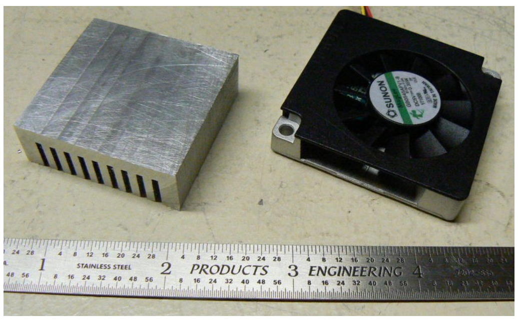
Low Silhouette Heat Exchanger

I needed a compact heat exchanger for a miniature high-voltage linear power supply. The heat exchanger was required to maintain the junction temperature of a MOSFET pass transistor at safe operating levels for long-term reliability.

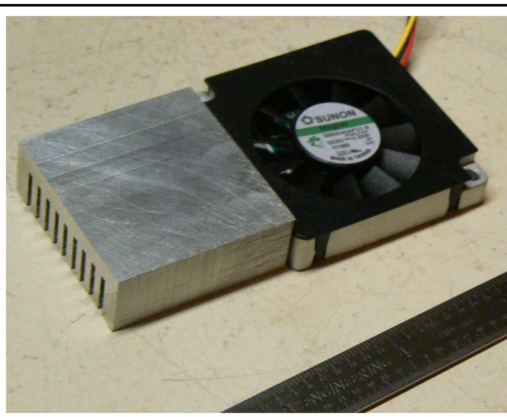
A passive heat sink would not be useful - there was no room for a device with the desired low thermal resistance so a forced-air heat exchanger was indicated.

I was further limited by the need for quick implementation requiring me to use a small fan model that I had in inventory. Since only one heat exchanger was required for the application, I made it in my small machine shop.

Here is the heat exchanger (before adding mounting holes) with the fan:

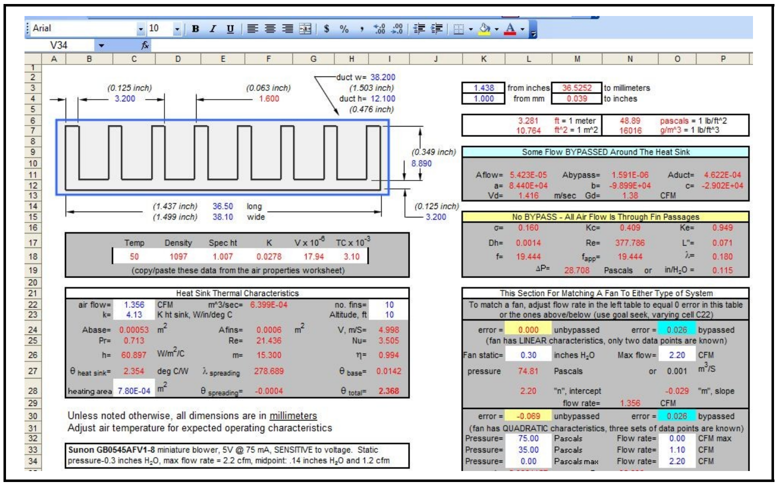


Both in normal operating position:



The fan employed had an axial air intake however it exhausted via a small rectangular port situated at right angles to the fan axis. This was perfect for my application.

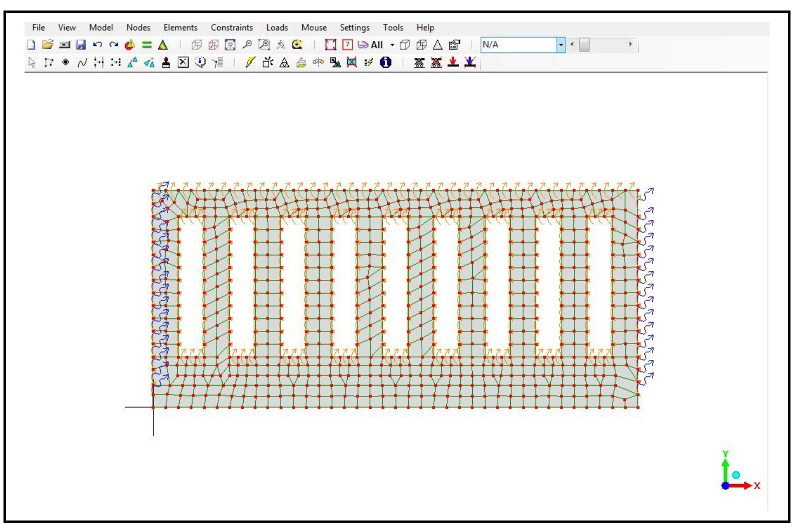
I used LISA to model and optimize the heat exchanger. The critical variable was the convection heat transfer inside the ducted array of fins. As a first-order approximation, I used a spread-sheet that I'd previously created to predict duct air flow, pressure and consequent heat transfer. This is a screen capture of the spread sheet:



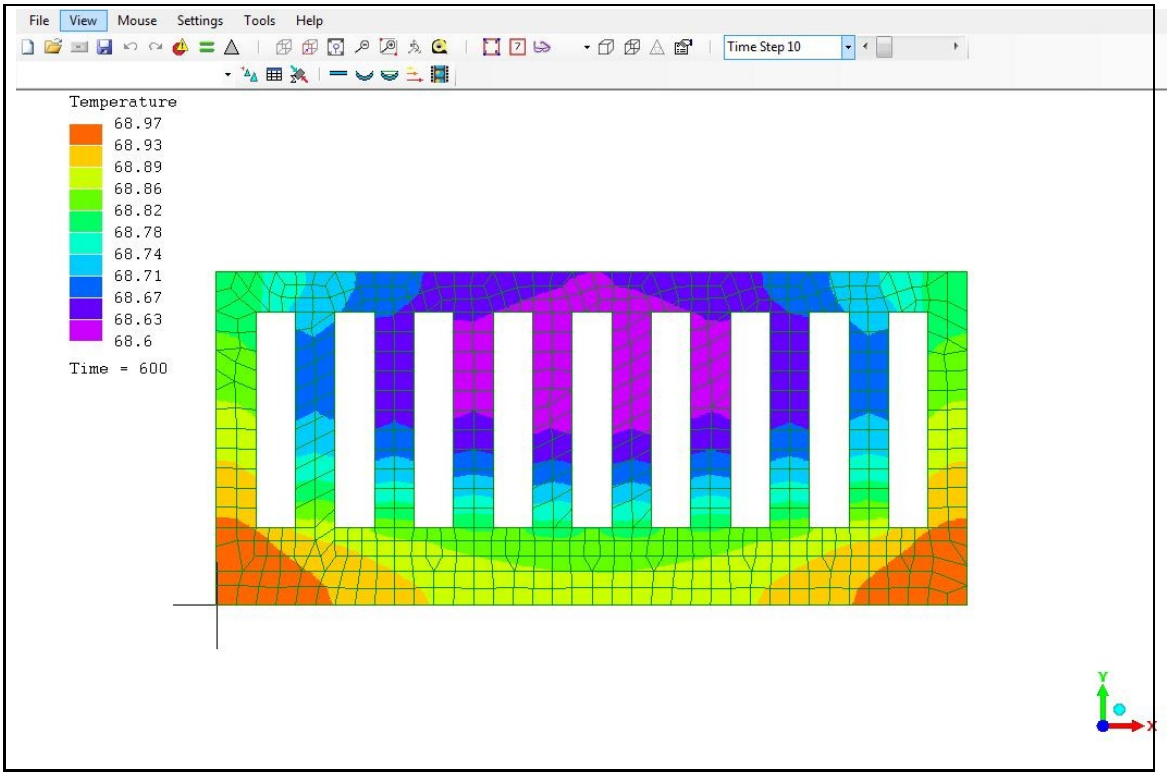
The spread sheet predicted a thermal resistance of about 2.4 degrees C/watt for the dimensions selected. This yielded an estimated temperature rise of 72 degrees C for a thermal load of 30 watts. For the selected MOSFET pass transistor, the estimated junction temperature was 112 degrees C, considerably higher than desirable, hence the desire to model the structure using LISA.

The estimated convective transfer within the ducts is about 61 W/m^2/degree C, which, after converting to the units of measure that I use in LISA, was used to model the exchanger. A free-air value of 3.4 W/m^2/degree C was used to model natural convection on the exterior surfaces of the heat exchanger. An emissivity of 0.7 and ambient temperature of 25 degree C was used to model radiation losses on the exterior exchanger surfaces. (*Note that these are negligible compared to the forced-air duct heat transfer*.)

Here is a screen capture of the modeled heat exchanger geometry:



And here is a screen capture of the results from LISA, assuming 30 watt thermal load:



The temperature is presented in degrees C so the predicted temperature rise above the ambient of 25 deg C is 44 degrees. The prediction results suggested that the junction temperature of the MOSFET could be reduced by 28 degrees from my initial estimate - a substantial and very welcome result.

The next step was to machine the heat exchanger and test it. Following this a representative MOSFET was attached to the heat exchanger and biased from an external power supply to produce a thermal load of 30 watts. Infra-red thermal measurements established temperatures at various points after twenty minutes of warm-up time.

(Note that the fan was somewhat isolated thermally from the heat exchanger by an air gap of about .010 inches. Note also that the power contribution of the fan was negligible at about 400 milliwatts.)

Measured inlet air temperature was 23 degrees C while the outlet air temperature was 70 degrees C so the temperature rise was 47 degrees C, compared to the LISA predicted temperature rise of 44 degrees. An error of about 6% was viewed as excellent correlation considering the following.

The LISA model that I constructed assumed that each of the nine ducts had the same heat transfer characteristic. Additionally, the convection heat exchange used for the ducts was an estimate based on manual calculations from my spread sheet. The fan exhausts at right angles to the inlet and the air flow isn't constant across the area of the exhaust duct.

I had no expedient means of determining the flow of the individual ducts so I simplified the model by assuming a constant air flow in each duct. Similarly, without measurement of the flow rate of the fan coupled to the heat exchanger, the transfer coefficient was an informed estimate based on data sheet characteristics for the fan.

The entire *design* effort, start to finish, took about two hours. A further hour and one-half was spent *making* the heat exchanger and about thirty minutes to confirm proper function. Total time expended to produce a successful heat exchanger: four hours.

Since I am not experienced in the design of heat exchangers, the use of LISA to refine my initial estimates for thermal resistance was critical. Had I relied on my simple spread sheet tool for the prediction of performance, I would not have attempted to make this special-purpose device. LISA provided the much-needed affirmation that what I was attempting to achieve was possible despite the initial conflicting estimate.

LISA is an extremely cost-effective and powerful tool for my purposes as a consulting engineer, working out of my home with modest lab and manufacturing facilities. I've used several other FEA applications, none of which produced substantially more accurate results than LISA but did cost substantially more.

LISA customer support is outstanding ! While learning the application, I asked scores of questions in the form of e-mails addressed to technical assistance. Typically, responses were waiting for me when I opened my e-mail the following morning.

As one becomes more accustomed to using the application, passing beyond the introductory phase, the real power of LISA starts to become obvious. Building up complex shapes and structures is much easier than the previous FEA applications that I used.

In the past, I found that generating a dimensional model took an inordinate amount of time. LISA reduces that time because of the simple means of creating a dimensional model - similar to using a computer-aided drafting tool.

The animation of analysis results is especially helpful for problems of vibration and mechanical displacement under load. The animation provides immediate feedback for the need (and location) of stiffening members.

I've just scratched the surface of this excellent FEA application but I can state unequivocally that this is the best software bargain that I've experienced in thirty-something years of design experience !

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