USING B2 SPICE FOR THERMAL MODELING OF A HEATSINK

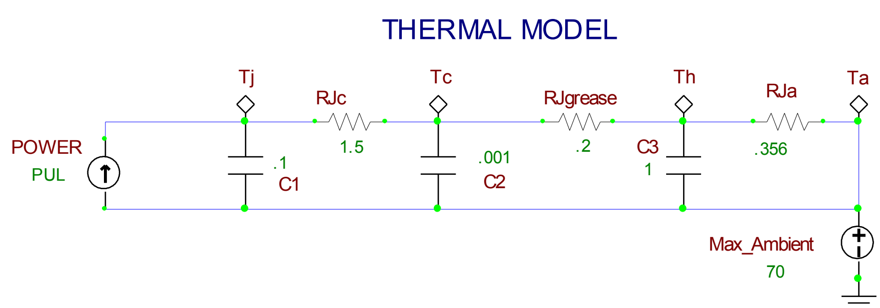
Introduction:

How many of you have designed a circuit only to find you forgot to take into account the power dissipation of a transistor or regulator. You experience that oh sh-- moment when you power up the circuit and watch the smoke slowly rise from the board. To compound matters, you're under the gun to ship by Friday. So you frantically leaf through the vendor catalog and buy the biggest heat sink that will fit and pray it works. I can honestly say I have experienced the above scenario - more than once; I'm a glutton for punishment.

Well I got to thinking, maybe I can do a little better job of selecting a heat sink than by gross overkill. Also, what if I could use B2 spice as an aid to demystify the daunting task of thermal analysis. In the following paragraphs I'll present a simple thermal model for heat sink analysis. The circuit topology is based on a thermal model by Marz & Nance.
http://www.iisb.fraunhofer.de/en/arb_geb/powersys_thermmod_gb_fhg.pdf

In short, the paper presents how to model a thermal circuit with an electrical transmission line equivalent. The model isn't as accurate as Finite Element Analysis; although for the vast majority of electrical power design requirements, it should suffice. Besides FEA software is big bucks.

For this discussion I will be using the following model.



Model Description:

The current source represents the power dissipation of the device-W, the voltage source the maximum ambient temperature the circuit will be subjected to-°C. The resistors represent the thermal resistance of the system-°C/W. Thermal capacity is modeled by their electrical counter part, capacitors-Ws/°C. However, since I'll only be working with steady state behavior these values won't be considered and have been chosen arbitrarily.

For the analysis a transient pulse with a pulse width of 10 seconds was used.

Case Study I:

Let's start with an Internet design taken from the WikipediA -
http://en.wikipedia.org/wiki/Thermal_resistance_in_electronics

The parameters of the design:

Tj_{max} = 125°C
$T_{ambient}$ max = 70°C
ΔT heat sink = 10°C (arbitrarily chosen)
R_{jc} = 1.5°C/W
R_b = 0.1°C/W – thermal compound or gasket material
Power Dissipation = 28.125 Watts

After reviewing the math for the analysis, everything appears okay. The only question is the heat sink ΔT. Well, this looks as good a starting point as any - will it work? The math says so.

Now what should I use for a heat sink? This is a simple problem and I could figure it out (case study II) but for now, I'll pretend I don't know and I'll regress to my old habits. I'll seek an off-the-shelf solution and go with the biggest heat sink I can find (lowest thermal resistance). First, I'll try convection cooling to avoid having the added expense of forced air cooling. After searching Aavid Thermalloy's website I come across one which has a 2.60°C/W thermal resistance; I'll try it.

http://www.aavidthermalloy.com/cgi-bin/stdisp.pl?Pnum=530002b00000g

Below are the thermal curves for this particular heat sink. More on this later.

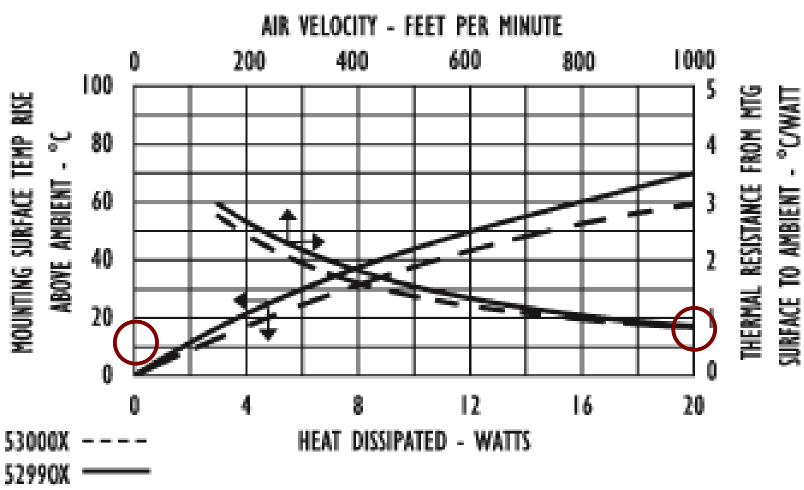
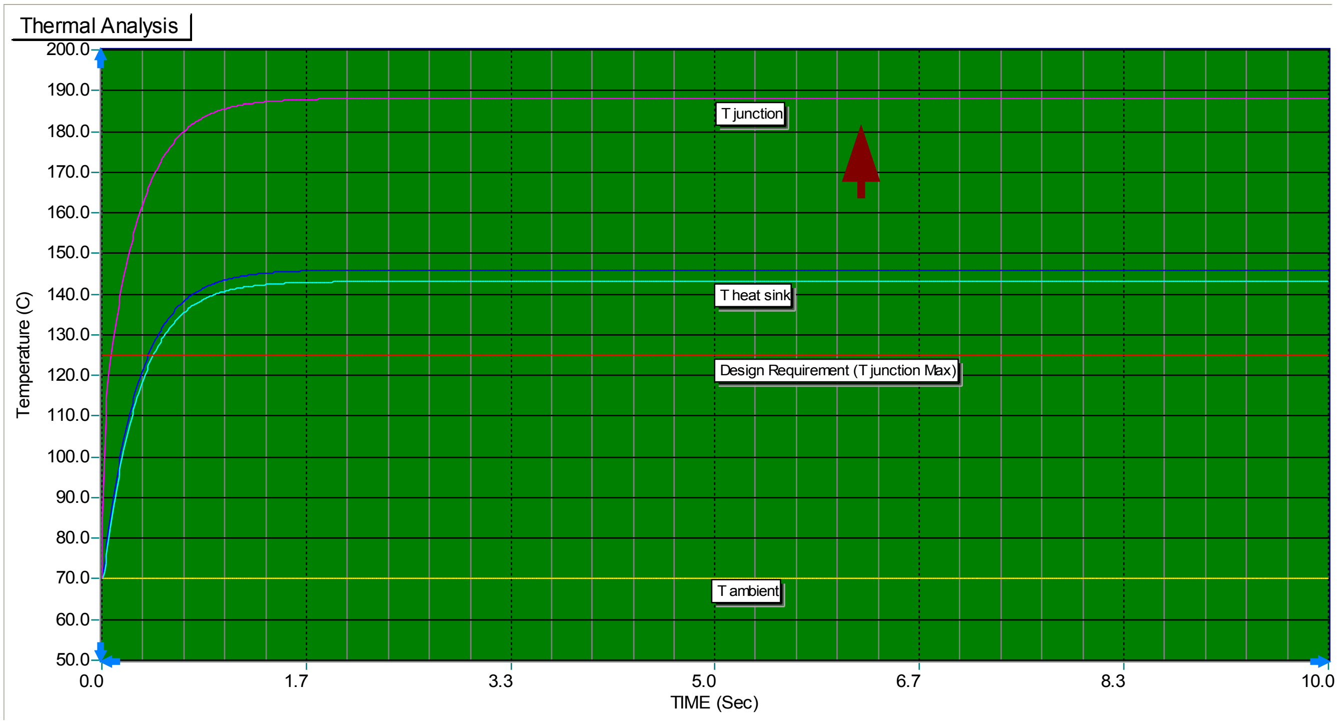


Illustration 1:

Applying the above parameters to the spice model the following graph is obtained.



Something is terribly wrong. The junction temperature is a whopping 188 °C. So much for the device – up in smoke. Well is the the wikipediA analysis questionable – maybe.

Case Study II:

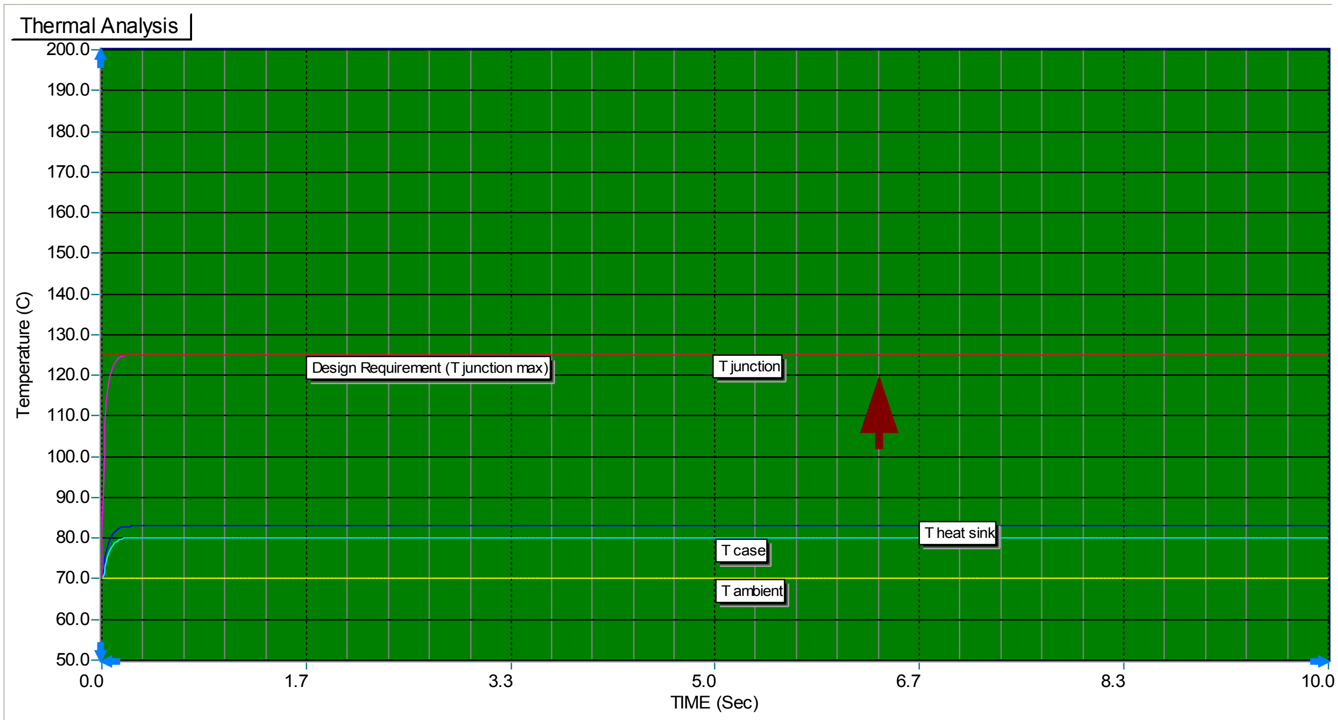
If I do some napkin math and rearrange the equation a little bit, I can solve for the heat sink thermal resistance. - 0.36°C/W.

$$PWR = Temperature / Thermal\ Resistance$$

$$28.125\text{W} = (125-70)/1.5+0.1+RjHeat\ Sink$$

$$RjHeat\ Sink = .356\ C/W$$

For now, I'll ignore the 10 °C ΔT for the heat sink. I'll add the new thermal resistance to my spice model as see what I get.



Eureka, everything meets the design requirement. Only one small problem, I can't use convection cooling, the thermal resistance isn't low enough . Well maybe I can use forced air. After referring to the thermal curve - illustration 1. I determine even at a 1000ft/min I can only realize a thermal resistance of 0.8 °C/W; not nearly enough. From my past analysis, I require 0.36°C/W. At this point, I think, I'm in deep stuff.

Conclusion:

The astute reader may have already determined the design didn't work from the get go. Hint: Take a look at the right side of illustration 1.

From the above analysis, it can be seen the WikipediA design was purely hypothetical and the ΔT heat sink temperature of 10°C may have been arbitrarily chosen to balance out the thermal equation. Even though the design went bust, what can can I conclude from the analysis:

- Anything can work in theory; no doubt the math was correct. Nevertheless, choosing a ΔT of 10°C may have been a poor choice.
- Using the manufacturer's thermal data and my spice model I have a tool to quickly and accurately predict the thermal requirements of a design.
- Is there a possible solution? Probably, but it might not be practical.
- Heat sink selection is an iterative process.
- Thermal management really is a science and not an art – Q.E.D.

Passing Thoughts:

Hopefully the design I chose had enough background material, was easy enough to follow and not too boring. The web link cited at the beginning is an excellent source for those wishing to explore thermal modeling further. Some ideas that pop into mind are:

- Would it be possible to incorporate this topology in some sort of PID control loop, such as control of a thermoelectric cooler.
- In theory, if I knew the geometry and material stack of a laser diode. I should be able to determine how much current I can pulse a diode with and stay within the thermal limits of the device - pulse application.
- Have fun using B2 spice playing what if games.