Fusing Current

When Traces Melt Without a Trace

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Many people have contacted me regarding my column "Trace Currents and Temperatures: How Hard Can We Drive 'Em?" in the May, 1998, issue. In that column I talked about the possibilities and the problems associated with developing a set of equations for the current/temperature curves we all have occasion to reference.

But many of you posed a different question. It typically went something like this: "I need the trace to carry 5 Amps for only about .5 seconds before…" something catastrophic happens. "Then I don't care if the trace melts or not. What size trace do I need?"

My first reaction was that this is a fuse question, something I've never seen discussed. When enough of you asked me about it I began digging for information. What I found was there isn't much to be found! But thanks to some direction from a few experts in the field (Note 1) I discovered that there is some very interesting theory to draw from.

CAUTION: The information that follows is based on theory and, to my knowledge, has never been tested on printed circuit boards. Designs based on this theoretical discussion should be significantly derated and/or tested before being committed to production.

Preece's Investigation:

W. H. Preece investigated the fusing (melting) current of a wire. He developed Equation 1 for fusing current (Note 2):

$I = a*d^{3/2}$ Eq. 1

where I is the fusing current, d is the diameter of the wire in inches, and a is a constant that depends on the material. He determined that a = 10,244 for copper.

A little algebra transforms this equation to:

$I = 12{,}277*A^{.75}$ Eq. 2

where I = fusing current in Amps and A = the cross sectional area of the wire in square inches.

Validation:

In my previous article I started with the relationship

$I = k*DT^{B1}*A^{B2}$

where I = Current in Amps, DT = change in temperature in ^{o}C., and A = cross sectional area in square mils.

Although I demonstrated that results could be improved if Area were broken into its component parts of width and thickness, the data still fit this model well and produced an empirical "best fit" equation:

$I = .04*DT^{.45}A^{.69}$

Now the melting point of copper is about 1083 ^{o}C, resulting in a DT from room temperature of about 1063 ^{o}C. Plugging this value for DT into the equation and converting A to square inches leads to

$I = 12{,}706*A^{.69}$ Eq. 3

These two results (Equations 2 and 3) are remarkably close considering how different is their source and approach!

Onderdonk's Investigation:

I. M. Onderdonk developed a fairly complicated equation that relates current and the time it takes for a wire to melt (Note 3). Using the melting point of copper for Tm and converting area to square mils, his equation reduces to:

$I = .188*A/t^{.5}$ Eq. 4

In this equation, I is the amount of current (Amps) that can be applied to a trace of cross sectional area A square mils for t seconds before the trace melts. **Figure 1** graphs this relationship.

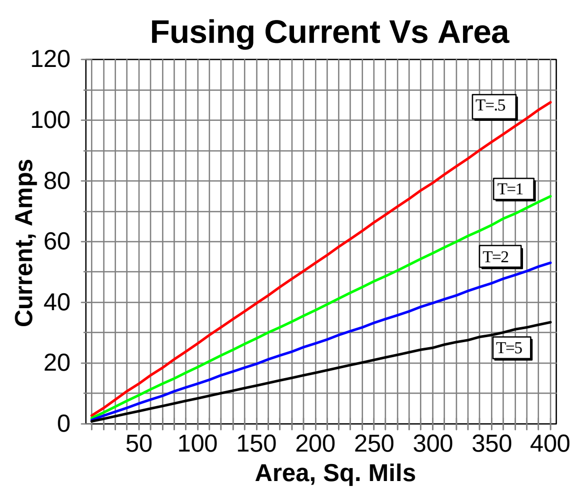

Figure 1.
Relationship between fusing current, cross-sectional area and time for PCB traces, based on Onderdonl's equation.

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Example:

Assume a 1 oz. (1.35 mil thick) copper trace must carry 20 Amps for 5 seconds. How wide must it be? Equation 4 leads to 176 mils in width. (Remember, there is NO safety margin in this calculation!)

Discussion:

Trace current/temperature studies we are familiar with have tried to discover the equilibrium temperature a trace will reach when a current is applied. Equilibrium occurs when the heating of the trace (I^2R) is the same as the cooling of the trace through convection and conduction. Preece’s equation reportedly assumes no heat loss except through radiation; i.e. no heat is conducted away from the wire. In practice on a PCB, there is heat conducted away from the trace by the board material itself, and by pads and components, etc. On the other hand, heat loss would be minimal in most applications in the first few seconds, especially in the first few fractions of a second. In this regard, Preece’s assumption appears to be a good one for a PCB application.

It is possible to calculate an “implied” time to failure for Preece’s equation by setting it equal to Onderdonk’s and solving for time. When this is done, the implied “time” for Preece’s equation to reach the melting point is purely a function of area and is given by:

$$T = .233*A^{.5}$$

where A is the cross sectional area of the trace in square mils. **Table 1** shows this relationship.

Summary:

Preece’s and Onderdonk’s equations seem to be straightforward ways to calculate fusing time and current for PCB traces when it is only necessary that the trace not fail (melt) within a defined period of time (say 10 seconds or less.) But they are not meant to be applied to longer periods of time. And remember, they have not been verified empirically on PCBs, so use them with caution and derate them appropriately.

Area, Sq. Mils	Time, Secs
10	0.7
20	1.0
50	1.6
100	2.3
200	3.3
500	5.2
1000	7.4

Table 1
Implied fusing time for Preece's equation based on Onderdonk's equation.

Notes:

1 I am indebted to Ralph Hersey, Ralph Hersey and Associates, Livermore, CA., and then Rich Nute, Hewlett Packard, San Diego, CA. for pointing me toward Onderdonk’s and Preece’s equations.

2. See “Standard Handbook for Electrical Engineers,” 12 Ed., McGraw-Hill, p. 4-74

3. Ibid. Onderdonk’s equation is

$$I = A*(\log(1 + (Tm-Ta)/(234+Ta))/33*s)^{.5}$$

Where I = current in Amps, A = cross sectional area in circular mils, Tm = melting temperature of the material in ^{o}C, Ta = ambient temperature, also in ^{o}C, and s = time in seconds.