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AN4505

High Voltage IGBT Thermal Budgeting and Module Mounting Guidance

Application Note

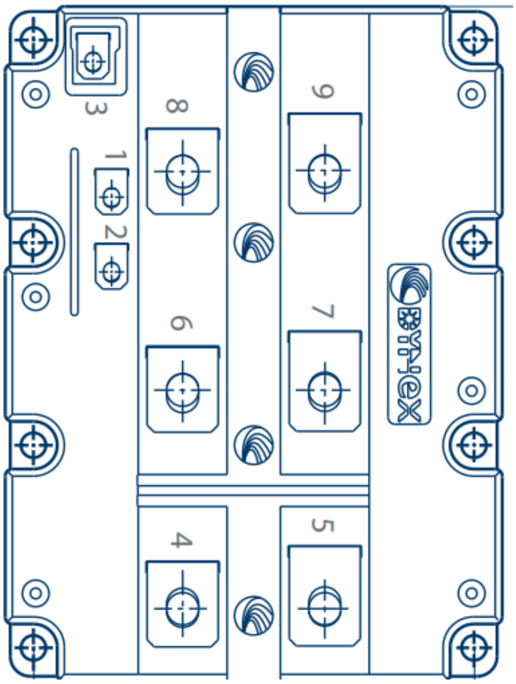
Replaces AN4505-6
AN4505-7 August 2021 LN41090

Introduction

This application provides background and guidance for the mounting of Dynex HV IGBT modules.

Refer to AN5700 for a complete explanation of Dynex's IGBT naming convention.

Refer to AN6156 for IGBT power loss estimation.



Background

All power semiconductors must operate below their maximum junction temperature, T_{jmax}; temporarily exceeding T_{jmax} can cause a reduction in IGBT lifetime (refer to Fig. 1) or lead to imminent device destruction. Therefore, it is essential the designer completely characterizes the thermal aspects of the utilized IGBT.

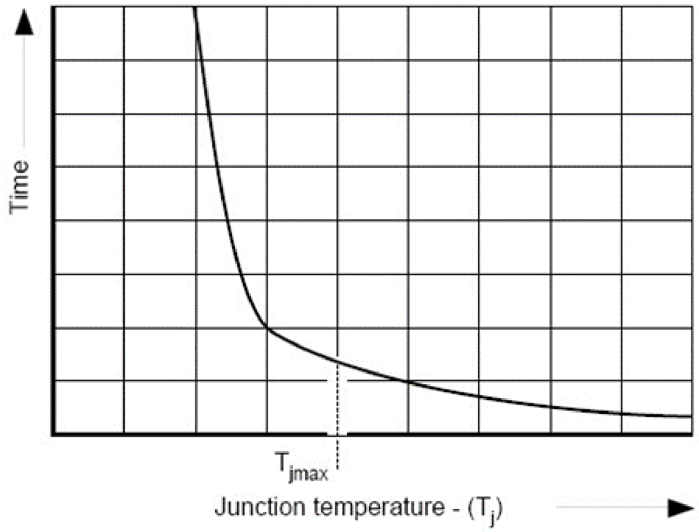


Figure 1. Silicon semiconductor life expectancy vs junction temperature

Thermal management of Dynex IGBTs require the following considerations:

Anticipated dissipated power
Maximum nominal junction temperature
Cooling method
Heat sink properties and configuration
Module to heat sink interface
Thermal interface material & application
Module mechanical mounting procedure

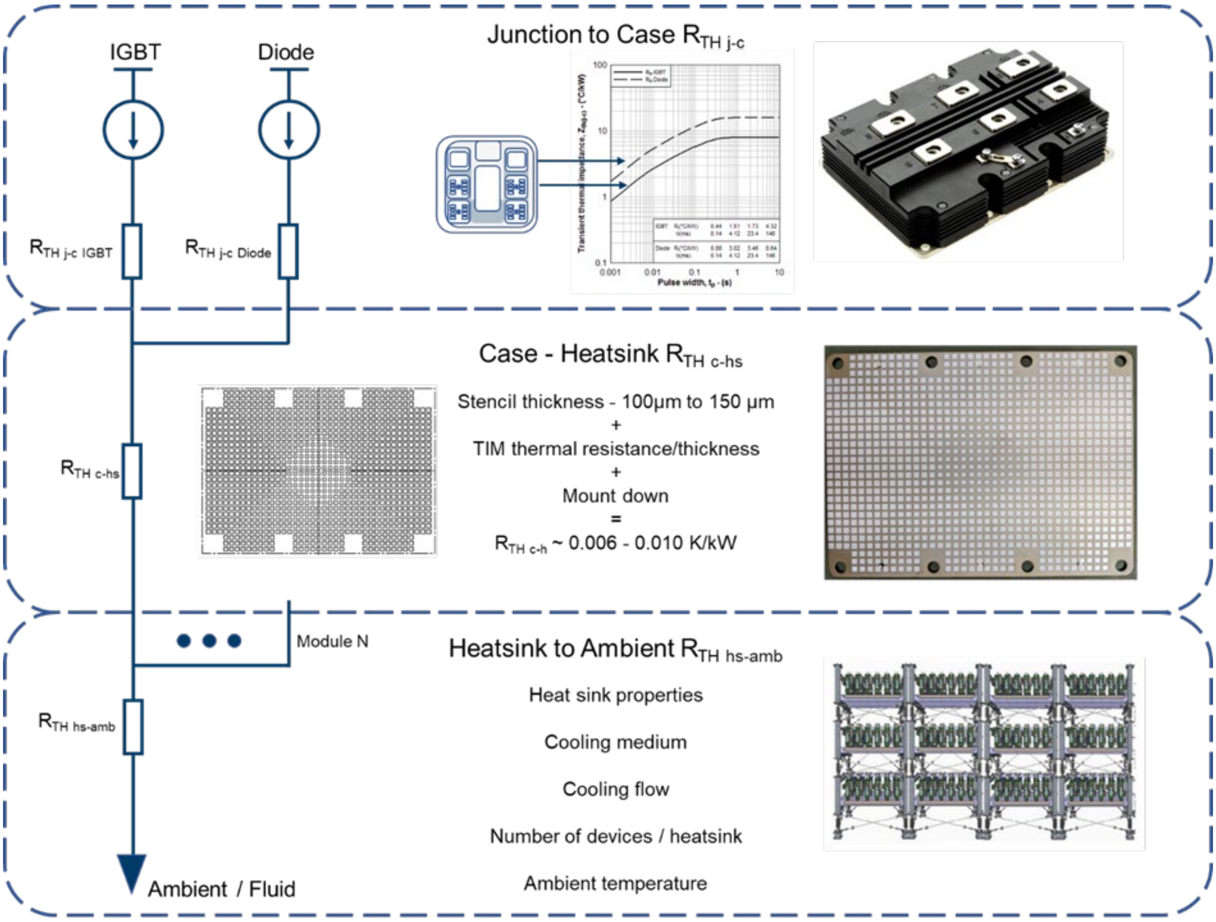


Figure 2. Thermal Circuit for High Voltage IGBT

Anticipated Dissipated Power & Junction Temperature

Application note AN6156 provides guidance on performing analytical estimations for device losses and junction temperature. Dynex's Design Tool and PLECS thermal descriptions library are powerful and efficient tools for part selection and power loss determination.

Normally device and operating point selection is an iterative procedure, in which commercial and technical needs are balanced.

Figure 1, depicts the general relationship of module lifetime vs junction temperature; in which, the lower the junction temperature, the longer expected device lifetime.

Thermal Circuit & Budget Determination

Figure 2 shows an equivalent thermal circuit for 1 to N modules that are mounted on one heat sink. As an example, a DIM1200ASM45-TF000 was simulated in a 2-level inverter application using the Design Tool with the following parameters:

Nominal voltage:	600 $V_{r.m.s.}$
Nominal Current:	400 A
DC-Link:	2700 V
Switching frequency:	750 Hz
T_{amb}:	50ºC
$T_{J(MAX)}$:	125ºC
Simulation Results	
P_{IGBT}:	1531W
P_{Diode}:	618 W

To determine the thermal budget the designer needs to estimate the temperature rise at the junction to case (ΔT_{JC}) interface and the case to heatsink (ΔT_{CH}) interface for both the IGBT and FRD. Then determine which device is more limited by the application.

The temperature rise of the junction-case and case-heatsink can be expressed as:

$$\Delta T_{J-C(IGBT)} = P_{IGBT} * R_{THjc(IGBT)}$$

$$\Delta T_{J-C(DIODE)} = P_{DIODE} * R_{THjc(DIODE)}$$

$$\Delta T_{J-C(IGBT)} = 1531\,W * 0.008\frac{℃}{W} = 12.3\,℃$$

The case-heatsink temperature rise is calculated as:

$$\Delta T_{CH} = (P_{IGBT} + P_{Diode}) * R_{TH(CH)}$$

$$\Delta T_{CH} = (1531W + 618\,W) * 0.006\,\frac{℃}{W} = 12.9℃$$

Depending on the mission profile, anticipated performance of the cooling regime, the system architect should consider applying a safety margin in which the nominal maximum operating junction temperature ($T_{Jop(max)}$) is specified to be 5-25K below the datasheet maximum operating junction temperature (T_j). The applied safety margin can aid in lengthening system lifetime (re. Figure 1), enhance fault tolerance or help in determining if a high volume forced air cooling system is suitable vs a water-cooled system.

In this example a 20ºC safety margin is applied:

$$T_{S.M.} = 20℃$$

The last element in the thermal budget is ambient air or cooling fluid temperature $T_{amb.}$

The thermal budget can now be expressed as an available temperature rise:

$$\Delta T_{available} = T_{JOP(max)} - T_{S.M.} - T_{amb} - \Delta T_{J-C(IGBT)} - \Delta T_{CH}$$

$$\Delta T_{available} = 125℃ - 20℃ - 50℃ - 12.3℃ - 12.9℃ = 29.8℃$$

The maximally allowed heatsink to ambient thermal resistance can be determined by:

$$R_{TH\,h-a(max)} = \frac{\Delta T_{available}}{P_{IGBT}}$$

$$R_{TH\,h-a(max)} = \frac{29.8℃}{1531\,W} = 0.019\frac{K}{W}$$

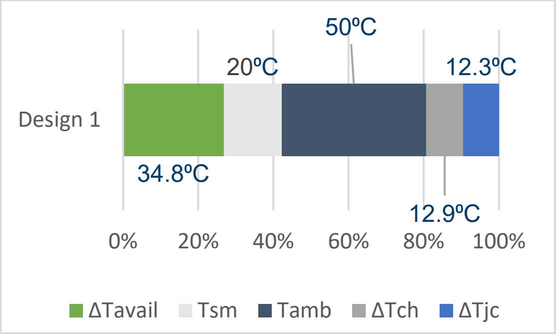


Figure 3. Example thermal budget, TVJOP(max) = 130ºC, DIM1200ASM45-TF000, single phase 240kVA inverter

Figure 3 illustrates how the thermal budget is allocated as a percentage.

Case to heat-sink interface

The case to heat-sink interface requires establishing an effective thermal contact regime between the module's baseplate and heatsink. This is comprised of the following elements:

Module baseplate properties
Thermal Interface Material – TIM
TIM application
Heatsink Properties
Module fastening

Module baseplate properties

Dynex IGBT modules are offered with metal matrix or copper baseplates; the baseplates are designed with a convex shape in order to ensure there is always a force compressing the TIM.

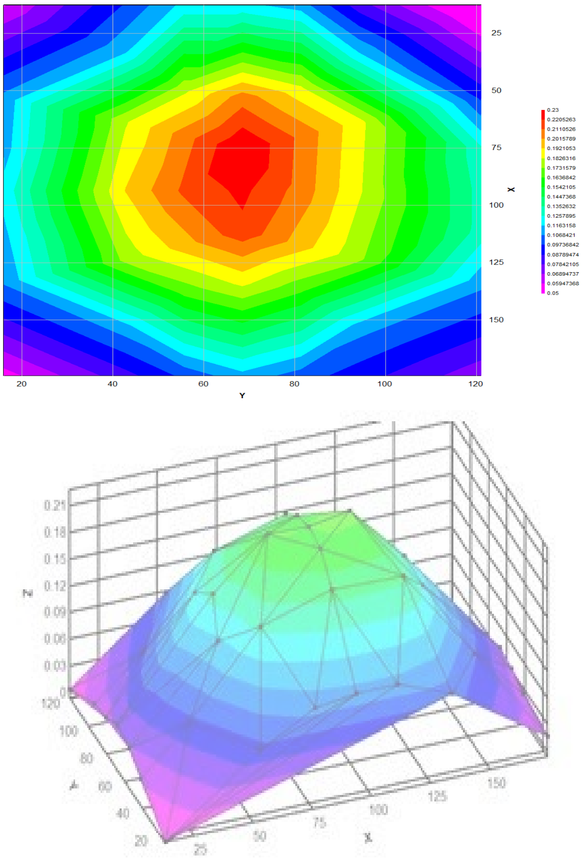


Figure 4. Convex profile of Dynex 190mm 140mm metal matrix baseplate

Thermal Interface Material (TIM)

When thermal grease is employed the Thermal Interface Material is a viscous material intended to provide the lowest thermally conductive path between the module's baseplate and heatsink. Typically, grease based TIM compounds are oil based and may require the use of solvents to dilute the TIM; which will subsequently have the solvents evaporate in order to improve the thermal performance.

Two key parameters of TIM are:

Viscosity (Pa·s)
Bulk Thermal conductivity (W/m·K)
Or
Thermal resistance (mm²·K/W)

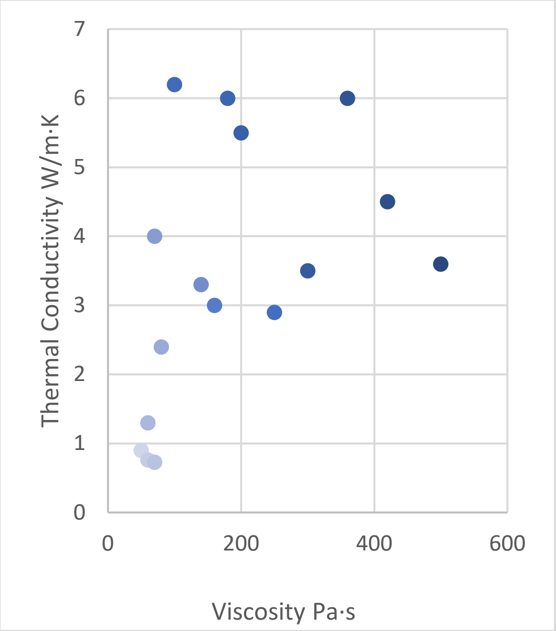


Figure 5. Generic TIM viscosity vs thermal conductivity values

Figure 5 shows a range of TIM materials with their associated viscosity and thermal conductivity; typically, it can be considered that the less viscous the material, the higher the resultant thermal resistance will be. However, this does not mean low viscosity TIM materials should be excluded, as TIM suitability depends on the combination of several factors, which are briefly listed below:

Solvent dilution
Base line thickness
Stencil pattern
Temperature upon application
Fastening regime
Contact pressure
Surface roughness

For case to heatsink thermal resistance, Dynex datasheets assume an applied $R_{TH(ch)}$ = 6 - 8 K/kW for 140 x 130mm & 140 x 1900mm footprint parts, which assumes a thermal conductivity of k_{TIM} = 0.75 to 1W/m-K and a Bond Line Thickness (BLT) of the paste = 80 to 100µm.

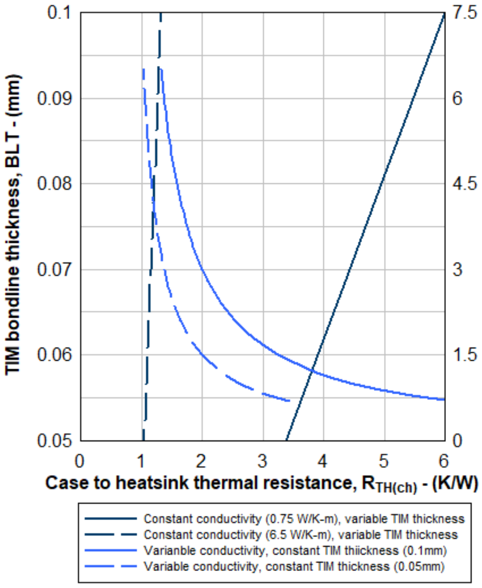


Figure 6. 190mm x 140mm TIM thickness (mm), conductivity (W/m-K) vs thermal resistance (K/W)

$$Specific\ resistance\ RTH(c-hs).mm^2 = \frac{BLT}{k_{TIM}}$$

$$= \frac{100\mu m}{1\,\frac{W}{m\cdot K}} = 100\,\frac{mm^2\cdot K}{W}$$

$$R_{TH(c-h)} = \frac{R}{A} = \frac{100\,\frac{mm^2\cdot K}{W}}{(130\ mm\ x140\ mm)} = 5.5K/kW$$

To account for surface roughness, contact pressure, TIM particle size and overall quality of the contact interface; a thermal contact resistance R_C should be accounted for. This value can range from 4 to 20 mm^2-K/W and considers both the baseplate – TIM and TIM – heatsink interfaces. Therefore, $R_{TH(c-h)}$ can be calculated as:

$$R_{TH(c-h)} = \frac{R+R_C}{A} = \frac{(100+20)\,\frac{mm^2\cdot K}{W}}{(130\ mm\ x140\ mm)} = 6.6K/kW$$

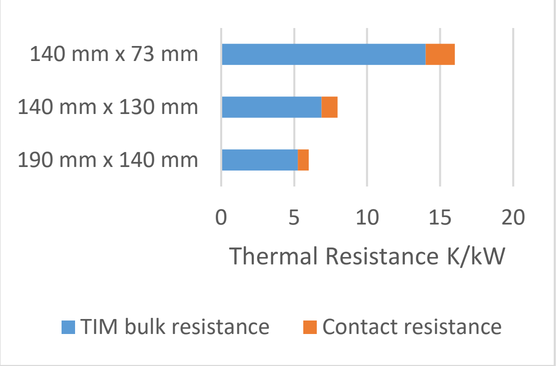


Figure 7 Rth(ch) composition, TIM bulk resistance and contact resistance vs package size. TIM BLT = 0.1mm, Rc = 20 mm2-K/W

As module size decreases, $R_{TH(ch)}$ will increase as shown in Figure 7.

Figure 6, compares the calculated thermal resistance of an applied TIM with a variable thickness (50µm to 100µm), the second axis shows how thermal resistance increases with increasing conductivity (0.75 W/K-m to 6.5 W/K-m) for a 190mm x 140mm contact area. This illustrates the trade off TIM thickness and TIM conductivity, in which informed design targets for case-heatsink thermal losses can be calculated.

Furthermore, the datasheet values for $R_{TH(ch)}$ assume relatively low TIM conductivity with thermal contact resistances of 20 mm^2 – K /W (high thermal losses); which can be considered as a suitable, yet cautious figure for thermal dimensioning..

TIM Application

TIM application is primarily preformed in one of three ways:

Manually (including hand tools)
Stencil with screen press (Fig 8)
Pre-applied

Manual Application

Manually application of TIM is skill intensive and seldomly consistent; for large quantities of

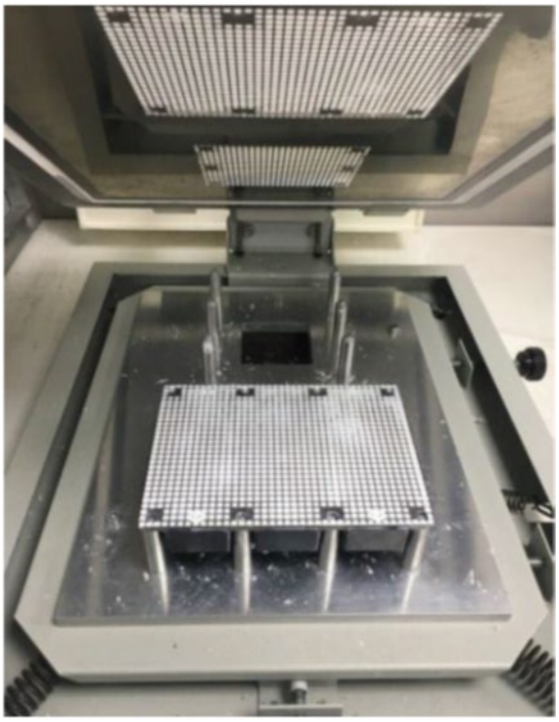


Figure 8 TIM stencil and screen press

Modules and should be avoided whenever possible. It is recommended a screen press with a suitable stencil and TIM be utilised. For manual TIM applications, the following procedure can be considered:

Target BLT = 100
Application tool: toothed spatula or roller
Wet film thickness gauge

Minimize TIM near mounting bolt holes, bolt holes contaminated with TIM will cause incorrect mounting force to module baseplate.

Screen Press Application

Utilisation of a screen press vastly increases the repeatability and quality of applied TIM when compared to manual application. Screen selection can ensure that appropriate amounts of TIM are applied in particular regions of a module by having varying screen ratios. Figure 9 shows three screen patterns which can be fabricated out of stainless steel in thicknesses ranging from 100µm to 150µm; all three patterns give a perimeter around the mounting holes and two out of the three patterns reduce the amount of TIM applied in the adjacent areas as well.

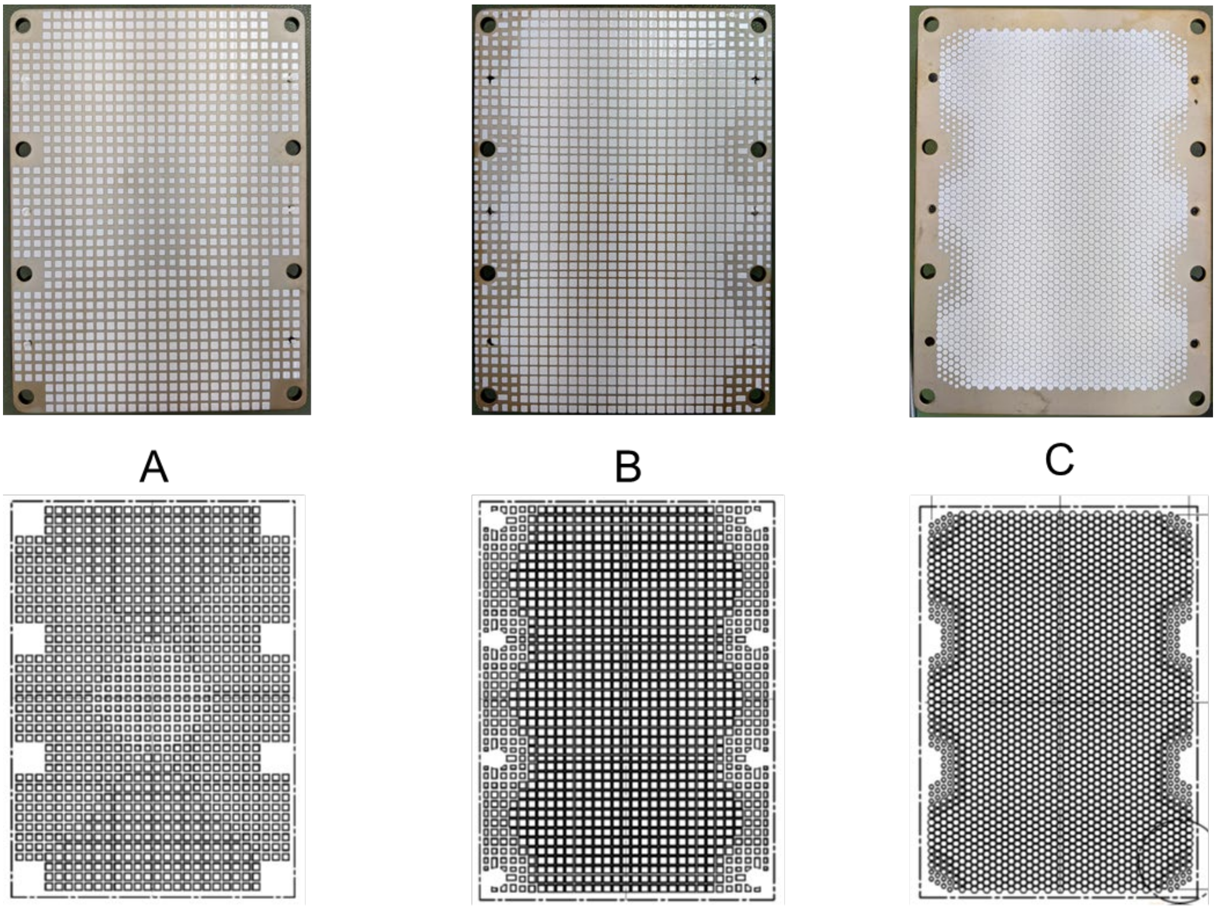


Figure 9 Stencil comparison

Application of the TIM should be applied with metal edged paste scraper.

Selection of the screen pattern and thickness requires an evaluation procedure in which the selected TIM, module and screen are combined and mounted (see mount down procedure) to a suitable heat sink surface or evaluation fixture.

Mount down procedure

Annex I of this application note provides the fastening order for each module package; the following general guidance applies to all Dynex modules.

Ensure all mounting holes are free of contaminants (TIM, solvents etc.) and dust

Ensure heat sink surface is clean, free from damage and not contaminated with other grease, TIM or hand prints.

Heatsink should have a roughness ≤ 10µm, flatness ≤ 30µm.

Placement of module in all cases should avoid incidental contact with mounting holes.

Impact wrenches are not recommended.

Interim and final torque values should be applied with an automatic release torque wrench.

Screws may jam or have elevated torque values if screwed in too fast.

Mounting screws should be of an appropriate length for the mounting hole depth, module baseplate thickness and any additional lock or spring washers (recommended).

Tighten all bolts by hand in the prescribed order.

Utilising a torque wrench, apply 50% of specified datasheet torque.

Allow a minimum 30 minutes (low viscosity TIM, may be longer for high viscosity TIM) before applying final torque in the specified order. The resting time between applying 50% and 100% of mounting torque, allows the TIM to flow and fill the any pockets.

Utilising a torque wrench configured to apply 100% torque value, tighten all screws in the prescribed.

After 15-30 minutes, repeat the final torqueing to ensure module/TIM/heatsink system has reached dynamic equilibrium.

Mounting imprint quality

Prior to production or any final installation, the intended mounting method, including TIM selection, screen pattern etc. should be completely verified by performing the procedure in its entirety and then subsequently dismounted and have its mounting imprint examined. Annex II provides a comparative analysis of a sub optimal mounting and an acceptable mounting, also included in Annex II are commonly used terms to evaluate the quality of a modules mounting, a red-yellow-green indication is provided to show how these aspects may affect the thermal resistance of the case to heatsink interface.

Heat Sink Selection

Naturally air-cooled assemblies (AN)

If there are no physical constraints on the size of the heatsink a reliable cooling solution is a Naturally Air Cooled Heatsink (AN). Typical high voltage IGBT applications far exceed the cooling capabilities of a naturally cooled heat sink.

Forced air cooled assemblies (FC)

Applications with available thermal resistance budgets exceeding 60K/kW can usually consider utilising FC heatsinks; this method requires active cooling effort in addition to the heatsinks’ thermal radiation. Design considerations depend on variety of factors ranging from the number of devices, available installation size/volume, target system efficiency, temperature monitoring etc.

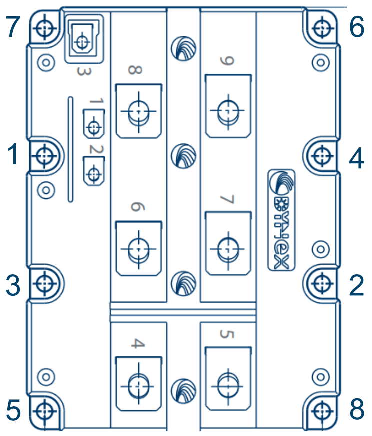
Water cooled heatsinks (WC)

When an application has an available thermal budget below 60K/kW; water cooled heatsinks become a viable option to an essential selection (for thermal budgets in the range of 10-30 K/kW). WC assemblies also benefit from reduced heatsink volume; however, this is at the expense of managing and maintaining the liquid coolant circuit. A higher design and installation effort are required for WC systems, as misaligned coolant plumbing and heatsink orientation can cause reduced performance due to air locking of the coolant circuit.

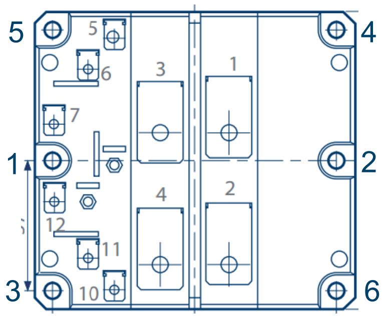
Conclusion

This application note provides a brief overview of the thermal considerations that must be evaluated when using high power IGBTs and a basis for an installation method. For further guidance and enquiries please contact Dynex for further support.

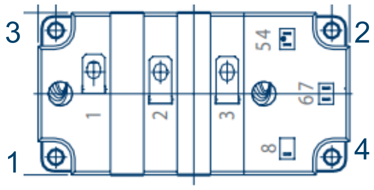
Annex I – Fastening order for module mountdown



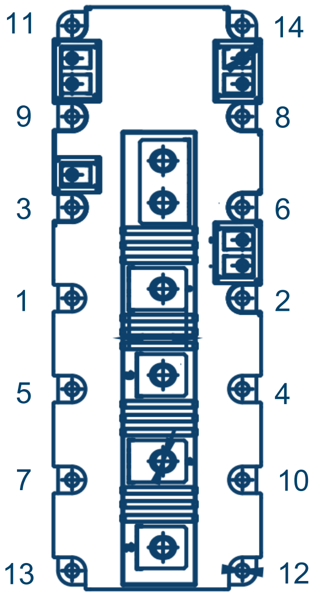
190mm x 140mm
Packages: A&E



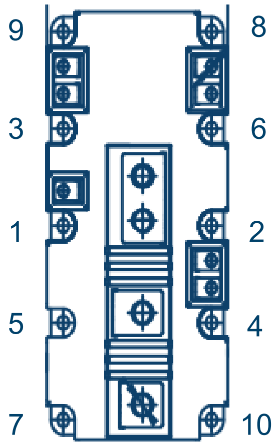
130mm x 140 mm
Packages: D, F, G, N, X



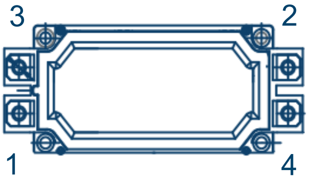
73mm x 140mm
Package: P



H1 Package



H2 Package



M1 Package

Annex II – Mounting imprint analysis

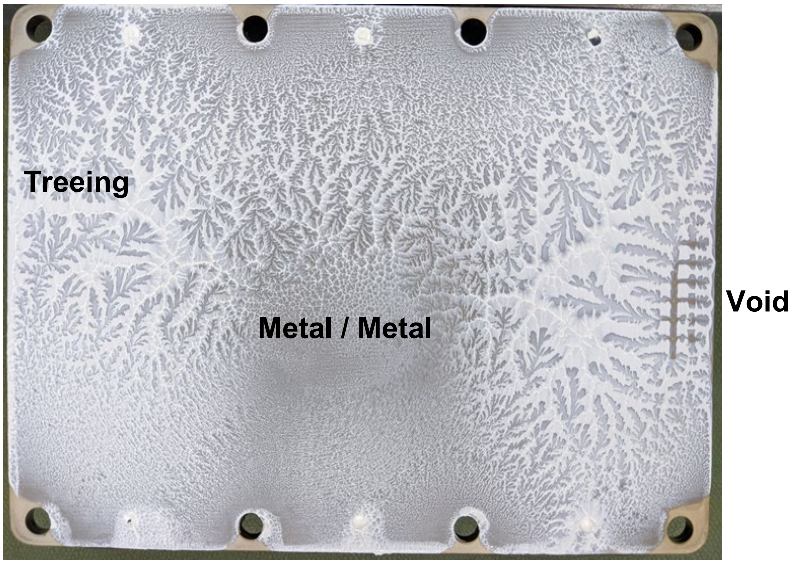


Figure 10. Sub optimal mounting imprint

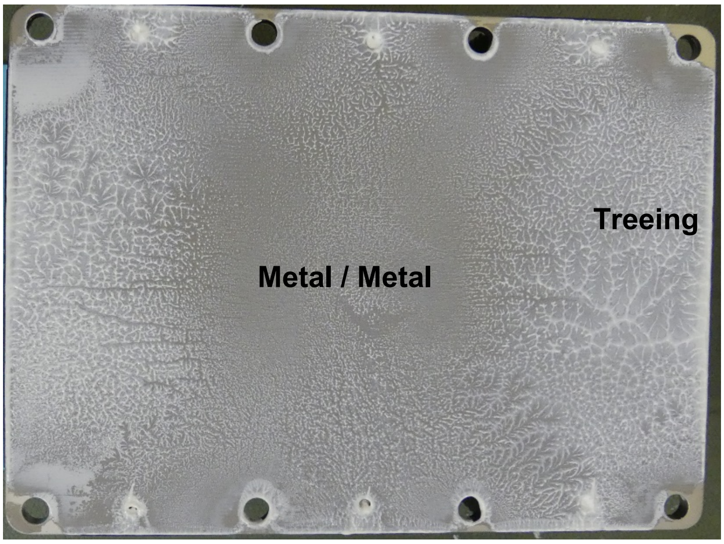


Figure 11 Acceptable mounting imprint

🟩	**Metal / Metal** – minimum TIM applied, all micro voids filled. Lowest thermal resistance.	🟨	**Treeing** – Can be an indication of excess grease in large portion of contact area. Consider different stencil pattern or thickness.
🟥	**Void** – No contact between module and heatsink, interrupts heat spread, cause localised elevated temperatures inducing thermal runaway.	🟨	**Excess grease near mounting hole** - Presents possible mounting hole contamination hazard, consider different stencil pattern or stencil thickness.

Analysis

Figures 10 and 11 show the difference between a sub optimal mounting and an acceptable mounting.

The voiding shown in figure 10 is the most harmful to the mounting and should initiate a re-evaluation of the mounting procedure. Figure 11 shows a wide metal to metal contact surface and treeing that has substantially less TIM than shown in Figure 10.

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