Thermal Considerations for Power Amplifiers

Overview

Proper heatsinking to control junction temperature is an extremely important consideration for use of all power amplifiers. Gallium Arsenide (GaAs) devices can tolerate considerably higher junction temperatures than Silicon (Si), but due to its lower thermal conductivity, it requires more consideration than Si to remove heat. The thermal conductivity of GaAs is only about one third that of Si, and it has a nonlinear relationship with temperature (the conductivity worsens with increasing temperature).

Although many factors inside and outside the package influence the junction temperature, the end user of the power amplifier can control the implementation of the connection and layout on the printed circuit board (PCB). The choice of the board material and thickness, the number of thermal vias placed beneath the part and the design of the heatsink are all important factors in properly using the part under difficult thermal requirements.

Application Requirements

ANADIGICS power amplifiers are typically packaged in LPCC (Leadless Plastic Chip Carrier) packages. These packages offer excellent thermal characteristics due to the thin copper paddle used for mounting the chip. The part itself (bare die) is also very thin and enables very good heat dissipation. A cross section of the package is shown in Figure 1.

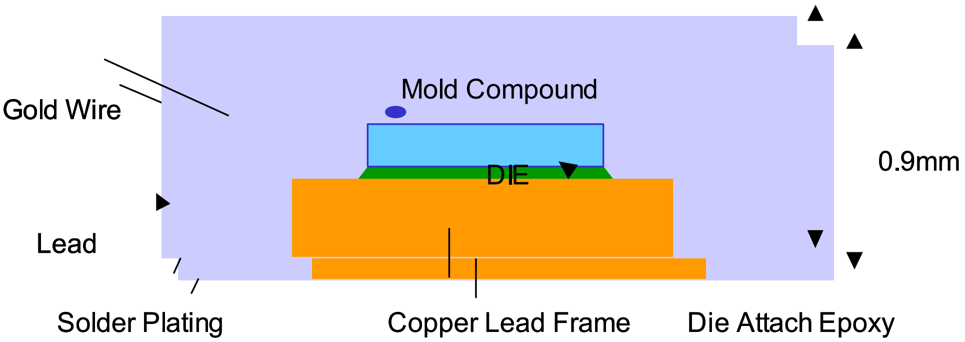

Figure 1. Cross section of an LPCC package.

The thermal design of such a part involves maintaining the junction temperature below a certain level, defined as T_{max}. The junction temperature depends directly on the case temperature, defined as the temperature at the bottom of the copper lead frame. Although each application is different, junction temperatures of 150°C are considered desirable with an almost infinite device life. Junction temperatures of 180°C are typical in many applications and yield device MTTFs (Median-Time-To-Failures) better than 1 million hours (114 years). Figure 2 indicates the MTTF curves[1] for the fabrication processes used in the ANADIGICS MESFET power amplifiers. Various applications may require different maximum junction temperatures depending upon the MTTF requirements.

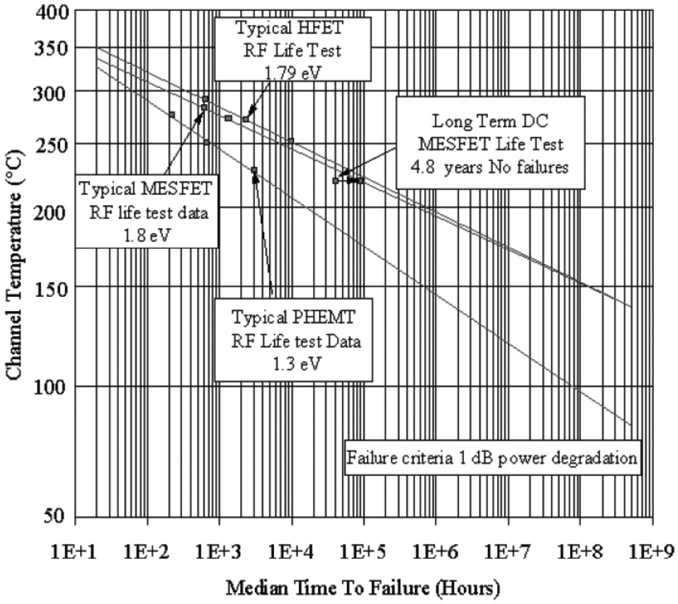

Figure 2. Typical MTTF data for TriQuint MESFET, HFET, and PHEMT.

In some applications, the device performance needs to be de-rated to ensure that the maximum acceptable junction temperature (T_{max}) is not exceeded. Figure 3 shows a generic de-rating curve. The device can dissipate the maximum power for case temperatures less than T_d. For case temperatures greater than T_d, the dissipated power is limited as indicated in Figure 3 in order to keep the junction temperature below T_{max}. ANADIGICS performs detailed thermal analysis of the junction to case temperature using finite difference software. These analysis results have been verified through the use of infrared microscope measurements, and are used to develop the de-rating curves.

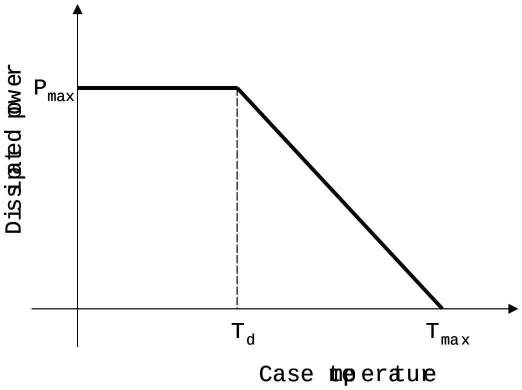

Figure 3. Generic de-rating curve.

ANADIGICS has developed a generic thermal analysis for power amplifiers. Although each design has unique implementation requirements, the typical dimensions of a 4x4 mm part are presented in Figure 4.

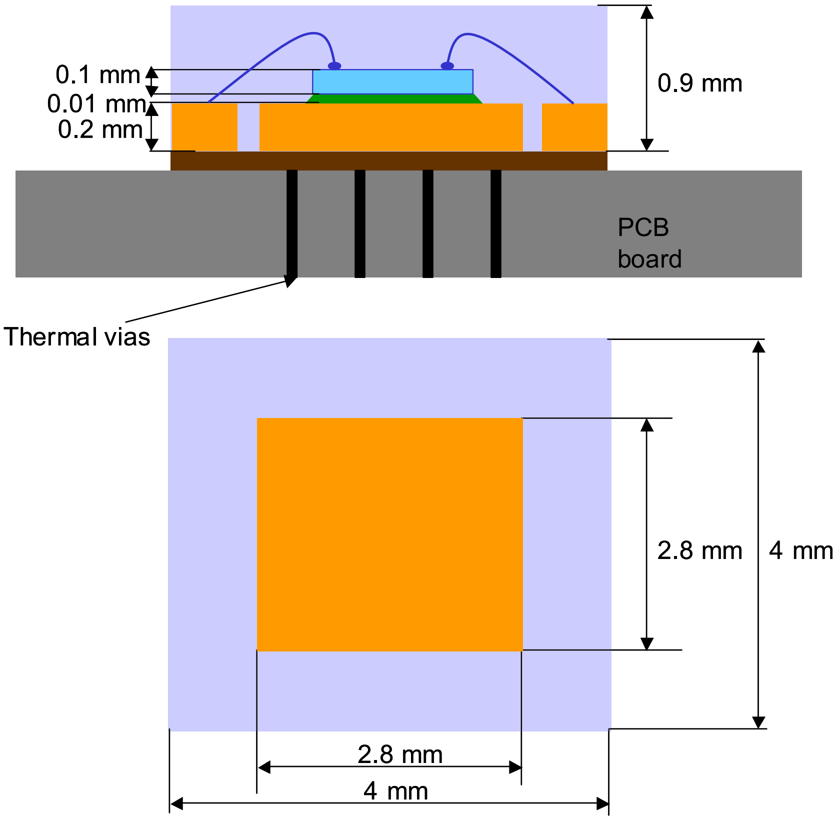

Figure 4. Typical dimensions of a 4x4 mm part.

PCB Thermal Capability

In typical applications the user should place a large number of thermal vias beneath the mounting pad for the paddle. For a 4x4 mm part mounted on a 0.032" (0.8 mm) PC board, it is possible to place approximately 16 vias under the part with each fabricated using a 0.014" (0.35 mm) drill. This drill size is typically used for holes of 0.010" (0.25 mm) finished size. Typically the plating thickness will be 0.001" (0.025mm). Thicker copper plating will lower the thermal resistance, helping to reduce the junction temperature.

The thermal resistance of a single copper via can be calculated as:

$$R_{TH} = \frac{L}{\sigma * \pi (R_O^{2} - R_I^{2})}$$

Where R_{TH} is the thermal resistance in °C/W, σ is the thermal conductivity in W/m*K, and the radii (R_O and R_I) and length (L) of each via are in meters. For a 0.032" thick board, with 0.001" plating, and using a thermal conductivity of 390 W/m*K, the thermal resistance of a single via is on the order of 80°C/W. The total thermal resistance is simply the result of Equation 1 divided by the total number of thermal vias beneath the part. For 16 thermal vias this yields approximately 5 °C/W.

Thermal simulations are also used in ANADIGICS IC design process. Figure 5 shows the results from an FR4 board simulation and the temperature distribution through the 16 thermal vias. The simulation included a 3.4W power amplifier die, which is not shown. The expected temperature rise through the board from previous calculations is 5 °C/W x 3.4W =17°C, in agreement with the plotted data.

As an example, a device with junction to case thermal resistance of 30°C/W, combined with a PCB layout configuration of 5 °C/W, will show a junction temperature rise of 35°C/W. For a device operating at 7V, 400 mA and delivering no RF power, all of the 2.8 Watts of power must be dissipated as heat. The part will operate at a lower temperature when it is delivering RF power to the load. This can sometimes contribute to "gain-expansion" when evaluating output power versus input power. In this example the junction temperature would rise by 98 °C. For typical operation where the case temperature reaches 85°C, the corresponding junction temperature would be 183 °C.

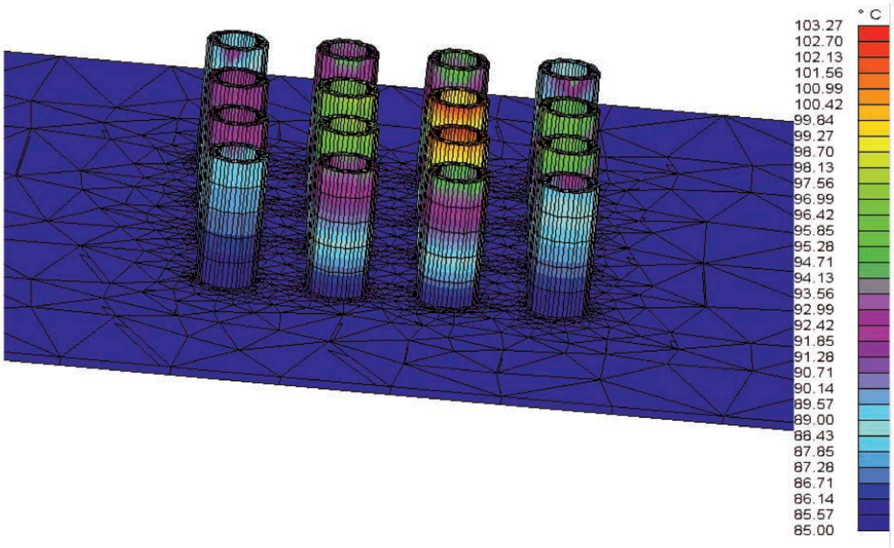

Figure 5. Thermal simulation of 16 thermal vias.

Manufacturing Suggestions

To properly use the parts in a manufacturing environment, it is recommended that an additional reflow process is used to ensure solder has filled the thermal vias beneath the part. The steps are as follows: 1.) Apply solder paste to area containing thermal vias; 2.) Reflow the board and the solder paste will wick through the via holes; 3.) Cover the backside of the board beneath the power amplifier with Kapton tape and reflow the part to the board. The solder will remain in the via holes and the power amplifier will be properly connected to the thermal/ground pad below it.

In some applications it will be possible to mount the PCB directly to the chassis at least in the critical area beneath the power amplifier. This is highly recommended as it provides the shortest path to the large surface area of the chassis. If this is not possible, then a heatsink should be attached directly beneath the amplifier. Heatsinks will be specified in degrees Celsius of temperature rise per Watt of dissipated power. Since the amplifiers are in small packages, the heatsink must be located directly beneath the amplifier and maintain good thermal contact with the board.

In order to maintain good thermal contact between the heatsink and the backside of the PCB, an interface material should be used to fill any voids. Many heatsink compounds are not very good thermal conductors but are inert, low cost and fill in the air gaps. Typical thermal conductivities of heatsink compounds are on the order of 0.6 W/m*K. These compounds should be used sparingly, and applied in a very thin layer. Alternative materials have been developed with better thermal properties such as Chomerics T725 THERMFLOW ™ or Thermoset's CoolPhase™ MPC-120. These materials are phase change interface materials. At room temperature they are typically applied as thin sheets, and must be heated slightly to cure and spread the material.

The Chomerics T725 exhibits a thermal impedance of 0.03 °C-in^2/W, and is available in 0.005" thick sheets. Below is the contact information of the two companies mentioned above.

THERMFLOW is a trademark of Chomerics.
Chomerics
Div. of Parker Hannifin
77 Dragon Court
Woburn, MA 01888-4014
www.chomerics.com
Ph: 1-781-935-4850

CoolPhase is a trademark of Thermoset, Lord Chemical Products.
Thermoset, Lord Chemical Products
5101 E. 65th Street
Indianapolis, Indiana 46220-0902
www.thermoset.com
Ph: 1-800-746-8343

Conclusion

In general, it is important to keep the junction temperature of the devices low to extend the life of the part and to improve the overall performance. Proper heat sinking of GaAs devices will ensure optimum performance over the life of the part in your design.

---

[1] TriQuint Semiconductor website, http://www.tqs.com/MMW/Reliability/mmw_rel_ovr.htm

ANADIGICS, Inc.
141 Mount Bethel Road
Warren, New Jersey 07059,U.S.A.
Tel: +1(908)668-5000
Fax: +1(908)668-5132

URL: http://www.anadigics.com
E-mail: Mktg@anadigics.com