BL-Cellular Systems, MST RF Power
Basestations DEV&QAS

Title:	Bolt down mounting recommendations for Ldmos Power Amplifier
Author:	Josselin FAY / Raimond DUMOULIN
Doc. Nr.	
Date:	2007/03/27

Bolt down mounting recommendations for Ldmos Power Amplifier

TABLE OF FIGURES

1 Introduction

The bolt mounting packages are flange mounted and accommodate fixing holes to attach them to heatsinks. Screwing the package to the surfaces requires a minimum and a maximum torque. By using a torque screwdriver the applied torque is reproducible. This report will examine the main considerations in mounting the devices for best thermal performance and electrical contact. In addition, some specific simulations are presented to show the influence of different heatsink and flange flatness.

2 Practical points

The flatness of the contact areas of both heatsink and flange will contribute to a better thermal conductivity as well as the use of heatsink compound. Usually heatsink compound is used together with mechanical fasteners. The commonly used Allen key bolts or screws with washers, M3 and UNC4-40 will provide sufficient pressure when a torque between 0.6 and 0.8 Nm is applied for optimal thermal contact. Higher torques will not automatically contribute to a better thermal contact even could be potential reliability risk when stressing the bolt too much.

3 Surface conditions

3.1 Flatness and cleanliness

Check the flatness of the heatsink before mounting and the cleanliness of both heatsink (including mounting holes) and the back of the flange. Check if there are no burrs. If there are any burrs, de-burr the surface to avoid a gap between flange and heatsink. These kinds of gaps cannot be filled with heatsink compound and can also lead to bad electrical contact. NXP recommend to machine the surface respectively from total heatcase to ensure proper flatness and roughness.

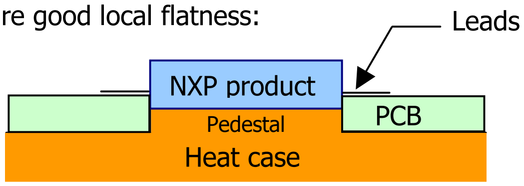
3.2 Thermal compound

To improve the thermal conductivity a layer of heatsink compound can be applied. It will have a better thermal conductivity than pure metal contact. The layer must be thin and evenly spread over the flange/heatsink contact surface of the package before mounting (spread before placing the component) in order to fill all the air gaps between the package and the heatsink.
Take care not to use too much compound because it is worse than using none. Excessive use of thermal compound adds a "layer" of thermal resistance.
Besides of that the compound may leak out of the gap when the bolts are tighten and will contaminate the area of the PCB and smear over the surface of the PCB.

3.3 Recommendations

NXP recommends the following:

- Minimum depth of tapped holes in heatsinks: 6 mm;
- Ensure that the holes are free of burrs;
- The minimum flatness of mounting areas is 0.01 mm (Norm ISO 1101);
- The roughness Ra must be less then 0.5 µm;
- To use pedestal to ensure good local flatness:



4 Torque

4.1 Recommendations

The force applied is important to ensure a good contact to the heatsink. It is recommended that the screws are tightened in two steps to ensure the devices are not damaged during mounting:

- First, the screws should be tightened by hand so they are finger tight on both sides;
- Secondly, the screws should be fully tightened with a controlled torque wrench like a torque screwdriver to the recommended torque.

Tightening one screw fully before the other can cause the flange to bend and in extreme cases crack if excessive force is used.

Washers are recommended to control the applied torque in order to spread the force of screws equally. Furthermore, check before using the torque screwdriver the setting of the screwdriver and modify it if necessary. Excessive torque may damage the device.
Do not use hexagonal bolts because it could interfere with some of the smaller flange-mount packages during the screwing step.

The table below regroups the specified range of torque recommended for flange packages (Cf. Appendix 1):

Package		Minimum value	Maximum value
SOT 121A SOT 262A SOT 391A SOT 467A SOT 502A SOT 540A SOT 608A SOT 895A SOT 539A	Torque (Nm)	0.60	0.75
	Force (N)	≈ 890	≈ 1110
	Weight (Kg)	≈ 90	≈ 110

Table 1 – Suggested torque ranges for flange packages

It is explained before that a minimum torque is necessary in order to have an optimal thermal contact. The maximum torque recommended to apply on the device is obtained for a M3 screw and details of the calculation are done in the following chapter.

4.2 Maximum torques supported by screws

The torque increase involves knowing the limit that can be achieved without having any problems. A maximum traction load supported by screws can be calculated by the approached formula:

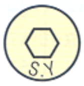
$$F_{\max} = 0.9 \cdot R_e \cdot S_{eq}$$

Equation 1 – Approached formula of the maximum traction supported by screws

- R_e : Elastic limit of the material;

- S_{eq} : Resistant section of the threading rod;
- 0.9: Load rate of 90% (security margin of 10%).

If M3 CHC screws are used to mount the flange on the heatsink, the application of the formula showed on the previous page (Cf. Equation 1) gives a maximum load of traction $F_{max} \approx$ 1800 N ($\approx$ 180 Kg). The result is calculated for the following CHC screw:

 CHC screws 	$S \cdot Y = R_e$ (daN/mm²) R_e = 400 N/mm² is taken

The maximum load of traction F_{max} is now known. To **change** a force in a torque value (and inversely to calculate the force F applied on the flange per screw when torque C is known) the equation used is:

$$C = (0.16p + 0.583 \cdot f_f \cdot d_2 + 0.5 \cdot f_t \cdot D_m) \cdot F$$
$$d_2 = d - 0.6495 \cdot p$$

Equation 2 – Holding torque, approached formula

On the following picture different variables of the equation above are showed. The force is calculated using values for a M3 screw.

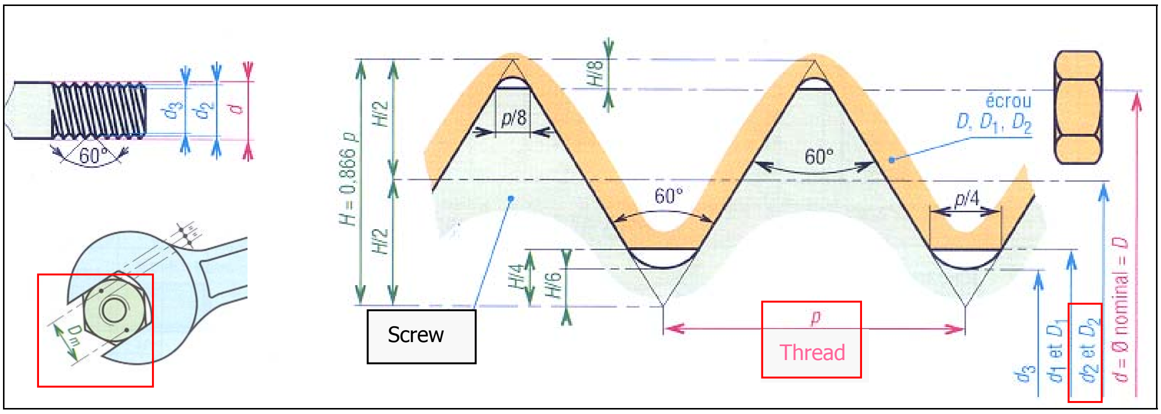


Figure 1 – Metrical threading ISO with triangular thread

f_f is the friction at the level of the threading and f_t is the friction between the head of the screw and the support. Both depend of the nature of support (or washers) and threading of the screws. Usually these values are in a range of:

$$0.10 \le f_f \le 0.18$$
$$0.10 \le f_t \le 0.18$$

Figure 2 – Friction values

In the table 1, the calculation of the forces (maximum and minimum) has been made with f_f and f_t values of 0.18 in order to stay in the less critical conditions.

To obtain the torque corresponding to the maximum load of traction F_{max} (≈ 1800 N) a range of torque values can be calculated depending of f_f and f_t (Cf. figure 2).

- If values of f_f and f_t are both taken at 0.10 the maximum torque C_{max}≈ 0.75 Nm;
- If values of f_f and f_t are both taken at 0.18 the maximum torque C_{max}≈ 1.20 Nm.

Based on these calculations NXP advises not be exceed the 0.75 Nm torque as seen in the Table 1.

5 Mechanical simulations

5.1 Description

5.1.1 Introduction

The simulations shown in the next paragraphs give an impression on what mechanical parameters are of influence when looking at mechanical stress and contact area between flange and heatsink.
Simulations can only be used for comparison reasons when charge is added (Cf. Table 2) and values cannot be seen as absolute. These simulations allow showing an illustration of stresses on dies areas and the behaviour of the contact areas which is very important for the electrical and the thermal conductivity.

The torques used correspond to a force applied by M3 screws, by using a 0.10 value for the friction at the level of the threading f_f and the friction between the head of the screw and the support f_t (Cf. § 4.2), corresponding to the most critical situation for the simulation.

Torque (Nm)	**0.4**	**0.6**	**0.8**	**1**
Force (N)	≈ 950	≈ 1450	≈ 1950	≈ 2400
Pressure ($N.mm^{-2}$)	≈ 90	≈ 130	≈ 180	≈ 220

Table 2 – The different pressures applied on the model and their corresponding torques

Finite element models have been performed. The pressures applied on these models correspond to forces applied on the flange without washers (Cf. table 2).

5.1.2 Global presentation of finite element models

Models are composed of a flange on a heatsink. Several models have been performed in order to take into account:

- **The shape of the flange:**
  - Flat flange;
  - Convex flange;
  - Concave flange.
- **The flatness of the heatsink:**
  - Flat heatsink;
  - A heatsink including a pedestal to simulate different flatness.
- **The material of the flange:**
  - Flange in CuW (Copper/Tungsten);
  - Flange in CPC (Copper/Copper Molybdenum/Copper).
- **The size of the flange:**
  - Small flange;
  - Bigger flange.

Air Cavity Plastic Package is taken as the worse case scenario. A model including a ceramic ring-frame is thus not made in order to be in the worse case scenario. The use of a ceramic ring-frame brazed on the flange would indeed add rigidity and therefore would allow being in a better situation.
Models are based on the qualification tool used by NXP. The heatsink is composed of a pedestal. Flanges are screwed on the heatsink as seen on the next page. A different height of the pedestal is taken into account in order to represent a flatness of the heatsink in a range of 0 µm (flat heatsink) to 50 µm.

Illustration of the fixture and global finite element model	
Qualification tool	**Global view of the model**

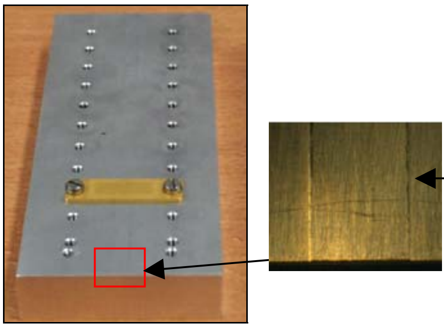
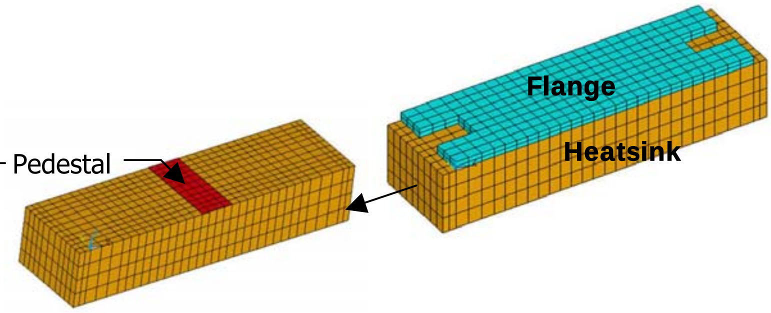

	

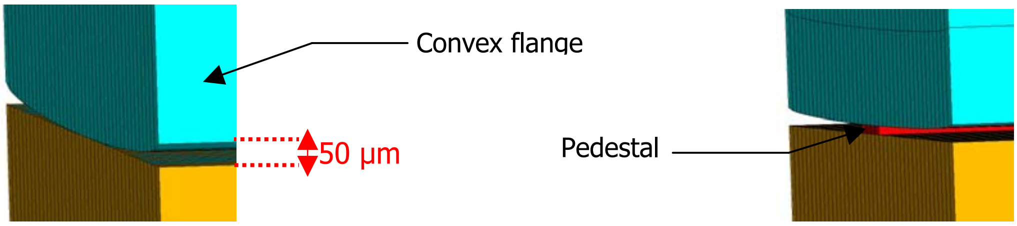
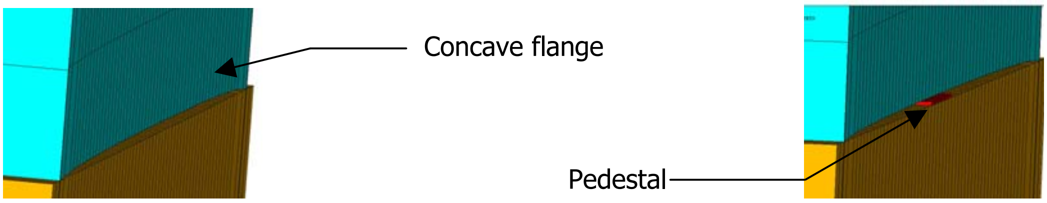
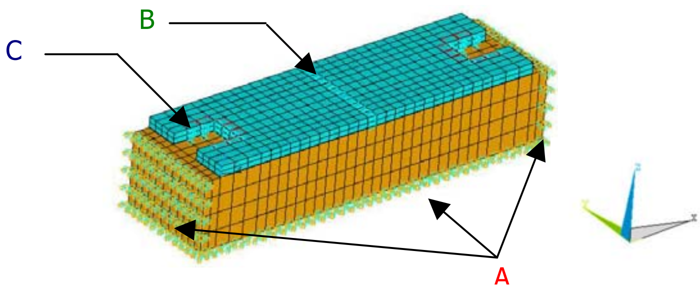
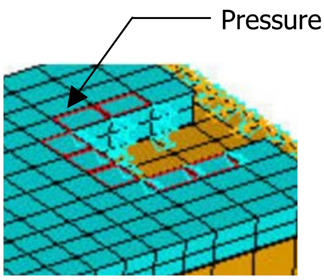
Illustration of the models including a convex flange and a concave flange (50 µm of bending) on a heatsink	
	
	

Table 3 – Illustration of the global finite element model

5.1.3 Presentation of loads applied on the models

The table below presents the limit conditions applied on the models in order to stay in a situation as close as possible to the reality.

Illustration of loads applied on the models	
Displacement conditions	**Pressure loads**
	
A-Heatsink: All degree of freedom blocked B-Flange: translation blocked on the X axes C-Flange: translation blocked on the Y axes	Pressures applied to simulate a torque from 0.4 Nm to 1 Nm (Cf. table 2)

5.1.4 Different parameters of the models

- Dimensions of both heatsink and flange

  - Models of the flange:

Two different sizes of flanges have been taken into account. The first flange is longer and thicker than the second flange. It will give an indication of the behaviour of the flange for several sizes.
The model of the smaller flange is the SOT895A (CuW[1] and CPC[2]) and the model of the bigger flange is the SOT539A (CuW).

  - Model of the heatsink:

The heatsink is always modelled with a 7 mm thickness and with a 4mm wide pedestal (based on the qualification tool seen table 3).

- Materials used

The table below gives the materials used for both heatsink and flange. The Young module (rigidity of the material) and the coefficient of Poisson used for both elements are given too.

	Material	**E (Gpa)**[3]	**ν**[4]
Heatsink	Aluminium	69	0.34
Flange	CuW	378	0.28
Flange	CPC	124/267/124	0.34/0.29/0.34

Table 4 – Mechanical parameters

5.2 Results

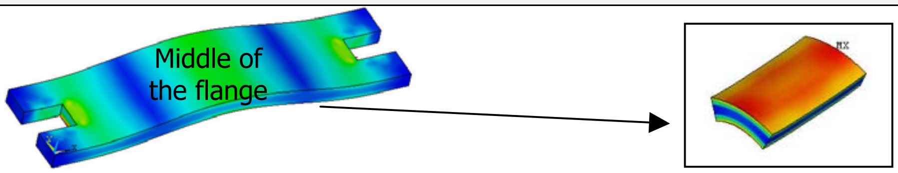
5.2.1 Stress results

Several results on stresses in the flange are obtained. It is important to take into account the stress on dies areas.

- Stress results depending on the torque applied

The following results give the maximum stress in the middle of the *flat flange* for different height of the pedestal when the torque applied per screw increases (Cf. Figure 3).

Stress results



[1] CuW: Copper/Tungsten
[2] CPC: Copper/Copper Molybdenum/Copper
[3] E: Young module
[4] ν: Coefficient of Poisson

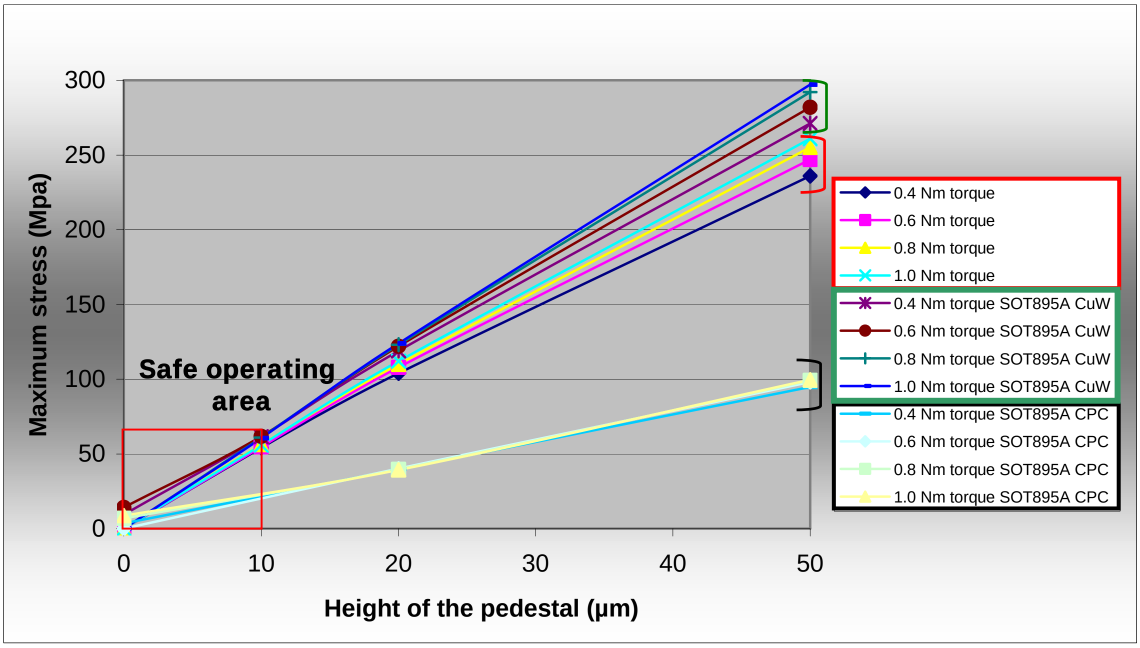


Figure 3 – Variation of the maximum Von Mises stresses in the middle of the flange versus the height of the pedestal representing heatsink flatness

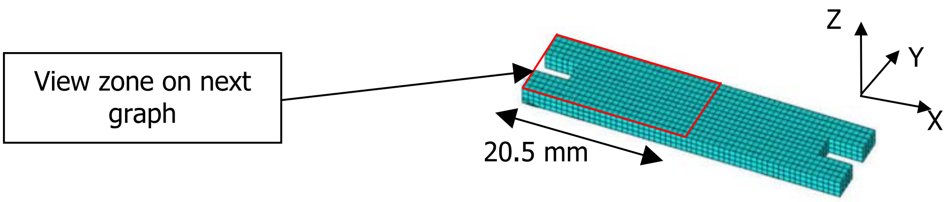
Several remarks can be made:

- For a given torque value, stresses increase in the middle of the flange when the height of the pedestal increases. Clamping specification from 10 µm to 50 µm will increase stress with a factor of ≈ 5 for CuW flanges.
- The values of stress are less important for the CPC flange because dies are soldered on a layer of copper which has a smaller rigidity compare to CuW flanges (Cf. Table 4).
- The graph also indicates that for a given height of the pedestal, the stress increases slightly when the torque applied increases.

The value of the stresses in the middle of the flange thus depends far more on the height of the pedestal, which represents the flatness of the heatsink.

- Variation of stresses in the flange

As stated in the previous remarks, the flatness of the heatsink has a more important effect on the value of the stress in the flange than the torque applied. In this part the variation of the stress is evaluated on half of the length of the flange (symmetrical model) for different height of pedestal when a 0.8 Nm torque is applied. Results are obtained for the SOT539A (the bigger flange) *flat flange*.



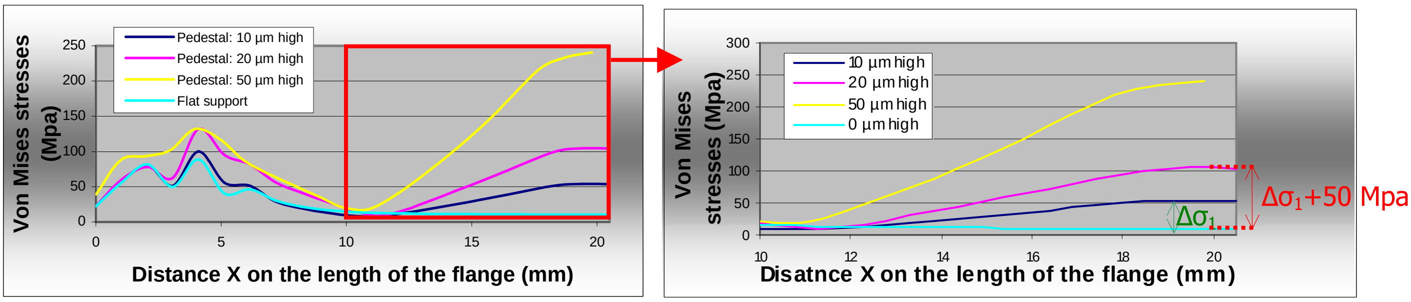


Figure 4 – Variation of the stress on the half part of the flange for different height of the pedestal when a 0.8 Nm torque is applied

The graph above indicates that:

- When the height of the pedestal increases the variation of the stress (Δσ) increases too. If dies are situated on a range of 10 mm to 17 mm (in this example: Cf. Figure 4) the variation of the stress is more important for a heatsink with a 50 µm pedestal than for a heatsink with a 10 µm pedestal;
- The increase of the variation of the stress versus the height of the pedestal is linear (*flat flange*). The results showed on the Figure 4 indicate an increase of the variation of the stress of ≈50 Mpa every 10 µm.

❑ Conclusion

From the simulations above it can be concluded that the flatness is the parameter having the main influence on the stresses in flanges. It is thus important to take care of the flatness of the heatsink. Silicon dies are particularly sensitive for stress variations. Therefore risk of die crack increases strongly when the height of the pedestal increases.

Then, NXP advises that the height of the pedestal should be in a safe operating area (from 0 µm to 10 µm high) as shown Figure 3. These remarks made on the **behaviour** of stresses in the *flat flange* are also valid for a *convex flange and a concave flange*.

As said in introduction, simulations are only done for comparison reasons and this should not be done without testing in order to ensure no problems with package and die.

5.2.2 Contact areas: flat and convex flanges

A variation of the contact areas can be studied with several models. This part is very important because the electrical and thermal contacts are depending on the contact areas between the flange and the heatsink. Results are only done for the *flat and the convex flanges*. The behaviour of the contact area of a *concave flange* is indeed different.

❑ General behaviour of the flange

In this part the behaviour of the flange is simulated when a torque is applied. The following graphs give the vertical displacement of the flange on its length (red line) and the vertical displacement of the flange on its width (blue line).

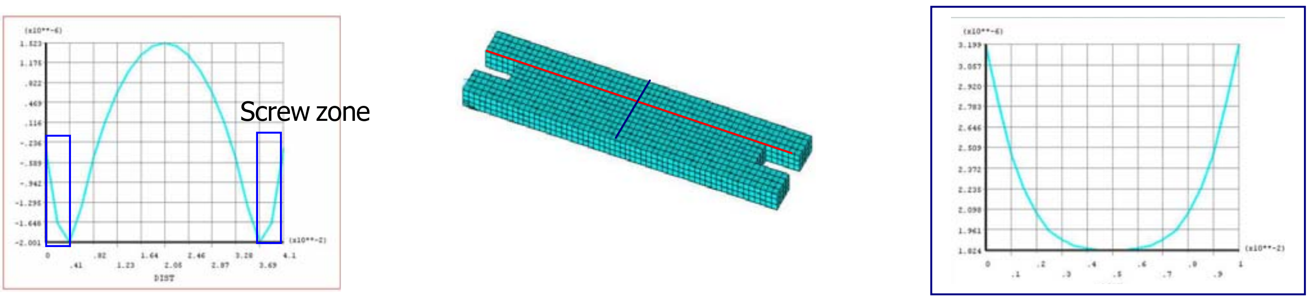


Figure 5 – Vertical displacement of the flange on its length and on its width

On the length of the flange there is a flexion of the flange and the vertical displacement has a peak in the middle of it. On its width the vertical displacement decreases to the middle of the flange. The behaviour of the flange in the screws parts showed Figure 5 (framed in blue) is depending on how the pressure is applied on the flange (Cf. § 5.1.3).
The following graph gives the vertical displacement (*from the top of the pedestal*) in the central point of ***CuW** flat flanges* depending on the height of the pedestal.

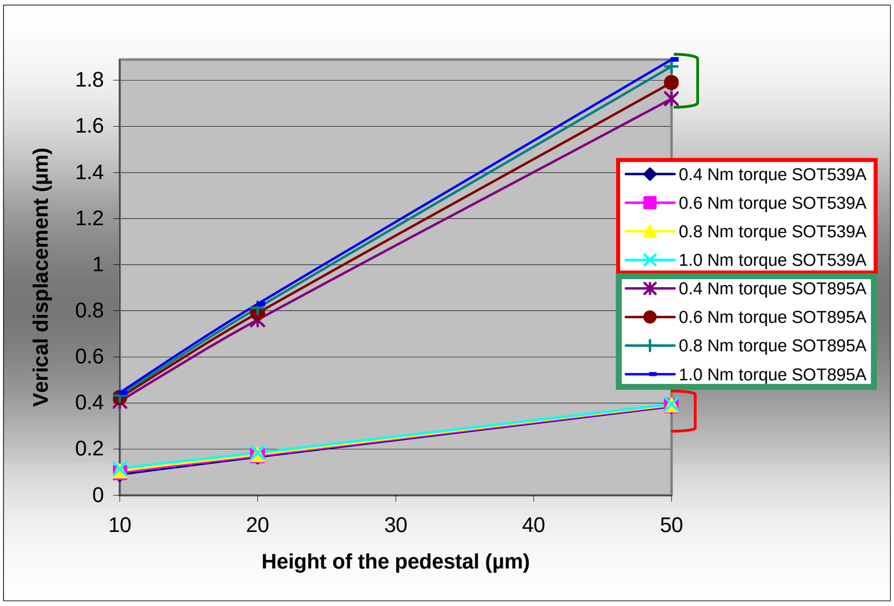


Figure 6 – Variation of the maximum displacement in the middle of the CuW flanges versus the height of the pedestal representing heatsink flatness

The following remarks can be made:

- For a torque applied on the flange the displacement increases linearly when the height of the pedestal rises;
- For a height of the pedestal the displacement increases slightly when the torque increases;
- The displacements are more important for the smaller flange. The values of stresses in this flange are thus bigger than values of stresses in the bigger flange as seen Figure 3 (green color and red color).

On this graph only results for the CuW flanges are taken into account. The value of the vertical displacement for the CPC flange is more important than for the CuW flanges due to a smaller rigidity.
When there is no pedestal (no showed Figure 6 above) the variation of the vertical displacement has the same behaviour but values of displacement in the middle of the flange (*from the top of the heatsink*) are bigger.

- Contact areas

In this part it is studied the contact areas for several models:

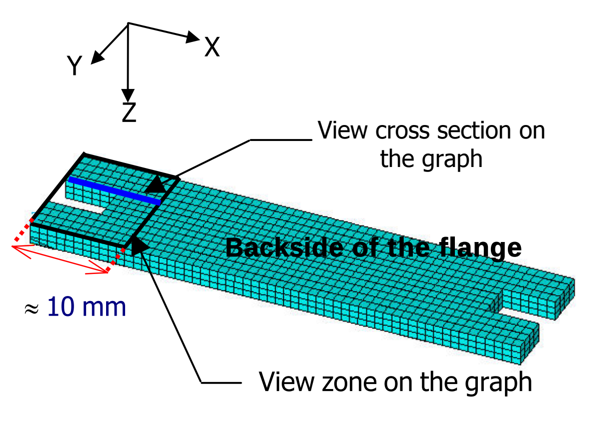
- First it is showed the contact areas when a flat flange is used;
- Secondly a view of the contact areas is done when a convex flange is used.

The results are obtained only for one flange (the bigger one: SOT539A) but the behaviour for a smaller flange (CuW or CPC) is the same.

- Flat flange on a flat heatsink

The simulations with a flat flange on a flat heatsink are performed (Cf. Table 5). When the torque increases from 0.4 Nm to 1 Nm the contact areas is stable (or almost: Cf. Table 5 red point). Only the deformation of the flange on the Z axe *(depth of the contact area)* rises. The flange and the heatsink are in contact on ≈ 9 mm in both sides of the flange.

Flat flange on a flat heatsink



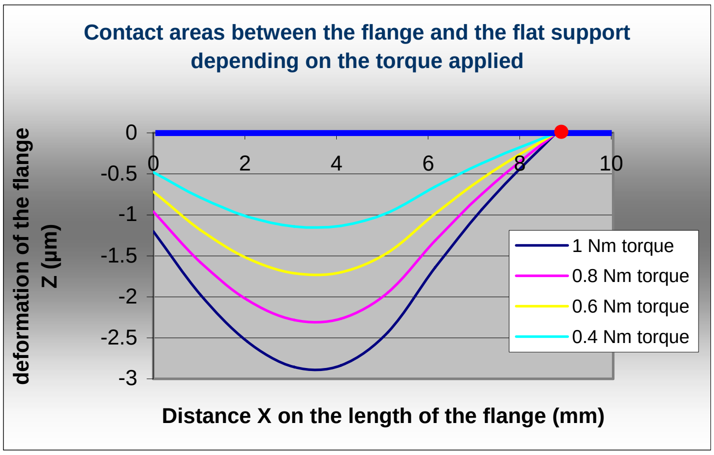
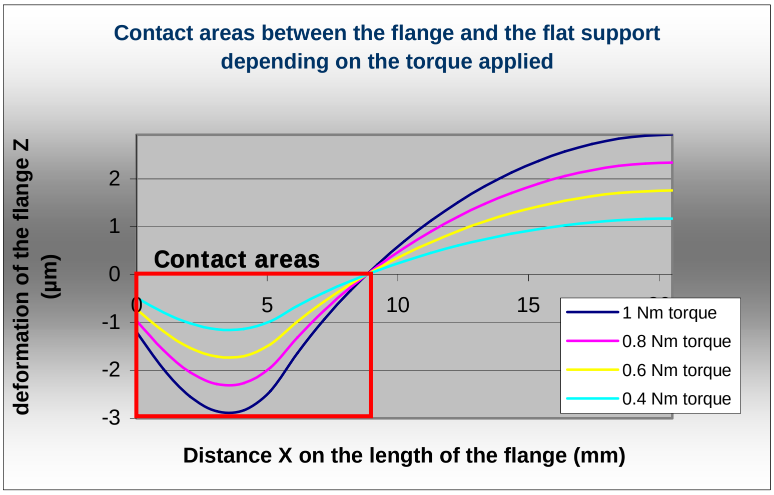


Table 5 – Contact areas between a flat flange on a flat heatsink

On the graph above it is only shown the contact area between the flange and the heatsink. The following graph gives a view of the deformation on half of the length of the flange (symmetric) and the contact areas shown in the Table 5 are framed in red.



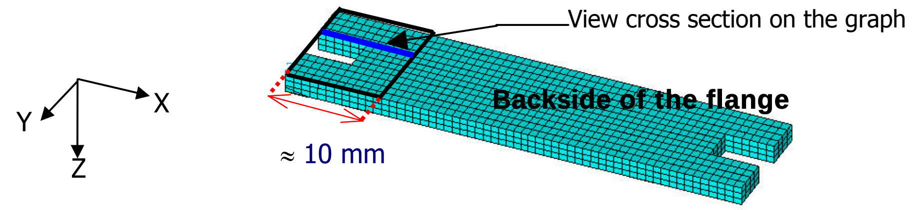
After the contact area the displacement Z of the flange arrives to a peak in the middle of it as shown Figure 5. This peak depends of the torque applied. When the torque rises the peak is bigger.
In next results it is only taken into account the contact areas.

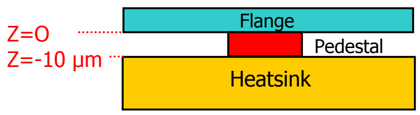
- Flat flange on a heatsink with a pedestal

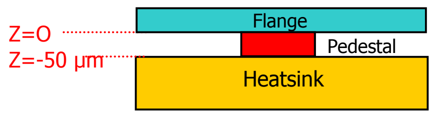
The contact area is obtained for a heatsink with a 10 µm pedestal and the results are compared with the results found when a 50 µm pedestal is used.

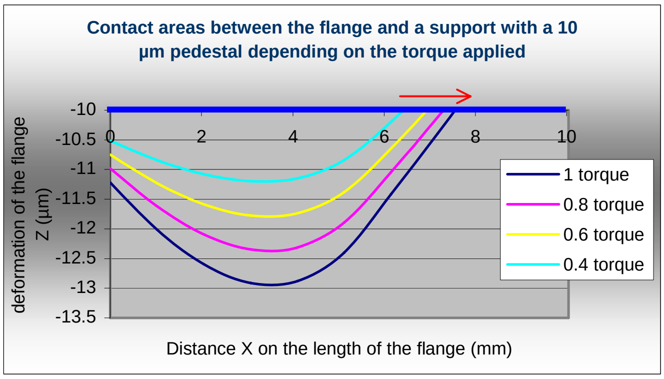
The different graphs inside the Table 6 indicate that when the torque increases the contact areas increase slightly (Cf. red arrows Table 6). The contact area is thus not really sensitive to an increase of the torque from 0.4 Nm to 1 Nm. Furthermore, when the height of the pedestal increases, there is an impact on the contact area. In fact, the contact area is smaller for a higher pedestal.

Flat flange on a heatsink with a pedestal









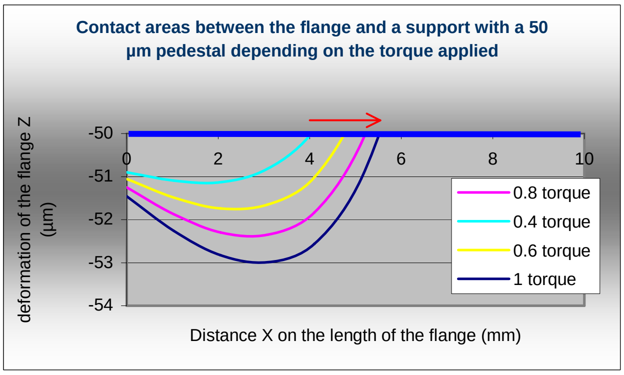
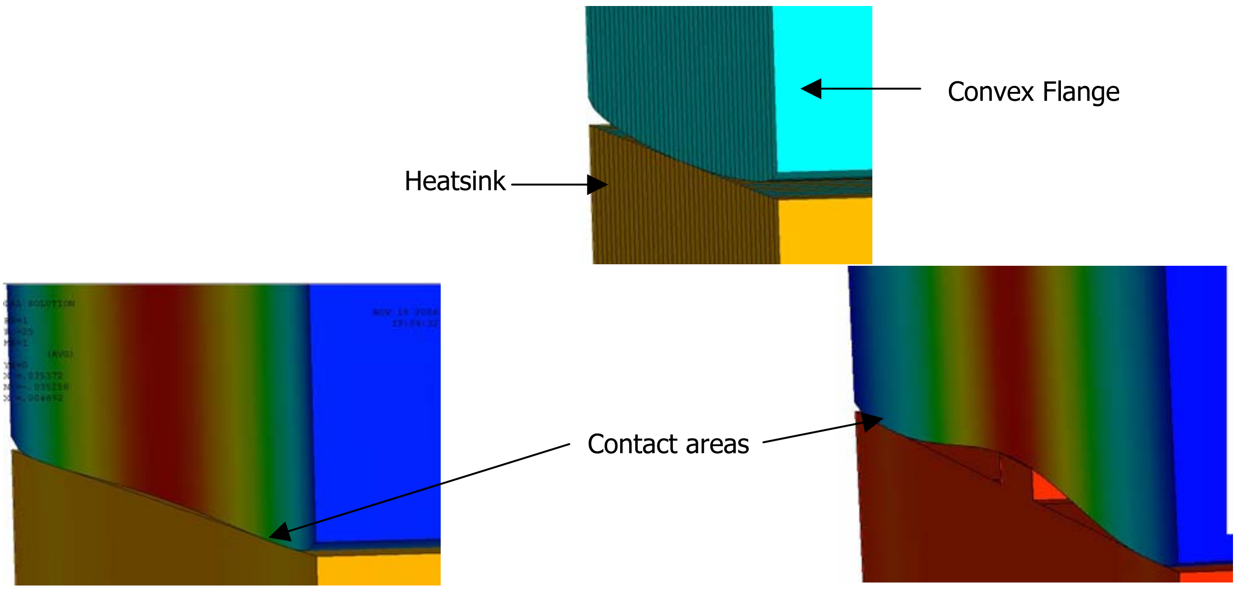


Table 6 – Contact areas between a flat flange and a heatsink with a pedestal

- ❖ Convex flange on a flat heatsink and on a heatsink with a pedestal

The results (behaviour of the flange in displacement) shown for a flat flange are the same than for a convex flange. There is never contact in the middle of the flange. As shown below the contact areas are located only on the side of the flange.



5.2.3 Contact areas: Concave flange

- Introduction

A model of a concave flange has been made based on the SOT 539A (bigger flange).

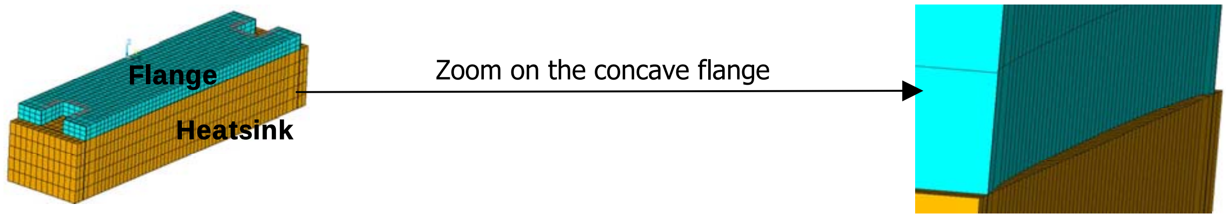
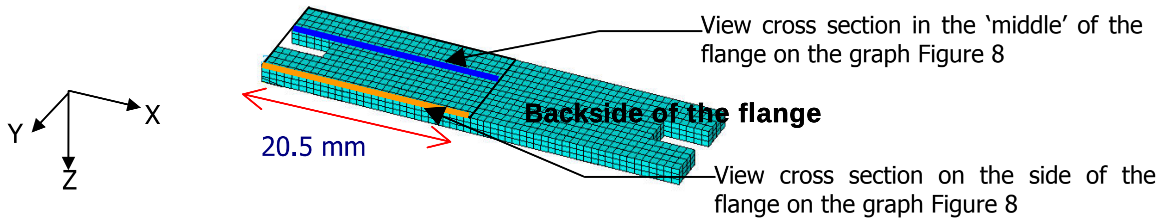
Model of the concave flange on a flat heatsink


Table 7 – Illustration of the concave model on a flat heatsink

To study the contact area of the concave flange onto the heatsink, two cross sections are taken into consideration.



- General behaviour of the flange

The behaviour of a concave flange is different of the behaviour of a flat flange and a convex flange for which ones there is never contact in the middle of the flange on the 'middle' cross section and obviously on the side cross section due to the vertical displacement of these flanges viewed Figure 5 and below.

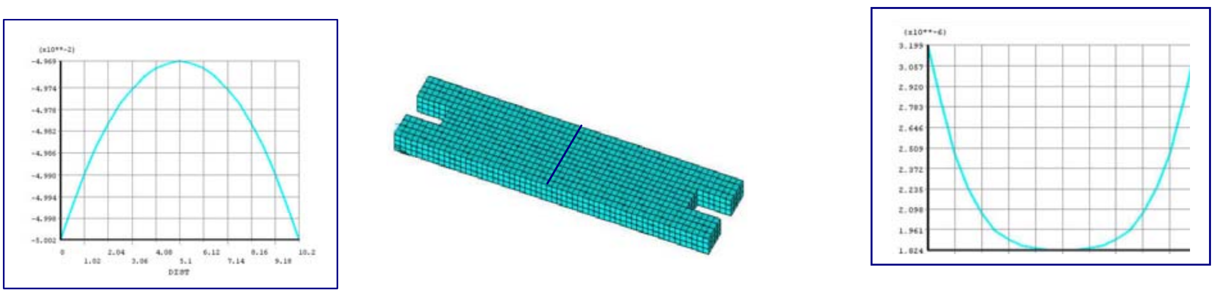


Figure 7 – Comparison of the vertical displacement of the different flanges on their width. On the left for a concave flange and on the right for a convex and flat flange

- Contact areas

The behaviour of the flange is simulated when a torque is applied. The heatsink is flat (no pedestal). The graph Figure 8 gives a view of the deformation on half of the length of the flange (symmetric) versus the torque applied and the cross section shown. The contact areas are framed in red.

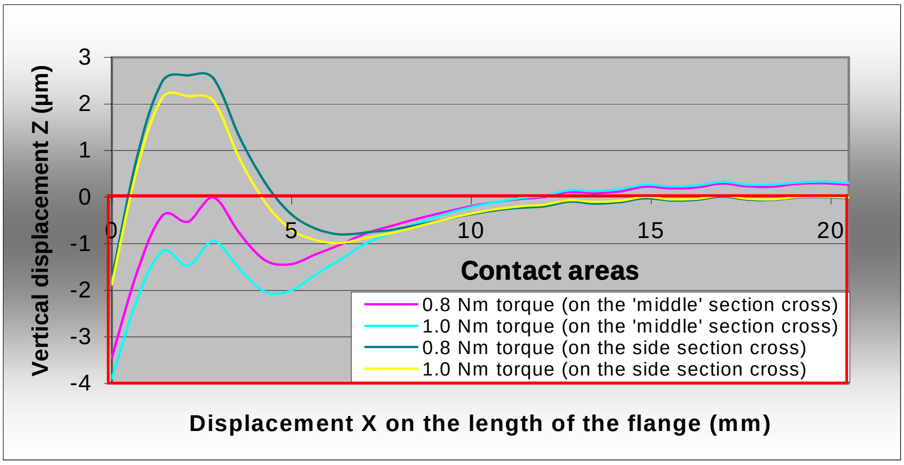


Figure 8 – Vertical displacement of the flange versus the torque applied and the cross section showed

When the vertical displacement of the concave flange on the 'middle' cross section (blue line) is shown:

- The gap between the flange and the heatsink in the middle of the flange is small.

When the behaviour of the concave flange on the side cross section (orange line) is shown:

- The flange is in contact (or almost) with the heatsink in the middle (Cf. the contact area framed in red Figure 8 and the pictures below with an exaggerate scale).

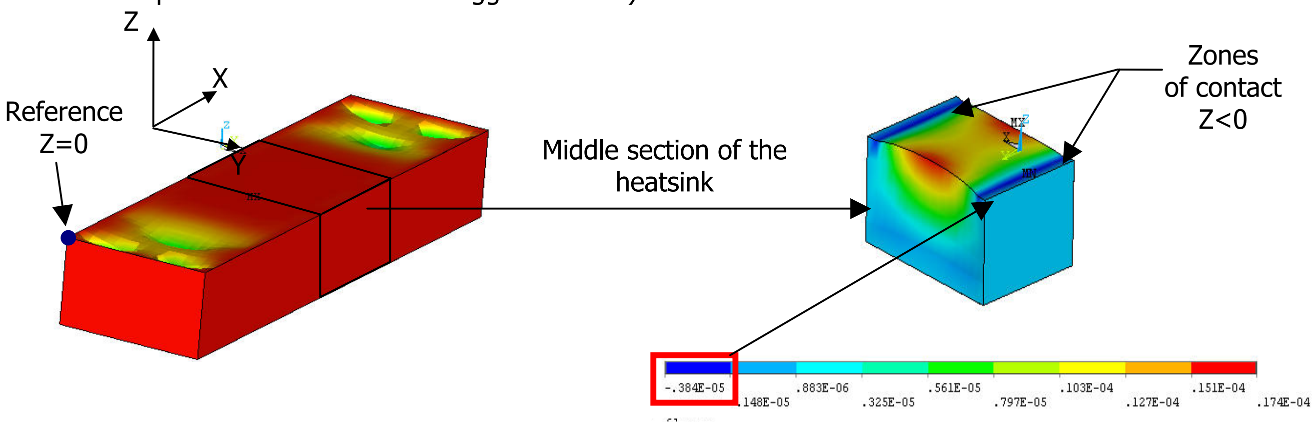


Figure 9 – 3D view of the heatsink

Secondly, when the torque increases the vertical displacement of the flange increases too and there is not an important impact on the contact area (These observations have also been done for a flat flange and a convex flange).

5.3 Conclusion

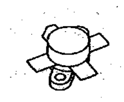
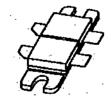
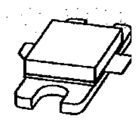
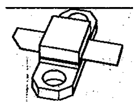
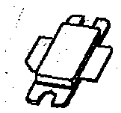
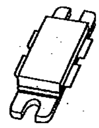
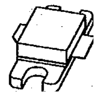
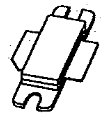
Regardless of the shape of the flange (flat, concave or convex) these finite element study results found on the stress in the flange and on the contact areas between the flange and the heatsink allow writing that increasing the torque has not an important impact on increasing the contact areas. Furthermore, it has been observed that the flatness of the heatsink is the parameter having the most important influence on the stress in the flange. The flatness must be as small as possible in order to avoid too much stress variations on dies areas with a higher risk of damages. Besides of that the control of the flatness allows to ensure a better contact area.

According to the simulations, the middle of the flat flange and the convex flange is never in contact with the heatsink. Inversely to that, the concave flange seems to be closer from the heatsink due to a different behaviour in displacement. However, the results for the concave flange are done without model the thermal compound which one adds a resistance layer on the contact area during the screwing step. Furthermore, using a concave flange is worse to allow an evenly spreading of the thermal compound on the contact areas.

In general if the surface between the flange and the heatsink is not prepared according to the recommendations, increasing the torque cannot repair the thermal and electrical contact.

APPENDIX 1: IMAGES OF PACKAGES

The mounting recommendations can be applied on the following packages showed Table 1:

Package	Image
SOT121A	
SOT262A	
SOT391A	
SOT467A	
SOT502A	
SOT540A	
SOT608A	
SOT895A	
SOT539A