AN90023

Thermal performance of DFN packages

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Document information

Information	Content
Keywords	Dual flat no leads package, DFN, AOI, ADAS, leadless thermally enhanced, side-wettable flanks
Abstract	This application note presents the thermal performance of Dual flat no leads packages (DFN)

1. Introduction

The increasing number of electronic functions in modern cars must be realized within a given (and limited) space. This has led to a growing device density on printed circuit boards. To tackle device density at a board level it is necessary to shrink the size of the utilized electronic components. At the same time, smaller packages need to dissipate the same amount of heat on a smaller footprint, leading to a higher power density on the board.

Dual Flat No Leads (DFN) packages are a family of very small leadless surface-mount plastic packages – the modern replacement of the bulky leaded surface-mount packages. This application note explains the thermal capability of automotive DFN packages compared to their leaded counterparts, and the required thermal management which is necessary for high power density packages.

2. Package concept

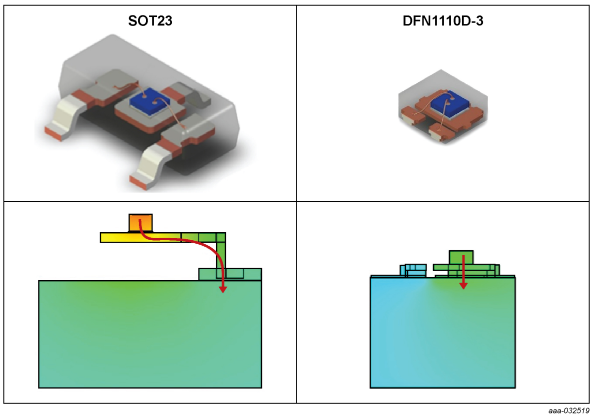

Fig. 1. Thermal simulation of heat flow in SOT23 versus DFN1110D-3

For decades leaded SMD packages have been the industry standard for discrete electronic devices. The structure of perhaps the world’s most prominent SMD package, the SOT23, is shown in Fig. 1. Here the die is positioned on a leadframe which together with the metal pads is fully encapsulated with mold compound. The dominant heat transfer mechanism is heat conduction, as heat convection and radiation are almost irrelevant in the given structure and temperature range. Generated heat is conducted through the die attach layer into the leadframe, and from there it flows through the long leads into the PCB. The thermal simulation in Fig. 1 shows a cross section of a SOT23 packaged device along the leadframe and across the middle of the package – highlighting the heat path.

With the DFN1110D-3, Nexperia’s DFN counterpart of SOT23, there are no leads. With no leads and shorter bond wire lengths, DFN packages have less parasitic inductance compared to their leaded counterparts. The metal pads are more compact and closer to the leadframe. In this way the package dimensions are significantly reduced while still having the same leadframe size below the die. The leadframe effectively serves as an exposed heatsink and electrical contact at the bottom of the package, leading the heat directly from the die into the PCB as shown by thermal simulations in Fig. 1. This explains why DFN packages show excellent power dissipation capability in spite of their very compact dimensions.

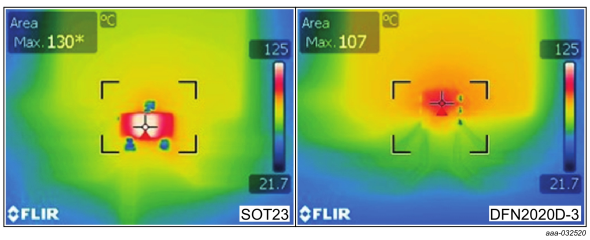

Fig. 2. Infrared measurements on SOT23 and DFN2020D-3

To take full advantage of the DFN packages it is mandatory to use PCBs with low thermal resistance and sufficient thermal conductivity to allow for proper lateral heat spread. The heat is fed directly through the exposed heatsink into the PCB and is transferred through a smaller area on the PCB. The high power density is illustrated by the infrared pictures in Fig. 2, showing a comparison between a SOT23 and DFN2020D-3 dissipating the same power (250 mW). The higher power density and good dissipation of the DFN2020D-3 is obvious, especially as there are no white spots on the package.

3. Overview of Nexperia automotive DFN package range

Table 1 summarizes the available DFN packages and their leaded counterparts. It also illustrates the potential space saving that can be achieved by switching to DFN packages. The space saving is calculated based on the recommended footprint area for reflow soldering. The table does not imply a one to one replacement of leaded packages by DFN packages without an in-depth thermal management. The thermal characteristics of DFN packages and a thermal comparison of some selected DFN packages with their leaded counterparts will be discussed in the next paragraph.

Table 1. Nexperia automotive DFN package range

DFN package type dimensions (mm)	Leaded conterpart package dimensions (mm)	Space saving on PCB (%)
DFN1006BD-2 1.0 x 0.6 x 0.5	SOD323 1.70 x 1.25 x 0.95	78
	SOD523 1.2 x 0.8 x 0.6	57
DFN1110D-3 1.1 x 1.0 x 0.48	SOT23 2.9 x 1.3 x 1.0	75
DFN1412D-3 1.4 x 1.2 x 0.5		66
DFN1608D-2 1.6 x 0.8 x 0.37	SOD123 2.7 x 1.6 x 1.15	81
	SOD123F 2.7 x 1.6 x 1.1	81
DFN2020D-3 2.0 x 2.0 x 0.6	SOT89 4.5 x 2.5 x 1.5	77
	SOT223 6.5 x 3.5 x 1.65	90

4. Thermal performance

Table 2 summarizes the measured typical thermal resistance between junction temperature and the ambient temperature as thermal ground for different PCB types and settings. The resulting P_{tot} is calculated for a ΔT of 125 k (25 °C ambient temperature with a maximum junction temperature of 150 °C). In the following paragraphs the thermal performance of some of the packages are discussed and compared to the leaded counterparts. The die sizes in the following comparison are the same for the leaded packages and the DFN version, so the impact of the die size on the difference in the thermal performance can be excluded.

Table 2. Nexperia automotive DFN package range

DFN package	PCB type dimensions (mm)	Typical $R_{th(j-a)}$ (K/W)	Typical P_{tot} T_j = 150 °C T_{amb} = 25 °C (mW)
DFN1006BD-2	FR4, 70 µm single-sided copper, standard footprint	315	400
	FR4, 70 µm single sided copper, mounting pad for cathode 1 cm^2	160	780
DFN1110D-3	FR4, 35 µm single-sided copper, standard footprint	310	400
	FR4, 70 µm single-sided copper, standard footprint	230 - 260[1]	480 - 540[1]
	FR4, 35 µm single sided copper, mounting pad for cathode 1 cm^2	175 - 200[1]	625 - 715[1]
	FR4, 70 µm single sided copper, mounting pad for cathode 1 cm^2	155	800
DFN1412D-3	FR4, 35 µm single-sided copper, standard footprint	285	440
	FR4, 70 µm single-sided copper, standard footprint	220 - 240[1]	520 - 570[1]
	FR4, 70 µm single sided copper, mounting pad for cathode 1 cm^2	125 - 150[1]	830 - 1000[1]
DFN1608D-2	FR4, 70 µm single-sided copper, standard footprint	270	460
	FR4, 70 µm single sided copper, mounting pad for cathode 1 cm^2	125	1000
	Ceramic (Al_2O_2), standard footprint	78	1600
DFN2020D-3	FR4, 70 µm single-sided copper, standard footprint	210 - 250[1]	500 - 595[1]
	FR4, 70 µm single sided copper, mounting pad for cathode 1 cm^2	110 - 130[1]	960 - 1140[1]
	Ceramic (Al_2O_2), standard footprint	60	2080

[1] The given range for $R_{th(j-a)}$ and P_{tot} highlights the impact of the size of the die in the package on the thermal resistance

5. DFN1110D-3 versus SOT23

As shown in Table 2, the DFN1110D-3 package is capable of dissipating 400 mW on a single sided FR4 board with the standard footprint and 70 µm copper thickness, based on a typical $R_{th(j-a)}$ of 310 K/W. Its leaded counterpart the SOT23 (with 3.4x larger body dimensions) has a typical $R_{th(j-a)}$ of 350 K/W leading to a dissipated power of 360 mW, 10 % less than DFN1110D-3. The measured data are in relatively good agreement with the thermal simulations as shown in Fig. 3.

In the simulation a dissipated power of 250 mW is assumed leading to a junction temperature of 130 °C for the SOT23 and 115 °C for the DFN1110D-3. The lower junction temperature of the die in the DFN package for a given dissipated power level can also be used as extra head room in case de-rating the maximum junction temperature is required due to reliability standards for a specific application. So, the device runs much cooler while delivering significant space savings on the PCB. The excellent thermal performance of DFN1110D-3 can be explained by the already mentioned exposed heatsink leading the thermal power directly into the PCB.

As displayed in Table 2 an increased mounting pad side of 1 cm^2 enables a potential doubling of the dissipated power. The leaded SOT23 package can be simply replaced by the leadless DFN1110D-3 without any loss of thermal capability and with gaining a higher P_{tot} and a huge space saving of 75 % on the PCB.

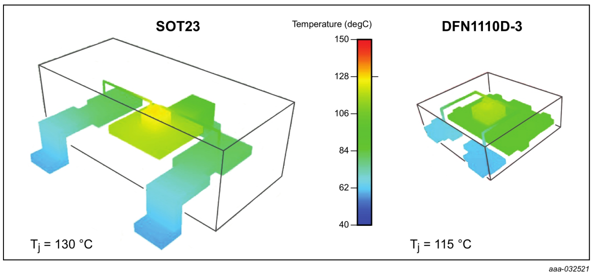

Fig. 3. Thermal performance of SOT23 and DFN1110D-3

Fig. 3: Simulation of the thermal performance of DFN1110D-3 (right) versus SOT23 (left).
Simulation settings: FR4 PCB with 35 µm thick Cu lanes, standard footprint, T_{amb} = 25 °C.
A dissipated power of 250 mW is asumed in the simulation leading to a junction temperature of 130 °C in case of SOT23 and 115 °C for DFN1110D-3.

6. DFN1608D-2 versus SOD123

The two-pin DFN1608D-2 package with a body dimension of 1.28 mm^2 is significantly smaller than its leaded potential counterpart SOD123 which has a body dimension of 4.32 mm^2. DFN1608D-2 achieve impressive 81% space saving on the PCB and has no negative impact on the thermal performance. A comparison of the $R_{th(j-a)}$ values reveals that the DFN1608D-2 already has a significantly lower $R_{th(j-a)}$ compared to SOD123, even on a single Cu layer FR4 board with standard footprint (270 K/W compared to 300 K/W in case of SOD123). Once again, the excellent thermal performance of the DFN package on much smaller footprint can be explained by the exposed heatsink and the direct path of the heat into the PCB. On a ceramic PCB the dissipated power in DFN1608D-2 can be increased up to 1600 mW, showing the impressive power density possible with this package.

Table 3. Nexperia automotive DFN package range

Product	Package	PCB type	Typical $R_{th(j-a)}$ (K/W)	Typical P_{tot} T_j = 150 °C T_{amb} = 25 °C (mW)
BCP68	SOT223	FR4, 35 µm single-sided copper, standard footprint	150	830
		FR4, 35 µm single sided copper, mounting pad for collector 1 cm^2	110	1140
		FR4, 35 µm single sided copper, mounting pad for collector 6 cm^2	80	1560
BC868	SOT89	FR4, 35 µm single-sided copper, standard footprint	200	570
		FR4, 35 µm single sided copper, mounting pad for collector 1 cm^2	125	1090
		FR4, 35 µm single sided copper, mounting pad for collector 6 cm^2	80	1560
BC68PAS	DFN2020D-3	FR4, 35 µm single-sided copper, standard footprint	260	480
		FR4, 35 µm single sided copper, mounting pad for collector 1 cm^2	130	960
		FR4, 35 µm single sided copper, mounting pad for collector 6 cm^2	100	1250
		FR4, 4-layer copper, mounting pad for collector 1 cm^2	65	1920

Table 3: A comparison of a 20 V, 2 A NPN BJT in three different packages: SOT223, SOT89 and DFN2020D-3. The thermal capability of the packages is compared based on the measured $R_{th(j-a)}$ for different PCB settings. The P_{tot} is calculated for a maximum junction termperature of 150 °C and on ambient temperature of 25 °C.

7. Comparison to leaded packages with large heatsinks

The two DFN packages that have been highlighted come with superior thermal performance in spite of the massive space saving compared to their leaded counterparts. This comes from the exposed heatsink and the described thermal flow directly into the PCB. The question then arises how DFN packages compare to big leaded packages with large heatsinks, for example the SOT223 and SOT89.

Table 3 illustrates the measured typical $R_{th(j-a)}$ and the corresponding P_{tot} for a 20 V, 2 A, NPN transistor housed in 3 different packages: SOT223, SOT89 and DFN2020D-3. On a single-sided FR4 PCB with standard footprint, the highest P_{tot} can be dissipated in the SOT223 package due to the massive heatsink of this package. However by increasing the area of the mounting pad of the collector to 6 cm^2 (this setting mimics a ceramic board – compare Rth(j-a) in Table 2) the typical P_{tot} in the DFN package is increased to 1250 mW. This corresponds to approximately 80% of the P_{tot} in the 5.7 times larger SOT223. With a 1 cm^2 mounting pad of the collector, a typical P_{tot} value of 960 mW can be achieved, equivalent to 88 % of the dissipated power in the 2.8 times larger SOT89

Using a 4-layer FR4 PCB with a mounding pad area of 1 cm^2 results in an impressive P_{tot} of 1920 mW, illustrating the excellent thermal capability of the DFN2020D-3 package. The thermal capability of DFN2020D-3 is also demonstrated by its $R_{th(j-sp)}$, the thermal resistance from junction to solder point. Table 4 illustrates the maximum thermal resistance in comparison to SOT223 and SOT89. The maximum $R_{th(j-sp)}$ of DFN2020D-3 is only 25 % higher than its bulky and much larger counterparts.

Table 4. Maximum thermal resistance from junction to solder point

Package	Maximum $R_{th(j-sp)}$ (K/W)
SOT223	16
SOT89	16
DFN2020D-3	20

8. Summary

DFN packages with their compact dimensions are the right choice for replacing bulky leaded packages on PCBs. The higher power density that arises from densely populated PCBs requires packages with excellent thermal capability. DFN packages satisfies this requirement thanks to their exposed heat sink and optimized heat path. PCB types with improved thermal conductivity are recommended to take full advantage of DFN packages.

Small DFN packages like the DFN1110D-3 and DFN1412D-3 come with a higher P_{tot} compared to their leaded counterparts even on a standard FR4 board with standard footprint while still offering a huge space saving on the board. But even very large leaded packages like the SOT223 and SOT89 with huge heat sinks can be replaced by DFN2020D-3 package. In this case a mounting pad of 1 cm^2 on a standard FR4 PCB is required to dissipate the same amount of power compared to the 5.7 times larger SOT223. By switching to a 4-layer PCB or a ceramic board, a dissipated power of up to 1900 mW can be achieved, more than twice the dissipated power of a SOT223 on an FR4 board.

9. Revision history

Table 5. Revision history

Revision number	Date	Description
3.0	20201123	• Table 1 updated: DFN1412D-6 removed
2.0	20201118	• DFN1110(B)D-3 revised to DFN1110D-3
1.0	20201102	AN90023 initial version

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