LTM4600 DC/DC µModule® Regulator Thermal Performance

Eddie Beville, Jian Yin

INTRODUCTION

The LTM4600 DC/DC µModule regulator is a complete high power density stepdown regulator for 10A continuous (14A peak) loads. The device has two voltage options: $20V_{IN}$ maximum for the LTM4600EV and $28V_{IN}$ maximum for the LTM4600HVEV each housed in a small 15mm × 15mm × 2.8mm LGA surface mount package. Load current derating curves are provided in the datasheet for several input voltage, output voltage, and ambient temperatures with air flow. These derating 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 regulator in ambient environments with or without air flow. The goal is to measure the temperature of a design, derive thermal models for different cases and finally determine the junction-to-ambient thermal resistance (θ_{JA}) in units of °C/W in the heat path. The data includes power loss curves, safe operating curves (SOA), thermal camera images and current derating curves verses ambient temperature with and without a heatsink. The influence of air flow is also included in the derating curves. The 24V designs are analyzed for a worse case temperature rise due to the lower efficiency exhibited in these higher input voltage designs.

THERMAL MODEL

An example is shown in the schematic (Figure 1(a)), with a µModule regulator attached to a 4-layer PCB with a size of 95mm × 76mm. To analyze this physical system, a simplified 1-D thermal model, which is presented in Figure 1(b), is employed to show the heat paths in the system. The heat is generated from the µModule regulator and flows to the top and bottom sides. For the topside heat path, R_{JT} is used to represent the thermal resistance from junction to the top surface, while R_{TA} represents the resistance from the top surface to ambient. Similarly, for the bottom side, R_{JB} is the thermal resistance from junction to the bottom surface, and R_{BA} is the resistance from the bottom surface to ambient. The double-sided cooling scheme can be realized easily if heat sink is used for the top side.

THERMAL IMAGING

Case 1: No Heatsink

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 power module 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

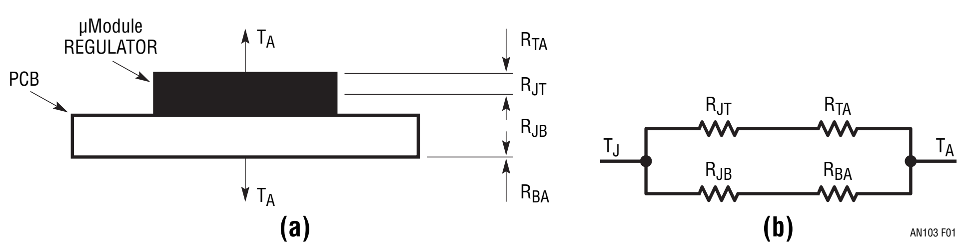


Figure 1. Thermal Model in the Design

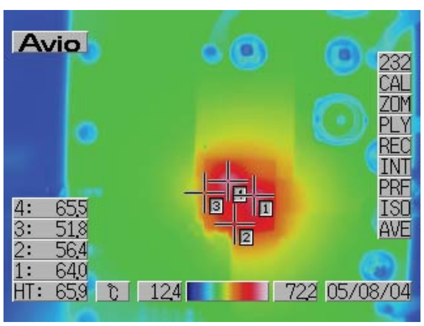
top MOSFET. This loss can be reduced by about 2%, or an efficiency of 89% from the 24V design, by connecting the $EXTV_{CC}$ pin to a 5V bias supply with a 50mA capability. The $EXTV_{CC}$ voltage must be sequenced after the main input supply. Figure 2 shows a thermal image of the 12V to 3.3V design with several thermal image data points, and Figure 3 shows the 24V to 3.3V design with several thermal image data points. The maximum temperature in Figure 2 is equal to 66°C on the µModule regulator with 3W of dissipation in the design, and Figure 3 has a maximum temperature of 82°C on the µModule regulator with 4.25W of dissipation.

We have analyzed a worse case with no heatsink and 4.25W of dissipation in Figure 3. Since it has a small top surface area at 15mm × 15mm, the heat dissipation from the package topside can be ignored. So the thermal model shown in Figure 1 can be redrawn in Figure 4, which only has thermal resistances R_{JB} and R_{BA} at the bottom side heat path. To measure the internal temperature of the device, a thermocouple is inserted at a point close to the power MOSFET. This measured internal temperature is 89.8°C. The average temperature at the bottom side of the PCB is about 75°C. Therefore, R_{JB} and R_{BA} can be calculated at 3.5°C/W and 11.7°C/W respectively. The total thermal resistance from junction to ambient in this case is only 15.2°C/W.

Case 2: With A BGA Heatsink

Figure 5 shows a thermal image with a surface mount BGA heatsink on top of the µModule regulator. From the measurement, the average temperature at the bottom side of the PCB is about 54°C on the 12V to 3.3V design and about 73°C on the 24V to 3.3V design.

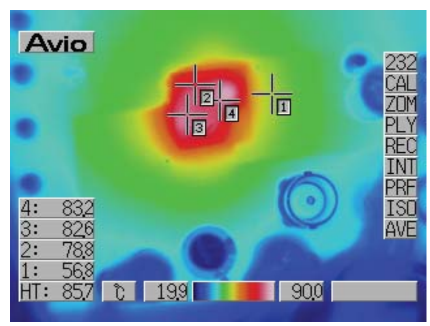
Figure 5 shows a side view of the LTM4600 with the surface mount BGA heatsink. Data point 2 indicates the heatsink temperature, and data point 4 indicates the joint point of



AN103 F02

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

Figure 2. LTM4600 12V to 3.3V at 10A, Top view



AN103 F03

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

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

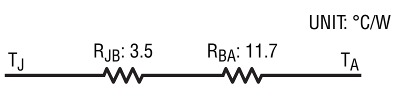
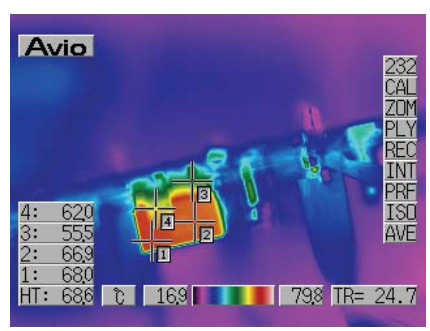


Figure 4. Thermal Model for Case 1 in Figure 3



AN103 F05

CONDITIONS: 25°C, NO AIR FLOW,
WAKEFIELD ENGINEERING PN# 20069,
15mm × 15mm × 9mm HEATSINK, NO $EXTV_{CC}$

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

the BGA heatsink and power module. The topside of the LTM4600 is now very effective in transferring heat into an external heatsink. There is only a 4°C delta between the device and the heatsink with 4.25W of dissipation. The output current derating curves section will be discussed later with and without heatsinks under ambient conditions. The thermal model, which represents the scenario in Figure 5 with 4.25W of dissipation, is shown in Figure 6. In this situation, the heat flows to both top and bottom sides. For topside heat path, the heat generated from the module first flows from the junction (R_{JH}) to the μModule case, and then it reaches the heatsink and dissipates into ambient air (R_{HA}). For the bottom side heat path, the heat first flows to the 4-layer PCB before it dissipates to the ambient air from the PCB. Here, R_{JB} is the thermal resistance from the junction to PCB dissipation surface and it includes R_{JP} (junction to module pin) and R_{PB} (pin to PCB dissipation surface).

Since the heat sink temperature is about 66°C in Figure 5 and R_{HA} under natural convection condition can be obtained to be about 21.5°C/W from the datasheet of the manufacturer, we can know that the heat dissipation to topside is about 1.9W. The measured junction temperature in this case is about 84°C, so we can calculate all thermal resistances in the model as shown in Figure 6(b). Compared to the case without a heatsink in Figure 4, the heat spreading area to the bottom side in this case becomes smaller due to lower heat dissipation to bottom side, so the thermal resistances at bottom side heat path become larger in Figure 6. The total junction-to-ambient thermal resistance for this case with a BGA heatsink is about 13.9°C/W.

Case 3: With A Metal Plate

Figure 7 shows the back side PCB view of a LTM4600 design that is mounted to a metal plate with a size of 100mm × 80mm. This thermal test case is analyzed for consideration of use in systems that desire back side PCB mounting of the power μModule regulator. The module can then be mounted to a metal carrier through a thermal conductive pad on a heatsink. This test case uses a

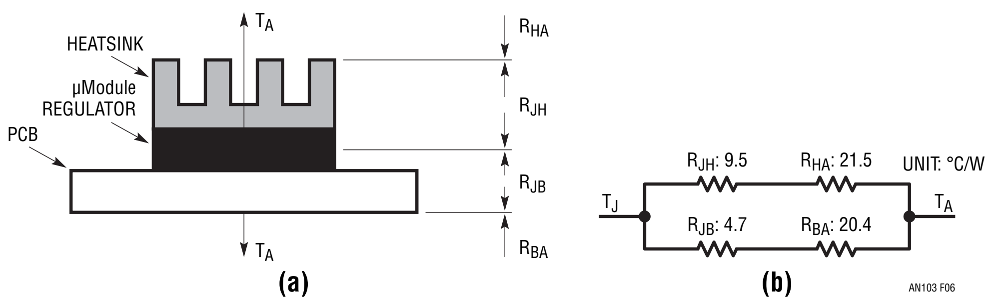
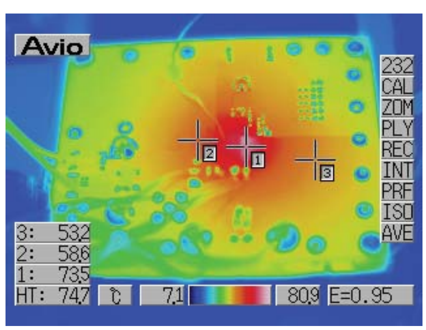


Figure 6. Thermal Model for Case 2



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

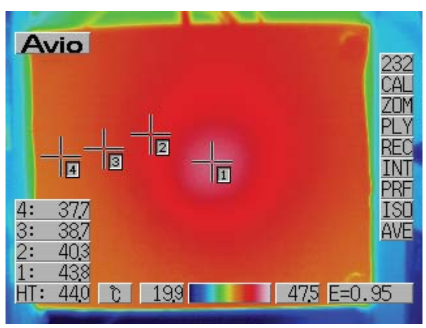
Figure 7. LTM4600 24V to 3.3V at 10A, Back Side of the PCB

Bergquist "Gap Pad" for the thermal connection between the power µModule and metal carrier. The conditions are noted below Figure 7.

Figure 8 shows the metal plate view of the 33W design with the conditions noted below in the photo. The metal plate transfers heat effectively, and would provide an even better result under air flow. Similar to previous analysis, the average temperature of the bottom side of the PCB is about 66°C in Figure 7 and the average temperature of the metal plate is about 40°C in Figure 8. And the thermal resistance R_{MA} from metal plate to ambient is only about 7.5°C/W due to the large dissipation surface of the metal plate. The measured junction temperature is about 76°C. There is a thermal resistance drop from the top of the package to the metal plate. The Bergquist "Gap Pad" that is used between the package and the metal plate has a thermal resistance of 2°C/W. The other 5°C/W thermal resistance drop is developed by the interface of the package and metal plate to the "Gap Pad". This total thermal resistance drop can be reduced by an improved thermal interface from the package to the metal plate. Here, R_{JM} is the total thermal resistance from junction to metal plate and it includes the thermal resistances from junction to dissipation surface of the metal plate: R_{JC} (junction to case), R_{PAD} (gap pad), $R_{INTERFACE}$ (interfaces of case and metal plate to gap pad) and $R_{METAL\ PLATE}$ (metal plate). For the bottom side heat path, the thermal resistance R_{JB} from junction to PCB board includes R_{JP} and R_{PB}. It is identical to the case with a BGA heatsink. We can obtain all thermal resistances as shown in Figure 9(b). In these thermal resistances, only R_{JC} (6°C/W to 9°C/W) and R_{JP} (1.5°C/W to 3°C/W) are dependent on the µModule regulator and all other thermal resistances are related to specific customer designs. The total thermal resistance from junction to ambient in this case is about 12°C/W.

DERATING CURVES VERSUS AMBIENT TEMPERATURE AND AIR FLOW

Several derating curves are shown below to provide a guideline for the maximum load current that can be achieved at certain ambient temperatures. These curves are



CONDITIONS: 24V TO 3.3V AT 10A, 25°C, NO AIR FLOW.
A BERGQUIST "GAP PAD 1000" IS USED BETWEEN THE µModule PACKAGE 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

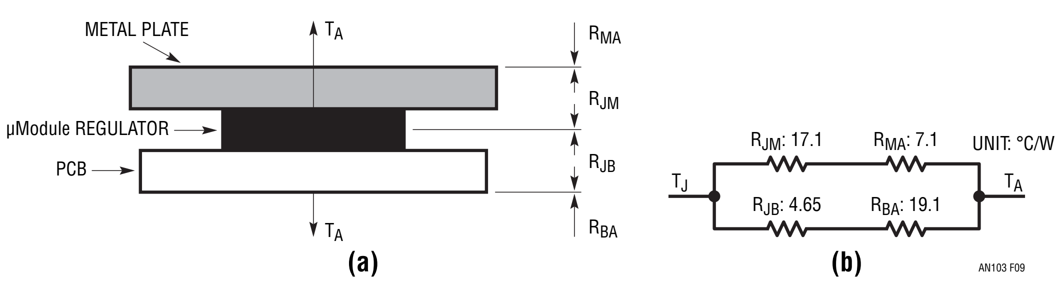


Figure 9. Thermal Model for Case 3

characterized with 0LFM, 200LFM, and 400LFM air flow. 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 derating 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 10 and 11 show the 1.5V and 3.3V power loss curves with load current and input voltages.

Figures 12, 13, and 14 are the three derating curves for 5V to 1.5V versus load current, air flow, and with and without heatsinks. Figures 15, 16, and 17 are the same derating curves for 12V to 1.5V. Figures 18, 19, and 20 are the derating 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.

Figures 21, 22 and 23 are the three derating curves for 12V to 3.3V at the different load currents, different air flow, and different heatsinks. Figures 24, 25, and 26 are the three derating 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.

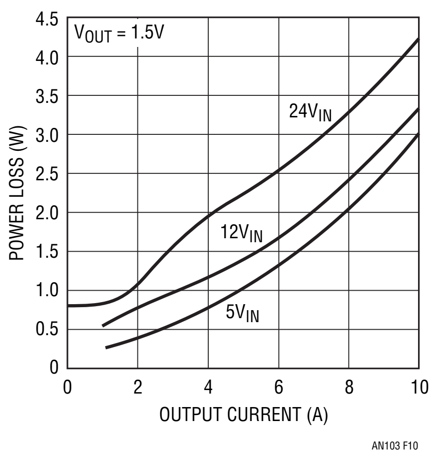


Figure 10. Power Loss vs Load Current

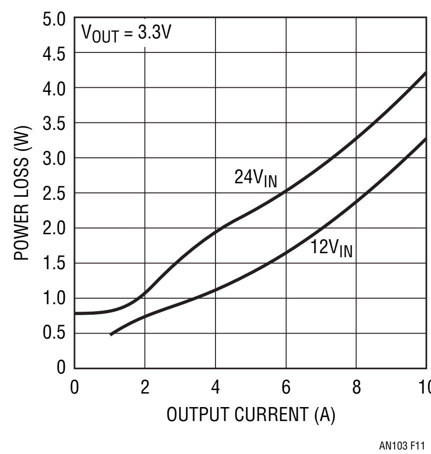


Figure 11. Power Loss vs Load Current

No Heatsink Column

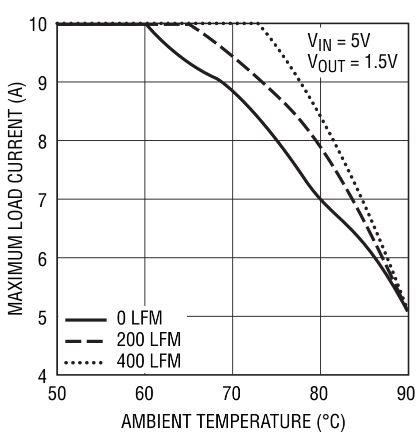


Figure 12

BGA Heatsink Column

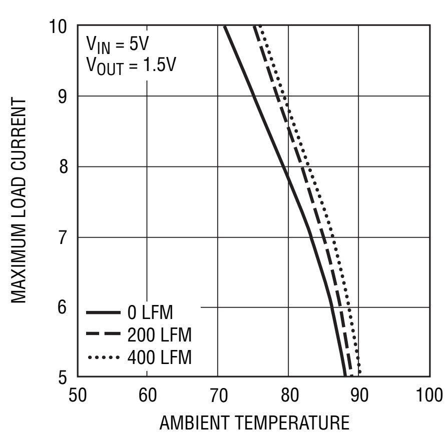


Figure 13

Metal Plate with Gap Pad Column

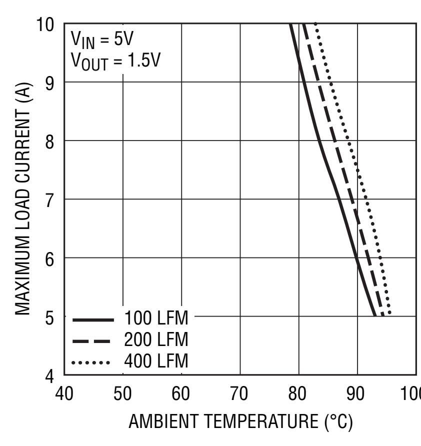


Figure 14

No Heatsink Column

BGA Heatsink Column

Metal Plate with Gap Pad Column

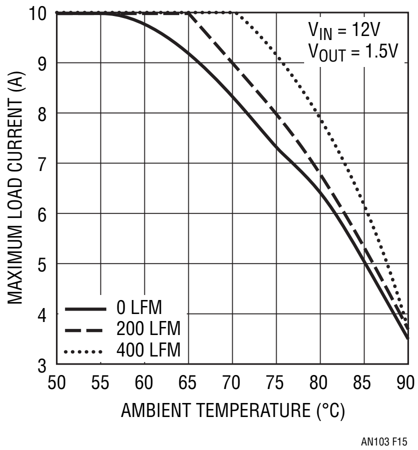


Figure 15

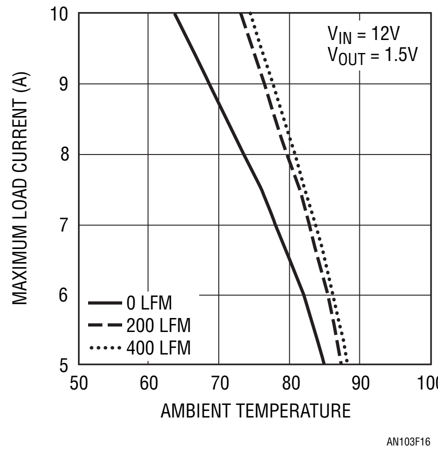


Figure 16

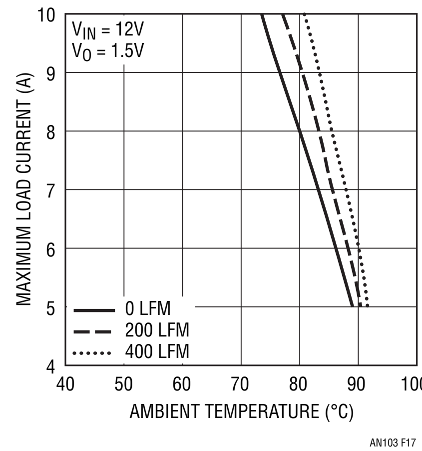


Figure 17

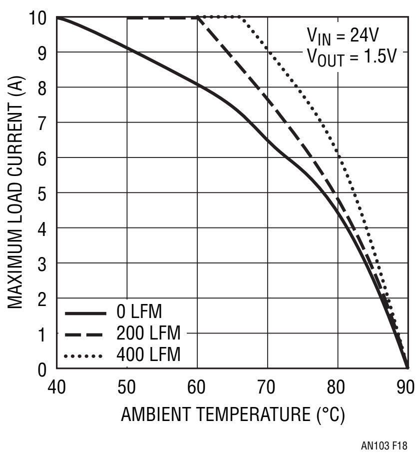


Figure 18

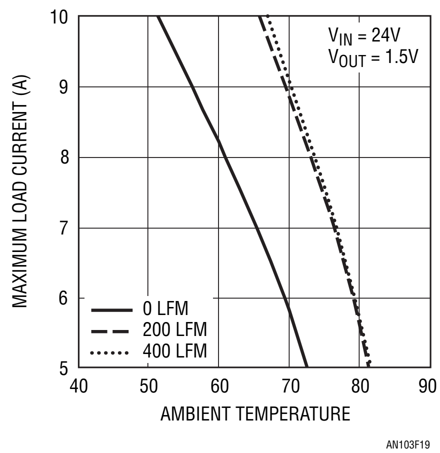


Figure 19

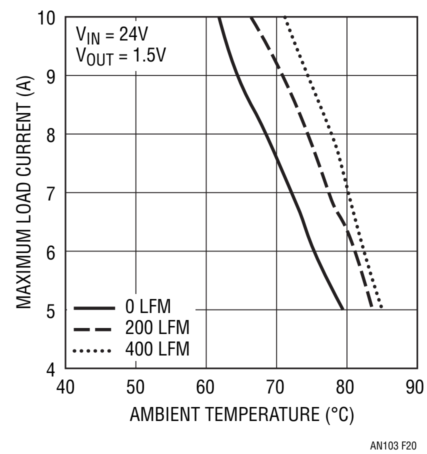


Figure 20

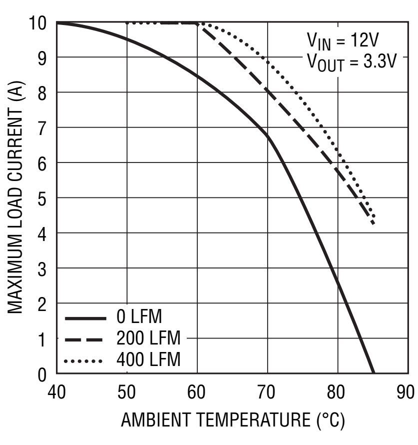


Figure 21

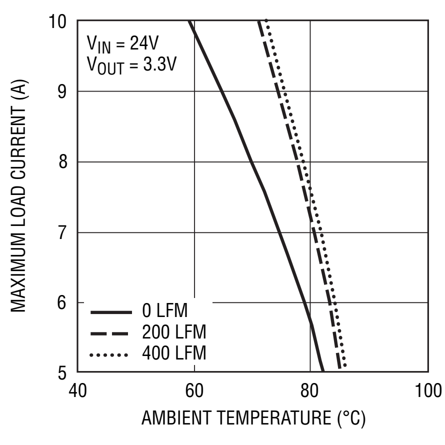


Figure 22

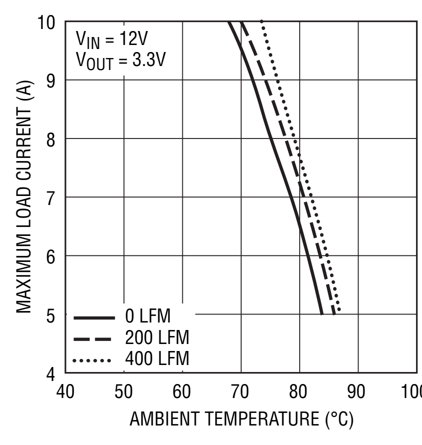


Figure 23

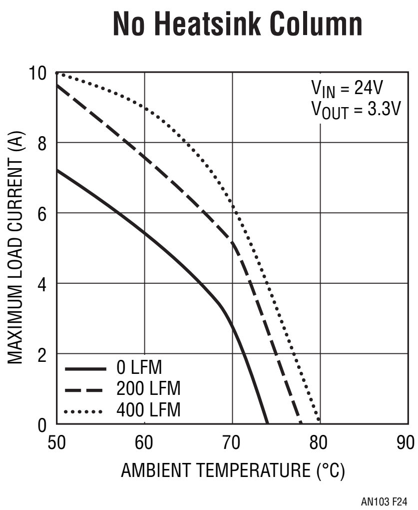


Figure 21

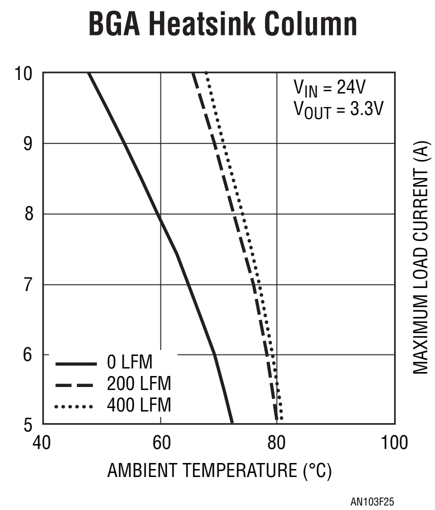


Figure 22

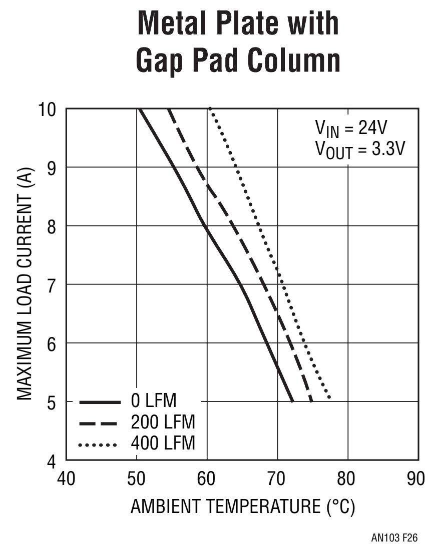


Figure 23

The power loss curves in Figures 10 and 11 will now be used in conjunction with the load current derating curves in Figures 12 through 26 to calculate an approximate θ_{JA}. Each of the load current derating curves will lower the maximum load current as a function of the increased ambient temperature to keep the case temperature of the power module at 100°C maximum. This 100°C maximum is to allow for a rise of about 13°C to 20°C inside the module with a thermal resistance R_{JC} from junction to case at 6°C/W to 9°C/W. This will maintain the maximum operating temperature below 125°C. Each of the derating 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.

CONCLUSION

The approximate θ_{JA} of the LTM4600 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 model are 15.2°C/W, 13.9°C/W, and 12°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

DERATING CURVE	V_{IN} (V)	POWER LOSS CURVE	AIR FLOW (LFM)	HEATSINK	$Ø_{JA}$ (°C/W)
Figures 12, 15, 18	5, 12, 24	Figure 10	0	None	15.2
Figures 12, 15, 18	5, 12, 24	Figure 10	200	None	14
Figures 12, 15, 18	5, 12, 24	Figure 10	400	None	12
Figures 13, 16, 19	5, 12, 24	Figure 10	0	BGA Heatsink	13.9
Figures 13, 16, 19	5, 12, 24	Figure 10	200	BGA Heatsink	11.3
Figures 13, 16, 19	5, 12, 24	Figure 10	400	BGA Heatsink	10.25
Figures 14, 17, 20	5, 12, 24	Figure 10	0	Metal Plate	12
Figures 14, 17, 20	5, 12, 24	Figure 10	200	Metal Plate	9.5
Figures 14, 17, 20	5, 12, 24	Figure 10	400	Metal Plate	8.15

Table 2. 3.3V Output

DERATING CURVE	V_{IN} (V)	POWER LOSS CURVE	AIR FLOW (LFM)	HEATSINK	$Ø_{JA}$ (°C/W)
Figures 21, 24	12, 24	Figure 11	0	None	15.2
Figures 21, 24	12, 24	Figure 11	200	None	14.6
Figures 21, 24	12, 24	Figure 11	400	None	13.4
Figures 22, 25	12, 24	Figure 11	0	BGA Heatsink	13.9
Figures 22, 25	12, 24	Figure 11	200	BGA Heatsink	11.1
Figures 22, 25	12, 24	Figure 11	400	BGA Heatsink	10.5
Figures 23, 26	12, 24	Figure 11	0	Metal Plate	12
Figures 23, 26	12, 24	Figure 11	200	Metal Plate	10.8
Figures 23, 26	12, 24	Figure 11	400	Metal Plate	10.3

HEATSINK MANUFACTURER	PART NUMBER	PHONE NUMBER
Wakefield Engineering	#20069	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

Linear Technology Corporation
1630 McCarthy Blvd., Milpitas, CA 95035-7417
(408) 432-1900 ● FAX: (408) 434-0507 ● www.linear.com

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