# PolarPAK® Thermal Impedance (Rth) vs. Heat Sink Assembly Clamping Torque

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## INTRODUCTION

PolarPAK®, the innovative power MOSFET package from Vishay Siliconix, provides enhanced thermal performance, especially when used with a heat sink and adequate airflow. This application note, one more in the series of support documents for PolarPAK, studies how the thermal performance of PolarPAK and a heat sink assembly vary with respect to the heat sink clamping torque. The extreme destructive test described in this note examines the mechanical limits of the package to determine the amount of clamping force/pressure it can sustain when the part is physically damaged. Two parameters – junction-to-ambient steady-state thermal impedance of the package on a PCB assembly and clamping torque between heat sink and PCB – are evaluated.

## EXPERIMENTAL SETUP

The experimental setup comprised of the following material and equipment:

(1) Samples of Vishay Siliconix SiE802DF PolarPAK MOSFET

(2) Test-printed circuit board, the standard PCB used for MOSFET datasheet characterization, as shown in Figure 1:

a. Dimensions: 1 in. x 1 in. x 0.062 in. (25.4 mm x 25.4 mm x 1.575 mm)

b. Material: FR4

c. Number of copper layers: 2

d. Copper thickness on both sides: 2 oz. (0.076 mm)

e. Area covered by copper on both sides: 100 % (only lead separation isolation on top side as shown in Figure 1)

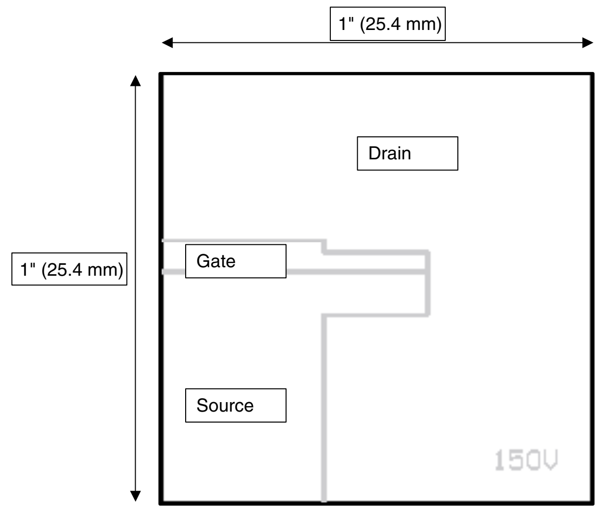


Figure 1. PC board design

(3) Aluminum heat sink measuring 1 in. x 1 in. x 0.18 in. (25.4 mm x 25.4 mm x 0.457 mm)

(4) Mechanical test fixture, Figure 2

a. 3-in. industrial C-clamp

b. Two clamp insulators prepared from FR-4 fiberglass PCB material without any copper on either side, 0.062 in. (1.575 mm)

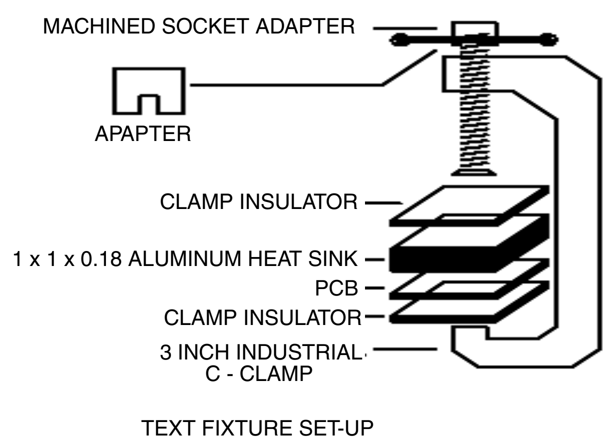


Figure 2. Mechanical text fixture

(5) Machined socket adaptor, Figure 3a and 3b

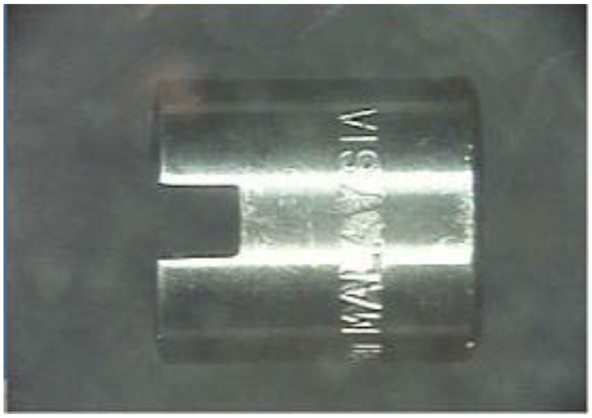

Figure 3a. Socket Adaptor Side View

Figure 3b. Socket Adaptor Bottom View

(6) Calibrated torque screwdriver set, Sturtevant Richmond Model 26/4, Figure 4

Figure 4. Torque screwdriver set

(7) Ana-Tech[1] computerized test set for thermal characterization of the MOSFET, Figure 5

Figure 5. Ana-Tech setup

Description of test:

(1) Part calibration file

The Ana-Tech[1] computerized setup produces transient thermal impedance characteristics of the unit under test – either a MOSFET or a MOSFET on a PCB assembly. The characteristics consist of a plot of the temperature rise of the MOSFET die per unit watt of power dissipation with respect to the duration of the power pulse. The die temperature is ascertained by measuring the forward voltage drop of the MOSFET's body diode. This necessitates body diode characterization, and in turn a part calibration file that relates the forward voltage drop of the body diode with its temperature. Figure 6 is a plot of the calibration file developed for the PolarPAK MOSFET sample. Note the negative temperature coefficient of the forward voltage drop of the body diode, $V_{fd}$, with respect to its junction temperature $T_j$. The green trace represents actual measurements recorded by the computer. The system software further smoothes the data to obtain linear data, represented by the straight blue trace, for the calibration file.

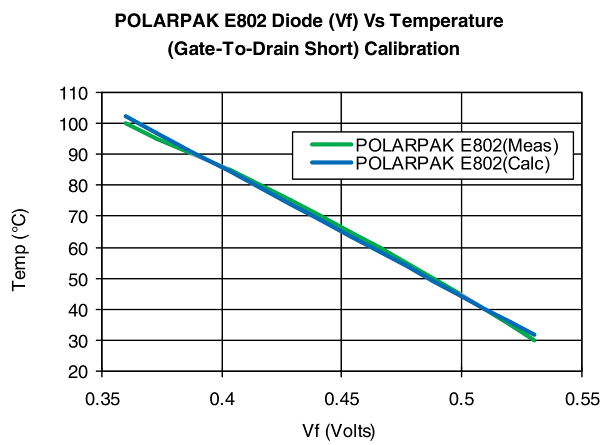


**Figure 6. Calibration**

(2) PCB assembly:
The PolarPAK SiE802DF power MOSFET was assembled on the test PCB, which is the standard printed circuit board used for MOSFET product characterization, as shown in Figure 7.

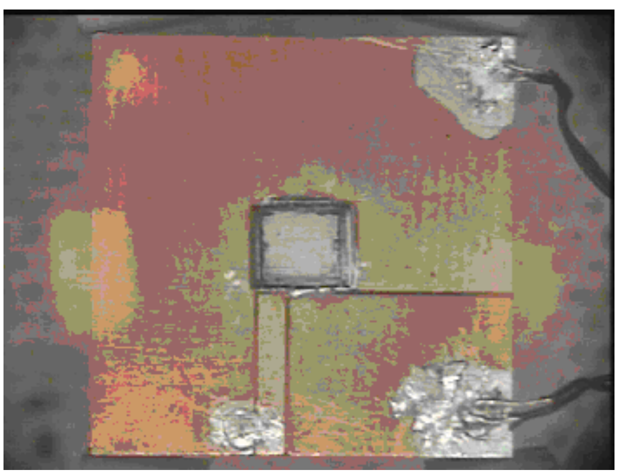

**Figure 7. PCB assembly**

An engineering lab-level soldering procedure developed for the assembly and re-work of the PolarPAK was employed to solder the part onto the PCB. Refer to the application note AN828[2] – "Working with PolarPAK, In-Lab Soldering and Re-Work Recommendations" – for details.

(3) Thermal charcterization of part without heat sink
Employing the Ana-Tech setup, junction-to-ambient transient thermal impedance characteristics were developed for the PCB assembly without any heat sink, as shown in Figure 8. The steady-state value establishes a baseline defining 66 °C/W as the maximum value of junction to ambient thermal resistance of PolarPAK on a standard 1 in. x 1 in. PCB.

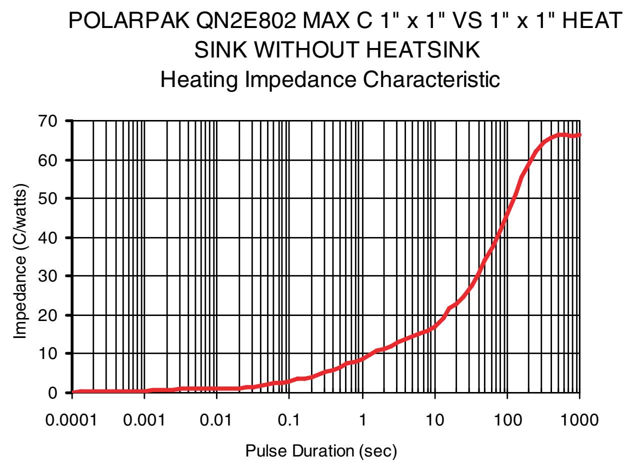


**Figure 8. Transient thermal impedance characteristics**

(4) Heat sink and PCB assembly
A C-clamp fixture was used to hold the aluminum heat sink and assembled PCB as shown in Figure 2. A thin layer of thermally conducting heat sink compoundwas applied between the heat sink and the top of the PolarPAK surface to establish a good thermal contact between the part and the heat sink. The PCB and heat sink were sandwiched between two clamp insulators that provide thermal insulation and minimize the heat sinking effect from the metal mass of the C-clamp.

(5) Clamping and torque adjustment technique
Using the torque screwdriver on the C-clamp was a challenge. A machined socket adaptor shown in Figure 3a and 3b was designed and developed in-house to overcome this challenge and facilitate the use of a calibrated torque screwdriver set. A milled adaptor was snug-fitted on the cylindrical head of the C-clamp handle at the same time "U" grooves on opposite sides gripped the handle bar. See figures 9b and 9c. Figure 9b shows C-clamp head without socket adaptor and figure 9c shows C-clamp with the socket adaptor. The top of the adaptor was machined to accept the hex-head of the torque screwdriver. This converted the radial movement of screwdriver to the circular movement of the C-clamp bar with adequate grip. Figure 9a shows the complete arrangement.

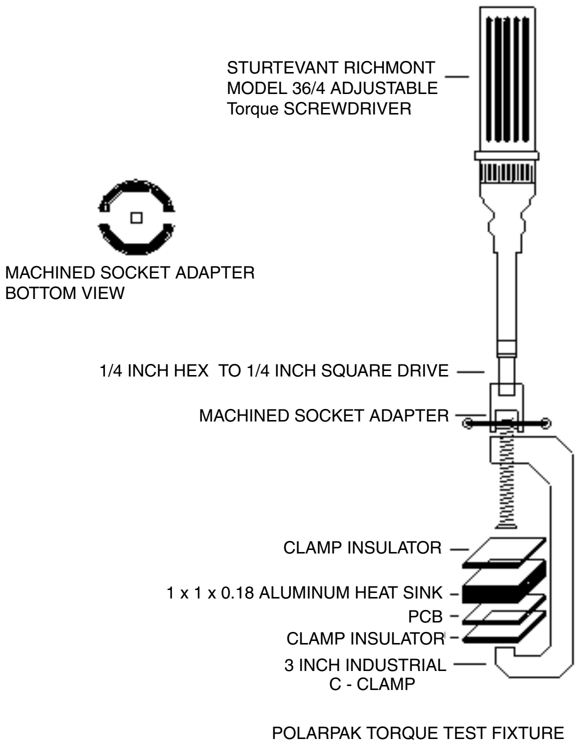


**Figure 9a. Complete clamping and torque setting arrangement**

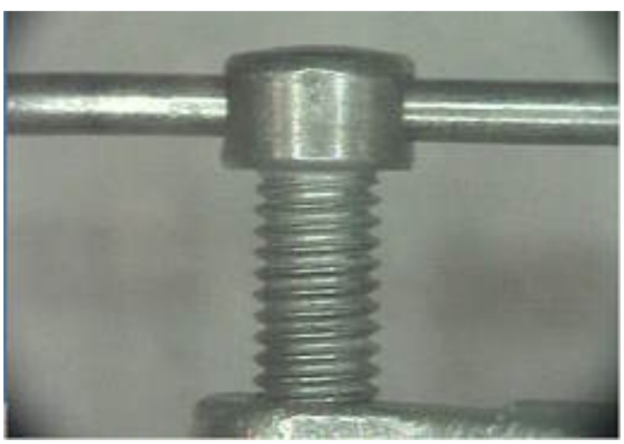

**Figure 9b. C-clamp head without socket adaptor**

**Figure 9c. C-clamp head with socket adaptor**

Accordingly, tightening the C-clamp with the desired torque setting on the screwdriver until it slipped ensured the correct torque value of the assembly between the part and heat sink. Different torque values used in the experiment are 2, 4, 8, 16, and 32 in.-lb.

(6) Thermal characterization
Transient thermal impedance characteristics were developed for the part assembly with heat sink using the different clamping torque values listed above. Figure 10 provides a graphical representation of the results.

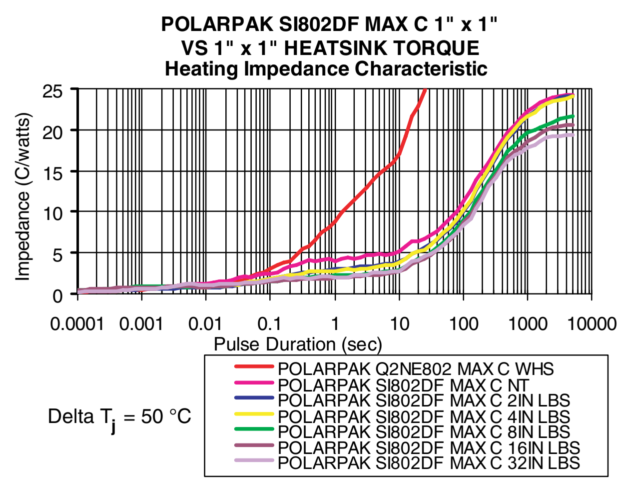


**Figure 10. Transient thermal characteristics at different torque values**

## RESULTS

Table 1 summarizes steady-state values of thermal resistance under various torque conditions.

**TABLE 1 RESULT SUMMARY**

| Torque (in.-lb.) | Steady-State Thermal Resistance (°C/W) | Heat Sink |
|---|---|---|
| 0 | 66.14 | No |
| 0 | 24.19 | Yes |
| 2 | 24.03 | Yes |
| 4 | 24.01 | Yes |
| 8 | 21.64 | Yes |
| 16 | 20.58 | Yes |
| 32 | 19.31 | Yes |

## LIMITING TORQUE VALUE

The MOSFET showed evidence of mechanical damage – cracks in the plastic package – when it was opened after applying the torque value of 32 in.-lb., as shown in Figure 11a. X-ray examination, figure 11b shows partial crack in the die.

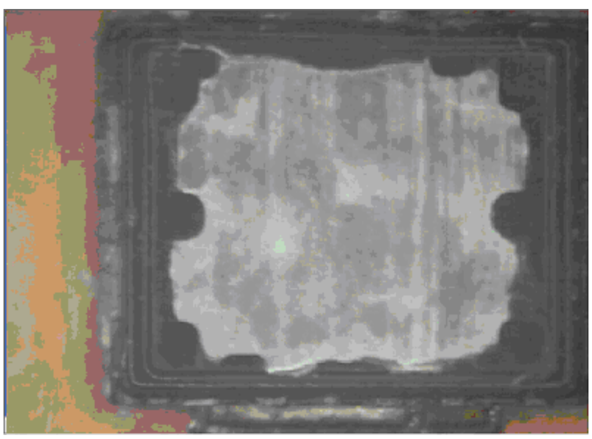

**Figure 11a. Damaged Part**

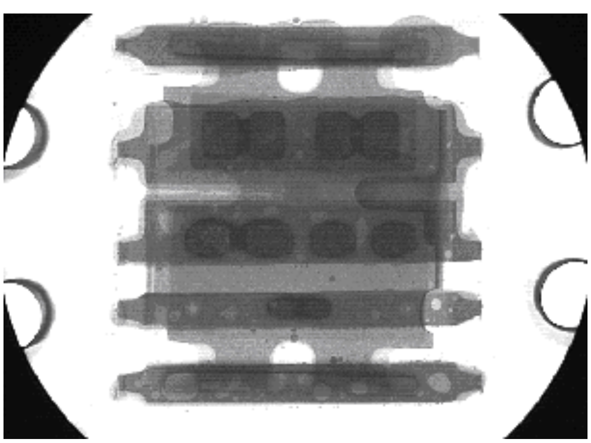

**Figure 11b. X-Ray of damaged part**

The electrical test revealed different resistance values between the gate and two drain terminations. This means the part was also damaged electrically by the test. However, no abnormality was observed on the body diode, which would have hampered the thermal characterization test itself.

Torque value recommendations:

Steady-state thermal resistance value at the highest level of torque, 32 in.-lb., was 19.31 °C/W, and torque a step lower at 16 in.-lb. was 20.58 °C/W. That means doubling the torque value lowers the thermal impedance but damages the package. Determining the optimum torque value that does not damage the part may be a lengthy exercise without much advantage, hence 16 in.-lb. is the recommended safe torque value. Furthermore, we know for sure that the latter value has a 50 % guard band.

## SUMMARY

- 66 °C/W is the junction to ambient, steady-state thermal resistance value for the part on a standard 1 in. x 1 in. PCB.
- Using a heat sink on top of the part with thermal glue without any extra torque brings down the thermal impedance value to 24.49 °C/W, a significant reduction from 66 °C/W.
- Increasing the amount of thermal glue thickness didn't show any noticeable improvements in the thermal resistance value.
- Increasing the mounting/clamping torque brings down the thermal impedance value by 16 %. The no-torque value of 24.49 °C/W drops to 20.58 °C/W with a torque value of 16 in.-lb.
- 16 in.-lb. is the recommended maximum torque value for the PolarPAK package.
- At 32 in.-lb. the part experiences mechanical and electrical damage. Hence, the thermal resistance value of 19.31 °C/W at 32 in.-lb. of torque is not of much practical use.

Acknowledgements:
The author wishes to acknowledge Dwight Kraus for his contribution in this experiment, particularly in designing, developing, and manufacturing the adaptor for interfacing the C-clamp and torque screwdriver.

References:

[1] Ana-Tech Thermal characterization setup - visit Analysis Tech web site for details www.AnalysisTech.com

[2] AN828 "Working with PolarPAK, In-Lab Soldering and Re-Work Recommendations)" web-site www.Vishay.com