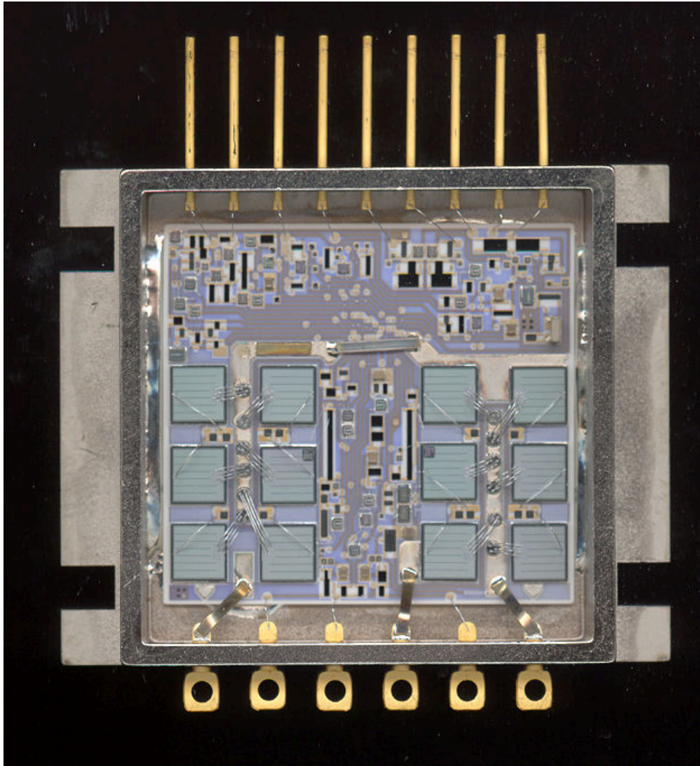
Cooling of a Hybrid Circuit Package

As a retired electrical engineer, I revisited some of my former designs to compare the results from simulation software with the observed values of cooling in the devices. This is a report on a high power hybrid amplifier (REX) circa 1990 delivering 4 kW of continuous power and a peak pulse power of 8 kW. The below image is that of the amplifier with no lid.



The square portion of the package measures 2.25 inches on the outside wall (lead frame), the base is 0.100 thick, the substrate is 0.030 thick, and the lead frame is 0.300 tall. After initial test a lid is laser welded on in a nitrogen environment.

There are three common forms of electronic circuit packaging, discrete, hybrid, and monolithic. Discrete is often seen in consumer electronics as it is the least expensive to design and requires the least capital equipment to manufacture, and typically has the lowest selling cost. In discrete there are individual components with cases typically soldered onto a fiberglass circuit board. Hybrids are middle cost to design, require more capital equipment to manufacture, and have a high selling cost. Here the components are bare without cases and are built into or mounted on a ceramic substrate with only one case around the whole assembly. Hybrids can be designed so as to dissipate a tremendous amount of heat in a small area. Monolithic is the most expensive to design and requires the most capital equipment to manufacture, but gives the lowest selling cost and highest component density. All of the components are integrated and manufactured into a single silicon chip.

Using a special cold-plate that applied liquid coolant directly to the back of the package, it could dissipate 1400 W. We decided to offer it to a more cost sensitive market with less dissipation. We mated it to an existing low cost heatsink that used water channels on each side. Although the side cooling was not optimum, the cost to the customer would be far less. We further decided that if we could get 1000 W dissipation on that heatsink, we would go with it. Luck was on our side and we did get the desired 1000 W with a very small margin. This short paper describes simulation of REX on the side channel heatsink using Lisa 8. REX was a 200 volt, 50 Amp operational amplifier with built-in thermal monitoring on top of the central fets and built-in thermal shutdown.

Highlights of the construction and materials include a base made of Tungsten-Copper alloy to match the Thermal Coefficient of Expansion of the Beryllium-Oxide substrate and still give good heat conduction, output stage of twelve 1/4” by 1/4” power mosfets for good dissipation and prevention of second-breakdown, a Kovar lead frame, and gold plated Kovar pins.

The final Lisa model consists of over 55,000 nodes, but simulates quickly (9 seconds for materials all having fixed thermal conductivity; 34 seconds when using thermal conductivity versus temperature tables for many of the materials). Transient simulation with adequate time resolution clocked in at 8 minutes for fixed conductivity, and 45 minutes using tables. These simulation times impressed me considering problem size. In the REX model, four of the six materials had a table. If you are not modeling a known situation as was my case, and you want to play “what if”, consider including temp-conductivity tables only after you are in the ballpark. Simulation times are on a PC with Intel Core I5 3470 at 3.6 GHz. The results closely matched the real world measurements.

Fig. 1 is a view of a part of the model showing the fets, solder, substrate, solder, base, thermal grease, and heatsink. The solder and grease layers are too thin to show here. The water cooling is set up as a constant 25 C temperature on the side walls of the heatsink, The heat is applied as sources on the top surface of the fets, and all nodes are initialized to 25 C.

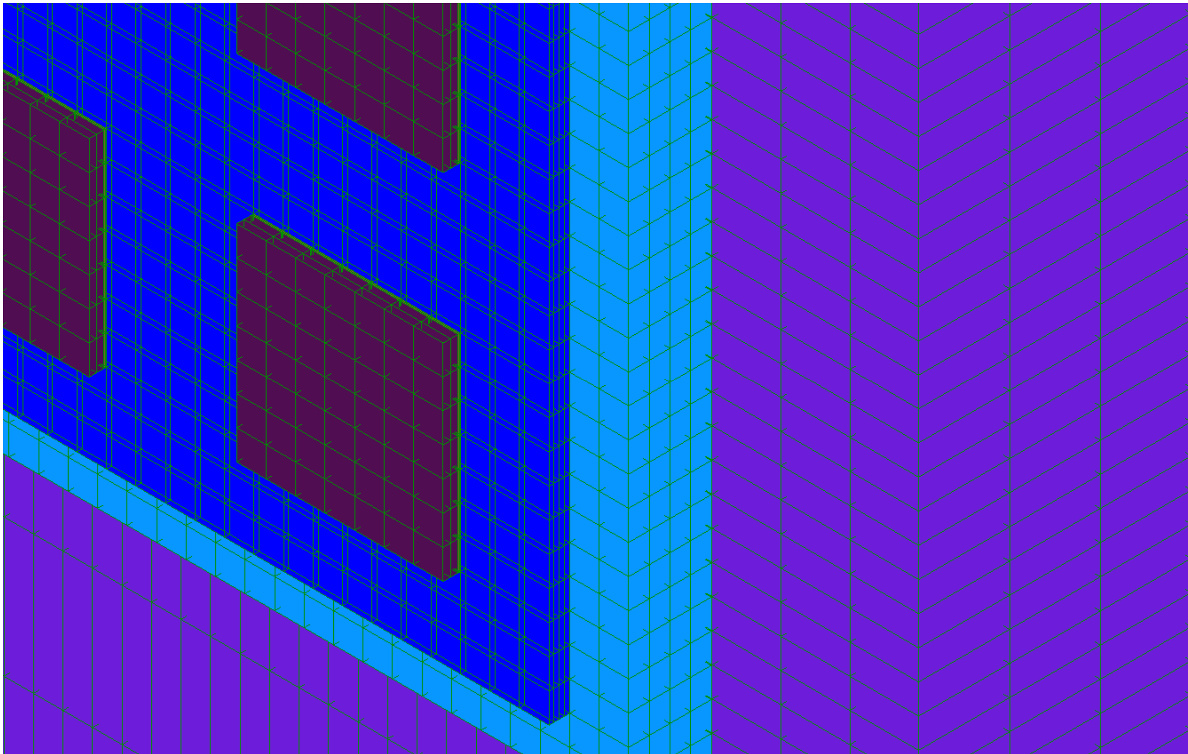


Figure 1

Fig 2 shows the entire model at temperature dissipating 1000W.

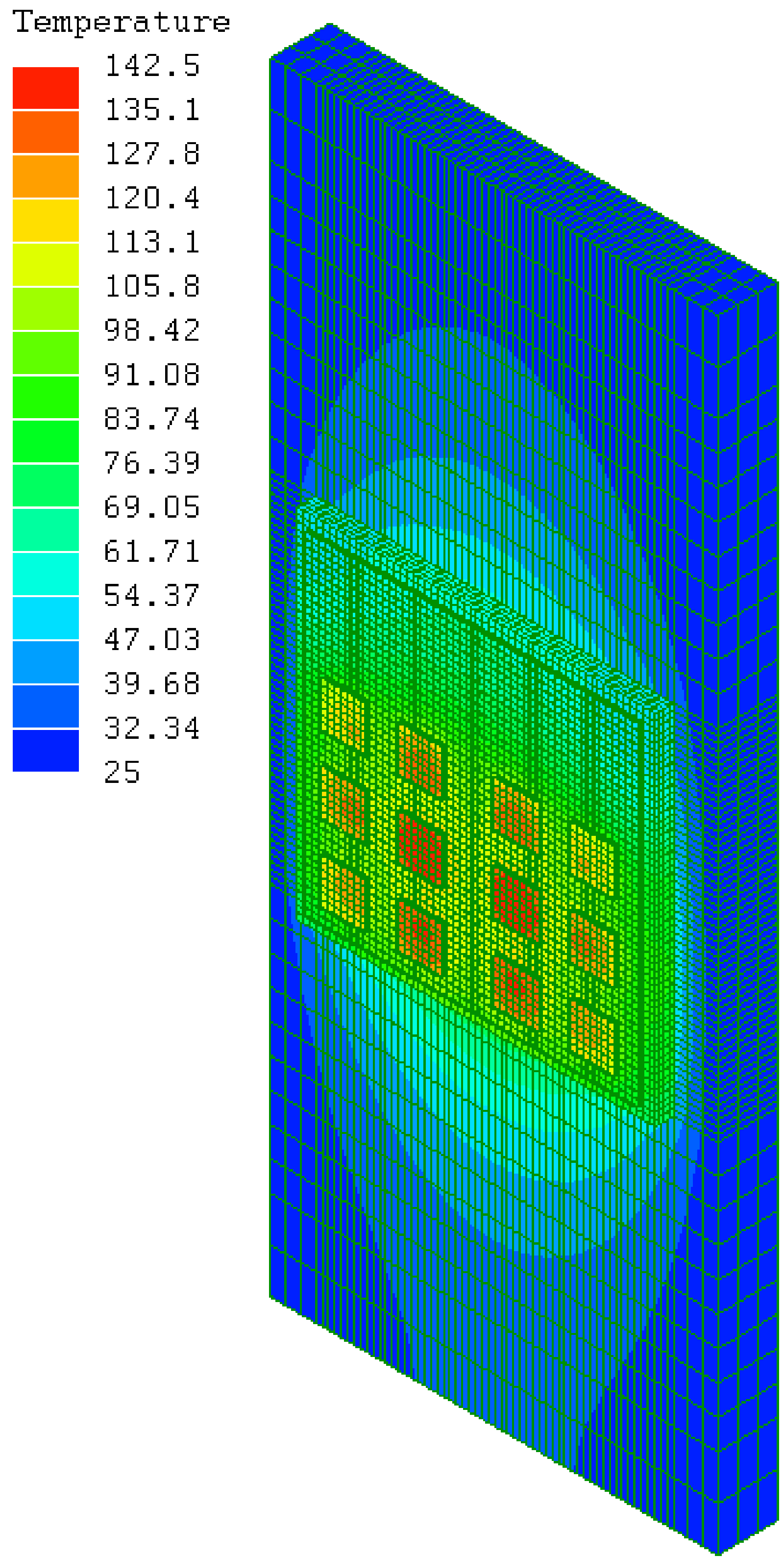


Figure 2

Fig. 3 is a bit closer and shows a little more detail.

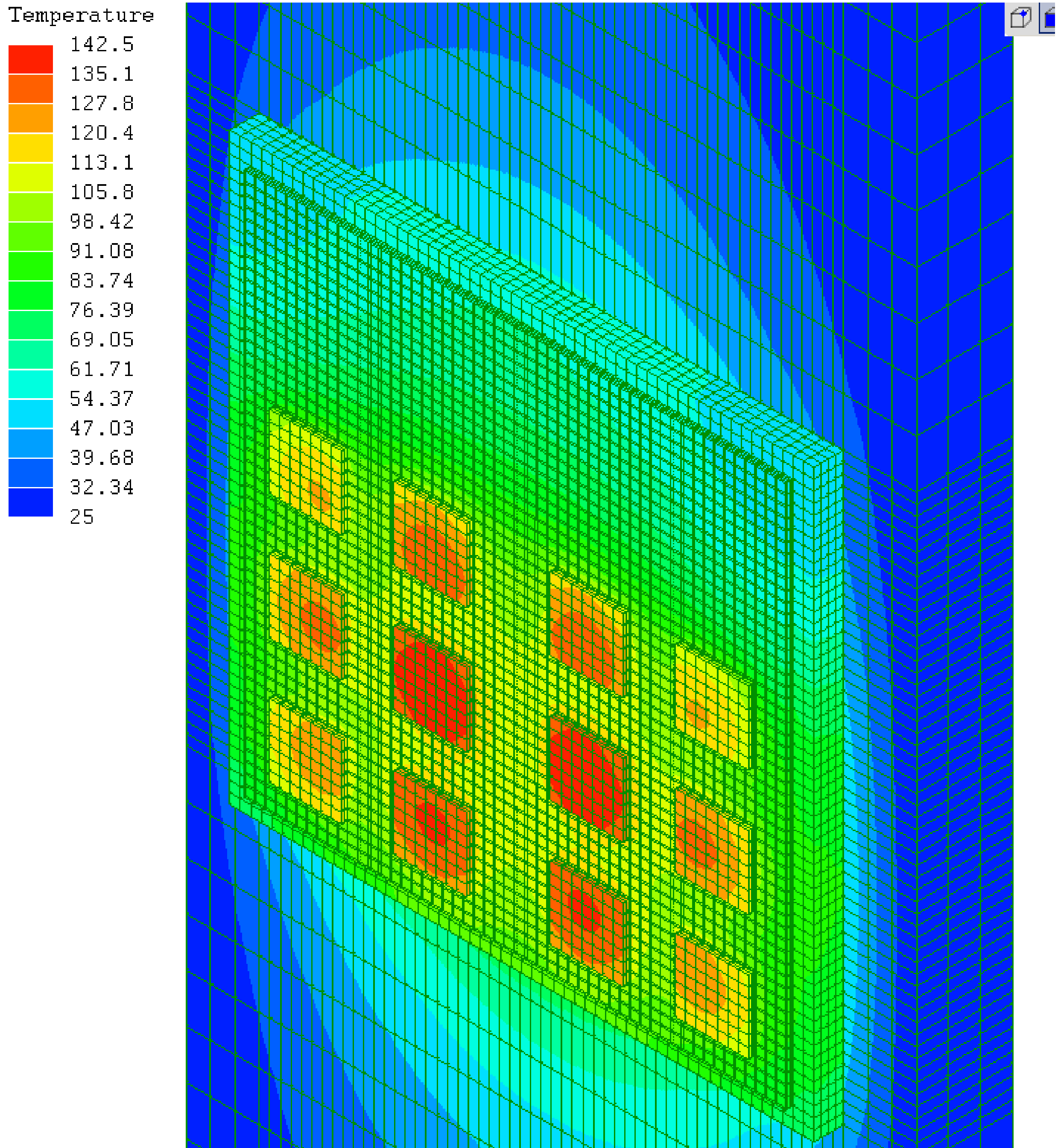


Figure 3

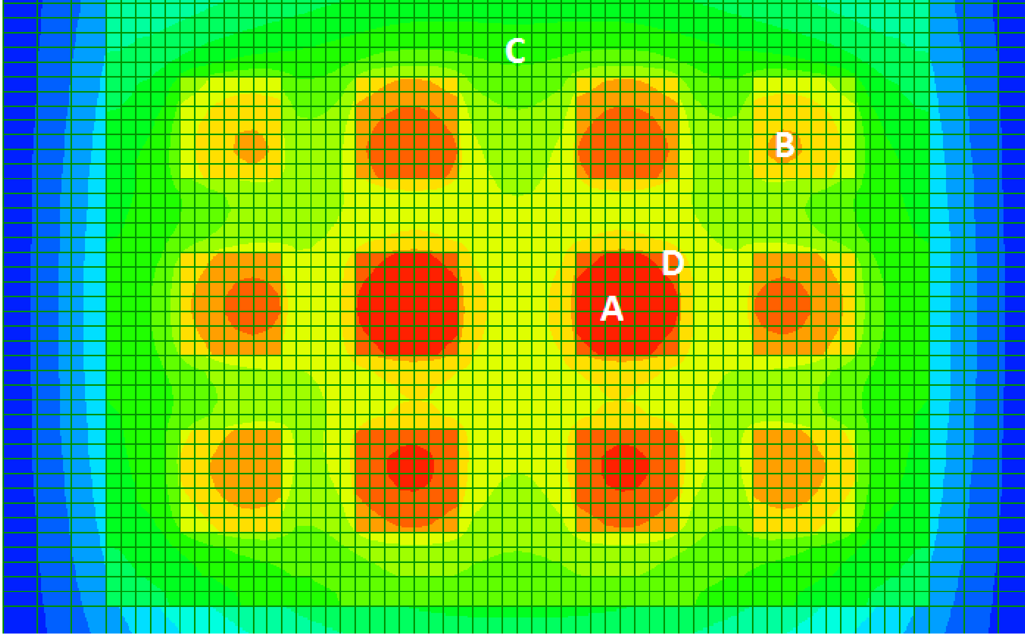


Figure 4

Results

The original measurements were made with an IR spot meter of +- 0.5 C accuracy and 1 C resolution and a Hughes IR imager that ran at 30 frames per second. Temperature and spacial resolution of the imager were limited, but frame rate was fast. Steady state data was from the spot meter and transient data was from the imager. To facilitate accuracy, the part was coated with 1-2 mils of grey paint of known insulating properties and known IR emissivity. Figure 4 is an x-y view of part of the model. Point A will be referred to as Tmax, A minus B will be referred to as fet-fet, A minus D will be referred to as center-corner, and C will be referred to as edge small signal area

Steady state:

	Sim	Actual	Error
Tmax	142.5	138	+3.1 % (error in rise from 25)
fet-fet	22	24	-9.1 %
center-corner	12.7	14	-10.0 %
edge small signal area	92.3	90	+2.6 %

Transient:

	Sim	Actual	Error
Tmax time to rise to 50% of max delta	70 mS	67+-17mS	-4.5+-25 %
Tmax time to rise to 90% of max delta	340 mS	300 mS	+13 %

Considering tolerance in the material specifications and lot to lot variance, the simulation results from Lisa 8 agree very well with the original measurements.

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