Product Safety and the Heat Sink - Dilemma of Minimizing Radiated Emissions and Maximizing Thermal Cooling

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Abstract — Microprocessors are designed with tens of thousands or millions of transistors that potentially can generate a significant amount of heat. Cooling of the package has become a challenge. Heat sinks are generally provided for the purpose of thermal dissipation, which helps keep components from becoming too hot. Destruction of the component may result. Designing heat sinks for optimal cooling within the constraints of size, space and airflow has become a challenge. In addition to being an efficient thermal radiator, a metal heat sink begins to appear as an efficient radiator of RF energy at higher operating frequencies.

During normal operation or maintenance of a product, the heat sink may become exposed to users or service personnel. The temperature of the heat sink must be low enough as not to cause a burn injury if accidentally touched. Product safety standards require a label be affixed to the heat sink when a certain temperature level is exceeded, or if the heat sink is at voltage potential to prevent electric shock. In addition, the device must be kept cool enough as not to exceed the glass transition temperature (T_g), or melting point of the printed wiring board material (PWB). Printed wiring boards, when exposed to high temperatures, may start to discolor, delaminate or even ignite causing serious safety consideration.

To satisfy areas of concern related to heat sinks (heat dissipation and product safety while minimizing the propagation of RF energy), designers must maximize thermal cooling. To minimize the total amount of radiated emissions, the heat sink must be physically small based on the wavelength of the highest generated frequency internal to the component. Conversely, to maximize cooling, the heat sink must be physically large. The designer must be cognizant of all concerns, and select or design a heat sink that meets operational requirements.

Introduction

A basic heat sink model was developed and characterized for radiated emissions and thermal dissipation (Fig. 1). By combining both types of characteristics, the designer can optimize the design of the heat sink to minimize affects of RF radiation from a monopole antenna while maintaining a high degree of cooling (Fig. 2). In doing so, products will remain complaint by being under EMI radiated emission limits while ensuring thermal requirements mandated by electrical product safety standards.

Basic heatsink design

In Fig. 1, the heat sink is one of typical construction. The fin length, *L*, is approximately 3.5 inches long. The fin spacing is approximately 0.38 inches. The arrow indicates the air flow direction.

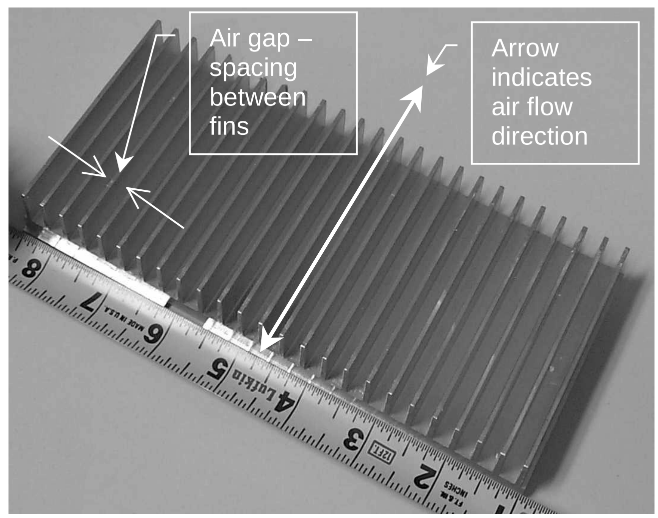

Figure 1. Basic heat sink design

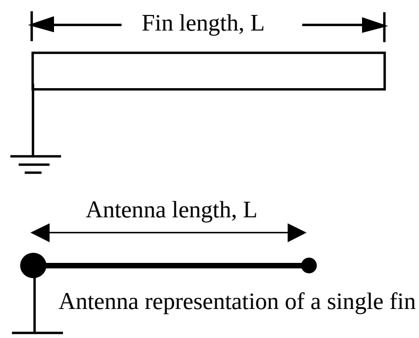

Figure 2. Basic heat sink EMI design analysis

Basic heat sink EMI design analysis

To keep electromagnetic interference (EMI) analysis simple and basic, the heat sink will be modeled as a monopole antenna. Grounding this antenna will change its propagation efficiency. Equation (1) calculates the expected radiating wavelength as a function of frequency. If any dimension of the heat sink matches the wavelength of the value λ, up to $\lambda/20$, one can expect to observe radiated EMI. EMI is developed in the silicon, internal to the component package, by virtue of common-mode currents present on the die. Common-mode RF current exists due to poor decoupling on the PWB. If the PWB is properly designed with a robust power distribution system, the semiconductor should not cause a radiated concern. This analysis *assumes* a poorly designed power distribution network.

$$\lambda = \frac{C}{f} = \frac{300}{f} \tag{1}$$

where:
λ = wavelength, meters (m)
C = speed of light (m); corrected for use with frequency
f = frequency, megahertz (MHz)

Table 1 details the frequency at which the heat sink will perform as an efficient radiating structure. Note that for very small fin lengths, the heat sink is not expected to radiate RF energy. For smaller size heat sinks, this frequency is well into the GHz range.

Heat sink thermal optimization

Thermal optimization involves calculating the physical dimensions and characteristics of the heat sink. For purpose of this paper, the attributes for the heat sink and fins are the physical dimensions; length, width, and thickness. In addition to physical dimensions, the number of fins and their spacing to each other contributes to the overall thermal effectiveness of the heat sink.

Equation 2 describes the fin spacing for optimal performance for thermal cooling by convection. This equation is from [1].

$$OS = \frac{2.9\left(L^{0.25} \times D^{0.5} \times T_{air}{}^{0.25}\right)}{g^{0.25} \times D_{air}{}^{0.5} \times T_{rise}{}^{0.25}} \tag{2}$$

where
OS = optimal spacing between fins
L = length of the fin in direction of air travel (feet)
D = dynamic viscosity (0.144 X 10-4 lb/ft sec)
T_{air} = bulk air temperature in absolute degrees (Rankine)
G = gravitational constant ($32.2 ft/sec^2$)
$D_{ai}r$ = air density ($0.06 lb/ft^3$)
T_{rise} = anticipated temperature rise of the heat dissipation surface, Fahrenheit (F)

From Eq. (2), Table 2 is developed for different fin lengths and temperature rise. The optimal spacing in Table 2 has been converted from feet to millimeters; *T*rise has been converted from Fahrenheit to Celsius.

fin length (cm)	Wavelength based on fin length (cm)				fin length (cm)	Wavelength based on fin length (cm)		
	λ (MHz)	λ/2 (MHz)	λ/4 (MHz)			λ (MHz)	λ/2 (MHz)	λ/4 (MHz)
0.5	60000.0	30000.0	15000.0		10.5	2857.1	1428.6	714.3
1.0	30000.0	15000.0	7500.0		11.0	2727.3	1363.6	681.8
1.5	20000.0	10000.0	5000.0		11.5	2608.7	1304.3	652.2
2.0	15000.0	7500.0	3750.0		12.0	2500.0	1250.0	625.0
2.5	12000.0	6000.0	3000.0		12.5	2400.0	1200.0	600.0
3.0	10000.0	5000.0	2500.0		13.0	2307.7	1153.8	576.9
3.5	8571.4	4285.7	2142.9		13.5	2222.2	1111.1	555.6
4.0	7500.0	3750.0	1875.0		14.0	2142.9	1071.4	535.7
4.5	6666.7	3333.3	1666.7		14.5	2069.0	1034.5	517.2
5.0	6000.0	3000.0	1500.0		15.0	2000.0	1000.0	500.0
5.5	5454.5	2727.3	1363.6		15.5	1935.5	967.7	483.9
6.0	5000.0	2500.0	1250.0		16.0	1875.0	937.5	468.8
6.5	4615.4	2307.7	1153.8		16.5	1818.2	909.1	454.5
7.0	4285.7	2142.9	1071.4		17.0	1764.7	882.4	441.2
7.5	4000.0	2000.0	1000.0		17.5	1714.3	857.1	428.6
8.0	3750.0	1875.0	937.5		18.0	1666.7	833.3	416.7
8.5	3529.4	1764.7	882.4		18.5	1621.6	810.8	405.4
9.0	3333.3	1666.7	833.3		19.0	1578.9	789.5	394.7
9.5	3157.9	1578.9	789.5		19.5	1538.5	769.2	384.6
10.0	3000.0	1500.0	750.0		20.0	1500.0	750.0	375.0

Table 1. Wavelength based on fin length

Combined analysis–temperature versus radiated energy

Combining Tables 1 and 2, to create Fig. 3, a design engineer can observe the relationship between optimal cooling and heat sink antenna efficiency. One must choose a heat sink that will provide sufficient cooling and minimize radiated emissions by selecting a fin length that is not resonant at the clock frequencies of interest.

References:

1. Soule, Christopher A. August 1, 2002, “Optimization of Fin Spacing: How Close Is Too Close?” *Power Electronics Technology*.

2. Montrose, Mark I., 2000. *Printed Circuit Board Design Techniques for EMC Compliance,* Second Edition, IEEE Press.

fin length (cm)	Heat sink temp rise - °C							
	10	20	30	40	50	60	70	80
0.5	4.81	4.04	3.65	3.40	3.21	3.07	2.95	2.86
1.0	5.72	4.81	4.34	4.04	3.82	3.65	3.51	3.40
1.5	6.32	5.32	4.81	4.47	4.23	4.04	3.89	3.76
2.0	6.80	5.72	5.16	4.81	4.55	4.34	4.18	4.04
2.5	7.19	6.04	5.46	5.08	4.81	4.59	4.42	4.27
3.0	7.52	6.32	5.72	5.32	5.03	4.81	4.62	4.47
3.5	7.82	6.57	5.94	5.53	5.23	4.99	4.81	4.65
4.0	8.08	6.80	6.14	5.72	5.41	5.16	4.97	4.81
4.5	8.32	7.00	6.32	5.89	5.57	5.32	5.12	4.95
5.0	8.55	7.19	6.49	6.04	5.72	5.46	5.25	5.08
5.5	8.75	7.36	6.65	6.19	5.85	5.59	5.38	5.20
6.0	8.94	7.52	6.80	6.32	5.98	5.72	5.50	5.32
6.5	9.13	7.67	6.93	6.45	6.10	5.83	5.61	5.43
7.0	9.30	7.82	7.06	6.57	6.22	5.94	5.72	5.53
7.5	9.46	7.95	7.19	6.69	6.32	6.04	5.81	5.62
8.0	9.61	8.08	7.30	6.80	6.43	6.14	5.91	5.72
8.5	9.76	8.21	7.41	6.90	6.53	6.24	6.00	5.80
9.0	9.90	8.32	7.52	7.00	6.62	6.32	6.09	5.89
9.5	10.03	8.44	7.62	7.09	6.71	6.41	6.17	5.97
10.0	10.16	8.55	7.72	7.19	6.80	6.49	6.25	6.04
10.5	10.29	8.65	7.82	7.27	6.88	6.57	6.32	6.12
11.0	10.41	8.75	7.91	7.36	6.96	6.65	6.40	6.19
11.5	10.52	8.85	8.00	7.44	7.04	6.72	6.47	6.26
12.0	10.64	8.94	8.08	7.52	7.11	6.80	6.54	6.32
12.5	10.75	9.04	8.17	7.60	7.19	6.87	6.61	6.39
13.0	10.85	9.13	8.25	7.67	7.26	6.93	6.67	6.45
13.5	10.95	9.21	8.32	7.75	7.33	7.00	6.73	6.51
14.0	11.05	9.30	8.40	7.82	7.39	7.06	6.80	6.57
14.5	11.15	9.38	8.47	7.89	7.46	7.13	6.86	6.63
15.0	11.25	9.46	8.55	7.95	7.52	7.19	6.91	6.69
15.5	11.34	9.54	8.62	8.02	7.58	7.25	6.97	6.74
16.0	11.43	9.61	8.69	8.08	7.64	7.30	7.03	6.80
16.5	11.52	9.69	8.75	8.14	7.70	7.36	7.08	6.85
17.0	11.60	9.76	8.82	8.21	7.76	7.41	7.13	6.90
17.5	11.69	9.83	8.88	8.27	7.82	7.47	7.19	6.95
18.0	11.77	9.90	8.94	8.32	7.87	7.52	7.24	7.00
18.5	11.85	9.97	9.01	8.38	7.93	7.57	7.29	7.05
19.0	11.93	10.03	9.07	8.44	7.98	7.62	7.34	7.09
19.5	12.01	10.10	9.13	8.49	8.03	7.67	7.38	7.14
20.0	12.09	10.16	9.18	8.55	8.08	7.72	7.43	7.19

Table 2. Air gap in mm between fins based on fin length at different temperature rises with *Tair* at 35^{o}C.

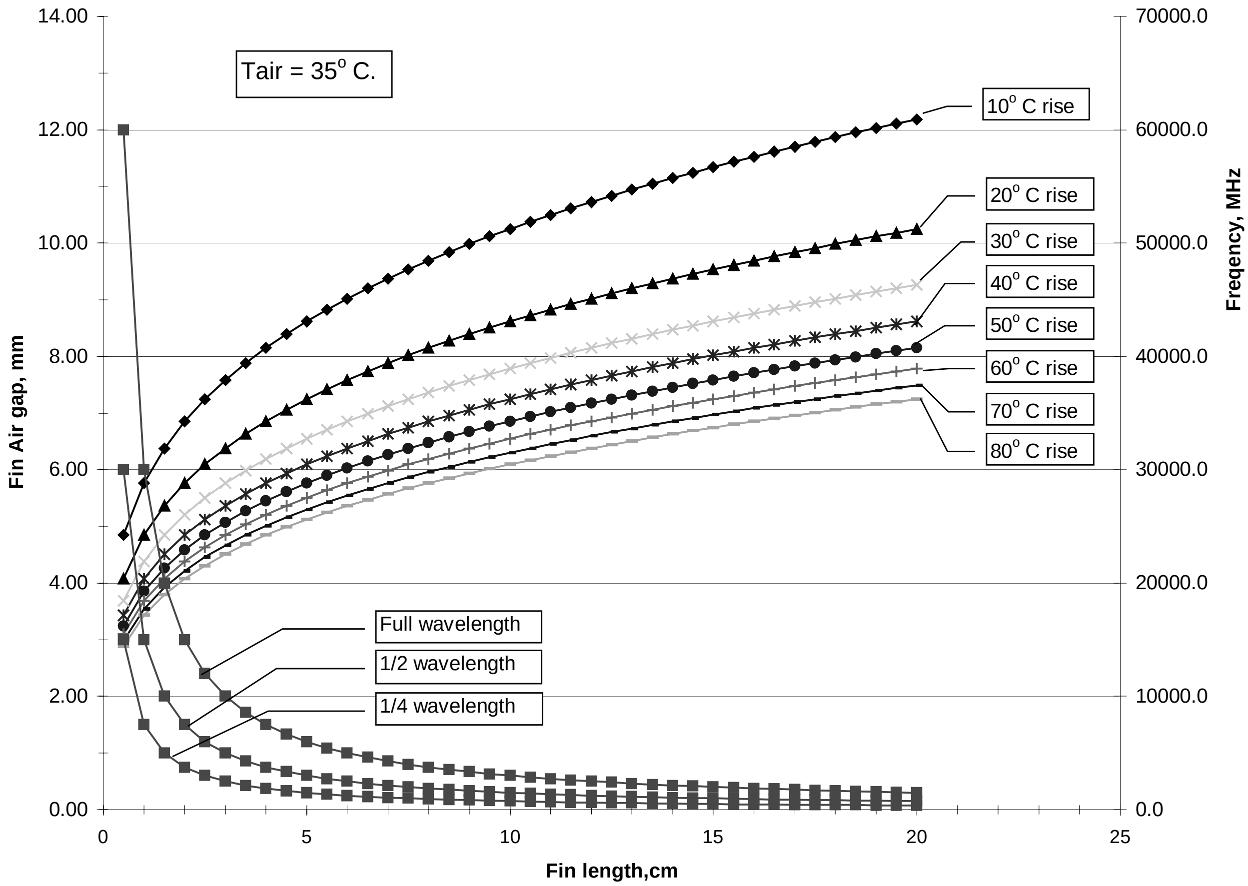

Chart 1. For a given Tair = 35°C, a fin length can be chosen that is not resonant at the frequency of interest, followed by selecting a fin air gap for a given temperature rise.