LTM4601 DC/DC µModule® Regulator Thermal Performance

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INTRODUCTION

The LTM4601 DC/DC µModule regulator is a complete high power density stepdown regulator for up to 12A continuous (14A peak) loads. The device is housed in a small 15mm × 15mm × 2.8mm LGA surface mount package, thus the large power dissipation is a challenge in some applications. This thermal application note will provide guidelines for using the µModule regulator in ambient environments with or without air flow. Load current derating curves are provided for several input voltages and output voltages versus ambient temperature and air flow. These derating curves provide guidelines for using the LTM4601 in ambient environments with regard to safe-operating-area (SOA). Also included are efficiency curves that are used to extrapolate the power loss curves used in this thermal application note. The approach 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 versus ambient temperature and air flow with and without a heatsink. 24V input designs are analyzed for a worse case temperature rise due to the relatively lower efficiency exhibited.

THERMAL MODEL

The thermal model is shown in Figure 1. A µModule regulator is attached to a 4-layer PCB with a size of 95mm × 76mm. To analyze this physical system, a simplified 1- D thermal model 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 the junction to the top package surface, while R_{TA} represents the resistance from the top package surface to ambient. Similarly, for the bottom side, R_{JB} is the thermal resistance from the 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, especially if a heat sink is used for the top side.

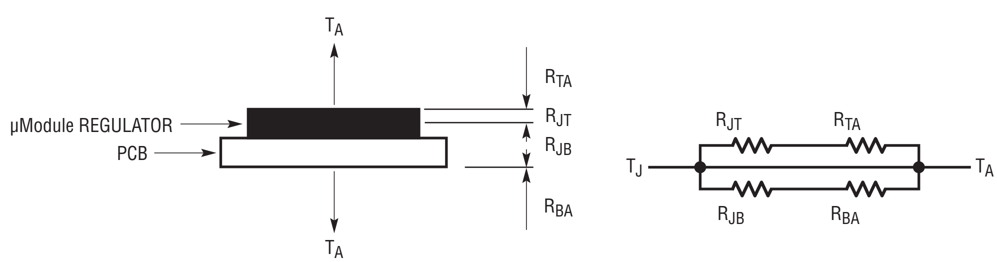


Figure 1. Design Thermal Model

THERMAL IMAGING

Case 1: No Heatsink

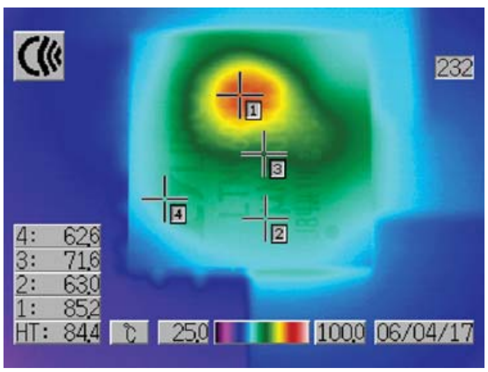
A $12V_{IN}$ to $3.3V_{OUT}$ at 12A design and a $24V_{IN}$ to $3.3V_{OUT}$ at 12A design are characterized for 39.6W operation at 91% and 87% conversion efficiency, respectively. This corresponds to a power loss of about 4.2W and 5.8W dissipated from the power module. The extra 4% loss on the 24V design 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 $24V_{IN}$ design, by connecting the DRV_{CC} pin to a 5V bias supply with a 50mA capability. The DRV_{CC} voltage must be supplied after the main input supply. Figure 2 shows a thermal image of the $12V_{IN}$ to $3.3V_{OUT}$ design with several thermal image data points, and Figure 3 shows the $24V_{IN}$ to $3.3V_{OUT}$ design with several thermal image data points. The maximum temperature in Figure 2 is equal to 85°C on the regulator with 4.2W of dissipation in the design, and Figure 3 has a maximum temperature of 100°C on the μModule regulator with 5.8W of dissipation.

For a worse case with no heatsink and 5.8W of dissipation in Figure 3, the heat dissipation from the package topside can be ignored. So the thermal model shown in Figure 1 can be redrawn as in Figure 4, with only thermal resistances R_{JB} and R_{BA} at the bottom side heat path. Refer to Application Note 103, the total thermal resistance from junction to ambient in this case is only 14.3°C/W. Therefore, the junction temperature of the μModule regulator is 108°C.

Case 2: With A BGA Heatsink

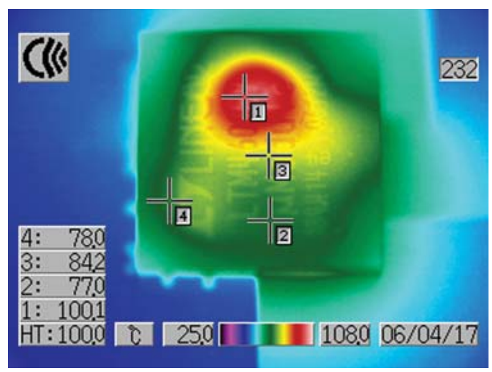
Figure 5 shows a side view thermal image with a surface mount BGA heatsink mounted on top of the module.

Data point 3 indicates the heatsink temperature, and data point 2 indicates the side temperature of the power



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

Figure 2. LTM4601 $12V_{IN}$ to $3.3V_{OUT}$ at 12A, Top View



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

Figure 3. LTM4601 $24V_{IN}$ to $3.3V_{OUT}$ at 12A, Top View

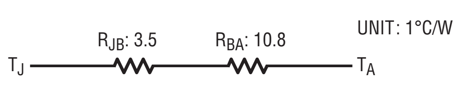
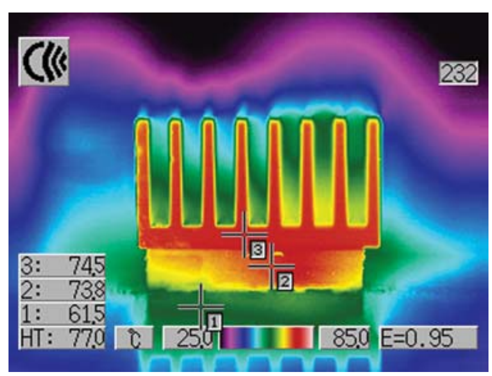


Figure 4. Thermal Model for Case 1 in Figure 3



CONDITIONS: 25°C AMBIENT, NO AIR FLOW, WAKEFIELD ENGINEERING PN#LTN20069 15mm × 15mm × 9mm HEATSINK, NO $EXTV_{CC}$

Figure 5. LTM4601 $24V_{IN}$ to $3.3V_{OUT}$ at 12A, Side View

module. The topside of the LTM4601 is very effective in transferring heat into an external heatsink due to the planar surface and the case material used. The thermal model, which represents the configuration in Figure 5 with 5.8W of dissipation, is shown in Figure 6. In this case, the heat flows to both top and bottom sides. For the topside heat path, the heat generated from the module first flows from the junction (R_{JH}) to the case/heatsink interface, 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 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 74°C in Figure 5 and R_{HA} under natural convection conditions can be obtained at about 30°C/W from the datasheet of the manufacturer, the power dissipation to topside is about 1.6W. So the junction temperature in this situation is about 95°C. Compared to the situation without a heatsink in Figure 4, the heat spreading area to the bottom side becomes smaller due to lower heat dissipation to the bottom side, so the thermal resistances in the bottom side heat path become larger as shown in Figure 6(b). The total junction-to-ambient thermal resistance for this scenario with a BGA heatsink is about 12°C/W.

Case 3: With A Metal Plate

Figure 7 shows the side view thermal image of a LTM4601 that is mounted to a metal plate with a size of 100mm × 75mm. This thermal test case is analyzed for consideration of use in systems that desire back side PCB mounting of the power module. The µModule regulator can then be mounted to a metal carrier either directly or through a thermal conductive pad.

This case uses a Bergquist “Gap Pad” for the thermal connection between the power module and metal carrier. The conditions are noted in Figure 7.

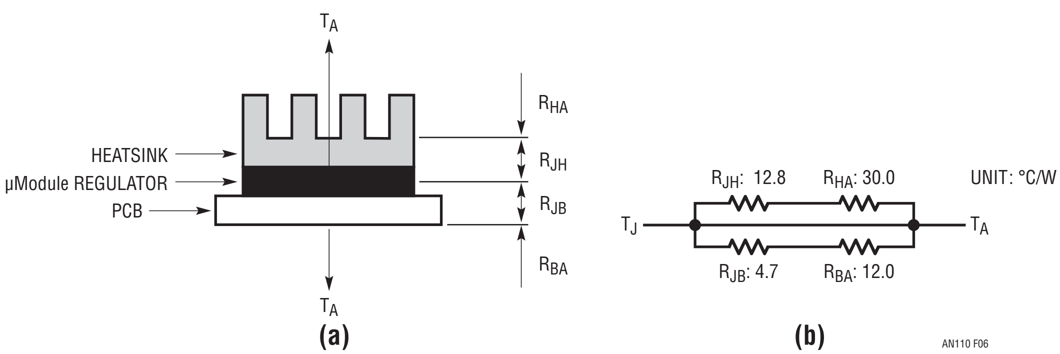
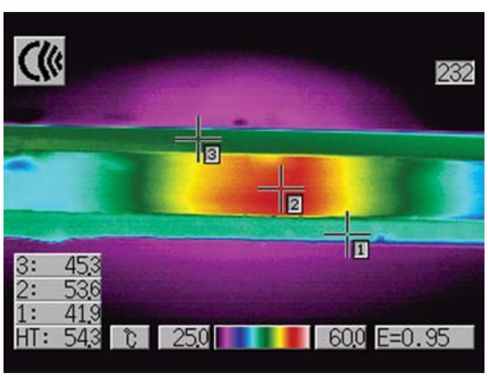


Figure 6. Thermal Model for Case 2 in Figure 5

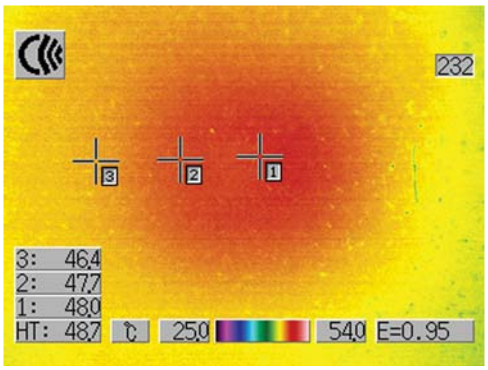


CONDITIONS: 24V TO 3.3V AT 12A, 25°C AMBIENT, NO AIR FLOW,
A BERGQUIST "GAP PAD 1000" IS USED BETWEEN THE
µModule REGULATOR AND THE METAL PLATE. 0.04 THICKNESS 2°C/W.
(METAL PLATE = 100mm × 75mm × 1.5mm)

Figure 7. LTM4601 $24V_{IN}$ to $3.3V_{OUT}$ at 12A, Side View

Figure 8 shows the metal plate view of the 40W design with the conditions noted below in the photo. The metal plate transfers heat effectively, and would provide an even better result with air flow. Similar to previous analysis, the average temperature of the metal plate is about 47°C (Figure 8). The thermal resistance RMA from the metal plate to ambient is only about 10.5°C/W due to the large dissipation surface of the metal plate. Using the thermal model in Figure 9, we can get the junction temperature at about 87°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 module 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 the junction to the 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 $R_{METALPLATE}$ (metal plate). We can obtain all thermal resistances as shown in Figure 9(b). Similar to case 2, the thermal resistance from junction to board R_{JB} includes two thermal resistances: R_{JP} (junction to module pin) and R_{PB} (pin to PCB dissipation surface). 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 situation is about 10.7°C/W.



CONDITIONS: $24V_{IN}$ TO $3.3V_{OUT}$ AT 12A, 25°C AMBIENT, NO AIR FLOW,
A BERGQUIST "GAP PAD 1000" IS USED BETWEEN THE
µModule REGULATOR AND THE METAL PLATE. 0.04 THICKNESS 2°C/W.
(METAL PLATE = 100mm × 75mm × 1.5mm)

Figure 8. LTM4601 $24V_{IN}$ to $3.3V_{OUT}$ at 12A, Metal Plate View

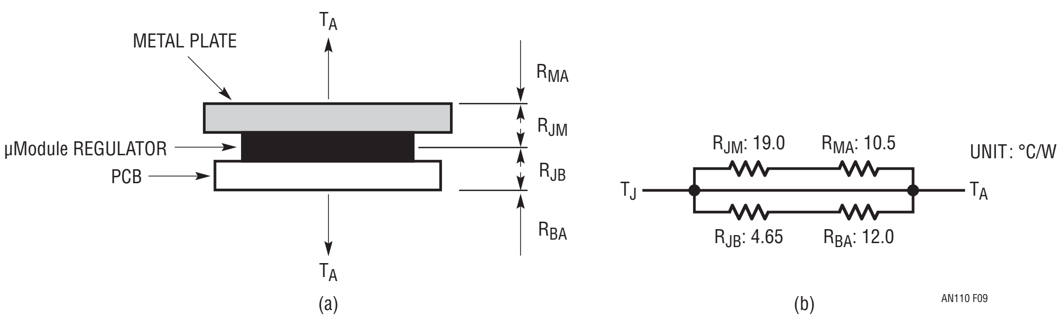


Figure 9. Thermal Model for Case 3 in Figure 7

DERATING CURVES VERSUS AMBIENT TEMPERATURE AND AIR FLOW

Several derating curves are shown 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 air flow. Also the curves are provided with and without heatsinks. The power loss curves establish an approximate θ_{JA} for the characterized operating conditions that correlates to the thermal images above. The power loss curves and derating curves are used to build a table to correlate θ_{JA} versus 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 $1.5V_{OUT}$ and $3.3V_{OUT}$ power loss curves versus load current and input voltages.

Figures 12, 13, and 14 are the three derating curves for $5V_{IN}$ to $1.5V_{OUT}$ versus load current and air flow, with and without heatsinks. Figures 15, 16, and 17 are the same derating curves for $12V_{IN}$ to $1.5V_{OUT}$. Figures 18, 19, and 20 are the derating curves for $24V_{IN}$ to $1.5V_{OUT}$. 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 $12V_{IN}$ to $3.3V_{OUT}$ at different load currents, different air flow, and different heatsinks. Figures 24, 25, and 26 are the three derating curves for $24V_{IN}$ to $3.3V_{OUT}$. All of these curves are put into columns to designate the type of heatsink used in the test conditions.

The power loss curves in Figures 10 and 11 are used in conjunction with the load current derating curves in Figures 12 through 26 to calculate an approximate θ_{JA}. In each of the load current derating curves, the maximum load current is shown 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, maintaining the maximum junction temperature below 125°C.

CONCLUSION

The LTM4601 thermal models were taken with no air flow for three cases: no heat sink, a BGA heat sink and a metal plate. The approximate θ_{JA} was then empirically derived, resulting in values of 14.3°C/W, 12.1°C/W, and 10.7°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 2.

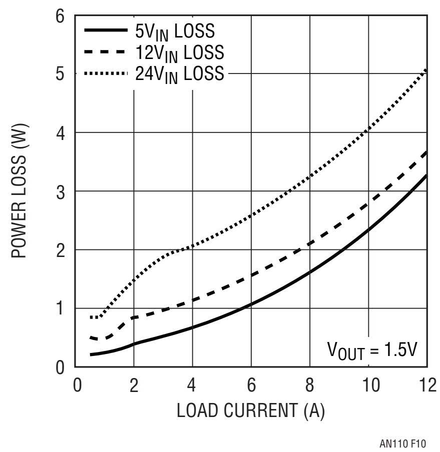


Figure 10. Power Loss vs Load Current

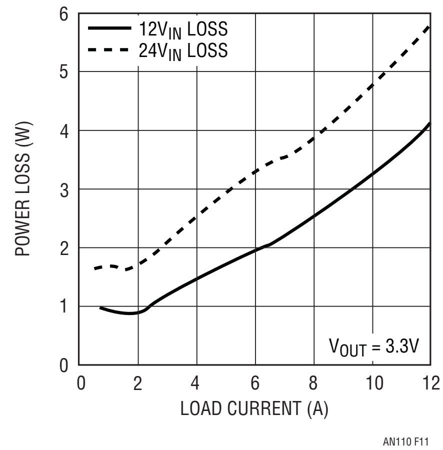


Figure 11. Power Loss vs Load Current

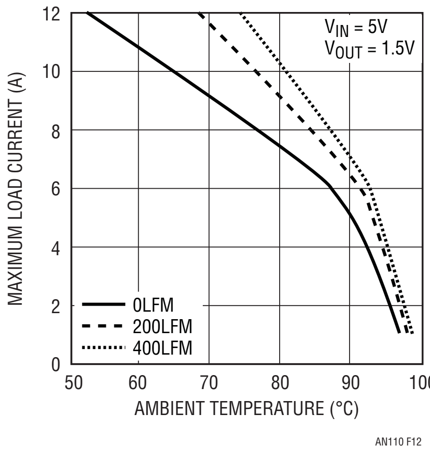


Figure 12. No Heatsink with $5V_{IN}$ and $1.5V_{OUT}$

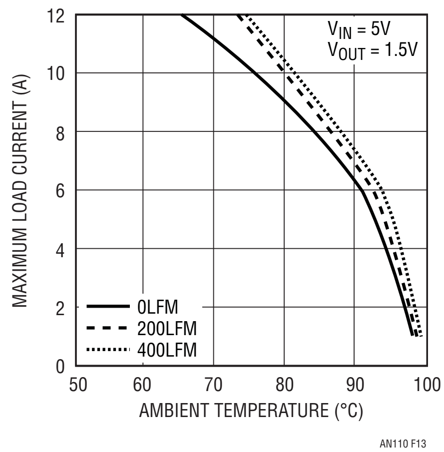


Figure 13. BGA Heatsink with $5V_{IN}$ and $1.5V_{OUT}$

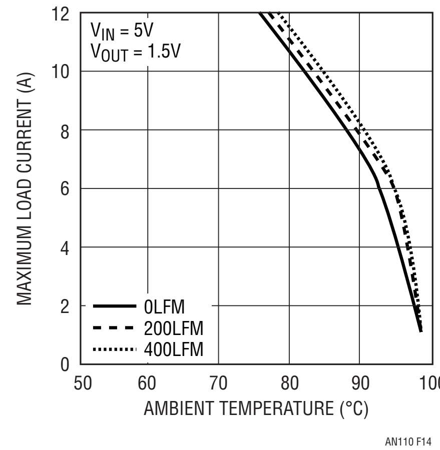


Figure 14. Metal Plate with Gap Pad at $5V_{IN}$ and $1.5V_{OUT}$

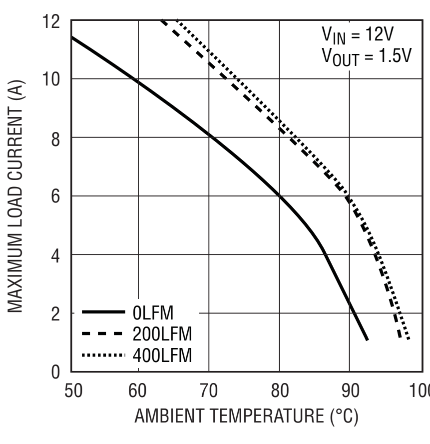


Figure 15. No Heatsink with $12V_{IN}$ and $1.5V_{OUT}$

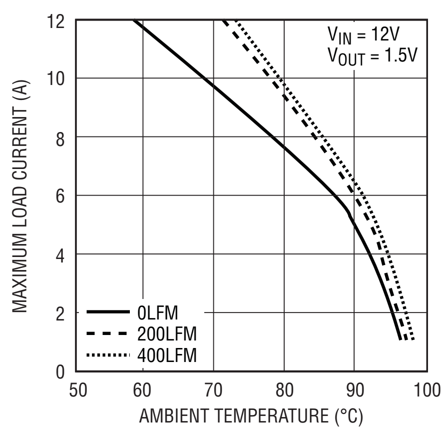


Figure 16. BGA Heatsink with $12V_{IN}$ and $1.5V_{OUT}$

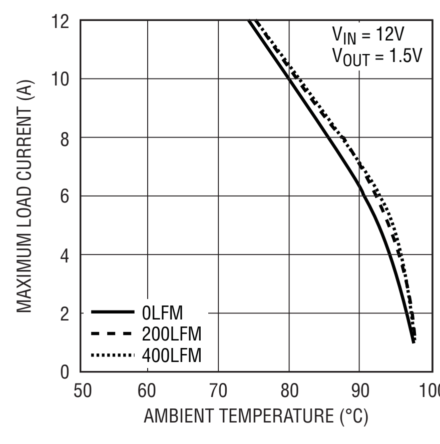


Figure 17. Metal Plate with Gap Pad at $12V_{IN}$ and $1.5V_{OUT}$

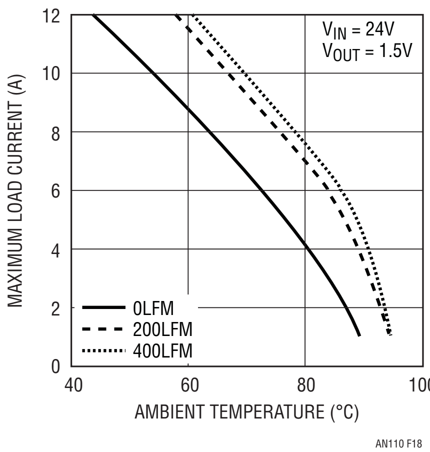


Figure 18. No Heatsink with $24V_{IN}$ and $1.5V_{OUT}$

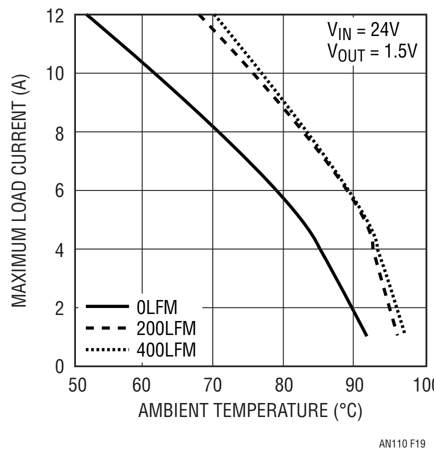


Figure 19. BGA Heatsink with $24V_{IN}$ and $1.5V_{OUT}$

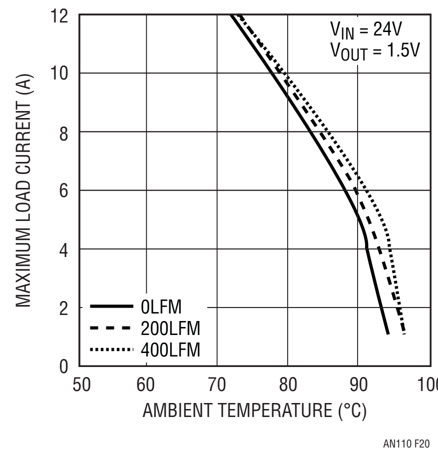


Figure 20. Metal Plate with Gap Pad at $24V_{IN}$ and $1.5V_{OUT}$

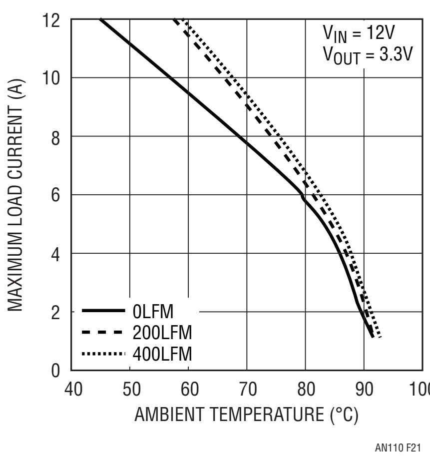


Figure 21. No Heatsink with $12V_{IN}$ and $3.3V_{OUT}$

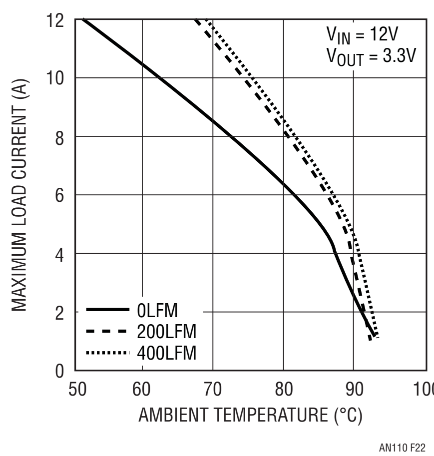


Figure 22. BGA Heatsink with $12V_{IN}$ and $3.3V_{OUT}$

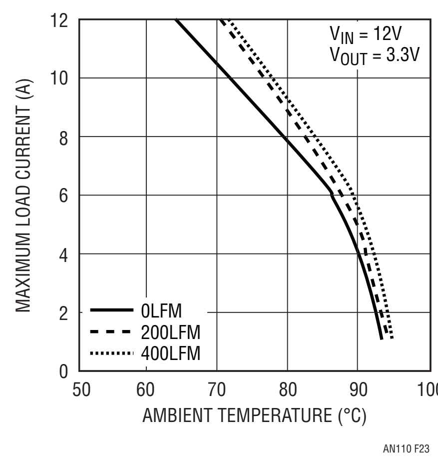


Figure 23. Metal Plate with Gap Pad at $12V_{IN}$ and $3.3V_{OUT}$

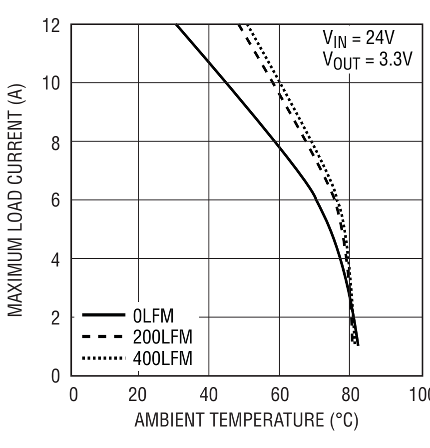


Figure 24. No Heatsink with $24V_{IN}$ and $3.3V_{OUT}$

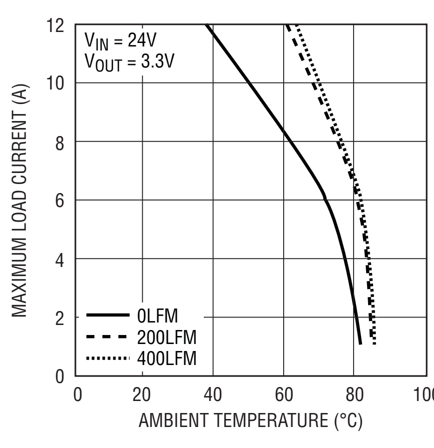


Figure 25. BGA Heatsink with $24V_{IN}$ and $3.3V_{OUT}$

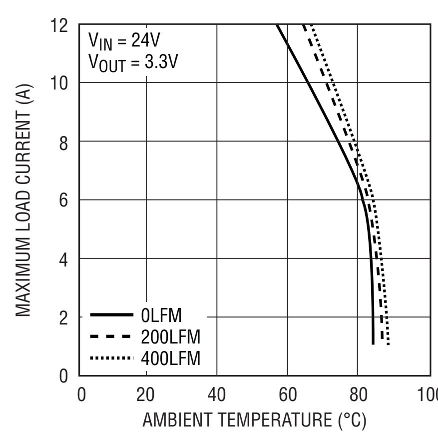


Figure 26. Metal Plate with Gap Pad at $24V_{IN}$ and $3.3V_{OUT}$

Table 1. 1.5V Output at 12A

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

Table 2. 3.3V Output at 12A

DERATING CURVE	V_{IN} (V)	POWER LOSS CURVE	AIR FLOW (LFM)	HEATSINK	θ_{JA} (°C/W)
Figures 24	24	Figure 11	0	None	14.3
Figures 24	24	Figure 11	200	None	13.1
Figures 24	24	Figure 11	400	None	11.1
Figures 25	24	Figure 11	0	BGA Heatsink	12.1
Figures 25	24	Figure 11	200	BGA Heatsink	9.6
Figures 25	24	Figure 11	400	BGA Heatsink	8.45
Figures 26	24	Figure 11	0	Metal Plate	10.7
Figures 26	24	Figure 11	200	Metal Plate	8.2
Figures 26	24	Figure 11	400	Metal Plate	6.85

HEATSINK MANUFACTURER	PART NUMBER	PHONE NUMBER
Wakefield Engineering	LTN20069	603-635-2800
Bergquist Company	Gap Pad 1000SF	952-835-2322

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