Extracted from **Designing Vacuum Tube Amplifiers and Related Topics**
Second Edition, Charles R. Couch February 2013
Download link: https://www.dropbox.com/sh/sutb3baaajypfzp/5jAs6MErWU

31.0 Thermal Considerations

Thermal design is probably not a topic considered by the intended readers of this book during the design of a vacuum tube guitar amplifier. We know that these devices produce considerable heat but the effects aren't usually predicted or quantified except by empirical observation, perhaps even by commercial manufacturers.

Manufacturers have the ability to measure internal temperatures with thermocouples, infra-red pyrometers and similar instruments. Where home-built amplifiers are concerned it is likely that the builder simply touches various points on the chassis to see if the completed assembly is overheated.

Rigorous analysis isn't normally a practical problem for several reasons. One is that we are somewhat conditioned to accept thermal conditions that have existed in vacuum tube guitar amplifiers for many decades.

But the primary reason is probably that prediction of temperatures is complex and tedious. I don't suggest that this is suitable for most new designers of vacuum tube amplifiers but a finite element analysis (FEA) thermal prediction was performed on the 40 watt amplifier design described in Chapter 29.0.

31.1 Computer Finite Element Analysis

Finite element analysis programs were once extremely expensive, limiting their usage to corporations (or *very* affluent engineers). That situation has changed now and freeware is even available. Freeware tools are not for average people, in my opinion. These are mostly basic packages developed with an assumption that the user has prior experience and knowledge of FEA, and are limited in application.

This analysis was performed with ***LISA***, a popular and inexpensive FEA application. Note that the predicted temperatures, as with most FEA applications are in degrees Kelvin. For those more comfortable with other scales:

degrees Fahrenheit = (1.8 x Kelvin) - 459
degrees Centigrade = Kelvin - 273

The vacuum tube thermal models were developed separately with ***LISA*** then imported and merged into the chassis model. For simplification, vacuum tube thermal models did not include most of the internal details because they are second-order heat contributors (or even third-order). The major heat sources are the plates, cathodes and filaments of the *power* vacuum tube models.

Here are some of the conditions assumed for the FEA simulation.

Ambient temperature is 300 degrees K (81 degrees F)

Chassis has *some* air circulation within the enclosure

Front and rear faces of chassis are open to ambient air

Power transformer has loss of 8 watts, converted to heat

Output transformer has loss of 5.5 watts, converted to heat

Internal circuits contribute 5 watts, converted to heat

Pre-amplifier tubes dissipate 1.9 watts each

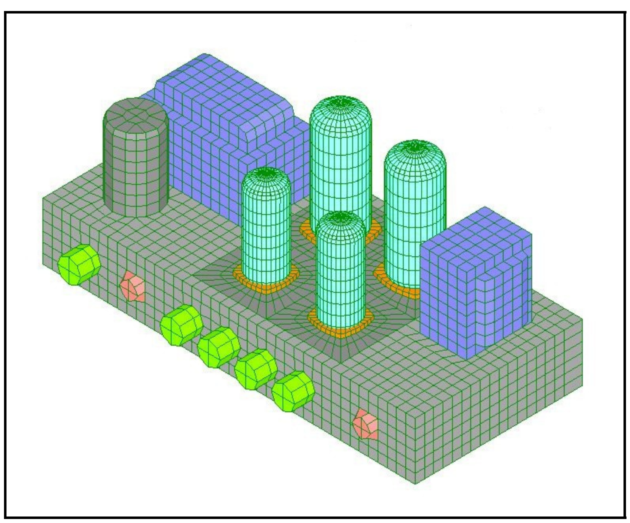
Power tubes dissipate 32.6 watts each

Pilot lights dissipate 1.2 watts each

Total amplifier dissipation is about 90 watts

Worst case analysis: *full power for an indefinite period of time*
This condition is never encountered in actual service.

This is a view of the amplifier chassis (enclosure not shown) as depicted by ***LISA*** after meshing:



After applying heat generation, convection and radiation properties to the FEA model the simulation was performed, the results of which are described below.

Distribution of temperature on the chassis is as one would expect; heat flux is flowing primarily from the output vacuum tubes as shown in the depiction. Some temperatures of interest were spot-checked with ***LISA*** tools:

Front panel: 323 degrees K average

Rear panel 324 degrees K average

Top of chassis 326 degrees K average

Sides of chassis 325 degrees K

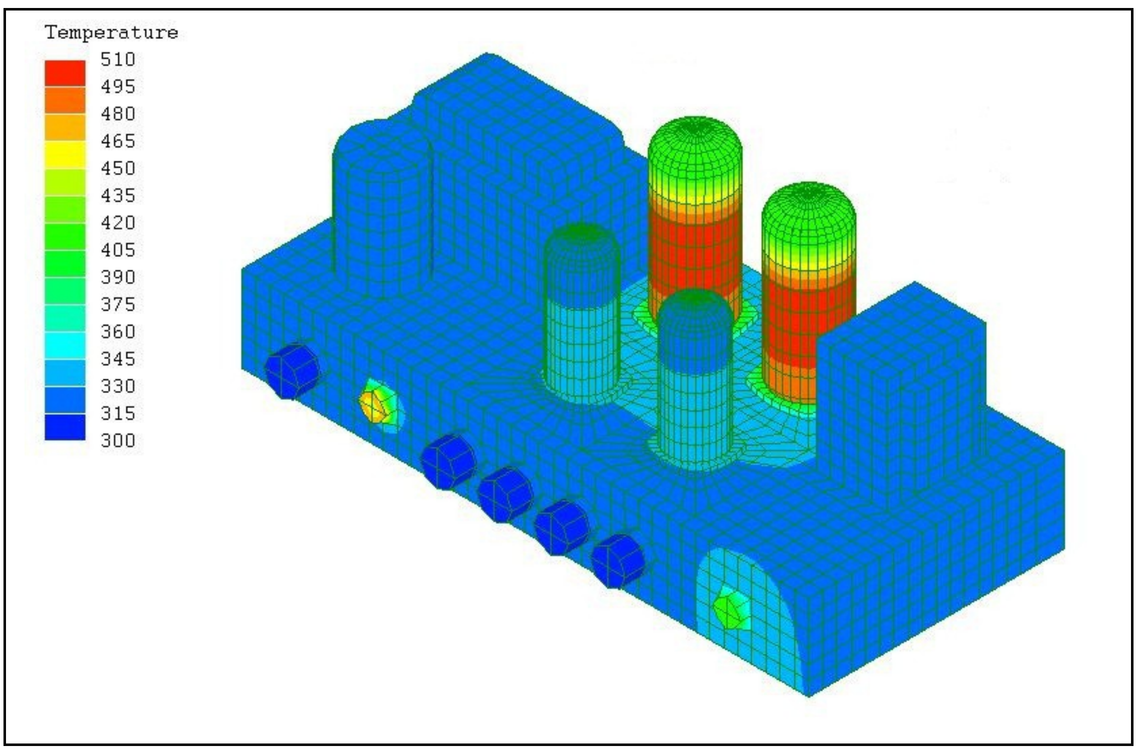
Top of chassis near power tubes 332 degrees K

Transformers are at 326 degrees K

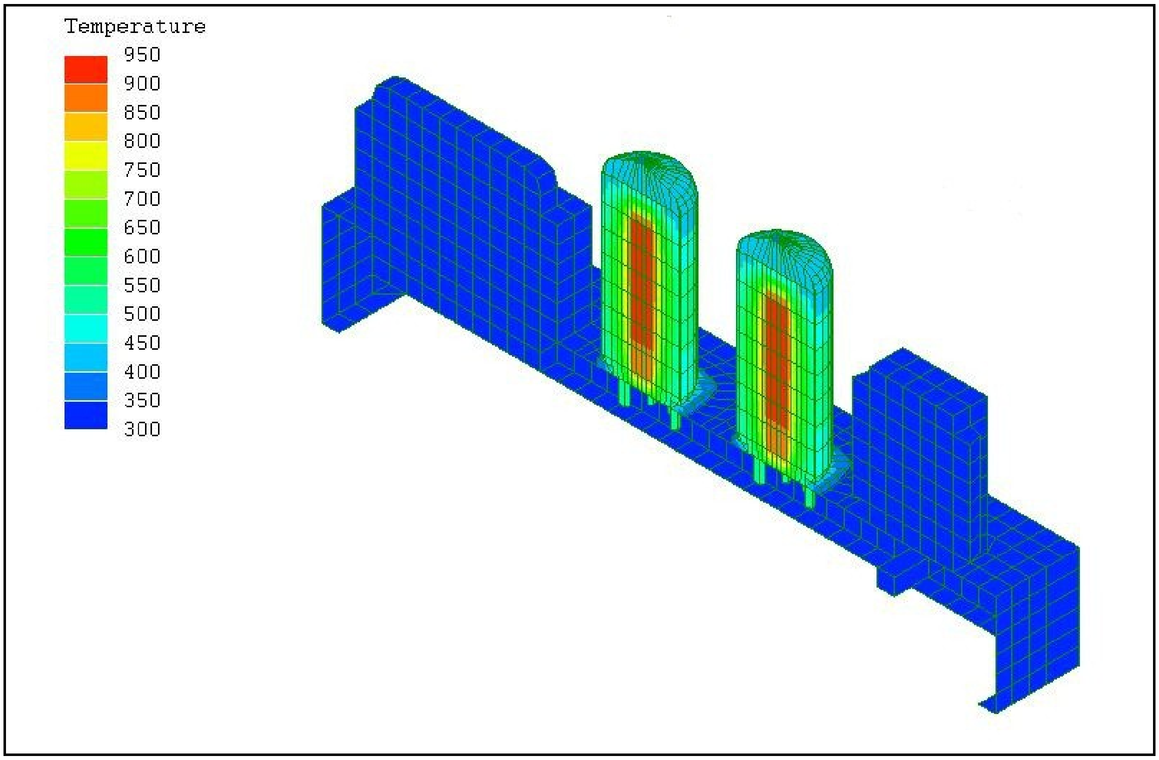
Surface of pre-amplifier tubes 335 degrees K (might be erroneous)

Surface of power tubes 508 degrees K

A view of steady-state chassis temperatures (maximum power) conditions:



To reveal maximum temperatures within the assembly, we can employ a "cutting plane", virtually slicing through the amplifier and revealing the interior temperatures of the output vacuum tubes under full drive.



Temperature color codes, temperature scales and the "cutting plane" are user-defined in this particular FEA application. As expected, maximum temperatures are found within these two vacuum tubes.

31.2 FEA Summary

The simulation closely resembles empirical observations of similar amplifiers. Note that the human threshold of pain from heat is said to be around 336 degrees K. With the exception of the two power tubes and possibly areas of the pre-amplifier tubes, one could safely touch any exterior surface of this amplifier. (The interior of the amplifier is off limits due to the presence of very high voltages.)