200	BGA Heatsink	6.25
Figures 12, 15, 18	5, 12, 24	Figure 9	400	BGA Heatsink	4.5
Figures 13, 16, 19	5, 12, 24	Figure 9	0	Metal Plate	11.5
Figures 13, 16, 19	5, 12, 24	Figure 9	200	Metal Plate	7
Figures 13, 16, 19	5, 12, 24	Figure 9	400	Metal Plate	6.25

Table 2. 3.3V Output

DE-RATING CURVE	V_{IN} (V)	POWER LOSS CURVE	AIR FLOW (LFM)	HEATSINK	θ_{JA} (°C/W)
Figures 20, 23	12, 24	Figure 10	0	None	13.5
Figures 20, 23	12, 24	Figure 10	200	None	11.6
Figures 20, 23	12, 24	Figure 10	400	None	10.4
Figures 21, 24	12, 24	Figure 10	0	BGA Heatsink	9.5
Figures 21, 24	12, 24	Figure 10	200	BGA Heatsink	6
Figures 21, 24	12, 24	Figure 10	400	BGA Heatsink	4.77
Figures 22, 25	12, 24	Figure 10	0	Metal Plate	11.5
Figures 22, 25	12, 24	Figure 10	200	Metal Plate	8
Figures 22, 25	12, 24	Figure 10	400	Metal Plate	8.5

HEATSINK MANUFACTURER	PART NUMBER	PHONE NUMBER
Wakefield Engineering	CIS20069	603-635-2800
Bergquist Company	Gap Pad 1000SF	952-835-2322

A color version of this Application Note is available at www.linear.com/micromodule

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