Heat sink in Switch Power Supply

Abstract: This paper presents the heat sink is very useful to transfer the heat generated by some electronic or a mechanical devices, also introduces the basic knowledge thermal resistance and how to reduce the thermal resistance by heat sink and others.

Introduction:

Recently years, with the high power density required and increased of heat generated by the devices in electronic equipments, the problem how to cool these electronic devices becomes a big challenge. Heat sink as a high cost-efficient heat exchanger, it is paid much more attention by thermal designer, the optimal design of heat sink can directly determines the device's reliability, service life and whole performance.

1: What's the heat sink?

Heat sink is a component designed to enhance the heat dissipation from an electronic device to a cooler ambient. Generally, MOSFET, IGBT, and some Power IC are the electronic devices in switch power supply need attach heat sink to maintain in safety temperature. Usually, Heat sink composed of base plate and fins, base plate can transfer the heat to fins, then transfer to surround air by fins. 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 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. Steal, Al and copper are the common materials, but aluminium alloys are the dominating materials for the air cooling heat sinks due to high cost-performance. Stampings, extrusion, casting, bonding, folding, die-casting, forging and skiving are the major production of heat sink.

2: Why the heats sink is needed

Thermal issue is the major cause of electronics failures, electronic devices life has definite relation with the environment temperature, high ambient temperature will lead to electronics devices life be multiply reduced, and reliability and life of electronics devices will be affected in serious. Other hands, with the increase in heat dissipation from microelectronic devices and high frequency IGBT, MOSFET, smaller dissipation space are utilized by high power density, and high ambient temperature with high reliability is required, heat sinks are necessary to enhance the heat dissipation in switch power supply by increasing surface area.

3: Thermal resistance

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

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

Where ∆T 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 low:

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

With ∆V being the voltage difference and I the current.

3.1: Conduction thermal resistance

Conduction is the transfer of heat energy through or across a medium. See fig.1,

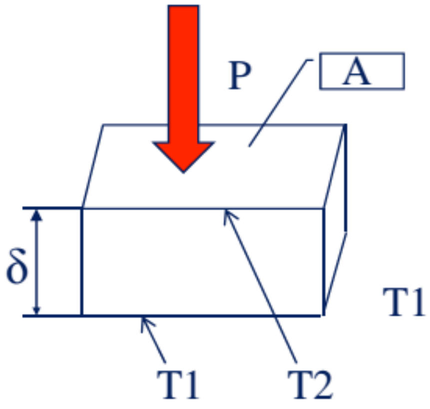


Fig.1 Conduction drawing

The energy transfer volume:

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

P: Power (Watt)
δ: Thickness (mm)
λ: Thermal conductivity [W/(mk)]
A: Area (mm2)

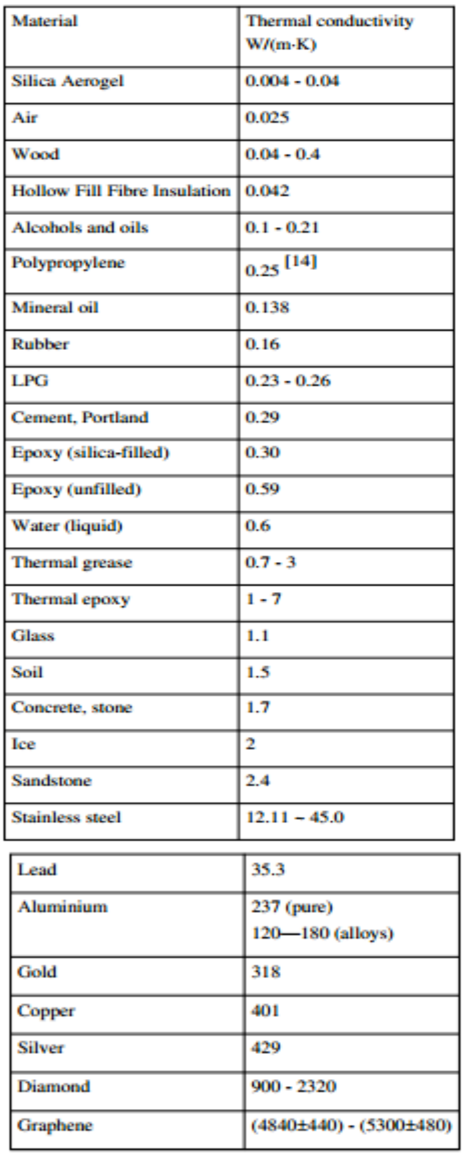
The thermal resistance depends on the medium area and thickness

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



Material	Thermal conductivity W/(m·K)
Silica Aerogel	0.004 - 0.04
Air	0.025
Wood	0.04 - 0.4
Hollow Fill Fibre Insulation	0.042
Alcohols and oils	0.1 - 0.21
Polypropylene	0.25 [14]
Mineral oil	0.138
Rubber	0.16
LPG	0.23 - 0.26
Cement, Portland	0.29
Epoxy (silica-filled)	0.30
Epoxy (unfilled)	0.59
Water (liquid)	0.6
Thermal grease	0.7 - 3
Thermal epoxy	1 - 7
Glass	1.1
Soil	1.5
Concrete, stone	1.7
Ice	2
Sandstone	2.4
Stainless steel	12.11 – 45.0
Lead	35.3
Aluminium	237 (pure) 120—180 (alloys)
Gold	318
Copper	401
Silver	429
Diamond	900 - 2320
Graphene	(4840±440) - (5300±480)

3.2: Convection thermal resistance

Convection is the transfer of thermal energy by the movement of fluids. See Fig 2.

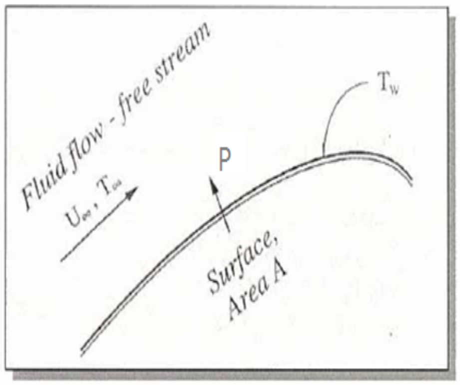


Fig.2 Convection Drawing

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/(m2*k)]
A: Area (m2)

Thermal resistance:

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

R: thermal resistance (K/W)

3.3: Radiation thermal resistance

Energy emit from the material surface by the electromagnetic wave, the active wave length usually in the range of infrared region (0.1-100um). Energy emission:

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

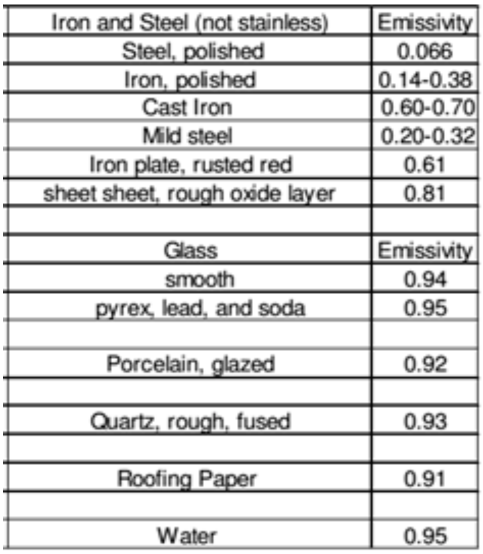
$$\varepsilon_{xt} = 1/[(1/\varepsilon 1)+(1/\varepsilon 2)-1]$$

5.67: Stefen-Boltzmann constant
A: Surface area (m2)
T1, T2: 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

The following is the list of material surface emissivity:

Aluminum	Emissivity
Highly polished	0.039-0.057
Commercial sheet	0.09
Heavily oxidized	0.20-0.31
surface roofing	0.216
Brass	Emissivity
Highly polished	0.028-0.037
Dull plate	0.22
Copper	Emissivity
Polished	0.023
Thick oxide layer	0.78
Gold	Emissivity
Pure, highly polished	0.018-0.035
Silver	Emissivity
pure, polished	0.0.020-0.032



Iron and Steel (not stainless)	Emissivity
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 sheet, rough oxide layer	0.81
Glass	Emissivity
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

4: How to lower the thermal resistance

With the heat transfer method of induction, convection, and radiation, we can make some measurement 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 Fig.3), which represent a significant resistance to heat transfer. To combat this problem, it is necessary to use a thermal interface material (TIM).

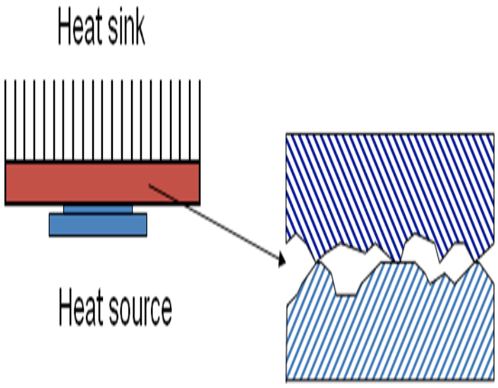


Fig.3 Air gap between heat sink and package

  - There are a number of technologies that can be used including thermal greases and thermally conductive compounds, elastomers, adhesive tapes, etc. Thermal designer can select the appropriate TIM to improve the thermal resistance, following table shows typical thermal resistance and thermal conductivity values for these TIMs.

Interface	Thickness (in)	Thermal Conductivity, k(W/m-K)	R_{cs}(°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

  - Select suitable thermal conductivity materials of heat sink.
- Lowering the thermal resistance in the conductive method.
  - Design an optimized thickness of heat sink base plate, thermal designer must consider the thickness which should affect conductive efficiency, if the thickness is not enough, it will impact the balance to transfer heat to the fins.
- Lowering the thermal resistance in convection method.
  - The convection of thermal resistance: $R= R=1/ (\lambda*A)$, λ: Heat transfer coefficient [W/ (m^2*k)], A: Area (m^2).
  - The thermal resistance can be reduced by increasing forced air flow (See. Fig. 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.

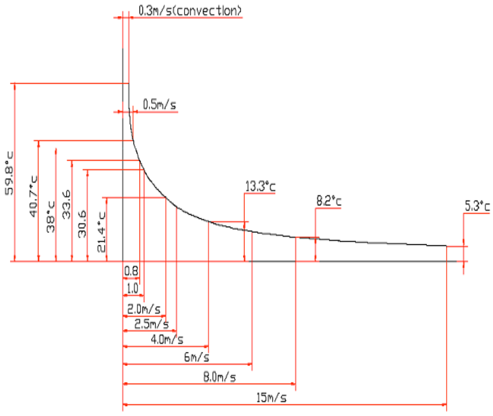


Fig.4 Air velocity Vs heat sink thermal resistance

- Increasing the heat transfer surface by fins at heat sink, but fins can reduce the air flow pressure. Thermal designer need select optimized density pins of heat sink. (See Fig.5)

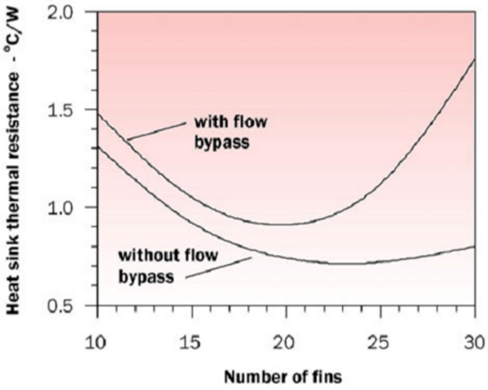


Fig.5 Fin density builds on heat sinks Vs. Thermal resistance

- Design an optimized height of fins to increase heat transfer surface, but the effect is not obvious after the fins to a certain height. The optimized height has relation to forced air flow and fins thickness.
- The fins are better designed to rectangular, rather than conical (See Fig.6)

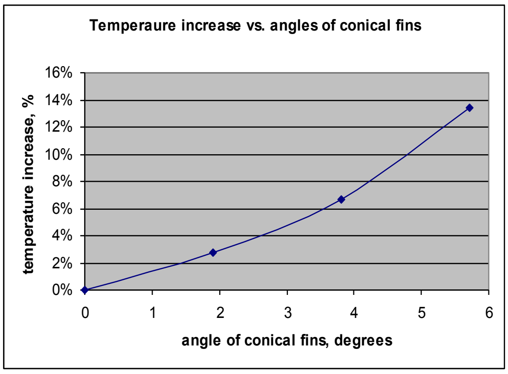


Fig.6 Temperature increase VS Angles of conical fins

- Layout the good direction of heat sink in switch power supply base on the laws: the buoyancy effects of air forces hot air to move up, and cold air to come down due to gravity (See Fig.7)

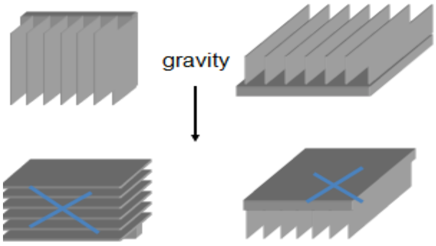


Fig.7 the orient of heat sink in the power supply under natural convection

- 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. The heat transfer efficiency will be affected too much in forced convection (See Fig.8).

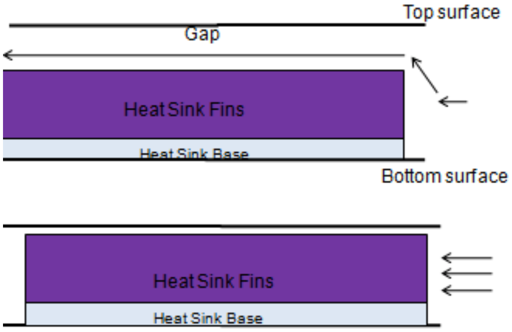


Fig.8 The air is forced to heat sink

  - Designs the optimized components layout in switch power supply to reduce the barrier which can reduce the air flow pressure.
- Lowering the thermal resistance in radiation method.
  - Optimize the layout to avoid radiation from higher heat area to cooler temperature area.

5: CoolX600 did it

With enhanced extremely high efficiency, CoolX600 also has great the heat transfer coefficient by following aspects:

- Optimized heat sink, TIM;

- Transfer the heat to chassis by conductive method;

- Optimized components layout to reduce the barrier in switch power supply which can reduce the air flow pressure.

- Optimized the layout to avoid radiation from higher temperature area to cooler temperature area.

References

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