# Application note for MERUS™ MA120xxx

## Thermal guide

## About this document

### Scope and purpose

This application note estimates the thermal resistance junction to ambient ($\theta_{JA}$) of the MERUS™ multi-level audio amplifers MA12040, MA12040P, MA12070 and MA12070P. The intention is to enable the user to do first-order approximated calculations to estimate the junction temperature of the MA120xxx devices in real use cases. The thermal resistance junction to ambient $\theta_{JA}$ will not be measured according to the JESD-51 standard. Instead a more practical approach will take place, and the $\theta_{JA}$ will be measured with the PCB placed horizontally on a table with only natural convection. The $\theta_{JA}$ will be measured with different PCB layer stack-ups.

### Intended audience

Audio amplifier design engineers, audio system engineers and audio software engineers.

## Table of contents

# 1 Introduction

The output power specification is different for every speaker product, and it's directly linked to the thermal design of the PCB, the power dissipation of the amplifier and the signal/music that is being played. The motivation behind this application note is to give the user an idea of how all this is linked together.

Amplifiers are sometimes tested with a 1 kHz sine wave at maximum output power with 10 percent THD + N to achieve more than 90 percent efficiency. It's important to be able to reproduce the maximum output power, but not continuously. This will in many cases lead to an unnecessarily over-designed, expensive system. The power supply, PCB, thermal design, battery, speaker, etc. must all be designed to support high continuous output power. For music reproduction a continuous output level of 1/8 of the maximum output power is in many cases sufficient. Designing for 1/8 of the output power will significantly lower the requirements and the cost of the whole system.

To optimize the whole system you start by analyzing the source and in this case the signal or music that are being played. A sine wave with 10 percent THD + N is something in between a square wave and a sine wave, and the crest factor (peak-to-average ratio) will therefore also be something in between 0 dB (square wave) and 3 dB. The crest factor for a pure sine wave is 3 dB, while it is 6 dB for heavily compressed music. Music normally have a crest factor between 10 dB and 14 dB, while classical music can go above 20 dB. In many cases, with music playback it is enough to design the continuous output power to 1/8 of the maximum output power; this corresponds to 9 dB. With a well-defined requirement for the signal and the crest factor, the designer can move on to the amplifier.

The power loss for the MA120xxx amplifier depends on the supply voltage, load impedance, power mode profile and output configuration. High power supply voltage and low impedance will lead to higher power loss in the amplifier. The power mode profiles of MA120xxx amplifiers have different properties and an impact on the efficiency of the amplifier. With the amplifier design in place, the next step is the PCB layout and stack-up.

The most important aspect to keep the amplifier cool is a good PCB layout and thermal heat flow. Follow the guide in section 2 Recommended PCB layout. The designer can now choose the PCB stack-up and decide if a heatsink is needed or not.

This document estimates the thermal resistance junction to ambient for different PCB stack-ups in real use cases. For an overview of the stack-ups, see **Error! Reference source not found.**. The four-layer PCB is tested with and without a heatsink, and a picture of the different boards is shown in Figure 1 and Figure 2.

**Table 1 PCB layer stack-ups**

| | Two-layer 1 oz | Two-layer 2 oz | Four-layer | Four-layer with heatsink |
|---|---|---|---|---|
| Top layer | 1 oz | 2 oz | ½ oz | ½ oz |
| Inner layer 1 | N/A | N/A | 1 oz | 1 oz |
| Inner layer 2 | N/A | N/A | 1 oz | 1 oz |
| Bottom layer | 1 oz | 2 oz | ½ oz | ½ oz |

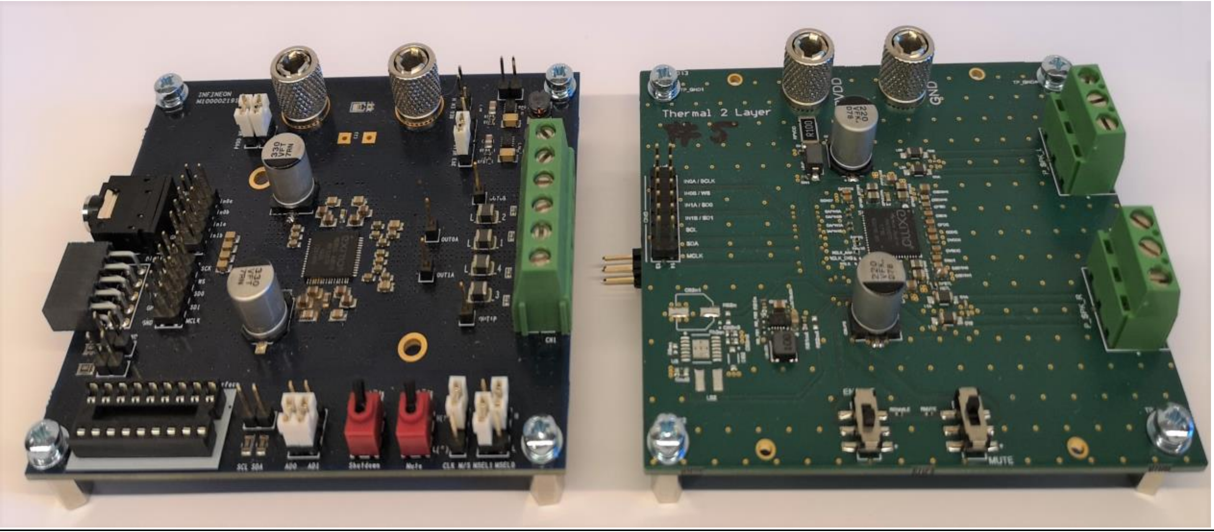


**Figure 1** Two-layer 1 oz PCB (EVK) (left), two-layer 2 oz PCB (right)

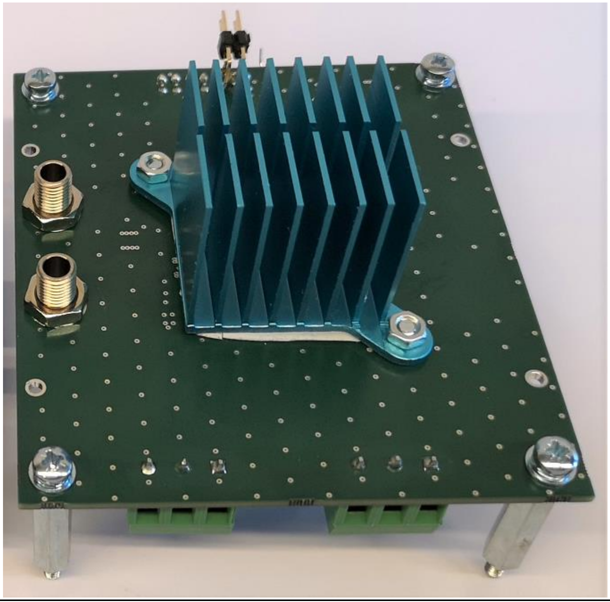

**Figure 2** Four-layer board with heatsink mounted on the bottom side

# 2 Recommended PCB layout

The QFN package with exposed thermal pad on the bottom side is thermally sufficient for most applications. However, in order to remove heat from the package care should be taken in designing the PCB.

The PCB footprint for the device should include a thermal relief pad underneath the device with a size of 6 x 6 mm. This thermal relief pad must be centered so the device can be soldered easily. It is recommended to use a PCB design with two or more layers of copper for good thermal performance. Using multiple layers enables a design with a large area of copper connected to the EPAD.

To achieve best thermal performance it is also important to design the surrounding connections in such a way as to avoid cutting the copper area into many sections.

Figure 3 shows a PCB design using 5 x 5 via connections directly underneath the chip between the top and bottom layers. These should be placed on grids, each with a 0.65/0.25 mm plated through-hole. A grid of 6 x 6 or 7 x 7 vias gives minor improvements to the thermal performance. The via connections ensure good thermal transfer from the top-side EPAD to a large section of ground-connected copper area on the bottom side of the PCB.

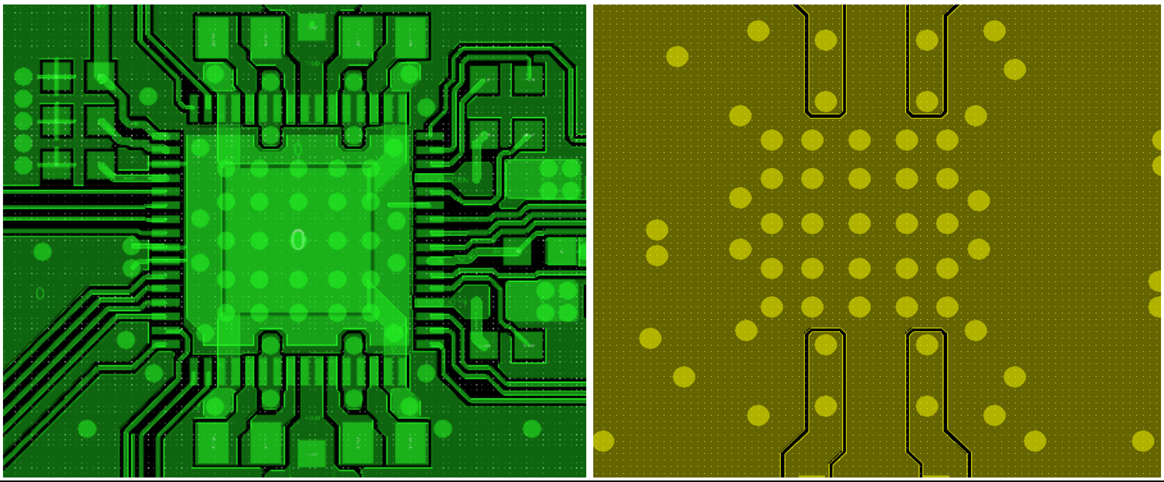

**Figure 3 Example of two-layer PCB layout, top and bottom layers**

It is recommended to use a PCB made from glass/epoxy laminate (e.g. FR-4) material. This type of material works well with PCB designs that require thermal relief, as it can endure high temperatures for a long duration.

PCB copper thickness is recommended to be a minimum of 35 µm (1 oz) and the PCB must be made to the IPC 6012C, Class 2 standard.

For information about the heatsinks see Appendix A.

# 3 Thermal resistance measurement

The thermal resistance is not measured according to the JESD51-x standards. The standards are made to compare thermal resistance across different manufacturers, but they do not provide thermal information on how the device performs in a real lab bench. The $\theta_{JA}$ in this application note is measured for the MA120xxx EVK boards when placed horizontally on a table. This will enable the user to estimate the junction temperature when the EVK is used in a lab bench. Before measuring the $\theta_{JA}$ it is necessary to calibrate the PN junction of the internal diode inside the MA120xxx devices. The diode will be used as temperature sensor to measure the junction temperature of the MA120xxx amplifiers.

## 3.1 Calibrating the thermal dependency of the diode

The following section is a description of the measurement method. It does not contain the full information of how to calibrate the thermal dependency of the diode. For more information contact Infineon.

A PN junction of a diode embedded in the IC is used as temperature sensor. When a current is injected in the diode, a voltage drop across it has a linear dependency with temperature. The temperature of the chip can be calculated based on the reading of the forward voltage drop of the diode. The procedure to calibrate the temperature sensor is as follows:

- Place the PCB in a calibrated temperature chamber with power supply, a voltmeter connected to the error pin and $I^2C$ communication to a PC.
- Set the temperature of the chamber to 25°C and let the temperature settle; this will take approximately 30 minutes. Keep the power supply off to avoid any self-heating.
- A script is used to set up the error pin (redirect the forward voltage to the error pin) and to read out the forward voltage drop of the diode. For more information, contact Infineon.
- As soon as the amplifier is turned on, run the script to measure the forward voltage.
- Repeat the steps with 50°C, 75°C, 100°C and 125°C.
- Calculate the linear trend line for the temperature/voltage dependency from the readings. This can be done with Excel.
- The junction temperature of the amplifier can now be calculated based on the temperature vs. voltage curve.

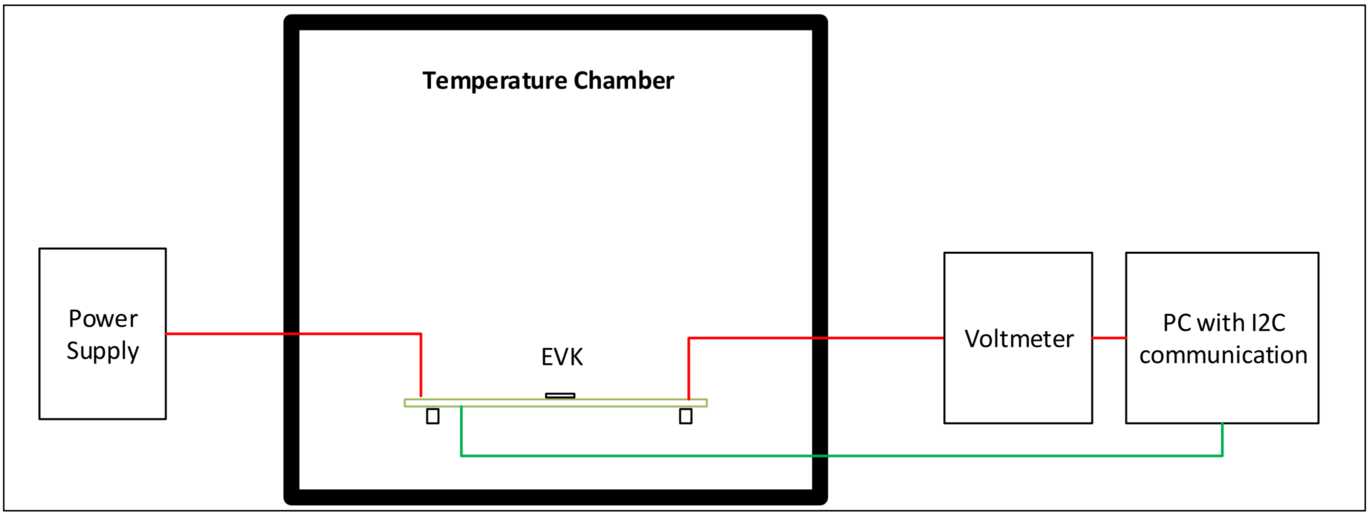


**Figure 4 Measurement set-up to calibrate the diode**

## 3.2 Thermal resistant junction to case and junction to ambient measurement

Use the calibrated diode voltage dependency to measure the thermal resistant junction to ambient $\theta_{JA}$ and a thermal camera to measure the junction to case $\theta_{JC\text{-}top}$. The following steps describe the procedure:

- Place the EVK on a table with power supply, load and an APx525 audio analyzer connected.
- Place a temperature sensor 30 cm from the board to measure the ambient temperature.
- Place a thermal camera above the amplifer to measure the case temperature. The amplifier case is made of black plastic and the emissivity of the camera is set to 0.95 – see Figure 5.
- The supply voltage PVDD is measured with a voltmeter with probes connected as close to the input pins of the amplifier as possible (not shown in Figure 5).
- The input current (PVDD) is measured with an ammeter in series with the power supply (not shown in Figure 5).
- The 5 V regulator on the EVK is bypassed, and an external 5 V supply voltage is connected in order to measure the input power for AVDD and DVDD.
- Measure the impedance of the load and use the APx525 to measure the output power.
- Increase the output power until the junction temperature of the amplifier reaches approximately 125°C, and let the temperature settle – see Figure 6.
- Measure the junction temperature, the case temperature, the ambient temperature and the power dissipation of the amplifier, and calculate the thermal resistances $\theta_{JA}$ and $\theta_{JC\text{-}top}$.

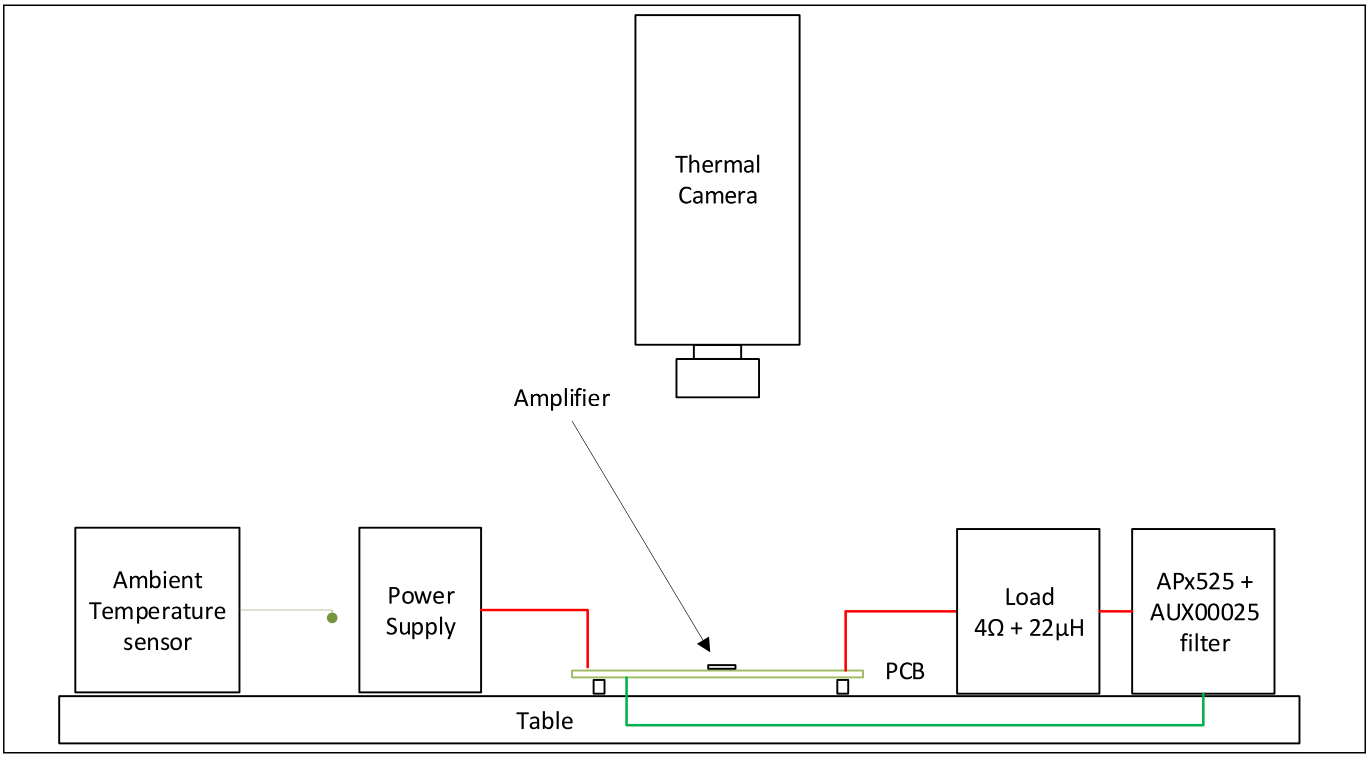


**Figure 5 Thermal resistance measurement set-up**

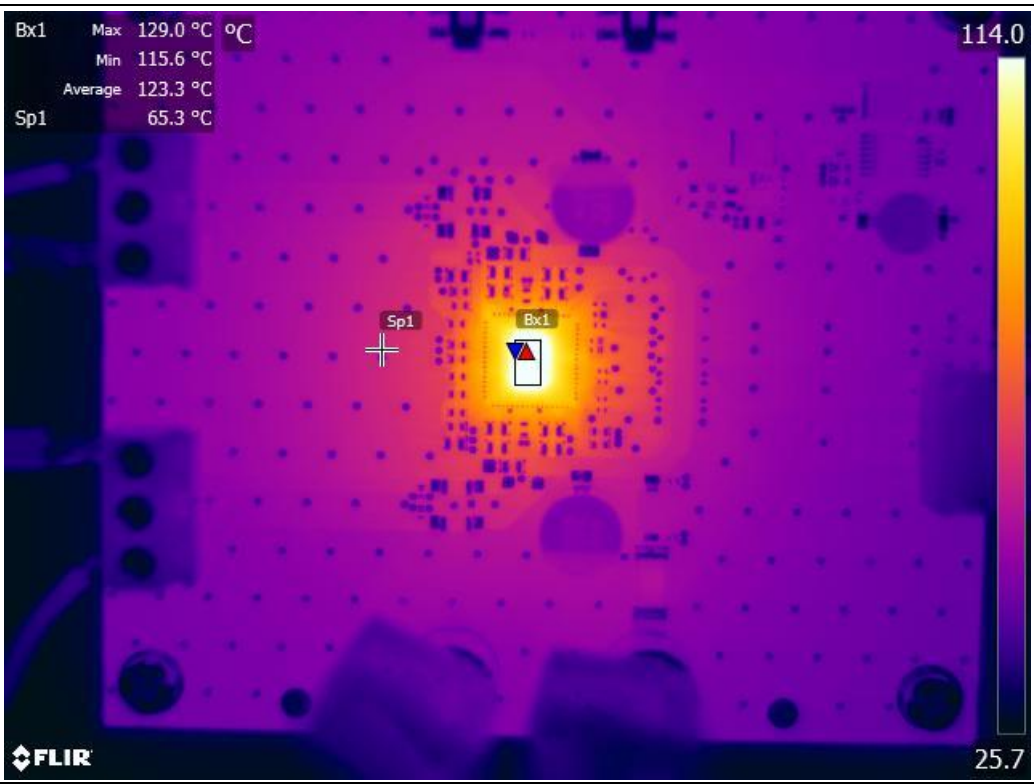


**Figure 6 Thermal image of four-layer board with the saturated temperature close to 125°C. Conditions are 24 V, 2 x BTL, 4 Ω load, PMP0, 2 x 11.23 W output power.**

# 4 Measurement results

Before measuring the thermal resistance the diode junction voltage vs. temperature must be calibrated – see section 4.1. Section 4.2 shows the results of the thermal resistance. Section 4.3 estimates the junction temperature vs. the output power, and the result is compared with real measurements. The profiles have an impact on the efficiency of the amplifier and therefore also the junction temperature.

## 4.1 Diode junction voltage vs. temperature

Calibrating the diode junction voltage vs. temperature is an intermediate result used to measure the junction to ambient and the junction to top case thermal resistance.

The measured results show a very linear voltage to temperature dependency of the diodes. The linear trend lines (dotted lines) are calculated in Excel and the equation is used to calculate the junction temperature of each device.

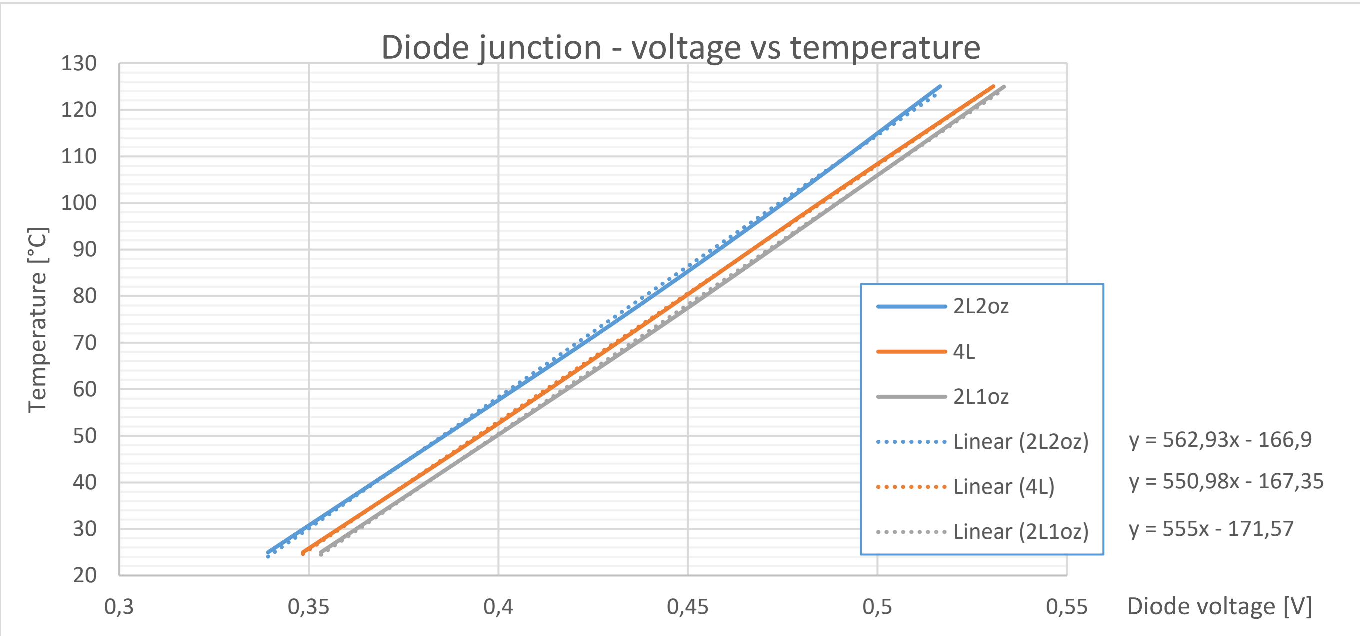


**Figure 7** **Diode junction voltage vs. temperature**

## 4.2 Thermal resistance $\theta_{JA}$ and $\theta_{JCtop}$

The thermal resistances $\theta_{JA}$ and $\theta_{JCtop}$ have been measured with the procedure described in section 3.2. The thermal approximation is based on efficiency measurements of the MA120xxx devices. These measurements were taken quickly, before thermal saturation of the PCB and before the $R_{on}$ resistance of the output stage had increased too much. The thermal resistance is measured when the PCB is thermally saturated and the $R_{on}$ resistance is at its highest. To compensate for these differences a 10 percent margin is added in table 2.

**Table 2** **Thermal resistance**

| Board type | $\theta_{JA}$ [°C/W] | $\theta_{JCtop}$ [°C/W] |
|---|---|---|
| 4L (1 oz inner layer, ½ oz outer layer) | 15.4 | 2.0 |
| 4L + heatsink on bottom | 10.2 | 2.0 |

| Board type | $\theta_{JA}$ [°C/W] | $\theta_{JCtop}$ [°C/W] |
|---|---|---|
| 2L 1 oz | 25.6 | 2.0 |
| 2L 2 oz | 17.2 | 2.0 |

## 4.3 Output power vs. junction temperature

Based on the results obtained in the previous sections the junction temperature for different output power levels can now be estimated. The saturated temperature is reached after approximately 30 minutes of continuous playback. The junction temperature estimation is based on the measured efficiency curves of the MA12070 and verified with measurements for the four-layer board – see Figure 8. The results should only be used as a guide, as many factors affect the thermal resistance of a PCB. Good layout is still crucial for good thermal performance.

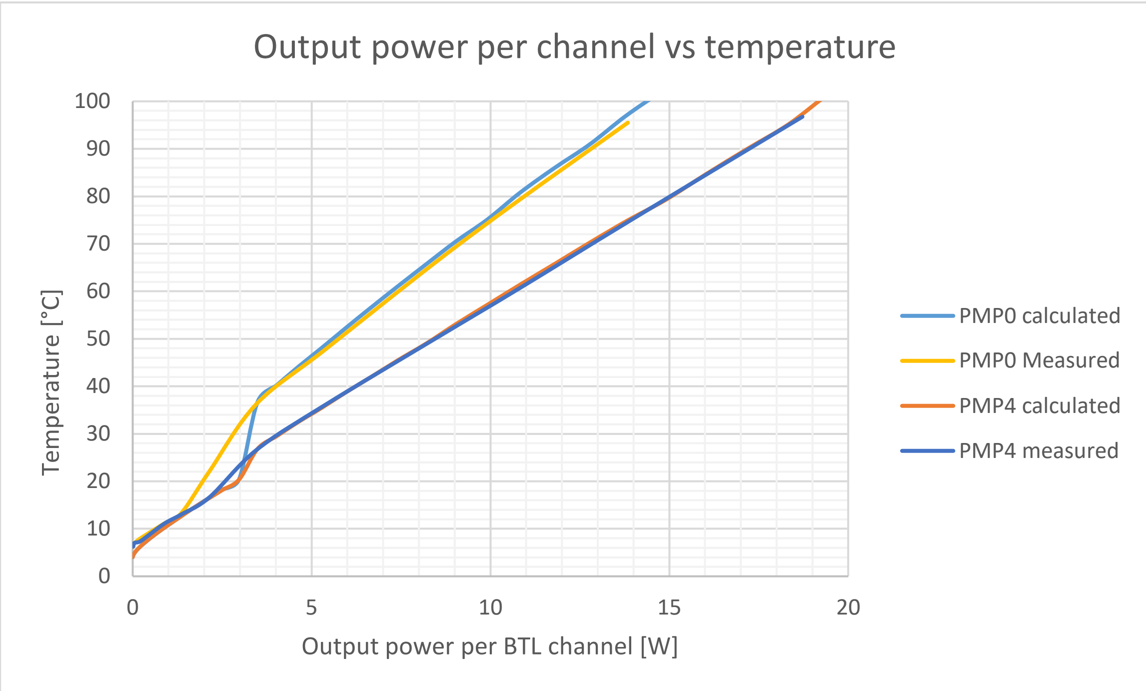


**Figure 8 Output power vs. junction temperature, calculated vs. measured, 18 V PVDD, 2 x BTL, 4 Ω load**

The estimated temperature for a MA12070 with the conditions 2 x BTL, 4 Ω load, PVDD 18 V, natural convection only, PCB placed horizontally 10 mm above the table: for PMP0 see Figure 9; for PMP4 see Figure 10.

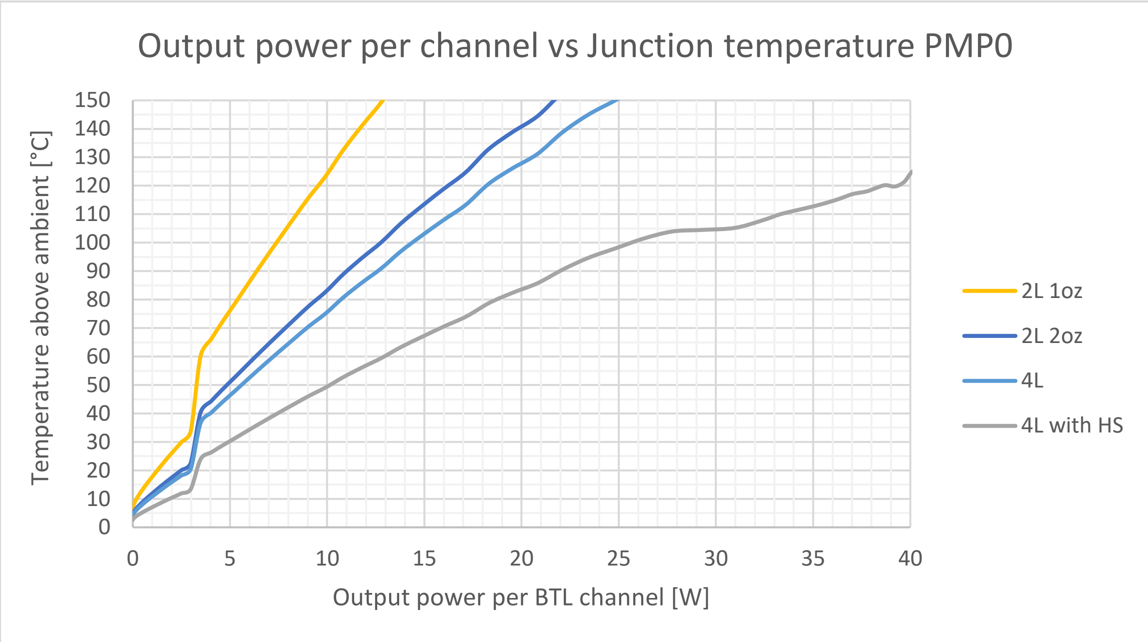


**Figure 9 Output power vs. junction temperature PMP0, 18 V PVDD, 2 x BTL, 4 Ω load**

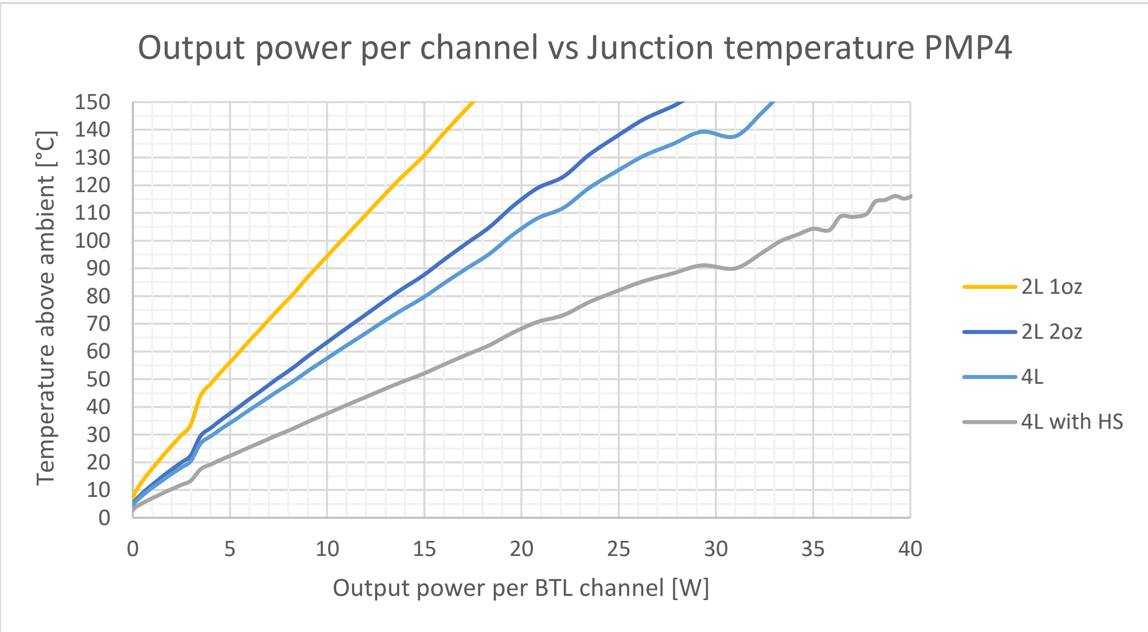


**Figure 10 Output power vs. junction temperature PMP4, 18 V PVDD, 2 x BTL, 4 Ω load**

The estimated temperature for a MA12070 with the conditions 2 x BTL, 8 Ω load, PVDD 26 V, natural convection only, PCB placed horizontally 10 mm above the table; for PMP0 see Figure 11; for PMP4 see Figure 12.

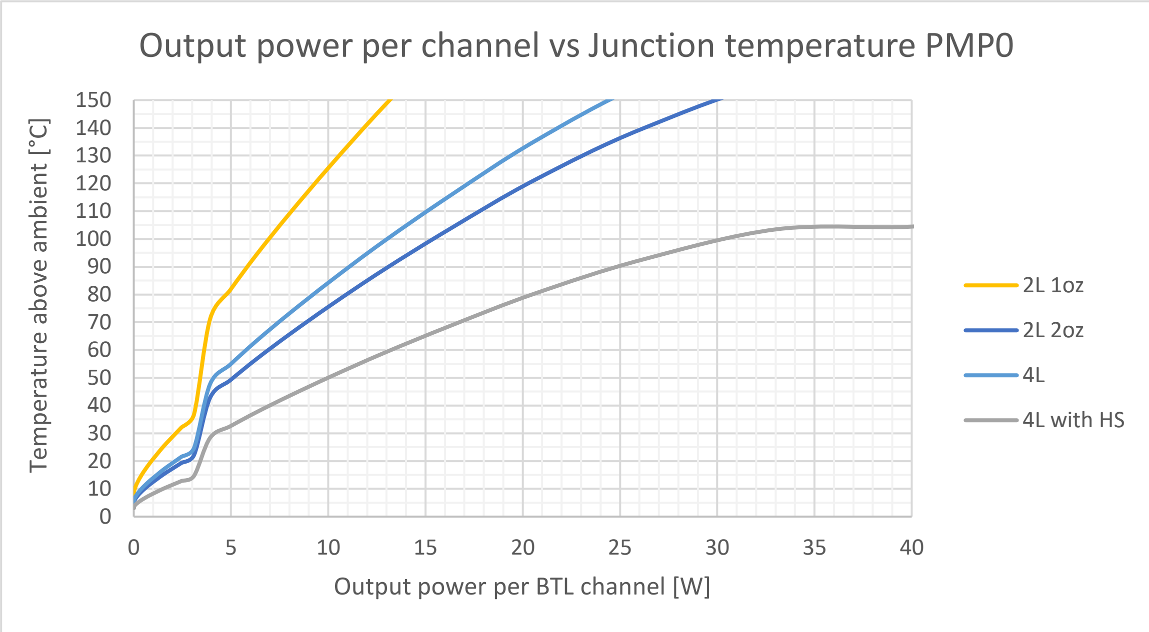


**Figure 11** **Output power vs. junction temperature PMP0, 26 V PVDD, 2 x BTL, 8 Ω load**

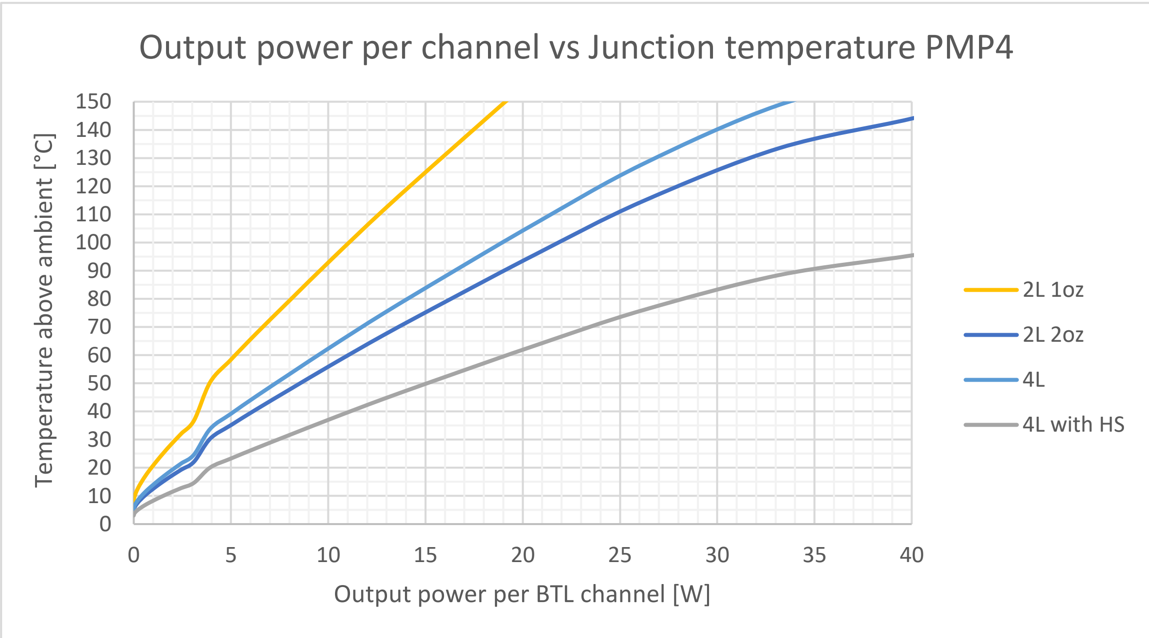


**Figure 12** **Output power vs. junction temperature PMP4, 26 V PVDD, 2 x BTL, 8 Ω load**

The estimated temperature for a MA12070 with different crest factor signal and a four-layer board is given, with the conditions 2 x BTL, 4 Ω load, PVDD 26 V, PMP0, natural convection only, PCB placed horizontally 10 mm above the table. Figure 13 estimates the junction temperature for a sine wave compared with 6 dB (1/4) and 9 dB (1/8) crest factor signals. For the 6 dB and 9 dB crest factor signals it is the peak power that is illustrated in Figure 13; the average output power is 1/4 or 1/8 of a sine wave. This shows that there is a huge difference between sine waves and music. The lower average output power of the 6 dB and 9 dB crest factor signals results in a lower efficiency of the amplifier; this is taken into account in the estimation. The 6 dB and 9 dB crest factor signals reduce the junction temperature significantly.

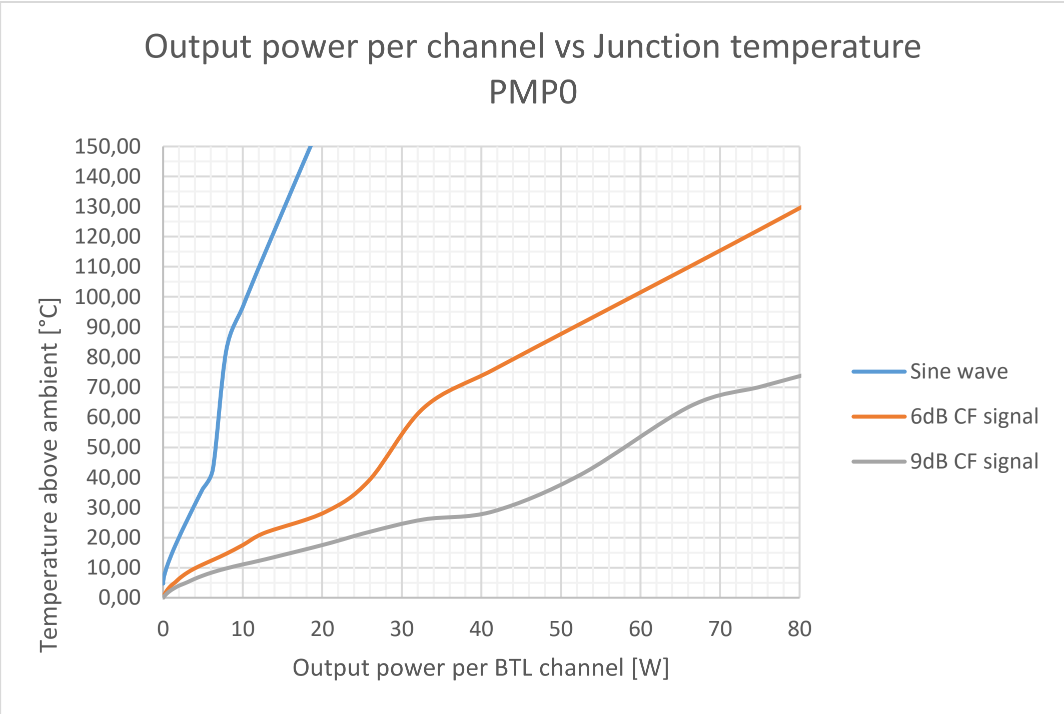


**Figure 13** **Sine wave vs. 6 dB and 9 dB crest factor signal, PMP0, 26 V PVDD, 2 x BTL, 4 Ω load**

# 5 PCB selection guide

Based on the measurement results it is clear to see that many parameters affect the junction temperature of the amplifier. Signal crest factor, supply voltage, power mode profile, load impedance and the output power all affect the selection of the PCB stack-up, and whether a heatsink is required or not. The pentagon in Figure 14 gives an estimate for how much cooling is required to keep the amplifier cool. The green pentagon shows a 1 oz, two-layer board. The orange pentagon shows a 2 oz, two-layer board or 1 oz, four-layer board. The red area shows a four-layer board with heatsink. An example is given with the requirements 9 dB crest factor, PMP4, 4 Ω load, 10 W to 20 W per channel output power and a supply voltage of 24 V. Connecting the dots will give an area that is close to the yellow pentagon; this means that a 2 oz, two-layer board or a 1 oz, four-layer board will provide sufficient cooling for the amplifier.

The selection guide is only a rough estimation to choose the PCB stack, it can't replace thermal measurements.

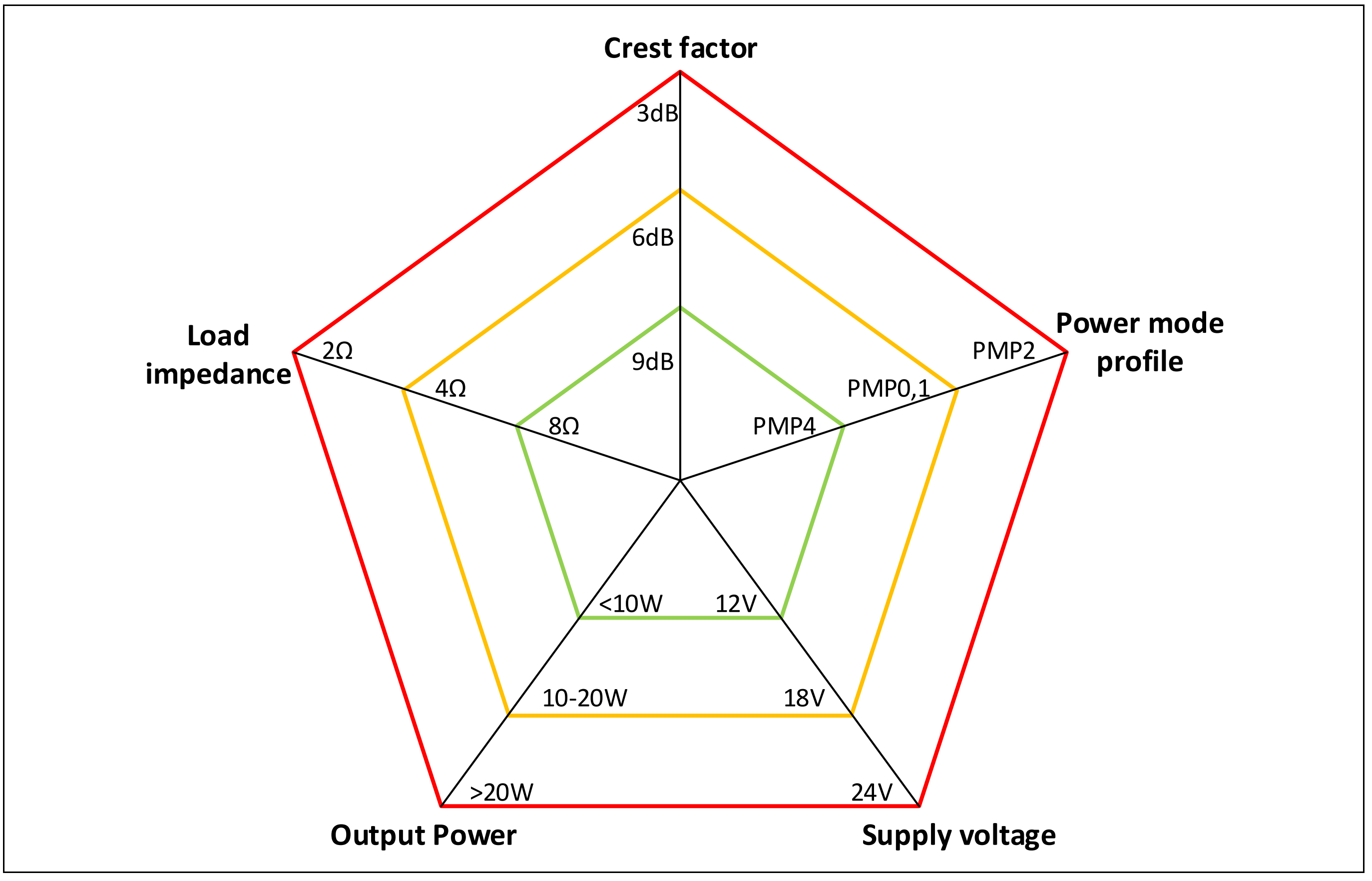


**Figure 14 PCB selection guide**

# 6 Conclusion

The thermal resistance junction to ambient for all amplifiers is highly dependent on the PCB layout, the PCB stack-up and the use of heatsinks. The thermal resistances found in this application note should only be used as a guide to the junction temperature. Many factors such as load impedance, power mode profile, supply voltage, etc. affect the efficiency of the amplifier and therefore also the junction temperature of the amplifier.

The MERUS™ MA120xxx amplifiers are optimized for music playback, and in many cases it is sufficient to only use the PCB as a heatsink. This is clearly shown in Figure 14, where the 6 dB and 9 dB crest factor signals reduce the junction temperature significantly compared to a sine wave (3 dB).

If high output power and sine wave playback is needed it is recommended to use a heatsink.

Comparing the estimated junction temperature with the measured junction temperature shows a good correlation for the four-layer board in both PMP0 and PMP4.

# 7 Appendix A

The heatsink to place on the bottom of the PCB for the four-layer board is ATS-CPX030030030-145-C2-R0.

https://www.qats.com/Product/Heat-Sinks/BGA-Heat-Sink---High-Performance/Push-Pin/ATS-CPX030030030-145-C2-R0/2710.aspx

## Revision history

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