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AND9016/D

Heat Sink Selection Guide for Thermally Enhanced SO8-FL

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APPLICATION NOTE

Introduction

Thermal management has become a critical element in today's electronic design, as more compact designs have led to greater difficulty in removing heat from the system. In order to keep the components within their safe operating area, the operating temperature of the components must not exceed the manufacturer specified maximum temperature. A reduction in operating temperature increases the component life expectancy and therefore increases the reliability of the system.

The use of heat sinks provides an affordable method to increase the performance of power MOSFETs with minimal impact to the design layout. ON Semiconductor has introduced a Thermally Enhanced (TE) SO8−FL MOSFET portfolio in order to aid in this endeavor. The SO8−FL TE utilizes a different mold compound that has over 3.5 times the thermal conductivity of the standard SO8−FL mold compound. As shown in the Guide to Thermally Enhanced SO8−FL (ON Semiconductor application note AND9014/D) the SO8FL−TE has the greatest advantage compared to a standard SO8−FL when it is used with a heat sink on the top of the device.

Heat Sink Basics

In power converters, heat sinks are used to move heat away from the device in order to maintain a lower device temperature. In general, increasing the heat sink surface area reduces the heat sink thermal resistance making it more effective in transferring heat from a component to the ambient air. To better understand how heat sinks accomplish this, let's review basic theory.

Heat flow can be described with Equation 1, where T_J is the device junction temperature, T_A is the ambient temperature, $R_{\theta JA}$ is the thermal resistance from device junction to ambient and P_D is the power dissipated.

$$P_D = \frac{T_J - T_A}{R_{\theta JA}} \qquad \text{(eq. 1)}$$

Heat sinks lower the thermal resistance $R_{\theta JA}$ between the device junction and the ambient air allowing heat to flow away from the device more effectively and thus reducing the temperature rise $T_J - T_A$.

Figure 1 illustrates a basic thermal resistance diagram for a device with a heat sink. For the purpose of this analysis, heat dissipation through the bottom of the package will not be addressed.

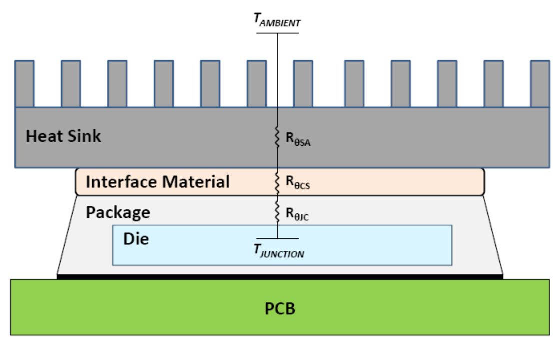

Figure 1. Thermal Resistance Diagram for Device with Heat Sink

The overall thermal resistance $R_{\theta JA}$ through the top of the device can be calculated as described in Equation 2. The junction-to-case thermal resistance $R_{\theta JC}$ is a property of the MOSFET, the case-to-heat sink thermal resistance $R_{\theta CS}$ is the resistance of the interface material and $R_{\theta SA}$ is the thermal resistance between the heat sink and the ambient air. Therefore, to maximize the heat spreading capability of the system, the interface material thermal resistance $R_{\theta CS}$ and heat sink thermal resistance $R_{\theta SA}$ must be minimized.

$$R_{\theta JA} = R_{\theta JC} + R_{\theta CS} + R_{\theta SA} \qquad \text{(eq. 2)}$$

Thermal resistance is also a factor of the convection coefficient, h_c, and the heat sink surface area, A, as shown in Equation 3. The thermal resistance can be reduced by increasing the surface area and by increasing the convection coefficient by moving from natural convection to forced convection.

$$R_{\theta JA} = \frac{1}{h_c \cdot A} \qquad \text{(eq. 3)}$$

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Heat Sink Categories

There are several different heat sink categories based on the cooling method for a given application: passive, semi-active, active, liquid cooled and phase change heat sinks (see Table 1). The remainder of this application note focuses on passive and semi-active heat sinks, as these are commonly used in computing, communication and power supply applications.

Table 1. HEAT SINK CATEGORIES

Heat Sink Category	Advantages	Disadvantages	Applications	Examples
Passive	• Widely available • Cost • Ease of use	• Limited in power dissipation capability	• Natural convection/systems that do not depend on air flow • Low power density applications	Metal plate
Semi-Active	• Lower thermal resistance for the same volume compared to passive heat sinks	• Limited in power dissipation capability	• Systems with existing air flow • Medium power density applications	Fin heat sink
Active	• Incorporates forced convection and heat sink into a single unit • Provides much greater heat dissipation capability compared with passive and semi-active heat sinks	• Long term reliability • Cost	• High power density applications	Fan heat sink
Liquid Cooling	• Provides much greater heat dissipation capability compared with passive and semi-active heat sinks	• Complexity • Cost	• High power density applications • Low profile applications requiring constant heat cycling	Liquid cold plate
Phase Change Cooling	• Heat is spread evenly • The cooling liquid very effectively removes heat	• Complexity • Cost • Requires additional board space and height	• High power density applications	Vapor compression phase-change cooler

Heat Sink Types

There are several different types of passive and semi active heat sinks depending on the defined air flow of the system. The heat sinks listed in Table 2 are available in both aluminum and copper. Aluminum is the most common heat sink material as it provides a low cost thermal solution. Copper has nearly twice the conductivity of aluminum, but it is also more expensive. Consequently, for applications which require a low cost solution, aluminum is the material of choice. For higher power density applications in which performance is the primary design consideration, copper provides a higher thermal dissipation for the same form factor.

Table 2. HEAT SINK TYPES

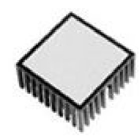
Heat Sink Category	Description	Advantages	Disadvantages	Applications	Examples
Stamped	• Sheet metal stamped into desired shapes	• Cost	• Limited power dissipation capability	• Low power applications • Natural convection applications	Metal plate
Extruded	• Heat sink with extruded fins	• Fins align in direction of air flow • Cross−cut fins for omni−directional air flow • Cost • Sizing flexibility	• Limited power dissipation capability	• Medium power density applications • Natural or forced convection applications	Extruded fin heat sink
Bonded Fin	• Thermally conductive aluminum-filled epoxy fins attached to a base plate	• Effectively increases the surface area of heat sink for the same form factor due to a much higher fin height-to-gap ratio	• Cost	• Forced convection applications • Higher power applications for smaller form factor	Aluminum filled epoxy fins
Casting	• High density fins or pins produced with die casting process	• Higher performance and heat sink shape flexibility compared with standard extrusion or bonded fin heat sinks	• Cost	• High density forced convection applications	Pin heat sink

Heat Sink Attachment Methods

There are several heat sink attachment options available in the market. The most commonly used methods are: thermal adhesive, pins and hooks. Table 3 highlights some design considerations for each attachment method.

An interface material must be used between the component surface and the heat sink in order to maximize the thermal transfer from the component to the heat sink. The two most common interface materials are thermal pads and thermal grease. Thermal grease offers the best thermal performance of the thermal interface materials available. This is because the grease fills in all the air gaps and creates a thin surface between the package and heat sink, resulting in an extremely low thermal resistance in the range of 0.1 – 0.2°C/W. For top metal devices that require an isolation material between the top of the case and the heat sink, an isolation pad must be used, resulting in a higher interface thermal resistance. The SO8−FL TE die is electrically isolated from the top of the case by the mold compound, and therefore does not require an isolation pad. The SO8−FL TE provides the greatest thermal performance advantage when combined with a heat sink and thermal grease.

Table 3. ATTACHMENT METHODS

Attachment Method	Advantages	Disadvantages	Applications	Example
Adhesive	• Does not require additional board space	• Pressure may not be uniform across the heat sink surface	• Single FET use • Small form factor designs	
Pins	• Provides uniform pressure across the heat sink surface • Reduces the thermal resistance of the interface material due to the amount of pressure applied	• Requires holes to be drilled through the PCB. Layout must consider the hole locations and ensure vias and board traces do not run through these areas	• Multiple FET use • Larger form factor designs	
Hooks	• Provides uniform pressure across the heat sink surface • Reduces the thermal resistance of the interface material due to the amount of pressure applied	• Requires additional board space and mounting of the hook attachments	• Multiple FET use • Larger form factor designs	

Heat Sinks in Forced Convection Applications

When selecting a heat sink for a forced convection application fin orientation is very important. If the air is flowing in a single direction, then orienting the fins in the direction of air flow provides the best heat sink thermal performance. Additionally, the heat sink fin design plays a significant role in the heat sink's effectiveness. Figure 2 illustrates two fin design options for standard horizontal heat sinks. In each case the fin creates a channel for the air to flow through. The design shown in Figure 2(b) is more effective than the design of Figure 2(a) because the channel length is minimized.

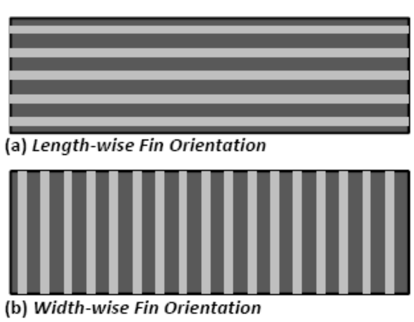


Figure 2. Heat Sink Fin Orientation

Selecting a Heat Sink

Heat sinks are rated based on the amount of heat they can dissipate. Heat sink manufacturer data sheets provide thermal resistances for natural convection and various air flow velocities, as shown in the Figure 3 example. The natural convection curve is given in temperature rise versus heat dissipated, and the forced convection curve is given in thermal resistance versus air velocity.

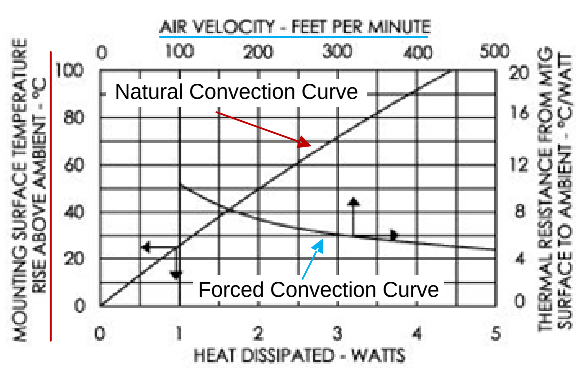


Figure 3. Example Manufacturer Data Sheet Thermal Performance Graph

Before selecting a heat sink for power MOSFETs, some basic calculations must be made. The first step to selecting a heat sink is calculating the total power dissipation of the components in the circuit application. Power dissipation can be determined from circuit calculations or from efficiency measurements. Once the total power loss is calculated the thermal resistance of the heat sink can be determined.

The maximum total thermal resistance of the component – heat sink system is calculated by using Equations 2 and 4. Solving Equation 4 yields the maximum acceptable heat sink thermal resistance that can dissipate the required power. $R_{\theta SA}$ is the thermal resistance of the heat sink, $R_{\theta JC}$ is a property of the MOSFET and can be found in the manufacturer data sheet, and $R_{\theta CS}$ is the thermal resistance of the interface material.

$$R_{\theta SA} < \frac{T_J - T_A}{P_D} - R_{\theta JC} - R_{\theta CS} \qquad \text{(eq. 4)}$$

As an example, assume that 1 W of power must be dissipated using the SO8−FL TE NTMFS4923NE device in a 30°C ambient while maintaining a junction temperature at or below 100°C. The SO8−FL TE thermal resistance $R_{\theta JT}$ is 8.3°C/W. Assuming a thermal grease with $R_{\theta cs}$= 0.1°C/W is used, Equation 4 becomes:

$$R_{\theta SA} < \frac{(100 - 30)^{o}C}{1\ W} - (8.1 - 0.1^{o}C/W) = 61.6^{o}C/W$$

Therefore the thermal resistance $R_{\theta SA}$ of the heat sink selected for this application must be less than 61.6°C/W. Repeating the same example using the standard SO8−FL NTMFS4935N device ($R_{\theta JT}$ is 27.8°C/W), Equation 4 becomes:

$$R_{\theta SA} < \frac{(100 - 30)^{o}C}{1\ W} - (27.8 - 0.1^{o}C/W) = 42.1^{o}C/W$$

In this case, the heat sink thermal resistance $R_{\theta SA}$ selected for this application must be less than 42.1°C/W.

As can be seen, the heat sink thermal resistance must be much lower when using the standard SO8−FL device than when using the SO8−FL TE device. This means that SO8−FL TE MOSFETs require smaller and less expensive heat sinks than standard SO8−FL MOSFETs.

Layout Considerations

Several items must be considered when incorporating heat sinks into a circuit layout including height restrictions, total available board space, and air flow. The presence or absence of air flow influences the type of heat sink selected, and the direction of air flow influences the orientation of the heat sink fins. Board space limitations will also determine the size of the heat sink that can be used as well as the heat sink attachment method implemented. For the pin attachment method, layout adjustments must be made to account for the pin hole size and location. Similarly, for the hook attachment method, additional surface mount pads and spacing must be accounted for. In applications where board space is very limited, a thermal adhesive may be the most practical solution. Be sure to follow the manufacturer recommendations pertaining to spacing and positioning of the heat sink mounting method on the board.

Layout Guide

This layout guide focuses on power MOSFET heat sinks in computing, communication and power supply applications. There are several heat sink manufacturers that provide standard and customized heat sink solutions including Aavid Thermalloy, Wakefield Engineering, Enzotechnology, Cool Innovations, Radian, Alpha and Alexandria Extrusion Company, and are only a few of the heat sink manufacturers available.

The following section illustrates various MOSFET spacing and layout options for a multi-phase CPU power converter application when a form factor similar to Figures 4 and 5 is used. A heat sink selection guide is presented at the end for use with SO8−FL TE power MOSFETs in these layout configurations.

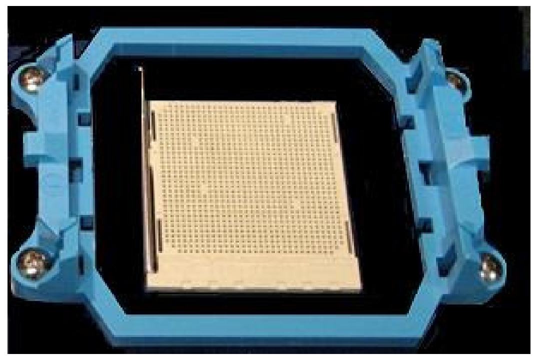


Figure 4. CPU Board Space Example

Figure 4 shows the standard CPU area known as the “keep out” area. Designers of the power circuitry that supports the CPU must account for this spacing and lay out the circuit components and phases accordingly. Design space for the power circuitry is often limited to a single side of the keep out area, as illustrated in Figure 5.

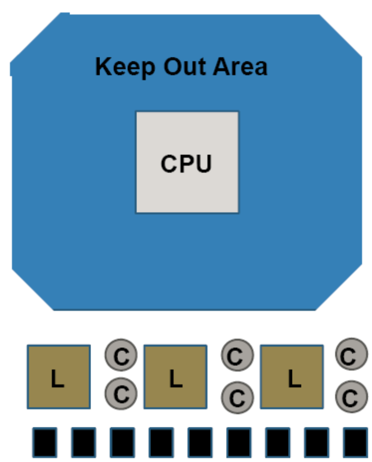


Figure 5. Example Power Circuit Layout

When selecting a MOSFET and heat sink layout, additional spacing must be present between the MOSFETs and other board components to provide enough space for the heat sink. Lower profile components may be placed nearer to the power MOSFETs if needed, but higher profile components must have enough clearance to ensure electrical isolation from the heat sink.

Figures 6 and 7 show example layouts for 1 × 1, 1 × 2 and 2 × 2 SO8−FL TE power MOSFET combinations when implemented in board designs similar to Figure 5. There are several heat sink options available for these layouts (See Table 4 for some examples). The following size estimates are made assuming a single heat sink is used for all MOSFETs.

Figure 6(a) shows an example layout for a 1 × 1 MOSFET combination. Assuming a 3 mm spacing between MOSFETs, the minimum length of the heat sink needed to fully cover all devices is: 13 mm for a single phase, 29 mm for a two phase circuit and 45 mm for a three phase circuit. Minimum width of the heat sink is 6 mm.

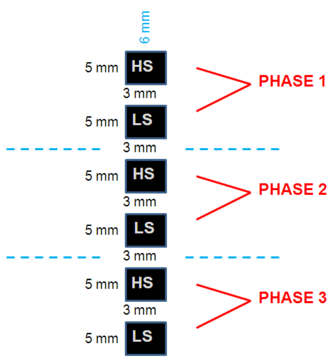


Figure 6. (a) Example Layout for 1 × 1 MOSFET Combination

Figure 6(b) shows an example layout for a 2 × 2 MOSFET combination. Assuming a 3 mm spacing between MOSFETs, the minimum length of the heat sink required is: 13 mm for a single phase, 29 mm for a two phase circuit and 45 mm for a three phase circuit. Minimum width of the heat sink is 15 mm.

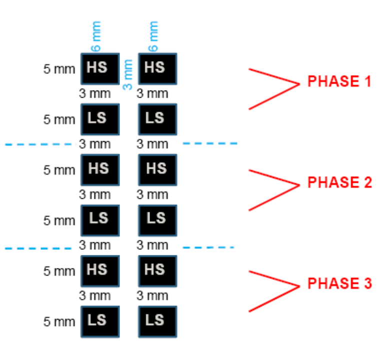


Figure 6. (b) Example Layout for a 2 × 2 MOSFET Combination

Figure 7 shows a possible layout for a 1 × 2 MOSFET combination. Assuming a 3 mm spacing between MOSFETs, the minimum length of the heat sink in order to fully cover all devices is: 21 mm for a single phase, 48 mm for a two phase circuit and 69 mm for a three phase circuit. Minimum width of the heat sink is 6 mm.

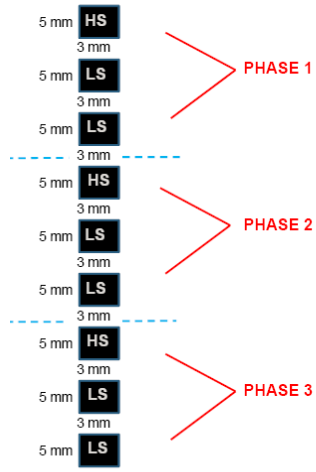


Figure 7. Example Layout for a 1 × 2 MOSFET Combination with a 3 mm Spacing

The spacing restriction is a critical design parameter and greatly influences both the circuit layout and the heat sink selection. The thermal resistance of the heat sink is inversely proportional to the heat sink surface area. Thus, for small form factor layouts it may be prudent to use a bonded fin heat sink or to switch from aluminum to copper. An additional consideration is the use of individual heat sinks for each MOSFET such as the 6 × 6 mm Enzotechnology MOS−C1 heat sink when space constraint is the most important design constraint. For all three layout examples, the heat sink size will be guided by the maximum thermal resistance calculated in the “SELECTING A HEAT SINK” section.

Practical Considerations

Often, a designer is interested in measuring the temperature of MOSFETs on the board. This can become cumbersome when a heat sink is attached, as the method of using infrared sensing is no longer applicable. In these circumstances, use of a thermocouple is recommended. In order to more accurately measure the device temperature when a heat sink is attached, the thermocouple must be placed on or as close to the drain of the MOSFET as possible, while remaining electrically isolated from the heat sink. The gauge of the thermocouple wire is of equal importance. If the thermocouple wire is too thick then it can partially sink the heat away from the device and thus produce inaccurate measurements. For these reasons, a 36 AWG K−type thermocouple is recommended.

Table 4. HEAT SINK SELECTION GUIDE (Note 1)

Circuit Parameters		Heat Sink Parameters						
						Dimensions		
Layout	# of Phases	Manufacturer	Part #	Pin / Fin	Air Flow (LFM)	Length × Width (mm)	Height (mm)	RθSA (°C/W) at 200 LFM
Single FET	n/a	Cool Innovations	3−0202xxU	Pin	0 − 800	6.86 × 6.86	5.1 − 20.3	121.75 − 28.76
		Cool Innovations	3−0404xxU	Pin	0 − 800	10.2 × 10.2	5.1 − 20.3	50.73 − 12.0
		Wakefield Engineering	16457	Fin	0 − 600	14 × 14	9.9	Contact Manufacturer
		Enzotechnology	MOS−C1	Pin	0 − 800	6 × 6	10	Contact Manufacturer
1 × 1	1	Aavid Thermalloy	62000	Fin	0 − 800	15.2 × 13.4	10.2	18
	2	Aavid Thermalloy	62000	Fin	0 − 800	30.5 × 13.4	10.2	12.8
	3	Aavid Thermalloy	62000	Fin	0 − 800	45.7 × 13.4	10.2	10.5
		Aavid Thermalloy	508700B00000G	Fin	0 − 800	50.8 × 13.46	4.83	20
		Enzotechnology	MST−DFI−DK	Pin	0 − 800	56.5 × 16	29.6	Contact Manufacturer
2 × 2	1	Aavid Thermalloy	61520	Fin	0 − 800	15.2 × 20.6	11.4	19.5
	2	Aavid Thermalloy	61520	Fin	0 − 800	30.5 × 20.6	11.4	13.9
		Cool Innovations	3−1207xxUK	Pin	100 − 400	31.2 × 17.3	5.1 − 27.9	15.46 − 3.12
		Cool Innovations	3−1510xxUK	Pin	100 − 400	38.1 × 24.1	6.6 − 18.2	9.07 − 1.83
	3	Aavid Thermalloy	61520	Fin	0 − 800	45.7 × 20.6	11.4	11.3
		Cool Innovations	3−2010xxUK	Pin	100 − 400	52.1 × 24.1	5.1 − 20.3	6.64 − 1.34
		Enzotechnology	MST−DFI−DK	Pin	0 − 800	56.5 × 16	29.6	Contact Manufacturer
1 × 2	1	Aavid Thermalloy	62000	Fin	0 − 800	21.6 × 13.4	10.2	15
	2	Aavid Thermalloy	62000	Fin	0 − 800	48.3 × 13.4	10.2	10.1
	3	Aavid Thermalloy	62000	Fin	0 − 800	69.9 × 13.4	10.2	8.6

1. The heat sinks listed in Table 4 are only a small fraction of what is available in the market for computing, communication and power supply applications. The reader is advised to do additional research and evaluation when making the final heat sink selection.

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