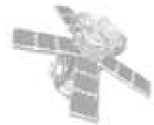
Application Note - Interpoint

Crane Aerospace & Electronics Power Solutions



Thermal Management

Thermal Management

APPLICATION NOTE

Although the concepts stated are universal, this application note was written specifically for Interpoint products.

Switching Power Supplies are devices which transform power from an input voltage level to one or more output voltages, generally different from that at the input. The conversion efficiency can range from less than 50% to more than 90% depending on the particular device and its type, the input voltage, and the percent of full load to which the outputs are loaded. The internal power dissipation, the difference between input and output power can cause a significant rise in the device case temperature unless some means are provided to remove all or part of this energy. The following will discuss the various options available to solve this Thermal Management problem.

Interpoint metal packaged power converters are generally intended to have thermal energy removed by conduction from the baseplate as indicated in Figure 1. A metal surface or cold wall in contact with the mounting base, with a thermal grease or elastomer to fill air voids, is recommended. The removal of thermal energy by convection in still or moving air is possible for low power applications where the air temperature is not very high. Heat transfer by radiation, where the heat transfer rate varies as the 4th power of the absolute temperature is also possible particularly where convection is ineffective. In this case, all of the case surface not in contact with a thermal sink should be painted a dull black to raise the emissivity as close to unity as possible.

The Interpoint power converters of the first generation have full load case temperature ratings of 85°C maximum, with derating along a straight line to zero at 125°C. Parts which fall into this category are MHE, MTW, MTO, MRH, and MFW. Second generation parts have full load case temperature ratings of 125°C, with derating along a straight line to zero at 135°C case temperature. Parts which fall into this category are MSA, MGA, MHF+, MHD, MTR, MFL, MFLHP, MOR, MHV, MHP, MCH, and MGH. The individual data sheets should be consulted for each part contemplated for use.

The first step in assessing the magnitude of a thermal problem is to determine the internal power dissipation, the magnitude of the heat source. First, determine the maximum output power to the load in watts. Once this is known, the efficiency can be determined from the minimum full load value and the typical performance curves on the data sheet. Divide the decimal efficiency into the maximum output load power to arrive at the input power. Subtract the output power from the input power to determine the internal power dissipation.

$$P_{DISS} = (P_{in} - P_{OUT}) = P_{OUT}\left(\frac{1}{Eff} - 1\right)$$

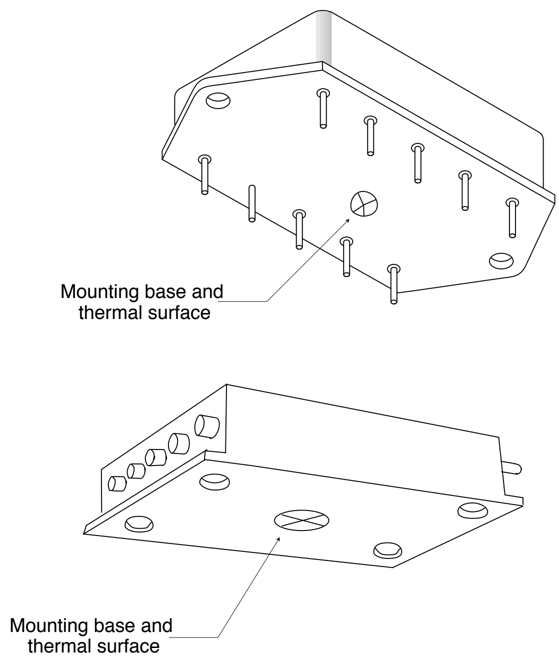


FIGURE 1: MOUNTING BASE AND THERMAL SURFACE

For example, assume we are going to use an MSA2805S with a maximum load power of 2.0 watts. From the datasheet's Electrical Characteristics table (see Figure 2) the minimum full load efficiency is found to be 66%. Assume that extended periods of operation are required at an input voltage of 40 volts. Although 28 volts is the normal value. Referring to the Typical Performance Curves (see Figure 2) we see that the efficiency will be minimum at 40 rather than 28 volts, so we should use the 40 volt curve to be safe. From Figure 2, we get a typical efficiency of 55% at a 2.0 watt output load. This should be adjusted by the ratio of minimum to typical full load efficiency, 0.66/0.71 as found in the data sheet performance tables. See Figure 2 again. The minimum efficiency for this example is then 55%(0.66/0.71) = 51.1%. Then, the internal power dissipation is,

$$P_{DISS} = P_{OUT}\left(\frac{1}{Eff} - 1\right) = 2.0\ W\left(\frac{1}{0.511} - 1\right) = 1.91\ W$$

The various means by which temperature rise can be minimized are examined in the following.

1) Convection

The term convection applies to heat transfer due to the motion of the heated material due to differences in density. The material can be a fluid or gas, and in the case being discussed, it is air. The heat source is the internal dissipation of the power converter. The temperature rise above the free air temperature can be expressed as,

$$T_{RISE} = (P_{DISS})/\big((K_c)\ (A)\big) = (P_{DISS})\ (\text{Thermal Resistance})$$

K_C has units of W/(in^2 • °C); A has units of inch^2

Where K_C is the convection coefficient, and A is the total surface area of the heat source. Temperature rise is an inverse propor-

PARAMETER	CONDITION	MSA2805S MIN	TYP	MAX
INPUT VOLTAGE	Tc = - 55°C to + 125°C NO LOAD TO FULL NORMAL TRANSIENT [1]	16 0	28 —	40 50
INPUT CURRENT	Tc = - 55°C to + 125°C NO LOAD FULL LOAD INHIBITED	— — —	27 250 3	40 — 5
OUTPUT VOLTAGE	FULL LOAD	4.95	5.00	5.05
OUTPUT CURRENT [2]	V_{IN} = 16 TO 40 Vdc Tc = -55°C to + 125°C	0	—	1000
OUTPUT POWER [2]	V_{IN} = 16 TO 40 Vdc Tc = -55°C to + 125°C	—	—	5
EFFICIENCY	FULL LOAD	66	71	—
LINE REGULATION	Tc = - 55°C to + 125°C FULL LOAD V_{IN} MIN TO MAX	—	10	50 [3]
LOAD REGULATION	NO LOAD TO FULL Tc = - 55°C TO + 125°C	—	10	50
OUTPUT RIPPLE VOLTAGE	FULL LOAD, 10 kHz-2 MHz	—	125	350
INPUT RIPPLE CURRENT	FULL LOAD, 10 kHz-2 MHz Tc = 25°C Tc = - 55°C to + 125°C	— —	25 30	100 150
LOAD FAULT POWER DISSIPATION [4]	SHORT CIRCUIT	—	1.5	2.0
LOAD FAULT RECOVERY [5]	SHORT CIRCUIT TO FULL LOAD	—	12.5	25
STEP LOAD RESPONSE TRANSIENT	50% to 100%; 100% to 50% 10% to 100% 100% to 10%	— — —	100 220 150	250 550 375
STEP LOAD RESPONSE RECOVERY [5]	50% to 100%; 100% to 50% 10% to 100% 100% to 10%	— — —	100 100 200	250 250 500
STEP LINE RESPONSE TRANSIENT [6]	16 TO 40 Vdc 40 to 16 Vdc	— —	50 50	150 150
STEP LINE RESPONSE RECOVERY [5]	16 TO 40 Vdc 40 to 16 Vdc	— —	100 200	250 500
INPUT/OUTPUT CAPACITANCE [6]		—	50	—
START UP DELAY OVERSHOOT	FULL LOAD FULL LOAD	— —	10 0	25 50

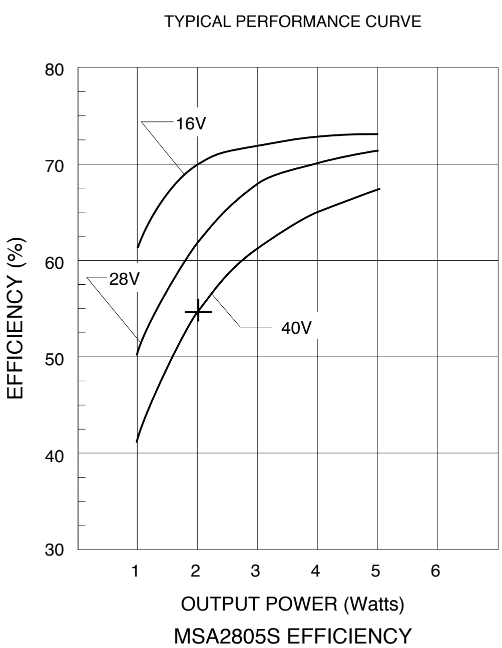


FIGURE 2: MSA SPECIFICATION TABLE AND PERFORMANCE CURVE

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tion of surface area and K_c, and K_c will also vary as a function of orientation such as horizontal, vertical, etc. Table 1 shows the convection coefficients for various Interpoint metal package type power converters in °C/watt. The value of the coefficients have been determined empirically and apply in still air with the package thermal surface horizontal but oriented down. This is pins down for all but MFL style cases. For cases where the thermal surface is in a vertical plane or horizontal on the top, Kc is slightly larger, giving a slightly smaller temperature rise.

For the MSA2805S example, where P_{diss} was found to be 1.91 W, the case temperature rise from Table 1 will be on the order of,

$$T_{RISE} = (1.91\ W)(32°C/W) = 61.1°C.$$

Since the maximum case temperature for this part is +125°C, the maximum ambient air temperature should not exceed +64°C. However, since the MTBF varies as an inverse exponential of case temperature, some other means of conducting thermal energy away, such as conduction and/or radiation, should be looked at to help lower case temperature rise. Each 20° to 30°C rise in case temperature, will reduce the MTBF by roughly a factor of 2. Refer to the following paragraphs.

Some additional thermal information for the MSA, also determined by measurement is as follows. For an MSA centered on a single sided copper clad vector board 1.8” x 2.8”, with the copper on the opposite side in traces and ground plane, and with filter components on the MSA side and the MSA and components connected thru to the copper, the following was observed:

With the MSA having a spacing of 0.05” above the board, the thermal coefficient from case to ambient was measured as 29°C/watt. The board was horizontal with the MSA on the upside.

With the MSA in contact with the vectorboard, 0.05” spacing removed, the thermal coefficient from case to ambient was measured as 22°C/watt. The reduced thermal rise is due to some conduction in the epoxy glass board, and convection from the increased area immediately surrounding the MSA.

2) Conduction

Removing thermal energy by conduction is analogous to the conduction of electrical current in a wire, usually of copper. Copper is used because it is an excellent and economical electrical conductor. Silver is the best but not generally used because of cost and problems with migration. Good electrical conductors are also good thermal conductors. For thermal conduction, aluminum may sometimes be preferable because of its low density, 2.7 grams/cubic centimeter, as compared to 8.9 for copper. Aluminum has about 1.6 times the resistivity of copper.

THERMAL RESISTANCE - CASE / AMBIENT CONVECTION ONLY, IN FREE AIR			
MODEL	Θ_{CA} °C/Watt	**~SURFACE AREA** in inches^2	K_C W / (inch^2 • °C)
MCH, MGH	45	2.32	9.57×10^{-3}
MSA, MGA	32	3.28	9.53×10^{-3}
MSR	29	4.50	7.66×10^{-3}
MHF, MHF+, MHF+ T	26	5.01	7.68×10^{-3}
SAME WITH FLANGES	24	5.6	7.44×10^{-3}
FM704A, MHV,	19	7.34	7.17×10^{-3}
MHE, MHD, MTR	19	7.34	7.17×10^{-3}
SAME WITH FLANGES	17	8.14	7.22×10^{-3}
MRH, MTO,	18	7.9	7.03×10^{-3}
MTW, MTR T, MHV T	18	7.9	7.03×10^{-3}
SAME WITH FLANGES	16	9.02	6.93×10^{-3}
MFL, MHP, MOR, MFLHP	13.5	12.0	6.17×10^{-3}
MFW	8.0	22.0	5.68×10^{-3}

Table 1: Convection Coefficients and Thermal Resistance in Free Air Convection

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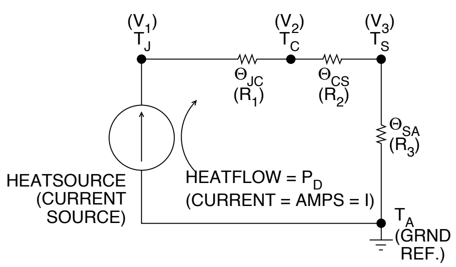
Figure 3 shows a Thermal-Electrical Analog which may be helpful in understanding thermal conduction. The circuit is a single loop driven by a current source and consisting of a series of 3 resistors terminating at the ground reference to complete the loop. The electrical current, which flows in the direction of the arrow, causes a series of voltage drops in the resistors, V3 being the lowest and V1 the highest, with respect to the ground reference. The units involved are Amperes, Ohms, and Volts respectively. For the thermal model, the current source is replaced by a heat source which becomes the rate at which thermal energy is generated, and has units of joules/second, or watts. Heat flows in the direction of the arrow as with the electrical case.

The electrical resistances are replaced by thermal resistances having units of °C/watt, and the voltage drops are replaced by thermal differences having units of °C. The electrical resistors are replaced by mechanical components such as the metal case, thermal interface pad, metal thermal ladder, and heatsink. The analog example shown has a power semiconductor in a metal case as the heat source. The metal case is in turn mounted on a heatsink with a thermal interface pad used to fill air voids. The highest temperature, T_J, is the semiconductors junction temperature, and the lowest the ambient air, T_A. In between are the case, T_C, and heatsink temperatures, T_S. Heat flows from the highest to the lowest temperature with intermediate temperatures in between as defined by the various thermal resistances (Θ). The thermal resistance for convection could also be added as a parallel path in the thermal circuit model, where the area is modified to exclude that portion in contact with another surface for conduction.

The thermal resistance of a material is determined from the reciprocal of its thermal conductivity multiplied by the ratio of length to cross sectional area. This is shown on Figure 3, with some materials properties shown on Tables 2 and 3. For materials listed in Table 3, copper has the best conductivity, and air the worst. The Sil Pad 1500 has a conductivity in the middle of the former two, and is about 100 times better than air. It is available in sheets or pre-cut pads in a thickness of 0.01”. It can be used to fill air voids between the power converter thermal surface and a thermal sink or other surface. Air voids in thermal interfaces can result in hot spots and serious problems down the road if they are not filled. Thermal grease is another alternative to the Sil Pad for this purpose.



ΔT_{JC} = $P_D\,\Theta_{JC} \sim (V_1 - V_2) = I\,R_1$

ΔT_{JA} = $P_D\,(\Theta_{JC}+\Theta_{CS}+\Theta_{SA}) \sim V_1 = I\,(R_1+R_2+R_3)$

ΔT_{JA} = $(T_J - T_A)$ = TEMP. DIFF. – JUNCTION TO AMBIENT

$\sim (V_1 - 0)$ = TOTAL VOLTAGE DROP

THERMAL:

HEATSOURCE IS INTERNAL P_D IN WATTS

Θ = THERMAL RESISTANCE IN °C/WATT

= $\left(\frac{1}{K}\right)\left(\frac{\ell}{A}\right)$, K = THERMAL CONDUCTIVITY IN $\frac{\text{WATTS}}{\text{cm °C}}$

A = CROSS SECTIONAL AREA OF PATH IN cm^2

ℓ = LENGTH OF THERMAL PATH IN cm

T_J = JUNCTION TEMP IN °C

T_C = CASE TEMP IN °C

T_S = HEATSINK TEMP IN °C

T_A = AMBIENT TEMP IN °C

ELECTRICAL:

I = CURRENT IN AMPS

R = RESISTANCE IN OHMS

= “ρ” $\left(\frac{\ell}{A}\right)$, “ρ” = RESISTIVITY IN Ohm-cm

“ρ” = the Greek letter Rho

V = VOLTAGE IN VOLTS

FIGURE 3: THERMAL ELECTRICAL ANALOG

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BERQUIST THERMAL INTERFACE PADS

	SIL-PAD 400(.009)	SIL-PAD 400(.007)	SIL-PAD 600(.009)	SIL-PAD 1000	SIL-PAD 1500
Color	Gray	Gray	Green	Pink	Green
Thermal Resistance, ˚C/watt	.50	.45	0.35	0.35	0.23
Dielectric Constant, 1000 (Hz)	5.5	5.5	5.0	4.5	4.0
Continuous Use Temp. ˚C	-60 to +180	-60 to +180	-60 to +180	-60 to +180	-60 to +180
Thermal Conductivity W/m-k nominal	0.9	0.9	0.9	0.9	0.9
Thickness Inches (mm)	.009±.001 (.23±.025)	.007±.001 (.18±.025)	.009±.001 (.23±.025)	.009±.001 (.23±.025)	.010±.001 (.25±.025)
Volume Resistivity, Ohm Metre Typical Normal	1.0×10^{11}	1.0×10^{11}	1.0×10^{12}	1.0×10^{11}	1.0×10^{11}
Moist	1.5×10^{8}	1.5×10^{8}		1.5×10^{8}	
Breakdown Voltage (minimum AC)	4500	3500	4500	4500	4000
Thermal Vacuum Weight Loss Percent (TML) Max. As Manufactured	.40	.40		.22	
Post Cure 24 HRS. 440˚F, 225˚C	.25	.25			
Volatile Condendsable a Material, Percent Maximum (CVCM) As Manufactured	.11	.11		.08	
Post Cure 24 HRS. 440˚F, 225˚C	.07	.07			
Hardness, Shore A	85	85	85	85	80
Specific Gravity	2.0 - 2.1	2.0 - 2.1		1.5	
Tensile Strength, K Psi, Typical (MPa)	11 (75)	14 (100)	11 (75)	11 (75)	6 (40)
Breaking Strength, Lbs/inch kN/m	100 18	100 18	100 18	100 18	65 11
Elongation Percent Nominal	4	4	4	4	4
Construction	Silicone/ Fiberglass	Silicone/ Fiberglass	Silicone/ Fiberglass	Silicone/ Fiberglass	Silicone/ Fiberglass

INTERPOINT'S "TMP" ACCESSORY
SIL - PAD 1500 MATERIAL

$$K_{(1500)} = 0.02 \ \frac{W}{c\,m˚C}$$

~ 100 x Better than air

Assume Pad Dimensions are:

Area = 2.5 cm x 5.0 cm = 12.5 cm^2

Thickness = Length = 0.025 cm

$$\Theta_{CS} = \left[\frac{1}{K_{1500}}\right]\left[\frac{L}{A}\right] = \left(\frac{50cm˚C}{W}\right)\left(\frac{.025cm}{12.5cm^2}\right)$$

$$\Theta_{CS} = 0.10 \ \frac{˚C}{W}$$

ASSUME P_D = 11.0 WATTS

$$\Delta T_{CS} = P_D\,\Theta_{CS} = (11w)\left(\frac{0.1˚C}{W}\right) = 1.1˚C$$

Si conversions are approximations and are not intended to be exact.

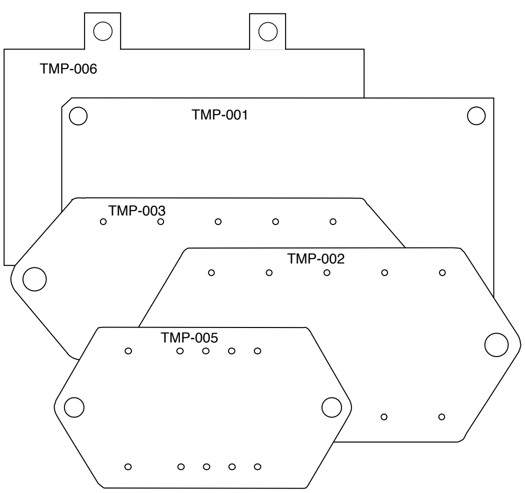

Table 2: Thermal Interface Pads

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MATERIAL	THERMAL Conductivity K (Watts/cm - ˚C)	THERMAL Expansion Coefficient $\alpha(10^{-6}/\ ^{\circ}C)$	Specific Heat c (joules/gm/ ˚C)	Density π_d (gm/cm^3)
ALUMINA (96%)	0.30[1]	6.4	1.13	4.0
ALUMINUM	2.14[1]	23.0	0.9	2.7
ALUMINUM SILICATE	0.013	3.2	1.04	2.3
BERYLLIA	2.20[1]	6.0	1.25	2.9
BRASS	0.85	18.5	0.38	8.4
COPPER	3.2[1]	17.0	0.39	8.9
EPOXY (INSUL.)	≈ 0.014	≈ 30.0	—	2.3
EPOXY (COND.)	≈ 0.08	≈ 35	—	2.6
FUSED SILICA	≈ 0.014	0.55	0.75	2.2
GRAPHITE [2]	1.4	≈ 5.4	≈ 1.67	1.8
KOVAR	0.15	6[2]	0.50	8.0
LEAD	0.38	29.0	0.14	11.3
MOLYBDENUM	1.34	4.9	0.25	10.2
NICKEL	0.58	13.0	0.44	8.9
SILICON	0.84[1]	4.2	0.70	2.33
STEEL (C.R.S.)	0.55	13	0.45	7.8
STEEL (S.S. #316)	0.15	16.5	0.50	8.0
TUNGSTEN	1.56	5.0	0.13	19.3
SIL PAD 1500	0.02			
AIR	0.00024			

1. STRONG FUNCTION OF TEMPERATURE
2. APPROXIMATION ONLY

TABLE 3: THERMAL PROPERTIES OF COMMON MATERIAL

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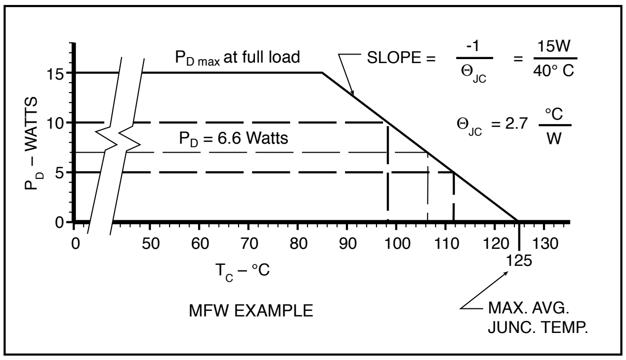


$$P_D = \frac{P_O}{EFF} - P_O = P_{IN} - P_O$$

MAX CASE TEMP. = 125° C – $(P_D)(\Theta_{JC})$

EXAMPLE:

P_O = 30W & EFF = 82%

$$T_{C\,MAX} = 125°\,C - \left(\frac{P_O}{EFF} - P_O\right)\Theta_{JC}$$

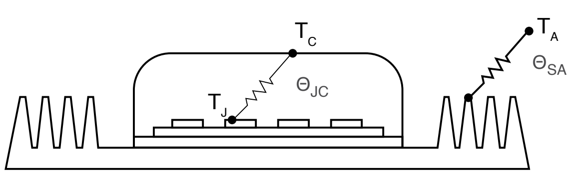
$$T_{C\,MAX} = 125°\,C - \left(\frac{30}{0.82} - 30\right) 2.7$$

$$T_{C\,MAX} = 125°\,C - (6.6W)\left(2.7\frac{°C}{W}\right) = 107°\,C$$

Figure 4: Thermal Considerations

Figure 4 is an example of how to determine Θ_{JC} from the derating curve for an MFW power converter, and then the maximum allowable case temperature for an assumed load of 30 watts. At full load, 70 W, the internal dissipation will be about 15 watts. Since derating to zero occurs along a straight line from 85°C to 125°C, the thermal resistance, Θ_{JC}, is equal to (125 - 85) °C/15 watts = 2.7°C/watt. Based on an internal dissipation of 6.6 watts, the max allowable case temp is found to be 107°C. This procedure can be used to determine Θ_{JC} on any Interpoint power converter. On the second generation parts, the derating to zero occurs over 10°C rather than 40°C, so the thermal resistances will be smaller than in the former case.

Figure 5 is an example of an MFW power converter with a 30 watt load but now mounted on a heatsink. The heatsink could just as well have been a thermal ladder with the other end connected to a cold wall. For simplicity, flat surfaces with no air voids are assumed without fillers. In reality a thermal pad would



$$\Delta T_{JC} = P_D\,\Theta_{JC} = [W]\left[\frac{°C}{W}\right] = °C$$

$$\Delta T_{JA} = P_D(\Theta_{JC} + \Theta_{SA}) = P_D\Theta_{JA} = °C$$

Θ_{CS} = 0 FOR SIMPLIFIED EXAMPLE

EXAMPLE:

T_A = 55°C, P_O = 30W and EFFICIENCY = 82%

WHAT IS MAX. Θ_{SA} FOR HEATSINK?

$T_{C\,max}$ = 107° C from Figure 4 above

$$\Delta T_{SA\,max} = P_D(\Theta_{SA\,max})$$

$$[107°C - 55°C] = \left[\frac{30}{0.82} - 30\right] \text{WATTS} \,[\Theta_{SA}]\,\frac{°C}{W}$$

$$52°C = [6.6W]\left[\Theta_{SA}\frac{°C}{W}\right]$$

$$\Theta_{SA\,max} = \frac{52°C}{6.6W} = 7.9°\,C\,/\,W$$

Figure 5: Case Mounted on Thermal Sink

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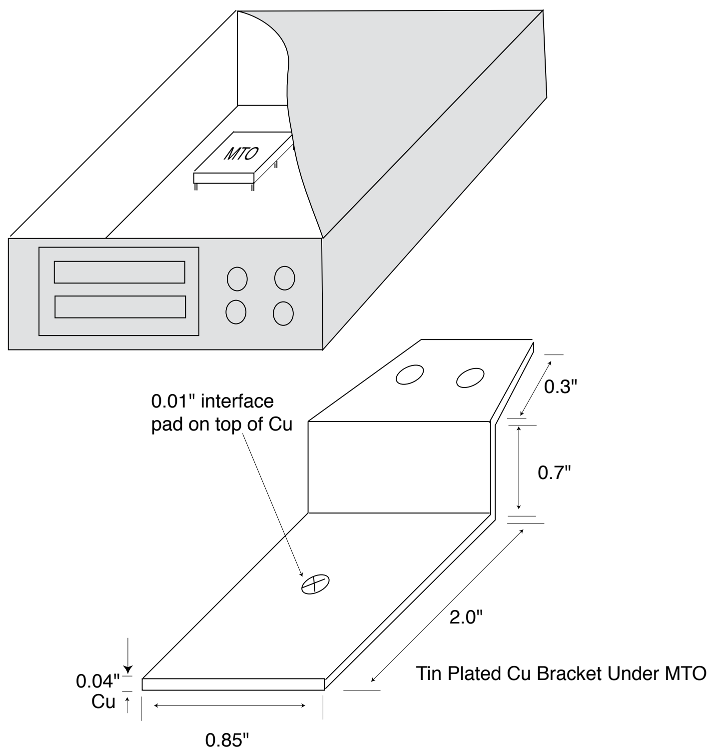
be used resulting in an additional thermal resistance in the equations. The Θ_{JC} of 2.7°C/watt from Figure 4 is used here. The ambient temperature is 55°C, and the object of the calculation is to determine the largest allowable heatsink thermal resistance, Θ. The maximum case temp from Figure 4 is 107°C, and the delta T over which derating occurs is found to be 52°C. From the calculation of Figure 5, the maximum allowable heatsink thermal resistance to ambient, Θ_{SA}, is found to be 7.9°C/watt. The next step is to find a heatsink which meets this among other requirements, either by design or in a manufacturers catalog.

Figure 6 shows an example of a real problem. A three output power converter, MTO28515T, is used in a small avionics system where there was a thermal problem follows:

The system is in a small metal box of the type having perforations in the walls to allow air circulation from the outside environ-



$$\Theta_{BRACKET} = \frac{1}{K_{CU}}\left(\frac{\ell}{A}\right) = \left(\frac{1\text{ cm° C}}{3.2\text{ W}}\right)\left(\frac{2.54\text{ cm° C}}{0.22\text{ cm}^2}\right) = \frac{3.6\text{° C}}{\text{W}}$$

$$\Theta_{PAD} = \frac{1}{K_{PAD}}\left(\frac{\ell}{A}\right) = \left(\frac{1\text{ cm° C}}{102\text{ W}}\right)\left(\frac{0.025\text{ cm}}{11.0\text{ cm}^2}\right) = \frac{0.11\text{° C}}{\text{W}}$$

$$\Delta T = 1.9\text{ W}\left(\frac{3.6\text{° C}}{\text{W}} + \frac{0.11\text{° C}}{\text{W}}\right) = 7.03\text{° C}$$

WHERE:

$\ell_{BRACKET}$ = 1" = 2.54 cm

$A_{BRACKET}$ = 0.85" X 0.04" = 0.034"^{2} = 0.22 cm^2

ℓ_{PAD} = 0.01" = 0.025 cm

A_{PAD} = 2" x 0.85" = 1.72"^{2} = 11 cm^2

Figure 6: MTO Heat Sink Design and Calculations

ment. The power output was about 6.0 watts, input power 7.9 watts at 76% efficiency, and internal P_D of (7.9 - 6.0) = 1.9 watts. From Table 1, temperature rise of the MTO case due to only convection is predicted to be about (1.9 watts)(18°C/watt) = 34°C. The maximum system case temperature spec is + 85°C, about what the ambient air will also be. Adding 34°C to this figure, the MTO case is predicted to rise to about 119°C, as verified by measurement, and too hot for this part, which derates to zero at +125°C. The solution was to find an additional thermal path to lower the case temperature.

The MTO was mounted on the top PC card just below the metal top cover of the box, and mounted about 0.05" above the PC card to allow inspection of solder joints. Here the solution was simple. A tin plated copper bracket, 0.04" thick, was attached to the PC card to form a thermal path between the mounting base and the system box cover. The MTO was seated on the bracket with an interface pad, the other end attached to the system box cover with mechanical fasteners. The part under the MTO is a heat spreader, and the thermal ladder is about 1.0" long. The calculation of Figure 6 indicates the predicted MTO case temp rise is lowered to about 7°C due to conduction through the bracket. Convection from the cover surface area will also still occur, but will have a minimal effect. Radiation should also be considered as an alternate means of heat transfer. Measuring the actual temperature is always recommended. A small thermocouple or glass junction diode should be attached to the thermal surface for this purpose wherever possible. Alternately, attach to the sidewall of the case as close to the base as possible.

3) Radiative Cooling

Radiation refers to the continual radiation of energy from a body and is referred to as radiant energy. It is in the form of electromagnetic waves, predominantly in the 1 to 10 micron area of the spectrum. The rate at which radiation occurs can be expressed by Stefan's law as in the formula,

$R = e \cdot c \cdot T^4$ where,

- e = emissivity having a range of 0 to 1, where a perfect blackbody = 1.
- c = 5.7 x 10^{-8} in MKS units.
- T = absolute Kelvin temperature.
- R = Rate of emission of radiant energy in Joules/Second/ square meter, or Watts/square meter.

The square meters refer to the surface area of the body emitting the radiant energy. In an application where the cover is painted a dull black, it will be the total cover area in square meters. The radiation calculation is simple except for determining what the emissivity is. An ideal blackbody might be a sphere having a dull black and rough surface, and an emissivity approaching one. For a rectangular shape with a dull black finish on a smooth surface, the emissivity will be less, and unknown at this point. The following experiment was conducted to determine the value.

The case temperature of an MSA power converter dissipating 1.05 watts internally was found to be 55°C when suspended with cover up in an ambient of 22°C. The thermal coefficient by convection is then calculated to be,

(55 - 22)/(1.05) = 31.4°C/watt.

The cover was then spray-painted a dull black. The label could still be read through the paint. The experiment was repeated and the case temperature rose to only 47°C, with the ambient temperature still 22°C. Since the temperature rise was lowered by 8°C, about 0.25 watts must have been removed by means other than convection - in this case radiation. Then, since everything else is known, the emissivity is calculated as,

$$e = \frac{P}{A \cdot c \cdot T^4}$$

where A is the cover area = 0.0013 meters

$$e = \frac{(0.25)}{(0.0013)(5.7x10\text{-}8)(320^4)} = 0.32,$$

or about one third. The remainder of the case was painted dull black with the result that the temperature rise was reduced an additional 3°C. The surface area in this case is 0.0019 meters squared. Our conclusion is that radiation should be considered as a means of heat transfer. It would have been of further benefit in the example of Figure 6.

