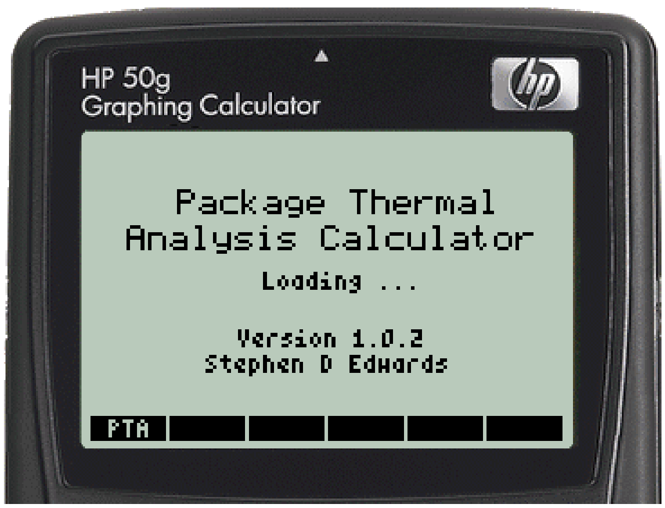
PACKAGE THERMAL ANALYSIS CALCULATOR USER'S GUIDE



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SECTION 1 - INTRODUCTION

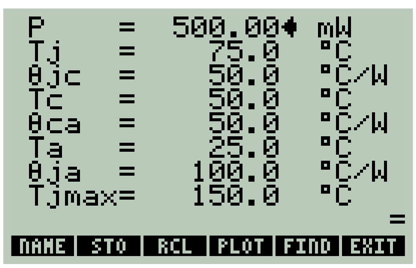
Package Thermal Analysis (PTA) is a program written for the HP50g calculator that aids in the analysis of the thermal properties of integrated circuit packages. These include thermal resistance, power dissipation and derating, and die, package, and ambient temperatures. PTA can find any of these parameters given the others. PTA can be run on a PC using the free program HPUserEdit 5.4, found at www.hpcalc.org, or the calculator page at www.maximintegrated.com.

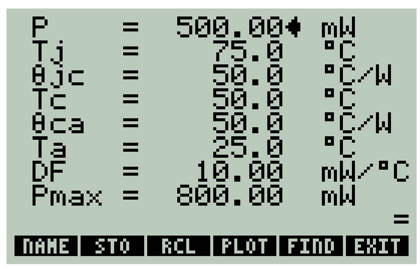
Ten parameters are used.

1. Power Dissipation, **P**, in mW
2. Junction Temperature, **Tj**, in °C
3. Junction-Case Thermal Resistance, **θjc**, in °C/W
4. Case Temperature, **Tc**, in °C
5. Case-Ambient Thermal Resistance, **θca**, in °C/W
6. Ambient Temperature, **Ta**, in °C
7. Junction-Ambient Thermal Resistance, **θja**, in °C/W
8. Power Derating Factor, **DF**, in mW/°C
9. Maximum Junction Temperature, **Tjmax**, in °C
10. Maximum Power Dissipation, **Pmax**, in mW

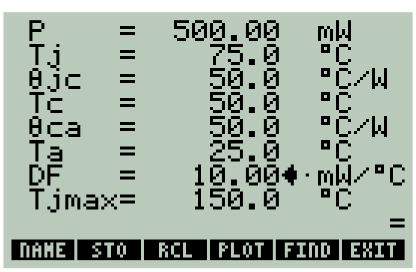
PTA allows ten parameters to be entered (**P**, **Tj**, **θjc**, **Tc**, **θca**, **Ta**, **θja**, **DF**, **Tjmax**, and **Pmax**), and nine found (**P**, **Tj**, **θjc**, **Tc**, **θca**, **Ta**, **θja**, **DF**, and **Pmax**) as a function of the other parameters.

These parameters appear in PTA as shown below:





The additional parameters **DF** and **Pmax** can be displayed by pressing the right arrow key, , when θjc or Tjmax are selected, respectively.



A small dot to the right of the selection arrow serves as a reminder that an alternative unit is available. Press the right arrow key, , to select the alternative units.

Refer to Section 7 for an explanation of these parameters and how they are calculated.

SECTION 2 - INSTALLATION

PTA can be installed on the HP50g calculator or a Windows PC.

Installing PTA on the HP50g Calculator

PTA may be installed in any one of three ways:

A. Best when installing one calculator:

   Copy the executable file PTA.hp to the home directory or subdirectory of the HP50g calculator. Launch PTA.hp.

B. Best when installing between two and six calculators:

   Copy the executable file PTA.hp to the root directory of an SD card, and the much smaller file PTA to the home directory or subdirectory of the HP50g calculator. Launch PTA.

C. Best when installing six or more calculators:

   Install PTA using the Calculator Launcher (CALC) utility found at www.maximintegrated.com/design/tools/calculators/hp50g/. Refer to the CALC User's Guide for an explanation of this utility.

Refer to the HP50g Graphing Calculator User's Guide for instructions on how to copy files to the calculator.

Installing PTA on a Windows PC

PTA can be run on a Windows PC using the free program HPUserEdit 5.4. HPUserEdit is an IDE for the HP50g and contains a suitable emulator.

To install HPUserEdit:

Download and install HPUserEdit 5.4, found at www.hpcalc.org. Search for "HPUserEdit5". The default language is Spanish. However, other languages can be selected as follows,

1. Select 'Opciones' (Options)
2. Select 'Idiomas' (Language)
3. Select the preferred language (English is assumed in this document)

To run PTA:

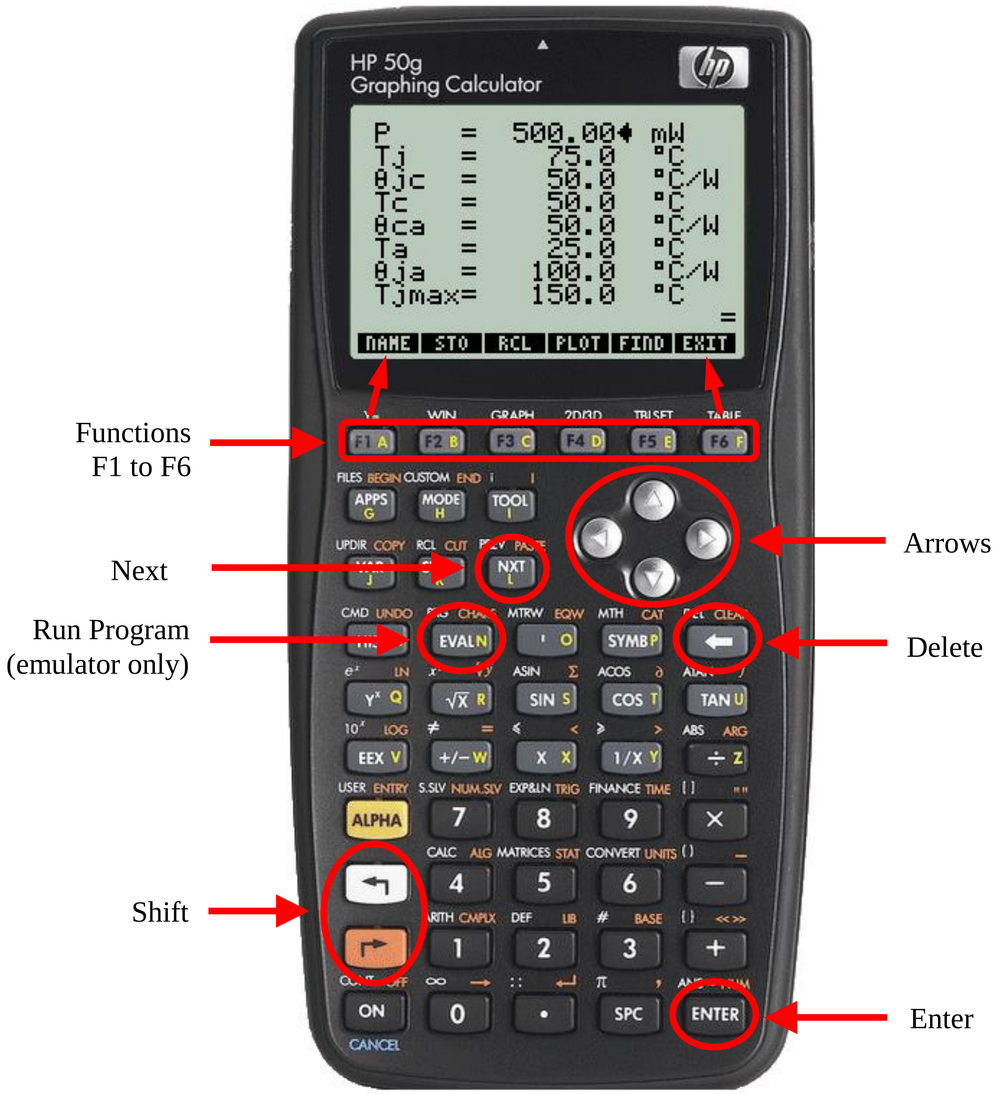
1. Launch HPUserEdit
2. Launch the HP50g emulator by selecting Emulator/Run_the_Emulator from the menu bar. A virtual HP50g appears.
3. Download *and unzip* the PTA program package. Drag and drop the unzipped PTA.hp executable file to the calculator screen and click the EVAL key.

The splash screen, shown on page 1 of this guide, is displayed when the calculator is loading. It appears momentarily, and may not be visible when run on a PC.

PTA creates a file named 'CalcDB' in the calculator's home directory the first time it is run. 'CalcDB' holds the parametric values used by PTA when launched, and is used by the STO and RCL commands to store and recall the parameters.

Section 3 - Keyboard

The following diagram shows the location of all keys used by PTA:



When using the emulator, the calculator keys map to the PC keyboard as follows:

Calculator Keys	↔	PC Keyboard
Numbers	↔	Numbers
Enter and Delete	↔	Enter and Delete
Yellow Letters	↔	Letters
Arrows	↔	Arrows
Left Shift	↔	Shift
Right Shift	↔	Control

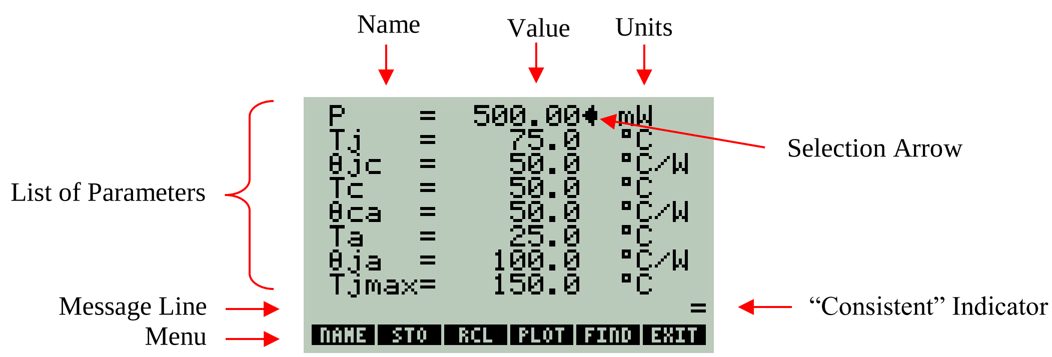
SECTION 4 - COMMANDS

PTA has two sets of commands:

- Main Menu Commands
- Extended Menu Commands
- Help Commands

Main Menu Commands

After launching PTA for the first time, the following screen appears, listing eight thermal parameters.

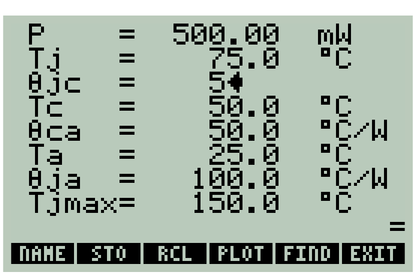


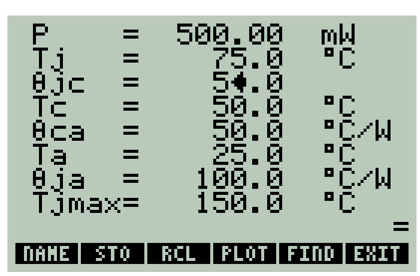
Use the ▼ and ▲ keys to select a parameter.
Use the ◄ (insert) or ⌫ (delete) key to enter or edit a parameter. Press ENTER when finished.
Use the ► key to display an alternative parameter (**θja** or **DF,** and **Tjmax** or **Pmax**) or remove **θja**, **TC**, and **θja**)

F1 (NAME) displays the name of the selected parameter in the message line
↰ F1 (NAME) displays the full precision of the selected parameter in the message line
F2 (STO) stores all parameters
F3 (RCL) recalls all stored parameters
F4 (PLOT) plots the power derating and junction temperature curves
F5 (FIND) finds the selected parameter
F6 (EXIT) or ON (Cancel) exits the program
↰ F6 (EXIT) launches previous run calculator (for physical calculators only - requires CALC)
↱ ON turns off the calculator

Enter or edit a parameter value by using one of the following keys:

the delete key (⌫), and the left arrow (insert) key (◄)



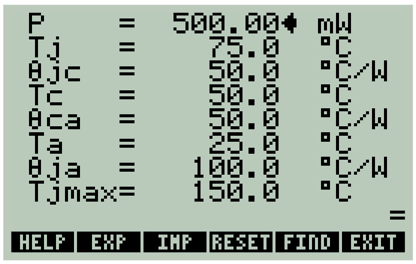


Press ENTER when finished.

The equal sign (=), in the lower right hand corner of the display, indicates that all the parameters are consistent with each other. The parameters are always consistent immediately following a F5 (FIND) command, and the "=" will appear. Any entry of a parameter value will display the "≠" sign, indicating that the parameters may no longer be consistent.

Extended Menu Commands

Press the NXT key to display the Extended Menu showing four additional commands. Press NXT again to return to the Main Menu.



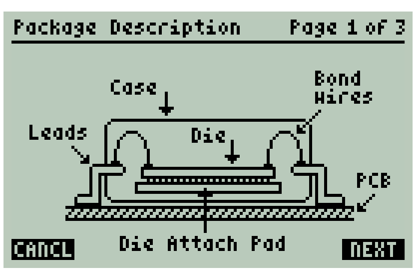
← The Extended Menu

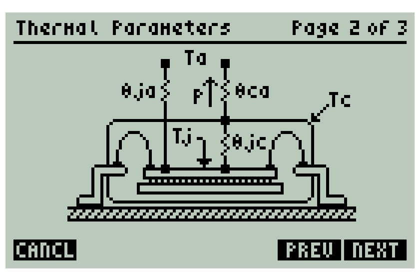
F1 (HELP) displays package and plot diagrams with the parameters used by PTA
F2 (EXP) exports the selected parameter to the stack upon exiting
F3 (IMP) imports a number present in level 1 of the stack when PTA was launched, to the selected parameter.
F4 (RESET) enters all default parameter values.

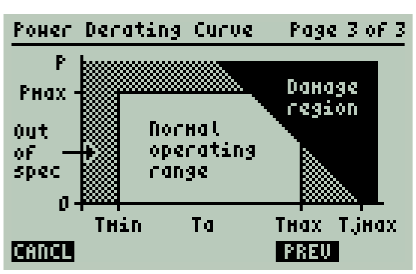
The Main Menu reappears after executing the extended menu key, NXT, again.

Help Commands

Press F1 (HELP) to display the help screen, and F5 (PREV) and F6 (NEXT) to view pages 1 through 3 shown below. Press F1 (CANCL) to return to the parameter display.



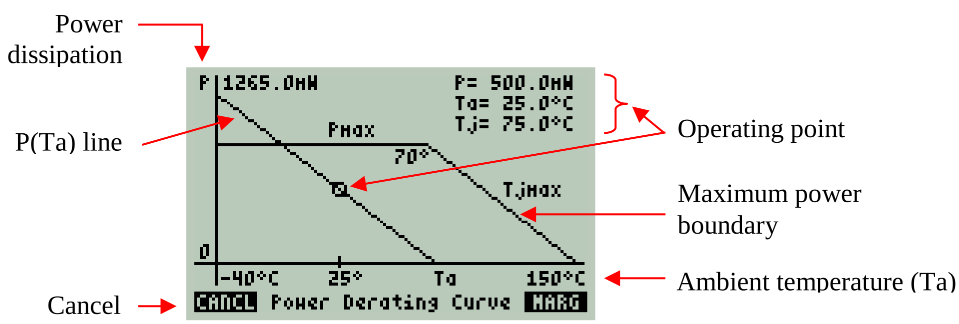




Plot Commands

PLOT (F4 in the Main Menu) plots the Power Derating Curve.

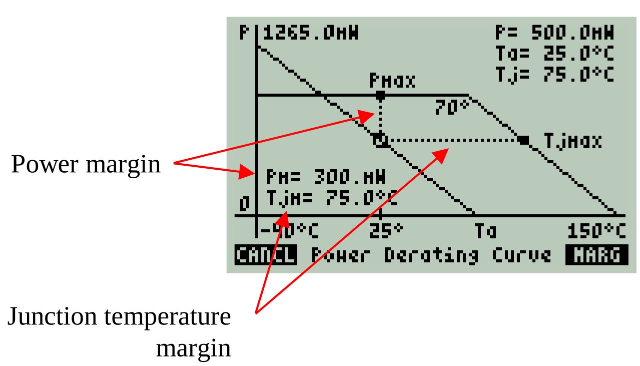
The key elements of the Power Derating Curve are show below.



The following keys are active when this plot is displayed:

	▲	Zoom out
	▼	Zoom in
↱	◄	Decrease Ta operating point to the next lowest significant temperature
	◄	Decrease Ta operating point by 5 C°
↰	◄	Decrease Ta operating point by 1 C°
↱	◄	Increase Ta operating point to the next highest significant temperature
	◄	Increase Ta operating point by 5 C°
↰	◄	Increase Ta operating point by 1 C°
F1	(CANCL)	Return to the parameter display
F6	(MARG)	Display the power and temperature margins

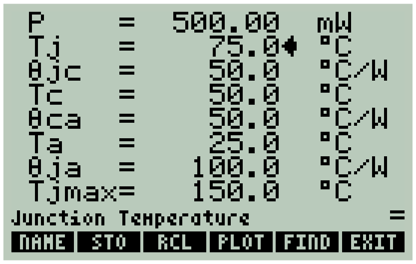
Pressing F6 (MARG) displays the margin values



SECTION 5 - MESSAGES

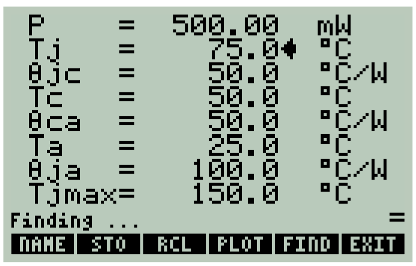
PTA displays five types of messages on the message line:

1. Name Messages



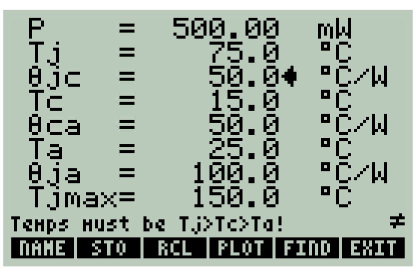
Name messages describe the selected parameter when NAME is active.

2. Busy Messages



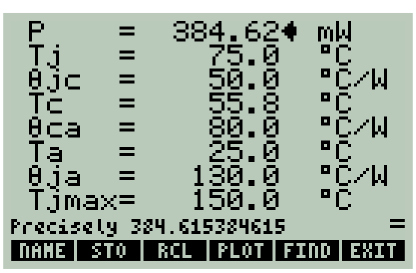
Busy messages explain what the program is doing.

3. Error Messages



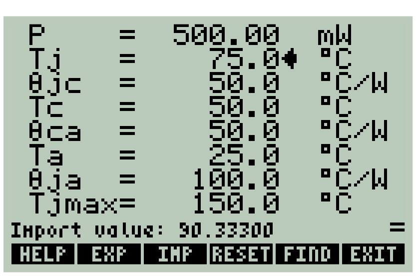
Error messages warn of an illegal entry, command, or result.

4. Full Precision Messages



Full Precision messages show the full precision of the selected parameter, when ↰ NAME is active.

5. Import Messages



Import messages show the value to be imported.

SECTION 6 - EXAMPLES

PTA can find nine thermal parameters (**P**, **Tj**, **θjc**, **Tc**, **θca**, **Tc**, **θja**, **DF**, and **Pmax**) as a function of the others. The following example is used to demonstrate how to use the calculator.

Entering (◀, ◀) and Finding (F5)

In this example, we will examine the suitability of the MAX5112, a 9-channel current output DAC, with regards to power dissipation, for a hypothetical tunable laser application. In this application, the maximum operating temperature is 80°C and the maximum junction temperature is 120°C.

Specifically, we will

1. Estimate the power dissipation
2. Select the package with the best thermal properties
3. Improve thermal performance by lowering θ_{CA}
4. Find the maximum power that can be dissipated

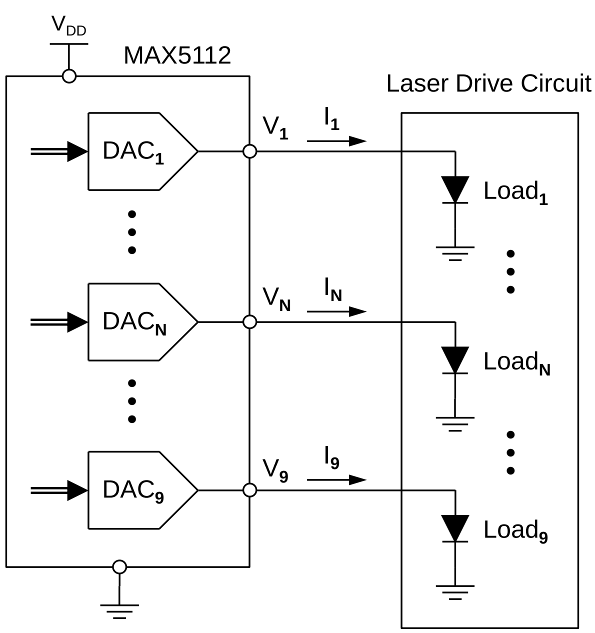
1. Estimating power dissipation

The first step in any thermal analysis is to estimate the typical and worst-case power dissipations.

In this example, the MAX5112's nine DACs are used to set the bias points of a high power tunable laser source. The power dissipated by each DACs is given by

$P_N = (V_{DD} - V_N) \cdot I_N$, where V_N and I_N are the load voltage and current of each DAC.

Schematically,



The total device power dissipation is the sum of the nine DACs plus its quiescent power dissipations.

$$P_{Total} = \sum_{N=1}^{9} (V_{DD} - V_N) \cdot I_N + V_{DD} \cdot I_Q$$

The typical and worst-case output currents and voltages for this application are tabulated below,

	Typical $V_{DD} = 3.0V$			Worst-case $V_{DD} = 3.3V$		
	I (mA)	VI (V)	P(mW)	I (mA)	VI (V)	P(mW)
DAC_1	10.0	1.70	13.0	10.0	1.60	17.0
DAC_2	10.0	1.70	13.0	10.0	1.60	17.0
DAC_3	20.0	1.40	32.0	20.0	1.40	38.0
DAC_4	80.0	1.30	136.0	90.0	1.30	180.0
DAC_5	170.0	1.60	238.0	180.0	1.60	306.0
DAC_6	200.0	1.60	280.0	300.0	1.60	510.0
DAC_7	80.0	1.30	136.0	90.0	1.60	153.0
DAC_8	15.0	1.60	21.0	35.0	1.60	59.5
DAC_9	15.0	1.60	21.0	35.0	1.60	59.5
Quiescent	0.5		1.5	0.6		2.0
Total Power			891.5			1,342.0

We find the typical power dissipation is 891.5 mW, and worst-case is 1,342 mW.

Datasheet thermal parameters

Examining the MAX5112 datasheet's Absolute Maximum Ratings section we find the following relevant thermal parameters:

All Other Pins to AGND.................................-0.3V to +4.0V
Continuous Power Dissipation (T_A = +70°C)
WLP (derate at 26.3mW/°C above +70°C).................2104mW
TQFN (derate at 34.5mW/°C above +70°C).............2758mW
Maximum Current Into Any Pin 380mA
Operating Temperature Range.......................-40°C to +105°C
Storage Temperature Range.........................-65°C to +150°C
Junction Temperature ....+150°C
Lead Temperature (TQFN only, soldering 10s).............+300°C
Soldering Temperature (reflow) ....+260°C

The Package Thermal Characteristics Section contains the following thermal resistance parameters:

TQFN
Junction-to-Ambient Thermal Resistance (θ_{JA}) ....29°C/W
Junction-to-Case Thermal Resistance (θ_{JC}) ....1.7°C/W

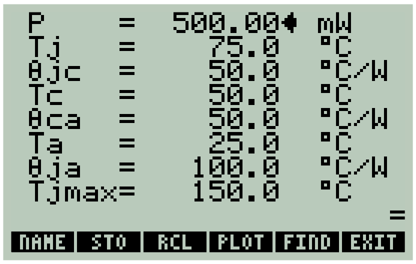
WLP
Junction-to-Ambient Thermal Resistance (θ_{JA}) ....38°C/W

Note that our power dissipation is safely below the maximum continuous power dissipation limit of 2,104mW for the WLP package, and 2,758mW for the TQFN package, when operating at or below 70°C ambient.

2. Selecting the best package

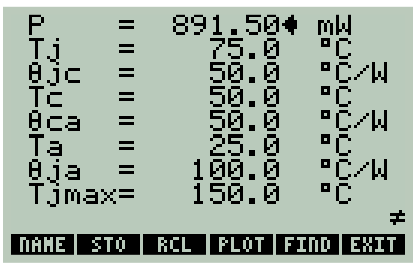
This device has two package options, TQFN or WLP, each with different thermal and power ratings. We will evaluate both, beginning with the WLP package.

First, enter all relevant application and device parameters.



Step 1:

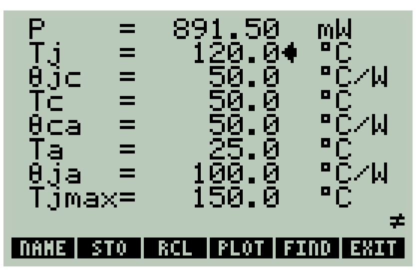
Start with the default parameter values.



Step 2:

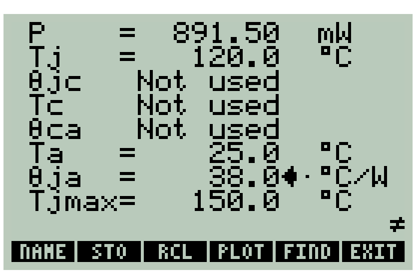
Enter the typical power dissipation. Use the up or down arrow keys to move the selection arrow ( ) to **P.** Then use the or key to enter 891.5mW.

Note that the consistency indicator has changed from “=” to “≠” indicating that all the parameters are now no longer consistent.



Step 3:

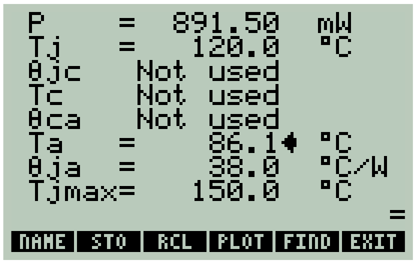
Enter the maximum acceptable junction temperature at **Tj**. Although this device specifies a maximum **Tj** of 150°C, it is prudent to operate below this value to add an additional margin. A 20% reduction, or 120°C, was specified for this application.



Step 4:

Select the WLP package by removing all parameters related to a case, because WLPs do not have cases. Remove the case parameters by pressing the right arrow key at **θjc**, **Tc**, or **θca**. Next, enter a **θja** of 38 °C/W.

Next, find the maximum ambient temperature.

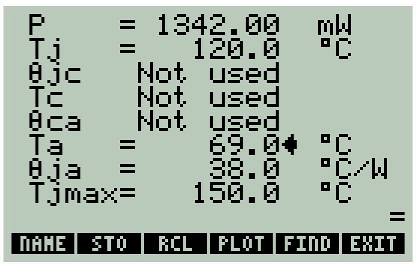


Step 5:

Find the maximum ambient temperature by moving the selection arrow to **Ta** and press the F5 (FIND) menu key. **Ta** becomes 86.1°C. Note that the consistency indicator has changed from "≠" to "=" indicating that all the parameters are now consistent.

It is seen that the WLP package, when dissipating typical power levels, *will* safely operate in an ambient temperature of up to 86°C, exceeding the requirement by 6°C.

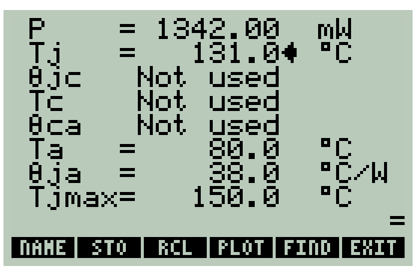
But will the WLP package operate reliably when dissipating the *worst-case* power of 1,342mW?



Step 6:

Enter the worst-case power, **P**, of 1342 mW, and find the maximum ambient temperature, **Ta.** **Ta** is found to be only 69°C.

Looking at it another way, find the junction temperature when operating at the maximum ambient temperature of 80°C.



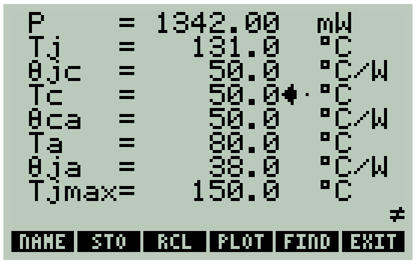
Step 7:

Enter an ambient temperature of 80°C for **Ta** and find **Tj.** **Tj** is 131°C, exceeding the maximum allowable junction temperature by 11°C

It is found that the WLP package *does not meet* the thermal specification of a junction temperature of less than 120°C under all conditions.

Next, examine the TQFN package option.

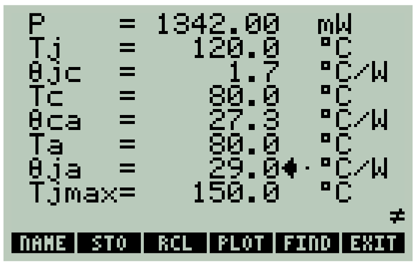
Finally, examine the TQFN package option.



Step 1:

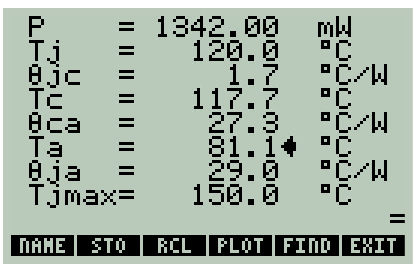
Deselect a WLP package by pressing the right arrow key at **θjc**, **Tc**, or **θca** to include the case parameters.

Enter the thermal resistances, and maximum junction temperature for the TQFN package.



Step 2:

Enter 120°C at **Tj**. Enter a **θjc** of 1.7 °C/W and a **θja** of 29°C/W. **θca** automatically changes to 27.3 °C/W, the value necessary to produce the specified **θja**.



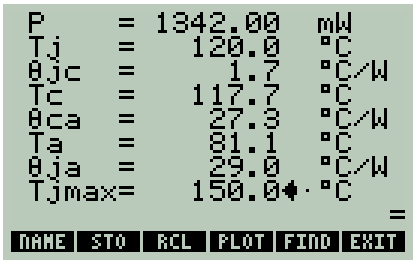
Step 3:

Find the maximum ambient temperature by moving the selection arrow to **Ta** and press the F5 (FIND) menu key. **Ta** becomes 81.1°C. This meets the application requirement of 80°C.

It is found that the TQFN package *will* meet the application's thermal requirements under worst-case conditions, but only by *a small margin*.

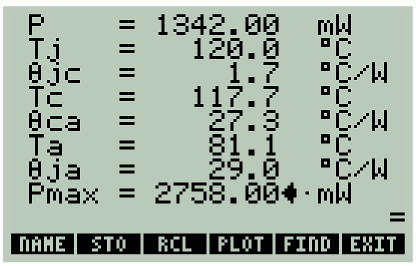
Plotting (F4 in the Main Menu)

Before plotting, enter **Tjmax** and **Pmax** from the data sheet



Step 1:

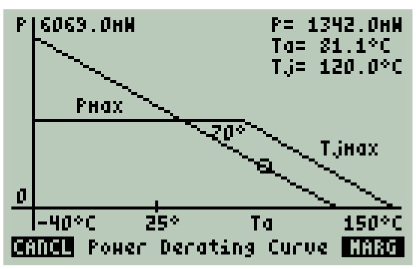
Tjmax is 150°C by default. No entry needed.



Step 2:

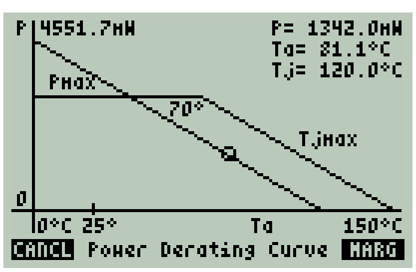
Enter 2758mW into **Pmax**

Press F4 to plot the Power Derating Curve of the entered parameters. The parameters must be consistent to be plotted.



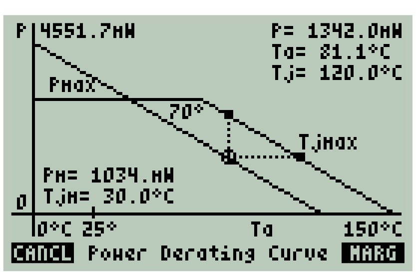
Step 3:

The circle indicates the operating point of the device with respect to maximum power dissipation and junction temperature. It is seen that the operating point (**Ta**=81.1°C, and **P**=1342mW) is within the maximum operating limits of the device.



Step 4:

Zoom in using the down arrow key. Press twice to start the plot at 0°C ambient.



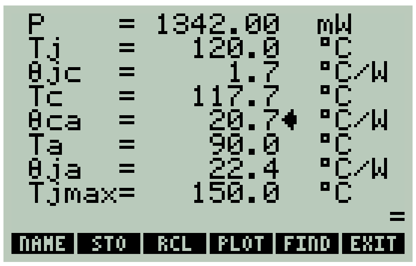
Step 5:

Press F6 (MARG) to display the margin values. The two dotted lines indicate a power margin (**Pm**) of 1034mW and a junction temperature margin (**Tjm**) of 30.0°C.

3. Improving thermal performance by lowering θ_{CA}

Although we found the TQFN package can safely operate at the required 80°C, it does so only with a small 1.1°C margin. In practice this application would like to have a greater operating margin of 10°C, allowing safe and reliable operation up to 90°C. The only way to do this, without lowering the maximum junction temperature, is to lower the case-to-ambient thermal resistance.

Find the **θca** required to safely operate at an ambient temperature of 90°C.



Step 1:

Enter **Ta** of 90°C. Move the arrow to **θca** and press the F5 (FIND) menu key. We find that **θca** must be reduce to 20.7 °C/W.

In many applications, it is possible to reduce θ_{CA} below the values specified (or implied) in the data sheet. θ_{JA} is the sum of θ_{JC} and θ_{CA}. θ_{JC} is a function *only* of the package and die assembly and cannot be changed. θ_{CA}, on the other hand, is a function of properties *external* to the package, an therefore, can potentially be reduced.

The θ_{JA} value (and by implication θ_{CA}) recorded in the data was measured under standard operating conditions, as defined by JESD51-1, -2, -5 and -7, these include,

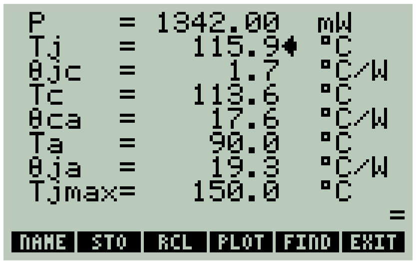
- Device mounted direct to PCB – no socket
- Four layer PCB, with top and bottom signal planes, and internal power and ground planes
- PCB size of 76 x 114 x 1.6mm, made of FR-4 material
- Fan-out trace length of 25mm
- PCB attach pad area equals the exposed paddle area, with thermal via on a 1.2 x 1.2mm grid
- Copper thickness of 0.070mm trace and 0.035mm power/ground planes
- Still air, with no heat sink

θ_{CA} can be reduced in the following ways:

1. Increase the attach pad area by extending it beyond the dimensions of the package's exposed paddle
2. Add more thermal vias in the attach pad area
3. Increase the copper thickness
4. Place the device near cooler components, such as connectors, capacitors, and transformers
5. Add a heat sink to the package
6. Increase airflow via ventilation and/or fans

In this example, items 1 and 4 were applied. The attach pad area was doubled, and the TQFN package was placed close to a large PCB mounting post providing additional heat sinking. These steps reduced **θca** by 15% to 17.6°C/W, below our 20.7 °C/W target.

Find the maximum junction temperature when operating at 90°C ambient, with the reduced θca.

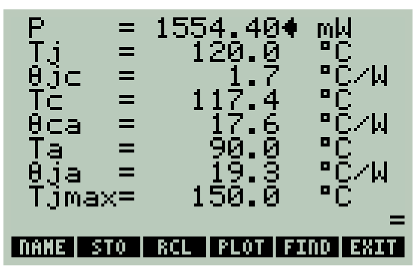


Enter **θca** of 17.6°C/W. Note that **θja** automatically decreases as a result. Move the arrow to **Tj** and press the F5 (FIND) menu key. We find that **Tj** can be as high as 115.9 °C/W.

It is found that reducing **θca** by 15% allows us to operate at 90°C ambient while decreasing the junction temperature, **Tj**, by 4.1°C – adding additional safety margin.

4. Finding the maximum power dissipation

Finally, using the PCB layout improvements made in the previous section, find the maximum power that can be dissipated when operating at the maximum ambient temperature of 90°C, and not exceed a junction temperature of 120°C



Enter a **Ta** of 90°C. Find by moving the selection arrow to **P** and pressing the F5 (FIND) menu key. We find that **P** can be as high as 1554.4mW.

In conclusion, with a little attention to PCB layout, the TQFN MAX5112 exceeds the thermal requirements of our tunable laser application. Specifically, it will safely operate with a

1. Worst case power dissipation (1,342 mW)
2. Worst case ambient temperature (90°C)
3. With a 20% safety margin in the maximum junction temperature (120°C).

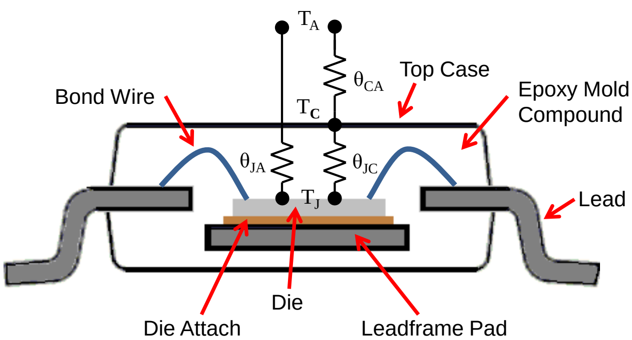
SECTION 7 – BACKGROUND

Introduction

Good circuit design requires careful attention to both the thermal and electrical domains. Over designing can add unnecessary cost, and under designing can cause overheating resulting in reduced reliability and product life. Finding the optimum solution requires a clear understanding of the thermal model used in integrated circuit packages. The thermal model and its application to integrated circuits are described below.

Thermal Model

This calculator uses the industry standard thermal model for integrated circuit devices. This model is expressed in the following diagram and equations,



$$T_J = T_A + P \cdot \theta_{JA} = T_A + P \cdot (\theta_{JC} + \theta_{CA})$$

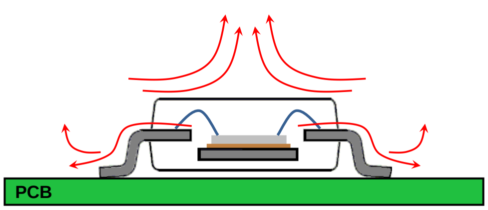
$$\theta_{JA} = \theta_{JC} + \theta_{CA}$$

$$T_C = T_A + P \cdot \theta_{CA}$$

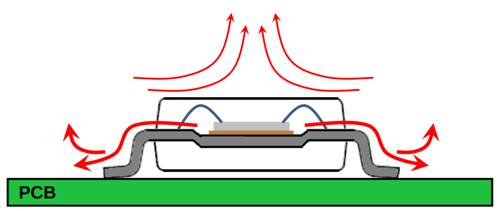
$$\theta_{JC} = \frac{T_J - T_C}{P}$$

Heat Flow

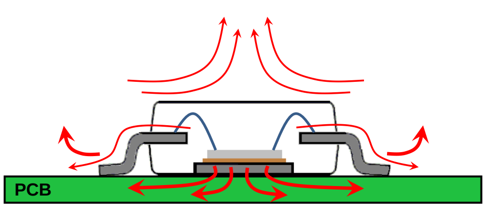
When power is generated within a die, heat is produced that flows toward the lower temperature of the surrounding air. The heat must travel via the molding compound, bond wires, leads, and (in some devices) an exposed leadframe pad. The inability of the package to immediately dissipate the heat results in a rise in die (T_J) and package (T_C) temperatures. The thermal resistance (θ_{JC} + θ_{CA}), and therefore the path taken by the heat, varies with the package construction, and PCB mounting. For example,



Standard Package



Thermally Enhanced Package

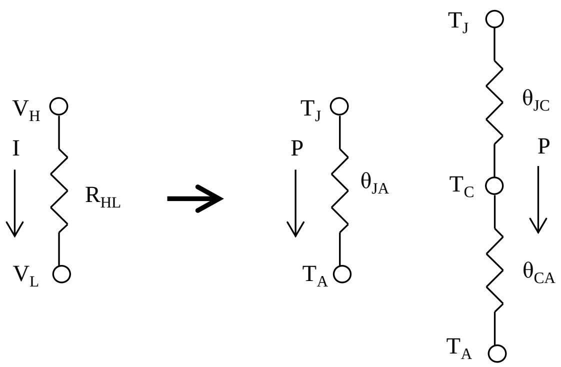


Exposed Pad Package

Each of these packages has an increasingly lower resistance to heat flow.

Thermal vs. Electrical Models

As can be seen, the thermal parameters of an integrated circuit are modeled as components of an electrical circuit, where temperature is analogous to voltage, power to current, and thermal resistance to electrical resistance. Schematically,



This model describes only the steady state condition of the package.

Heat, unlike charge in electrical circuits, is not restricted to flow through a particular component. Rather, heat flows in a diffuse manner throughout all three dimensions of the package, the PCB, and the surrounding air. This can involve any or all of the three heat transfer mechanisms of conduction, convection, and radiation.

Parameter Sensitivity

As a result of these different heat transfer mechanisms, thermal resistance is very sensitive to device mounting and the surrounding environment. Because of this sensitivity, standards test conditions have been established (i.e., JESD51 series) to insure a fair comparison between packages made by different manufactures. At a system level, however, a complete thermal analysis may require the use of 3D thermal analysis software, validated by empirical analysis (i.e., prototype testing).

Heat, Power, and Temperature

Heat, power, and temperature are related and often confused. Heat is energy (Q), measured in Joules (J), and power is heat flow (Q/t) measured in Watts (W, or J/s). Temperature is neither energy nor power, but the *average* energy of molecules in motion within a substance, measured in degrees (°C). Heat energy depends on the speed, number, and type of particles in a substance. Temperature does not depend on the number or type of particles. For example, the temperature of water in a small tea cup may be the same as the water in a larger teapot from which it came, but the teapot has more heat because it has more water, and thus more thermal energy. It is heat that will increase or decrease the temperature. Higher temperatures simply mean that the molecules are moving, vibrating, and rotating with more energy.

Thermal Parameters

1. Power Dissipation, P (mW)

The power dissipated in a die is the source of heat within an integrated circuit. Because the package cannot immediately remove this heat, there is a resulting rise in junction temperature. The power necessary to produce this rise in temperature can be deduced using the following equation,

$$P = \frac{T_J - T_A}{\theta_{JA}}$$

Where, T_J is the junction temperature, T_A is the ambient temperature, and θ_{JA} is the junction-to-ambient thermal resistance.

2. Junction Temperature, T_J (°C)

Junction temperature is synonymous with the average die temperature. The terms "Junction Temperature" and 'Die Temperature" are used synonymously throughout this guide. The term "Junction Temperature" comes from the early days of semiconductor thermal analysis where bipolar transistors and rectifiers were the primary sources of power dissipation. The junction temperature is always at or greater than the ambient temperature, in accordance with the following equation,

$$T_J = T_A + P \cdot \theta_{JA}$$

3. Junction-to- Case Thermal Resistance, θ_{JC} (°C/W)

The junction-to-case thermal resistance is the resistance to heat flow between the die and the case's outer surface. This is one of two components that comprise the total thermal resistance of a package (θ_{JC} + θ_{CA}). This resistance is entirely determined by package properties, and is not affected by device mounting or other external condition. Heat within a package is transported through conduction. θ_{JC} represents the theoretically lowest total thermal resistance that can be achieved with any PCB mounting and surrounding environment. Thermal resistance is defined as the ratio of the temperature difference across the resistance and the power dissipated by the resistance. In this case,

$$\theta_{JC} = \frac{T_J - T_C}{P}$$

4. Case Temperature, T_C (°C)

Case temperature is the temperature of the case measured at a specific point on the outside surface of the package. It is measure at pin 1 of a leaded plastic package, and at the center of the exposed pad surface of an exposed pad package. The case temperature is always at or greater than the ambient temperature, in accordance with the following equation,

$$T_C = T_A + P \cdot \theta_{CA}$$

T_C is *only* influenced by the case-to-ambient thermal resistance (θ_{CA}) and *not* by the junction-to-case thermal resistance (θ_{JC}) of the package.

5. Case-to-Ambient Thermal Resistance, θ_{CA} (°C/W)

The case-to-ambient thermal resistance includes the thermal resistances from all paths from the outside of the package to ambient. Heat paths can be via conduction, convection, and/or radiation. θ_{CA} is usually not reported by the package or integrated circuit manufacture, but can deduced indirectly by taking the difference between the junction-to-ambient thermal resistance and the junction-to-case thermal resistance,

$$\theta_{CA} = \theta_{JA} - \theta_{JC}$$

6. Ambient Temperature, T_A (°C)

The air mass surrounding a package is assumed to be sufficiently large as to leave its temperature unchanged by any heat dissipated by the package. Therefore, it is regarded as a thermal ground at a constant temperature, T_A. Ambient temperature can be deduced knowing the junction temperature, the power dissipated, and the junction-to-ambient thermal resistance,

$$T_A = T_J - P \cdot \theta_{JA}$$

Most device manufacturers define room temperature to be 25°C ambient when setting device test conditions.

7. Junction-to-Ambient Thermal Resistance, θ_{JA} (°C/W)

The junction-to-ambient thermal resistance is the sum of the junction-to-case, and the case-to-ambient thermal resistance. It is influenced by the package type, PCB mounting, and the surrounding environment.

$$\theta_{JA} = \theta_{JC} + \theta_{CA}$$

It can be deduced knowing the die temperature, ambient temperature, and power dissipated, using the following formula,

$$\theta_{JA} = \frac{T_J - T_A}{P}$$

8. Maximum Junction Temperature, T_{JMAX} (°C)

The maximum junction temperature is a temperature set by the device manufacturer, above which performance and reliability are not guaranteed. The semiconductor industry has adopted values of 150°C for molded packages, and sometimes 175°C for ceramic and open cavity packages for silicon devices.

High temperature has many detrimental effects on integrated circuits, these include:

- Long term failure rate increases
- Leakage current increases
- Gate oxides degrade faster
- Ionic impurities become more mobile
- Mechanical stress increases
- Diode forward voltage decrease
- MOSFET on-resistance increases
- MOSFET threshold voltages decrease
- Bipolar transistor switching speed decrease
- Bipolar transistor gains decrease
- Breakdown voltages increase

9. Maximum Power Dissipation, P_{MAX} (mW)

Maximum power dissipation is the maximum power allowed when operating at an ambient temperature of +70°C. Above +70°C the maximum power dissipation must be reduced by DF milliwatts for every degree centigrade (mW/°C), to keep the junction temperature below T_{JMAX}. When operating below +70°C, T_J will be less than T_{JMAX}, thereby guaranteeing safe operation. Historically, +70°C was chosen as the temperature to begin derating because it was also the maximum operating temperature of commercial devices of the day, and therefore would guarantee safe operation throughout the commercial ambient operating range of 0°C to 70°C.

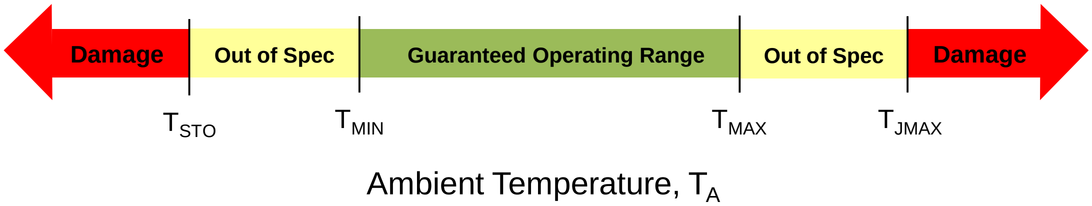
10. Power Derating Factor, DF (mW/°C)

The Power Derating Factor is the rate at which the maximum power dissipation, P_{MAX}, must be reduced when operating above an ambient temperature of +70°C, to guarantee that the junction temperature (T_J) does not exceed the maximum junction temperature (T_{JMAX}). The derating factor is related the junction-to-ambient thermal resistance by,

$$DF = -\frac{1}{\theta_{JA}}$$

11. Minimum and Maximum Operating Temperatures, T_{MIN} and T_{MAX} (°C)

These are the lowest and highest ambient temperatures within which the device performance is guaranteed. When no power is being dissipated the ambient temperature operating ranges for Guaranteed, Out of Spec, and Damage regions are given below.

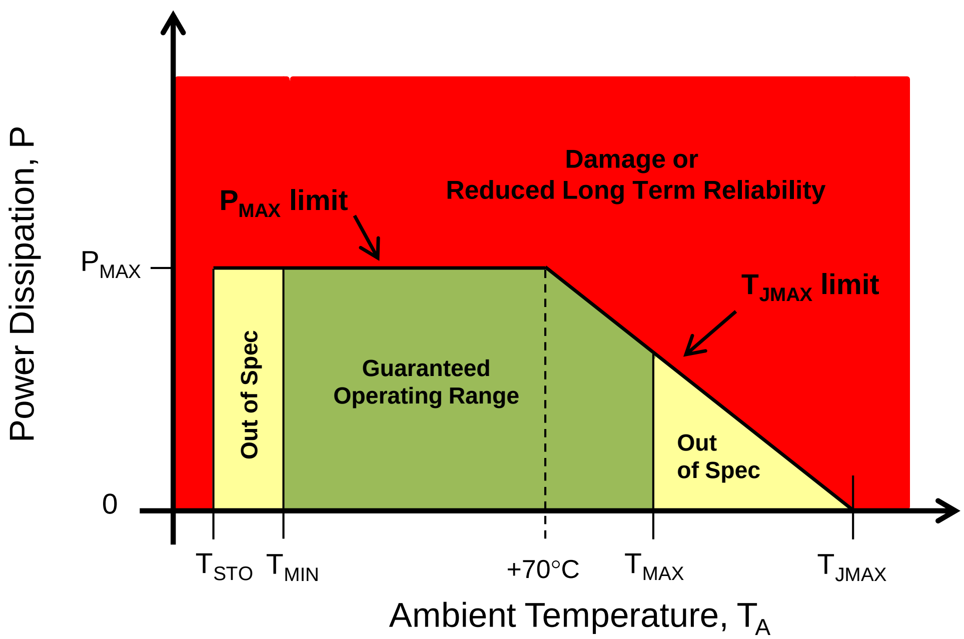


T_{STO} is the minimum storage temperature found in the Absolute Maximum Ratings section of the datasheet. It is typically -60°C.

For power dissipations greater than zero, consult the power derating curve.

12. Power Derating Curve (mW)

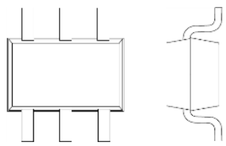
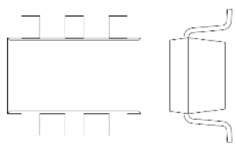
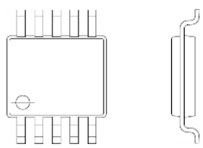
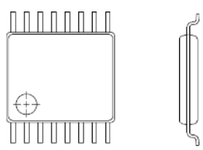
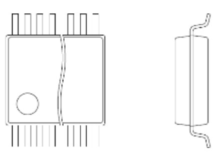
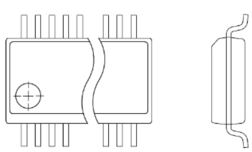
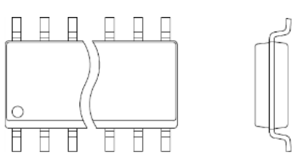
The power derating curve shows the allowable power dissipation at a given ambient temperature. It shows the P_{MAX} and T_{JMAX} lines that bound to the guaranteed operation range of the device.

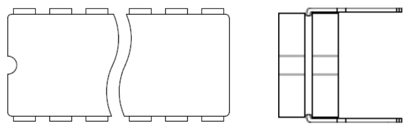
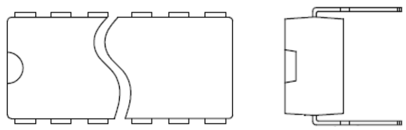
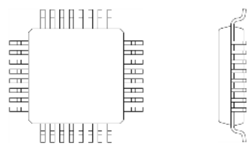
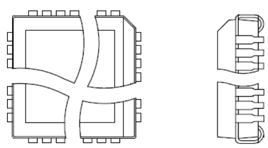
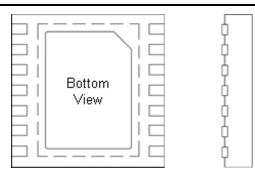
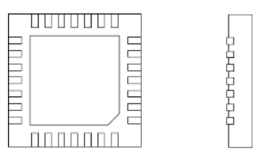
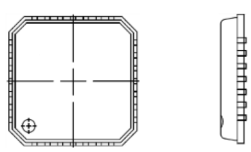
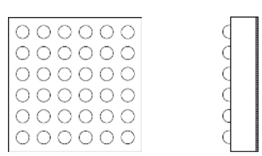
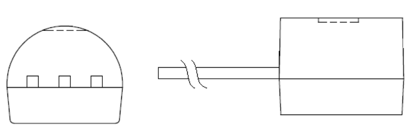


T_{STO} is the minimum storage temperature found in the Absolute Maximum Ratings section of the datasheet. It is typically -60°C.

Table of Packages

This table contains a sampling of integrated circuit packages with their thermal parameters. As can be seen, for each package type, its thermal parameters vary as a function of pin count. Junction-to-ambient thermal resistance, θ_{JA}, decreases with an increase in pin count. This table is given only for the purpose of providing a feel for the thermal performance for each package type. Always refer to a particular device's data sheet to find its actual thermal parameters.

Name (Pins)	Diagram	Pmax mW	DF mW/°C	θ_{JA} °C/W	θ_{JC} °C/W	Test Condition
SC70 (3 - 8)		235 - 245	2.9 - 3.1	340 - 326	115	JESD51-3
		235 - 245	2.9 - 3.1	340 - 326	115 - 120	JESD51-7
SOT23 (3 - 8)		240 - 696	3.1 - 8.7	324 - 115	82 - 80	JESD51-3
		238 - 1072	3.0 - 13.4	336 - 74.6	110 - 6.0	JESD51-7
µMAX (8 - 10)		444 - 825	5.6 - 10.3	180 - 97	36 - 5.0	JESD51-3
		386-1031	4.8 - 12.9	206 - 776	42 - 5.0	JESD51-7
TSSOP (14 - 28		727 - 1,778	9.1 - 22.2	110 - 45	30 - 2	JESD51-3
		798 - 2162	10 - 27	100 - 37	30 - 2	JESD51-7
SSOP (16 - 36)		571 - 941	7.1 - 11.8	140 - 84.7	34 - 19.3	JESD51-3
		930 - 1401	11.6 - 17.5	86 - 57.1	33 - 19	JESD51-7
QSOP (16 - 28)		667 - 860	8.3 - 10.8	120 - 93	37 - 27	JESD51-3
		772 - 1818	9.6 - 22.7	104 - 44	37 - 6	JESD51-7
SOIC (N) (8 - 16)		470 - 1,039	5.9 - 13	170 - 77	40 - 25	JESD51-3
		588 - 1739	7.4 - 21.7	136 - 46	38 - 6	JESD51-7

Name (Pins)	Diagram	Pmax mW	DF mW/°C	θ_{JA} °C/W	θ_{JC} °C/W	Test Condition
Ceramic DIP (8 - 24)		640 - 1,000	8 - 12.5	125 - 80	16 - 12	JESD51-3
Plastic DIP (8 - 24)		800 - 1333	10 – 16.7	100 - 60	29 - 20	JESD51-3
TQFP (32 - 144)		1529 - 3810	19.1 - 47.6	52.3 - 21	13 - 2	JESD51-7
PLCC (20 - 52)		800 - 1111	10 - 13.9	100 - 72	29 - 20	JESD51-3
TDFN (8 - 14)		615 - 1,482	7.7 - 18.5	130 - 54	48 - 9	JESD51-3
		784 - 2286	9.8 - 28.6	102 - 35	48 - 2.7	JESD51-7
TQFN (12 - 68)		1176 - 2352	14.7 - 29.4	68 - 34	11 - 0.5	JESD51-3
		1333 - 4000	50 - 16.7	60 - 20	11 - 0.5	JESD51-7
QFN (20 - 44)		1212 - 2424	15.2 - 30.3	66 - 33	15 - 1	JESD51-3
		1280 - 3636	16.1 - 45.5	62 - 22	15 - 1	JESD51-7
WLP (4 - 182)		776 - 2,424	9.7 - 30.3	103 - 33	-	JESD51-7
TO-92 (3)		500	6.3	160	4	JESD51-3
		606.5	7.6	131.9	4	JESD51-7

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