AN11753

Thermal considerations BGA3131

Rev. 2 — 23 March 2017 Application note

Document information

Info	Content
Keywords	BGA3131, DOCSIS 3.1, upstream amplifier, thermal management
Abstract	This document provides guidelines for designing the thermal management when applying the BGA3131

Revision history

Rev	Date	Description
1.0	20151112	First publication
2.0	20170323	Add minimum ambient temperature, Table 2 (impact of duty cycle) and temperature measurement through sensing diode / accuracy (diode voltage spread)

Contact information

For more information, please visit: http://www.nxp.com

For sales office addresses, please send an email to: salesaddresses@nxp.com

1. Introduction

This document provides guidelines for designing the thermal management when applying the BGA3131. It must be noted that the guidelines are general and must be checked against the actual application conditions.

In the BGA3131 datasheet a Delphi model (compact thermal model) can be found. This can be used to predict the BGA3131 junction temperature in an application based thermal simulation. In addition, on the BGA3131 PIP (product information page) a FloTherm model can be found.

2. Summary

To make sure the BGA3131 junction temperature does not exceed the maximum of 150 °C, attention must be paid to the board design.

The NXP evaluation board stack uses 4 layers with thermal vias below the BGA3131. With this type of board, multiple via and heatsink configurations were evaluated. In Table 1 the resulting maximum allowed ambient temperature per configuration is shown.

Table 1: Thermal requirement summary for BGA3131 versus PCB configuration in still air, 100% duty cycle (continuous on)

Via type	Via drill diameter	Amount of vias	Heatsink	Min* ambient temperature	Max* ambient temperature
Open / not filled	0.3 mm	*25*	No	-40 °C	40 °C
Cu filled	0.3 mm	25	No	-40 °C	50 °C
Open / not filled	0.3 mm	25	Yes	-40 °C	85 °C

* The ambient temperature is the temperature around the BGA3131(no shielding, still air) In case of using EM shielding where the BGA3131 is closed then the ambient temperature is the temperature inside of the shielding!

Table 2: Impact of duty cycle on BGA3131 versus TX_ENABLE frequency at 25 °C ambient temperature in still air, device with current at higher limit (worst case), 5 Vcc, using NXP evaluation board with 25 copper filled vias

Frequency	Duty Cycle	I [mA]	P [W]	Average T_Junction °C
--	*100%*	*718*	3.59	119
83	*50%*	*278*	1.89	85
10	50%	378	1.89	83
5	50%	378	1.89	84

Considering the real use case with 50% duty cycle (6 msec ON, 6 msec OFF) then the ambient temperature can be up to 34 degree higher.

3. BGA3131 evaluation board design

The NXP evaluation board is built up using 4 copper layers. The core as well as the two prepreg layers are FR4. Details of this stack can be found in Fig 1.

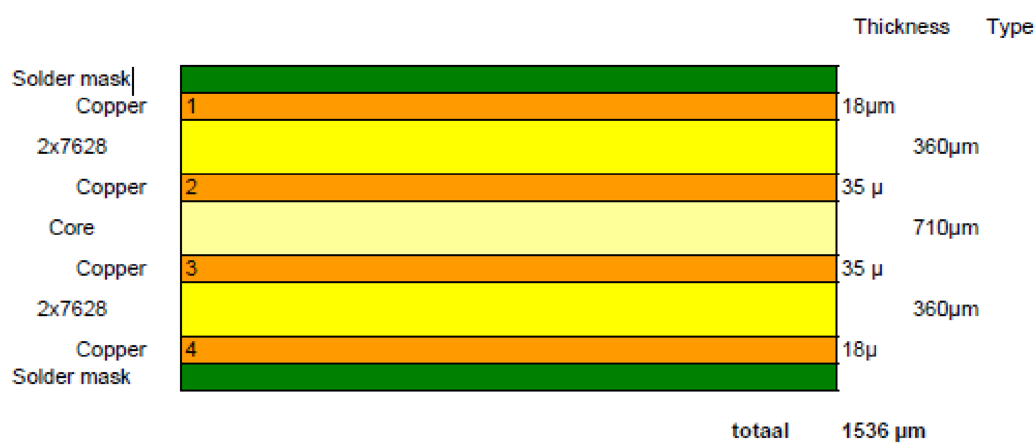

Fig 1. NXP evaluation board stack

The evaluation board is 60 mm wide and 50 mm long.

To remove the excess heat from the BGA3131, it is common practice to spread the heat in the copper layers and at the same time draw the heat from the package towards the bottom of the evaluation board using through vias.

To enable the heat spreading, as much copper as possible should be used in each layer.

4. Thermal considerations

4.1 Spreading versus conduction

As already mentioned, the evaluation board uses both heat spreading as well as conduction to remove the heat from the BGA3131. To determine the amount of spreading and conduction needed in the actual application depends on the available cooling method. If the heat is to be moved into the surrounding air, spreading is the most important factor. In case the topside of the PCB is enclosed (e.g. EM shielding), the heat needs to be conducted to the bottom of the PCB and spreading on the bottom layer is required. If a heatsink is applied, the PCB thermal conduction is more important.

On a typical PCB, comparable to the NXP evaluation board and using Cu filled vias, no heatsink is required until an ambient temperature of 50°C and a duty cycle of 100%. Here the cooling can be done using natural convection only, thus cooling by air. In case a higher ambient temperature is expected, application of a heatsink is required. Prerequisite is that the PCB contains thermal vias below the BGA3131 to allow the heat to flow towards the PCB bottom surface as well as the inner metal layers.

4.2 Via configuration

Purpose of adding through vias below the BGA3131 ground pad is, apart from an electrical connection to the ground layers, is to increase the thermal conductivity between the BGA3131 and the bottom side of the PCB.

Theoretically, the more vias are placed in the ground solder pad, the lower the thermal resistance of the PCB in that area. But this is only valid for solid vias as open vias create voids in the thermal path by themselves and might wick the solder away from the interface between BGA3131 and PCB. To prevent solder wicking, the vias should be capped or tented, as shown in Fig 2. Capping is the preferred option as it leaves the solder area as well as the potential heatsink contact area intact. The number of vias that can be applied depends on the PCB process capabilities.

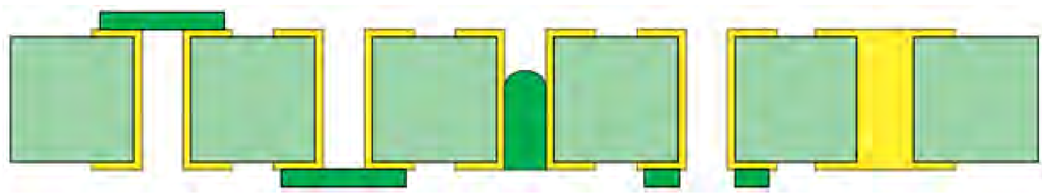

Fig 2. Via capping, tenting and filling, from left to right: via tenting from top, via tenting from bottom, via capping from bottom, via encroached from bottom and Cu filled via

In general, the optimal number of vias can be determined by calculating the copper area vs the dielectric material and air areas. By varying the via drill size and pitch, the amount of copper can be maximized. Because of the wide variety in process capabilities between materials and suppliers it is not possible to give a general recommendation.
In any case the copper area should be maximized while at the same time minimizing the air area.

To increase the thermal conductivity of the via and at the same time increasing the copper area below the BGA3131 and preventing solder wicking is to use Cu filled vias.

In the NXP evaluation board, 25 vias are placed in a 5x5 matrix below the ground pad. These vias have a diameter of 0.3 mm and are solid copper filled. With this via configuration, the maximum allowed ambient temperature is 50 °C and at 100% duty cycle.

If a higher ambient temperature is expected, a heatsink should be applied.

5. Application of a heatsink

5.1 Calculating the heatsink properties

When a higher ambient temperature is expected, the thermal resistance of the PCB might become too large to enable sufficient heat flow between junction and ambient. In that case a heatsink must be used. Goal of the heatsink is to draw the heat from the (bottom) of the PCB faster than natural or forced convection alone will do.

The heatsink is specified by a heat resistance. This heat resistance is depending on the heatsink material, but the most important contributor is the area of the fins. It depends on the airflow in the application what size this heatsink must be.

To calculate the required heatsink resistance, the required Rth,j-a must be known. Substracting the Rth,j-c, Rth,c-pcb_bot and Rth, pcb_bot-heatsink from this value results in the required heatsink resistance.

In some cases the application does not allow the size of the heatsink calculated. The solution would be to increase the convection heat transfer coefficient by increasing airspeed. The heatsink thermal resistance in inversely proportional to the convection heat transfer coefficient times the contact area of the heatsink to the PCB. E.g. if the application allows for a heatsink of only half the size calculated, the convection heat transfer coefficient needs to be increased by a factor of 2 to maintain the required heatsink thermal resistance.

5.2 Considerations

The most obvious way to control the airspeed is the use of fans. But it is also possible to create an increased airflow using natural convection by creating a chimney effect. To design this effect advanced flow simulator software is required.

To reduce the thermal resistance between PCB heatsink, it is advised not to have solder mask material on the PCB bottom side, at least not in the contact area between PCB and heatsink.

5.3 Heatsink requirements for the BGA3131 on the NXP evaluation board

Depending on the ambient temperature it may be required to apply a heatsink under the PCB below the BGA3131. Under the foreseen ambient temperature, the junction temperature of the BGA3131 is to be kept below 150 dC. On the NXP evaluation board with 25 vias and in still air, the maximum ambient temperature is 50 dC @ 5V, 660mA and 100% duty cycle. When the ambient temperature is expected to be higher, a heatsink needs to be used.

Good results have been achieved using an evaluation board with 25 vias and a heatsink (Fisher Elektronik SK567, length 50 mm) with a resistance of 3.8 W/K. But because of the size, this heatsink is considered to be non-realistic for actual applications.

Using the new evaluation board with the 25 via configuration, the calculation as described in 5.1 results in a heatsink with a thermal resistance of 7 K/W. A heatsink with this resistance value is significantly smaller in size than the original one, e.g. Fisher Elektronik SK179 with a length of 37.5 mm.

It is recommended to use a thermal paste between board and heatsink with a thermal conductivity of around 1 W/mK. At the same time it is recommended to (locally) remove the bottom PCB solder mask to decrease the resistance between board and heatsink as much as possible.

		Power				
		V [V]	I [mA]	P [W]		
		5	660	3.3		
Required maximum Tj [dC]			150			
					Rth, junction to case [K/W]	6.0
Required	Rth,j-a	=(Tj-Ta)/P	19.7		Rth, case to PCB bottom [K/W]	6.7
					Rth, PCB bottom to heatsink [K/W]	0.04
					Rth, heatsink to ambient [K/W]	7.0
Ambient temperature Ta [dC]			85			

Fig 3. BGA3131 heatsink thermal resistance

6. Effect of the duty cycle

The recommendations above are based on a 100% duty cycle or steady state. In the final application, the BGA3131 isn't used continuously but in a burst mode. In worst-case situation, the device is 6msec on and 6msec off, which can be tested with a 50% duty cycle signal of 83Hz. Under this condition, extra margin is found.

Measurements have been done to the BGA3131 on a NXP application board, but without heatsink. Temperature measurements were taken at room temperature and at 100% as well as 50% duty cycle. For the latter, measurements were taken at 10 and 83Hz.

Compared to 100% duty cycle, the average junction temperature was reduced by more than 30 degrees at 50% / 10 Hz and 50% / 83Hz.

7. Temperature measurement through sensing diode

To assess the thermal performance of the BGA3131, a temperature sensing diode has been built in. The characteristics of this diode can be found in Fig4.
Please note that the offset between diode and junction is already compensated for in this data.

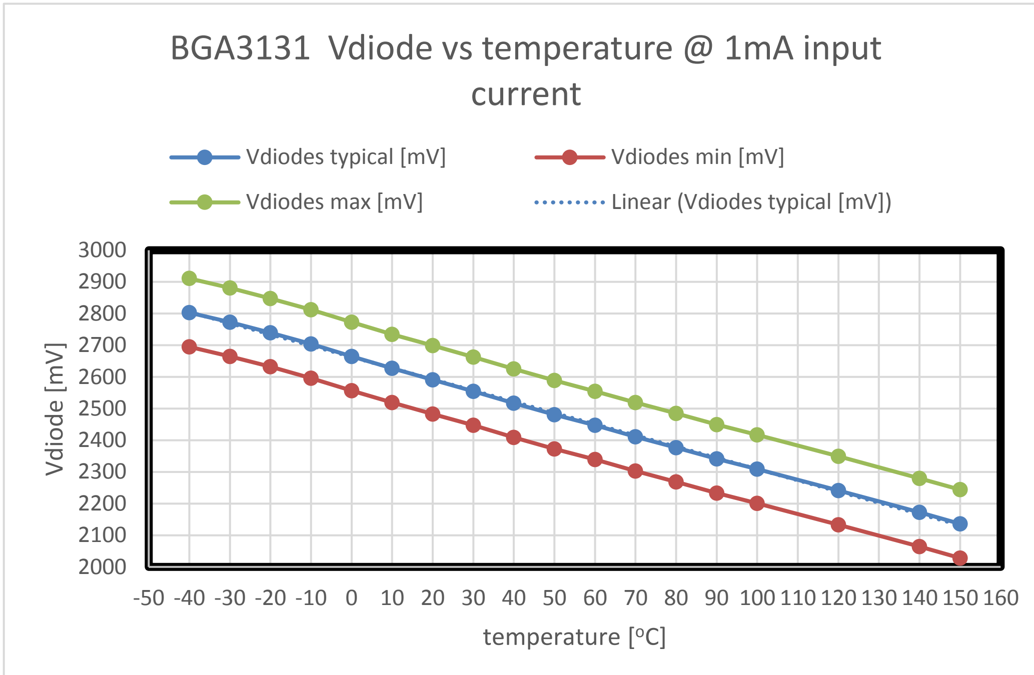

Fig 4. Thermal diode voltage spread as function of junction temperature

The Vdiode voltage can be calculated as Vdiode = -m*x+b+c
m = slope (low spread) 3.5 mV/ °C
b = constant (high spread) 2650 mV
c = offset between diode and junction (15 mV = roughly 4 °C)
x = junction temperature in °C

The Thermal diode voltage can vary up to +/- 30 °C as showing in the Fig 4.

The junction temperature can be measured more accurate by recording the diode voltage versus temperature on the actual used BGA3131.
This can be done by measuring the diode voltage (at 1mA) at two different ambient temperatures (for example 0 °C & 50 °C) and draw the function in a graph.

Measurement conditions/steps:

- 5V supply at BGA3131 (switch ON BGA3131)
- Roughly 660 mA current (at max gain)
- TX_OFF mode by applying 0V on the TX_EN (pin 9)
- Roughly 27 mA current (BGA3131 is in TX_OFF mode)
- Constant current (1mA) at BGA3131 pin 16 (TMP_SENS)
- Set Ambient temperature to 0 °C, read voltage (b = constant) at pin 16 after it's stabilized
- Set Ambient temperature to 50 °C, read voltage at pin 16 after it's stabilized.
- Calculate the slope (m) voltage @50 °C minus voltage @ 0 °C divided by 50
- Vdiode (Tj) = -m *(Tj) + b + 15mV
- Draw the graph using the formula above

- Now the BGA3131 can be switched on, measure the Vdiode (@1mA) at the desired ambient temperature and read out the junction temperature by using the graph

8. Conclusion

Defining the optimal via and heatsink configuration is highly dependent to the actual application. The configurations given in this document are valid for the NXP evaluation board in free air. For an application with a tight enclosure and/or forced convection, the circumstances can be very different. It is Extra margin is found when the BGA3131 is used at a lower duty cycle percentage.

Measurements have been done to the BGA3131 on a NXP application board, but without heatsink. Temperature measurements were taken at room temperature and at 100% as well as 50% duty cycle. For the latter, measurements were taken at 10 and 83Hz.

Compared to 100% duty cycle, the average junction temperature was reduced by more than 30 degrees at 50% / 5 Hz, 50% / 10 Hz and 50% / 83Hz.

9. Legal information

9.1 Definitions

Draft — The document is a draft version only. The content is still under internal review and subject to formal approval, which may result in modifications or additions. NXP Semiconductors does not give any representations or warranties as to the accuracy or completeness of information included herein and shall have no liability for the consequences of use of such information.

9.2 Disclaimers

Limited warranty and liability — Information in this document is believed to be accurate and reliable. However, NXP Semiconductors does not give any representations or warranties, expressed or implied, as to the accuracy or completeness of such information and shall have no liability for the consequences of use of such information.

In no event shall NXP Semiconductors be liable for any indirect, incidental, punitive, special or consequential damages (including - without limitation - lost profits, lost savings, business interruption, costs related to the removal or replacement of any products or rework charges) whether or not such damages are based on tort (including negligence), warranty, breach of contract or any other legal theory.

Notwithstanding any damages that customer might incur for any reason whatsoever, NXP Semiconductors' aggregate and cumulative liability towards customer for the products described herein shall be limited in accordance with the Terms and conditions of commercial sale of NXP Semiconductors.

Right to make changes — NXP Semiconductors reserves the right to make changes to information published in this document, including without limitation specifications and product descriptions, at any time and without notice. This document supersedes and replaces all information supplied prior to the publication hereof.

Suitability for use — NXP Semiconductors products are not designed, authorized or warranted to be suitable for use in life support, life-critical or safety-critical systems or equipment, nor in applications where failure or malfunction of an NXP Semiconductors product can reasonably be expected to result in personal injury, death or severe property or environmental damage. NXP Semiconductors accepts no liability for inclusion and/or use of NXP Semiconductors products in such equipment or applications and therefore such inclusion and/or use is at the customer's own risk.

Applications — Applications that are described herein for any of these products are for illustrative purposes only. NXP Semiconductors makes no representation or warranty that such applications will be suitable for the specified use without further testing or modification.

Customers are responsible for the design and operation of their applications and products using NXP Semiconductors products, and NXP Semiconductors accepts no liability for any assistance with applications or customer product design. It is customer's sole responsibility to determine whether the NXP Semiconductors product is suitable and fit for the customer's applications and products planned, as well as for the planned application and use of customer's third party customer(s). Customers should provide appropriate design and operating safeguards to minimize the risks associated with their applications and products.

NXP Semiconductors does not accept any liability related to any default, damage, costs or problem which is based on any weakness or default in the customer's applications or products, or the application or use by customer's third party customer(s). Customer is responsible for doing all necessary testing for the customer's applications and products using NXP Semiconductors products in order to avoid a default of the applications and the products or of the application or use by customer's third party customer(s). NXP does not accept any liability in this respect.

Export control — This document as well as the item(s) described herein may be subject to export control regulations. Export might require a prior authorization from national authorities.

Evaluation products — This product is provided on an "as is" and "with all faults" basis for evaluation purposes only. NXP Semiconductors, its affiliates and their suppliers expressly disclaim all warranties, whether express, implied or statutory, including but not limited to the implied warranties of non-infringement, merchantability and fitness for a particular purpose. The entire risk as to the quality, or arising out of the use or performance, of this product remains with customer.

In no event shall NXP Semiconductors, its affiliates or their suppliers be liable to customer for any special, indirect, consequential, punitive or incidental damages (including without limitation damages for loss of business, business interruption, loss of use, loss of data or information, and the like) arising out the use of or inability to use the product, whether or not based on tort (including negligence), strict liability, breach of contract, breach of warranty or any other theory, even if advised of the possibility of such damages.

Notwithstanding any damages that customer might incur for any reason whatsoever (including without limitation, all damages referenced above and all direct or general damages), the entire liability of NXP Semiconductors, its affiliates and their suppliers and customer's exclusive remedy for all of the foregoing shall be limited to actual damages incurred by customer based on reasonable reliance up to the greater of the amount actually paid by customer for the product or five dollars (US$5.00). The foregoing limitations, exclusions and disclaimers shall apply to the maximum extent permitted by applicable law, even if any remedy fails of its essential purpose.

9.3 Trademarks

Notice: All referenced brands, product names, service names and trademarks are property of their respective owners.

10. List of figures

11. Contents

Date of release: 23 March 2017
Document identifier: AN11753