Advanced Energy

USING HEAT SINKS WITH A SWITCH MODE POWER SUPPLY

This paper aims to introduce a basic knowledge of thermal resistance and how to reduce the thermal resistance of a heat sink and other means of thermal transfer.

INTRODUCTION

In recent years, with high power density requirements and increased heat generated by devices in electronic equipment, the problem of how to cool these electronic devices has become a big challenge. A heat sink is a highly cost-efficient heat exchanger. The optimal design of a heat sink can directly determine the device's reliability, service life, and overall performance.

WHAT IS A HEAT SINK?

A heat sink is a component designed to enhance the heat dissipation from an electronic device. Generally, MOSFETs, IGBTs, and power ICs are the electronic devices in switch power supplies that need heat sinks attached to maintain a safe temperature. Usually a heat sink is composed of a base plate and fins. The base plate can transfer the heat to fins and then transfer heat to the surrounding air. While adding fans to the heat sink increases surface area, it also increases the pressure drop. This reduces the volumetric airflow, which also reduces the heat transfer coefficient. Therefore, there exists a number of fins that can obtain the highest performance under a given fan; also a certain thickness of base plate to determine effect of the transfer heat from heat source to fins. Heat sinks can be classified in terms of manufacturing methods and materials. Steel, aluminium, and copper are the most common materials, but aluminium alloys are the most common materials for air cooling heat sinks due to high cost-performance. Stampings, extrusion, casting, bonding, folding, die-casting, forging, and skiving are all methods used for the production of heat sinks.

WHY A HEAT SINK IS NEEDED

Thermal issues are a major cause of electronics failures. Electronic device lifetime is directly affected by environment temperature. High ambient temperature will lead to electronics device life to be drastically reduced. On the other hand, with the increase in heat dissipation from microelectronic devices and high frequency IGBT, MOSFET, and similar devices a smaller dissipation space is required, and for high ambient temperature high reliability is required. Heat can be indispensable to enhance the heat dissipation in switch power supplies by increasing surface area.

THERMAL RESISTANCE

Usually, conduction, convection, and radiation are the major methods of hot components transferring heat to a cooler area; thermal resistance expresses the heat transfer efficiency across the two locations of the thermal components.

$$R = \frac{\Delta T}{Q}$$

Where ΔT is the temperature difference between the two locations, and Q is the total power of heat dissipation in W. The unit of thermal resistance is in C/W, indicating the temperature rise per unit rate of heat dissipation. The thermal resistance is analogous to the electrical resistance R_e given by Ohm's law. With ΔV being the voltage difference and I the current.

$$R_e = \frac{\Delta V}{I}$$

Conduction Thermal Resistance

Conduction is the transfer of heat energy through or across a medium., see Figure 1. The energy transfer volume:

$$\Delta T = P^*\delta/(\lambda^* A)$$

P: Power (Watt)
δ: Thickness (mm)
λ: Thermal conductivity [W/(mk)]
A: Area (mm^2)

The thermal resistance depends on the medium area and thickness. Thermal resistance:

$$R = \delta/(\lambda^* A)$$

R: thermal resistance (K/W)

In physics, thermal conductivity, λ is the property of a material's ability to conduct heat. It appears primarily in Fourier's Law for heat conduction. Thermal conductivity is measured in Watts per Kelvin-meter

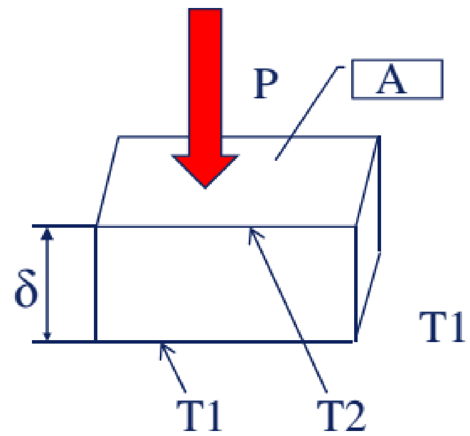

Figure 1

W/(K.m), The reciprocal of thermal resistivity is thermal conductivity. For some common materials, please consult Table 1 for thermal conductivities for more accurate values.

Table 1: Thermal Conductivity, W/(m-K)

Material	Thermal Conductivity	Material	Thermal Conductivity
Silica Aerogel	0.004-0.04	Thermal epoxy	1-7
Air	0.025	Glass	1.1
Wood	0.04-0.4	Soil	1.5
Hollow FIll Fiber Insulation	0.042	Concrete, stone	1.7
Alcohols and Oils	0.1-0.21	Ice	2
Polypropylene	0.25	Sandstone	2.4
Mineral Oil	0.138	Stainless steel	12.11-45.0
Rubber	0.16	Lead	35.3
LPG	0.23-0.26	Aluminum	237 (pure) 120-180 (alloys)
Cement, Portland	0.29	Gold	318
Epoxy (silica-filled)	0.30	Copper	401
Epoxy (unfilled)	0.59	Silver	429
Water (liquid)	0.6	Diamond	900-2320
Thermal grease	0.7-3	Graphene	(4840±440) - (5300±480)

Convection Thermal Resistance

Convection is the transfer of thermal energy by the movement of fluids, see Figure 2.

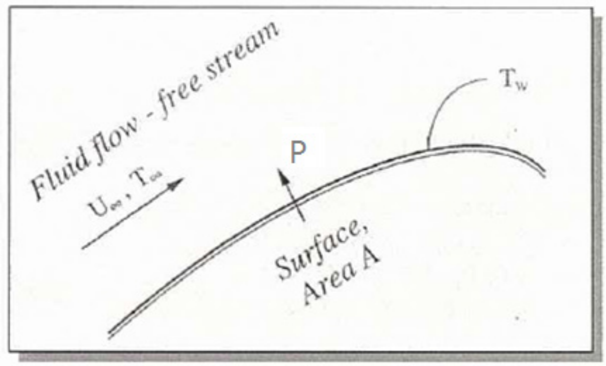

Figure 2

Two types of convective heat transfer may be distinguished:

- Free or natural convection: The fluid motion is caused by buoyancy forces that result from the density variations due to variations of thermal temperature in fluid. The hotter volume of fluid transfers heat toward the cooler volume of that fluid; typical velocity should be 0.2 m/sec.
- Forced convection: A fluid is forced to flow over the surface by an external source such as fans; the velocity of fluid depends on the fan and the local conditions

The basic relationship for heat transfer by convection, the temperature difference between solid-liquid interfaces:

$$\Delta T = P / (\lambda * A)$$

P: Power (Watt)
λ: Heat transfer coefficient [W/(m^2*k)]
A: Area (m^2)

Thermal resistance:

$$R = 1 / (\lambda * A)$$

R: thermal resistance (K/W)

Radiation Thermal Resistance

Energy emitted from the material surface by electromagnetic wave, the active wavelength is usually in the infrared range (0.1 to 100 µm).

Energy emission:

$$P = 5.67 * A * F_{12} * \varepsilon_{xt} * [(T_1/100)^4 - (T_1/100)^4]$$

$$\varepsilon_{xt} = 1/[(1/\varepsilon_1) + (1/\varepsilon_2) - 1]$$

5.67: Stefen-Boltzmann constant
A: Surface area (m_2)
T_1, T_2: Surface temperature (Kelvin)
P: Power (Watt)
F_{12}: Radiation Angle Factor
ε_1, ε_2: Surface emissivity

Thermal resistance: depend on surface, ΔT, radiation angle, and ε . Table 2 provides a list of material surface emissivity.

Table 2: Material Surface Emissivity

Material	Emissivity
Aluminum	
Highly Polished	0.039-0.057
Commercial Sheet	0.09
Heavily Oxidized	0.20-0.31
Surface Roofing	0.216
Brass	
Highly Polished	0.028-0.037
Dull Plate	0.22
Copper	
Polished	0.023
Thick Oxide Layer	0.78
Gold	
Pure, Highly Polished	0.018-0.035
Silver	
Pure, Polished	0.020-0.032
Iron and Steel (not stainless)	
Steel, Polished	0.066
Iron, Polished	0.14-0.38
Cast Iron	0.60-0.70
Mild Steel	0.20-0.32
Iron Plate, Rusted Red	0.61
Sheet, Steel, Rough Oxide Layer	0.81
Glass	
Smooth	0.94
Pyrex, Lead, and Soda	0.95
Porcelain, Glazed	0.92
Quartz, Rough, Fused	0.93
Roofing Paper	0.91
Water	0.95

HOW TO LOWER THE THERMAL RESISTANCE

With the heat transfer method of induction, convection, and radiation, we can make some measurements to improve the thermal resistance.

- Lowering the thermal resistance between the package and heat sink
  - Perfect contact can never be ensured between the heat sink and the package, this result in air gaps between them, see Figure 3, which represent a significant resistance to heat transfer. To combat this problem, it is necessary to use a thermal interface material (TIM).

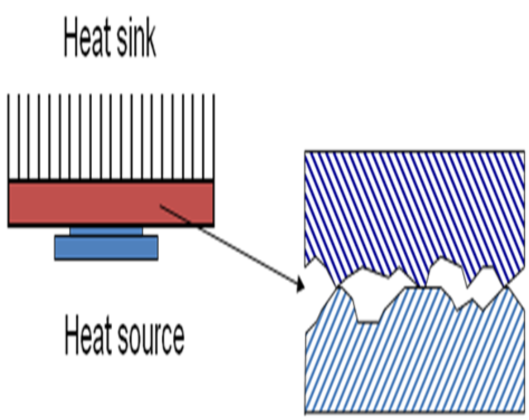

Figure 3: Air gap between heat sink and package

  - There are a number of technologies that can be used including thermal greases and thermally conductive compounds, elastomers, adhesive tapes, etc. The thermal designer can select the appropriate TIM to improve the thermal resistance, Table 3 shows typical thermal resistance and thermal conductivity values for these TIMs.
  - Select suitable thermal conductivity materials of heat sink.

Table 3: Typical Thermal Resistance and Conductivity Values for TIMs

Interface	Thickness (in)	Thermal Conductivity, k(W/m-K)	Rcs (°C/W)
Dry Joint	N/A	N/A	2.9
Thermal Grease	0.003	0.7	0.9
Thermal Compound	0.005	1.2	0.8
Elastomer	0.010	5.0	1.8
Adhesive Tape	0.009	0.7	2.7

- Lowering the thermal resistance in the conductive method.
  - Design an optimized thickness of heat sink base plate, the thermal designer must consider the ideal thickness to affect conductive efficiency, if the thickness is not enough, it will impact the balance of transfer heat to the fins.

- Lowering the thermal resistance in convection method.
  - The convection of thermal resistance: R= R=1/ (λ*A), λ: Heat transfer coefficient [W/ (m^2*k)], A: Area (m^2).
  - The thermal resistance can be reduced by increasing forced air flow, see Figure 4, although the air flow can be increased and thermal resistance can be improved by fans, it also can bring the noise in same time.

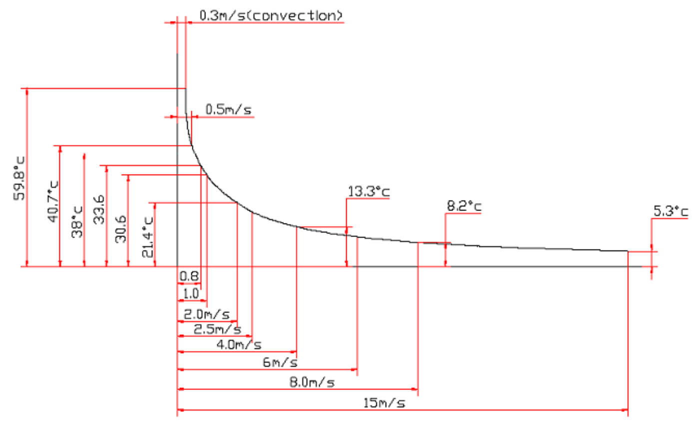

Figure 4: Air velocity vs heat sink thermal resistance

  - Increasing the heat transfer surface using fins on the heat sink, however, beware that fins can reduce the air flow pressure. The thermal designer needs to select optimized density pins of heat sink, see Figure 5.

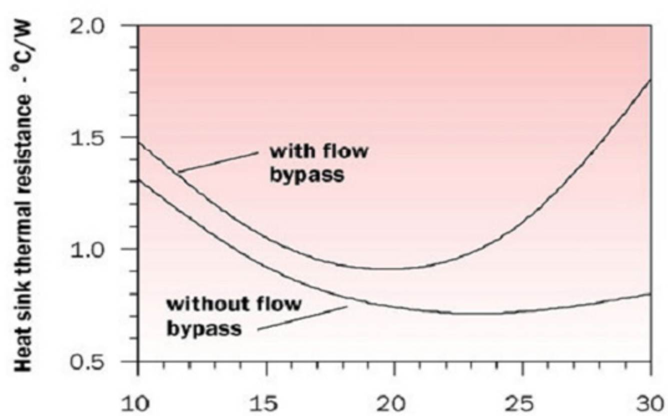

Figure 5: Fin density builds on heat sinks vs thermal resistance

  - Design fins of optimal height to increase heat transfer surface. The effect decreases once the fins reach a certain height. The optimal height takes into account forced air flow and fin thickness.
  - Rectangular, rather than conical fins are best for optimal design, see Figure 6.

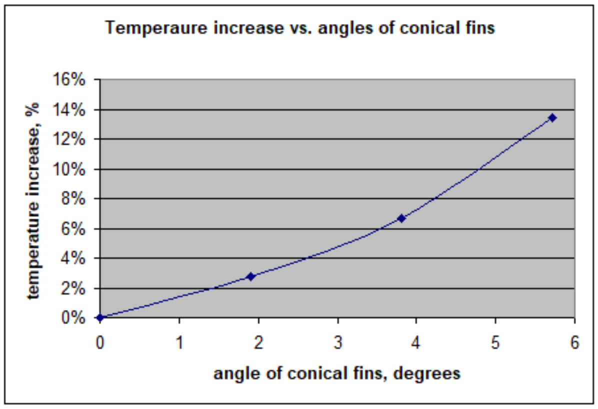

Figure 6: Temperature increase vs angles of conical fins

- The layout of a heatsink when used with a switched mode power supply should be based on the following principal: buoyancy effects of air forces hot air to move up, and cold air to come down due to gravity, see Figure 7.

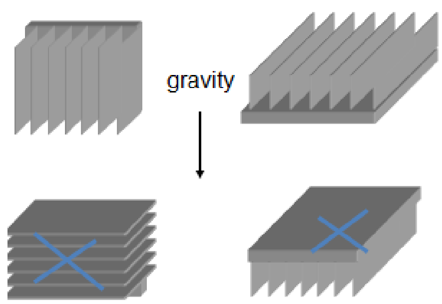

Figure 7: The orientation of heat sinks in the power supply under natural convection

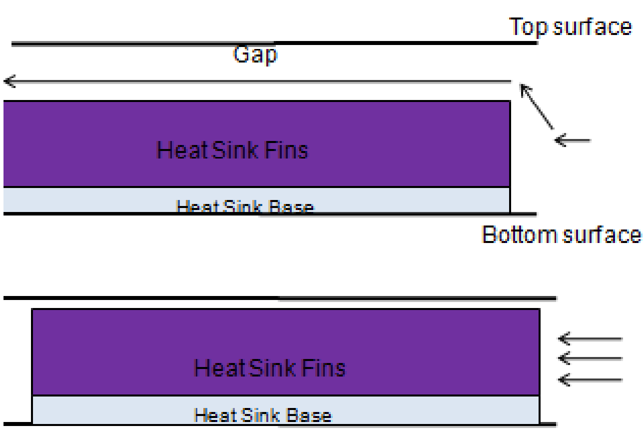

Figure 8: The air is forced to heat sink

- The air must be forced to go through the heat sink. If there is a significant gap between the heat sink and the top surface of the enclosure air will bypass the heat sink, see Figure 8.

- Lowering the thermal resistance in radiation method.
  - Optimize the layout to avoid radiation from higher heat area to cooler temperature area.

COOLX600 AND COOLX1000

For a highly efficient heat transfer coefficient when using the Excelsys CoolX®600 and CoolX®1000 fanless power supplies with a heatsink, follow these guidelines:

- Transfer the heat to chassis by conductive method.
- Optimize the layout to avoid radiation from higher temperature areas to cooler temperature areas.

When using a fan:

- Optimize component layout to reduce any barrier in the switch mode power supply which can reduce air flow pressure.

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