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## Introduction to FAM65CR51DZ1/2 and FAM65HR51DS1/2 650 V Power Modules



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### Introduction

ON Semiconductor has recently launched two automotive qualified power modules (FAM65CR51DZ1/2 and FAM65HR51DS1/2) for use in on board chargers (OBC) and various DC/DC converter applications in electric and hybrid electric vehicles (EV/HEV). These two modules can be used to build a typical OBC system including the power factor correction (PFC) circuit and the DC/DC converter stages. In this application note, we provide an overview of the modules and discuss their DC, AC and thermal characteristics, and provide mounting guidelines.

In a typical OBC topology, the two-phase interleaved PFC and LLC full bridge (or half-bridge) are cascaded. The FAM65CR51DZ1/2 PFC module and the FAM65HR51DS1/2 H-bridge module were developed to fit into this type of OBC system design. The FAM65CR51DZ1/2 module is composed of pair of MOSFETs and series connected diodes to form a two phase interleaved boost converter circuit. The FAM65HR51DS1/2 module was designed for a full bridge converter, with each phase leg composed of two series connected MOSFETs in totem pole configuration.

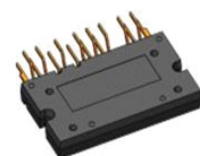
### Module Description

Figure 1 shows various views of the module package, and Figure 2 illustrates the application of the FAM65CR51DZ1/2 PFC module and FAM65HR51DS1/2 H-bridge module in a EV/HEV OBC system. As seen from Figure 3, the two pairs of series-connected MOSFET and diode are integrated in FAM65CR51DZ1/2 module to build a two-phase interleaved PFC circuit. In Figure 4, the four MOSFETs forming a H-bridge converter are contained in FAM65HR51DS1/2 module. The modules are all qualified according to AEC Q101 and AQG324. These two compact modules were designed to minimize the parasitic inductance and resistance in order to achieve the better switching and thermal performance.

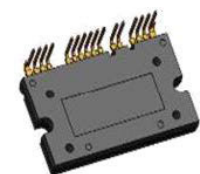
### APPLICATION NOTE



(a) Bottom View



(b) Top View (Y-Form)



(c) Top View (L-Form)

Figure 1. FAM65CR51DZ1 Module

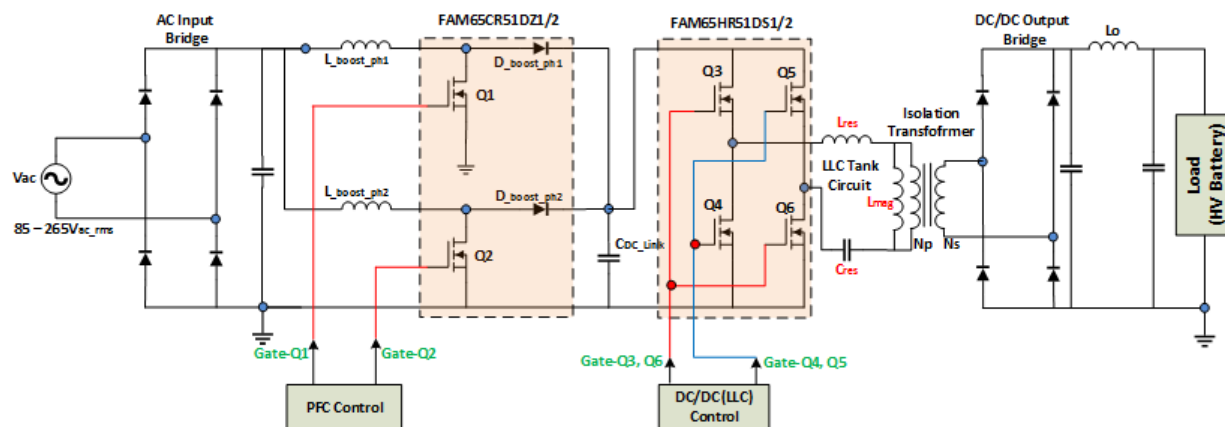
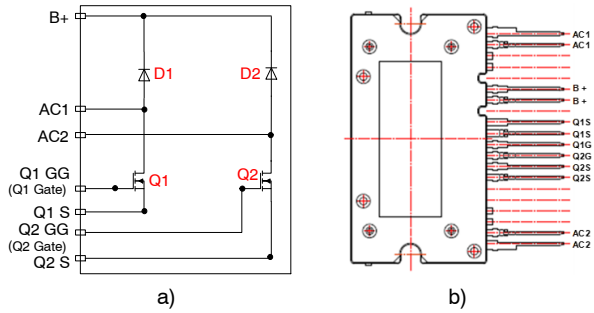
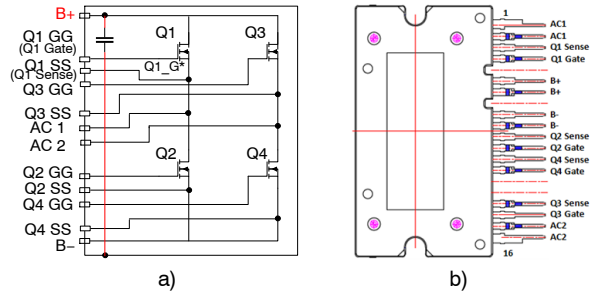


Figure 2. Typical Module Application in OBC System



**Figure 3. The Internal Circuit Diagram (a) and Pin-out Configuration of FAM65CR51DZ1/2 Module (b)**



**Figure 4. The Internal Circuit Diagram (a) and Pin-out Configuration of FAM65HR51S1/2 Module (b)**

## Electrical Characteristics

## ELECTRICAL SPECIFICATIONS

| Symbol       | Conditions   | Min  | Typ | Max  | Unit |
|--------------|--|------|-----|------|------|
| $BV_{DSS}$   | $I_D = 1 \text{ mA}$<br>$V_{GS} = 0 \text{ V}$                               | 650  | –   | –    | V    |
| $V_{GS(th)}$ | $V_{GS} = V_{DS}$<br>$I_D = 3.3 \text{ mA}$                                  | 3.0  | –   | 5.0  | V    |
| $R_{DS(on)}$ | $V_{GS} = 10 \text{ V}$<br>$I_D = 20 \text{ A}$                              | –    | 44  | 51   | mΩ   |
| $R_{DS(on)}$ | $V_{GS} = 10 \text{ V}$<br>$I_D = 20 \text{ A}$<br>$T_C = 125^\circ\text{C}$ | –    | 79  | –    | mΩ   |
| $g_{FS}$     | $V_{DS} = 20 \text{ V}$ ,<br>$I_D = 20 \text{ A}$                            | –    | 30  | –    | S    |
| $I_{GSS}$    | $V_{GS} = \pm 20 \text{ V}$ ,<br>$V_{DS} = 0 \text{ V}$                      | –100 |     | +100 | nA   |
| $I_{DSS}$    | $V_{DS} = 650 \text{ V}$ ,<br>$V_{GS} = 0 \text{ V}$                         | –    | –   | 10   | μA   |

## DYNAMIC CHARACTERISTICS

| Symbol                | Conditions   | Min | Typ  | Max | Unit |
|-----------------------|--|-----|------|-----|------|
| C <sub>iss</sub>      | V <sub>DS</sub> = 400 V<br>V <sub>GS</sub> = 0 V<br>f = 1 MHz                      | –   | 4864 | –   | pF   |
| C <sub>oss</sub>      |  | –   | 109  | –   | pF   |
| C <sub>rss</sub>      |  | –   | 16   | –   | pF   |
| C <sub>oss(eff)</sub> | V <sub>DS</sub> = 0<br>to 520 V<br>V <sub>GS</sub> = 0 V                           | –   | 652  | –   | pF   |
| R <sub>g</sub>        | f = 1MHz   | –   | 2    | –   | Ω    |
| Q <sub>g(tot)</sub>   | V <sub>DS</sub> = 380 V<br>I <sub>b</sub> = 20 A<br>V <sub>GS</sub> = 0<br>to 10 V | –   | 123  | –   | nC   |
| Q <sub>gs</sub>       |  | –   | 37.5 | –   | nC   |
| Q <sub>gd</sub>       |  | –   | 49   | –   | nC   |

## SWITCHING CHARACTERISTICS

| Symbol       | Conditions                                     | Min | Typ  | Max | Unit          |
|--------------|--|-----|------|-----|---------------|
| $t_{on}$     | $V_{DS} = 400\text{ V}$<br>$I_D = 20\text{ A}$ | –   | 60.5 | –   | $\mu\text{s}$ |
| $t_{d(on)}$  |  | –   | 50.5 | –   | $\mu\text{s}$ |
| $t_r$        |  | –   | 10   | –   | $\mu\text{s}$ |
| $t_{off}$    |  | –   | 241  | –   | $\mu\text{s}$ |
| $t_{d(off)}$ |  | –   | 117  | –   | $\mu\text{s}$ |
| $t_f$        |  | –   | 125  | –   | $\mu\text{s}$ |

## BODY DIODE CHARACTERISTICS

| Symbol          | Conditions  | Min | Typ      | Ma- | Unit |
|-----------------|---|-----|----------|-----|------|
| V <sub>SD</sub> | I <sub>SD</sub> = 20 A,<br>V <sub>GS</sub> = 0 V  | –   | 0.9<br>5 | –   | V    |
| T <sub>rr</sub> | V <sub>DS</sub> = 520 V,<br>I <sub>D</sub> = 20 A,<br>d <sub>I</sub> /d <sub>t</sub> = 100 A/μs | –   | 134      | –   | ns   |
| Q <sub>rr</sub> |   | –   | 702      | –   | nC   |

### PFC DIODE RATINGS

| Symbol      | Rating      | Unit |
|-------------|-------------|------|
| $V_{RRM}$   | 600         | V    |
| $V_{RWM}$   | 600         | V    |
| $V_R$       | 600         | V    |
| $I_{F(AV)}$ | 15          | A    |
| $I_{FSM}$   | 45          | A    |
| $T_J$       | -55 to +150 | °C   |
| $T_C$       | -40 to +125 | °C   |
| TSTG        | -40 to +125 | °C   |
| $E_{AVL}$   | 20          | mJ   |

### ELECTRICAL SPECIFICATIONS OF PFC DIODE

| Sym-<br>bol | Test Conditions   |                           | Typ  | Max | Unit          |
|-------------|---|---------------------------|------|-----|---------------|
| $I_R$       | $V_R = 600\text{ V}$  | $T_C = 25^\circ\text{C}$  | –    | 100 | $\mu\text{A}$ |
|             |   | $T_C = 125^\circ\text{C}$ | –    | 1   | mA            |
| $V_{FM}$    | $I_F = 15\text{ A}$   | $T_C = 25^\circ\text{C}$  | 1.65 | 2.2 | V             |
|             |   | $T_C = 125^\circ\text{C}$ | 1.24 | 1.7 | V             |
| $t_{rr}$    | $I_F = 15\text{ A}$<br>$dI_F/dt = 200\text{ A}/\mu\text{s}$<br>$V_R = 390\text{ V}$ | $T_C = 25^\circ\text{C}$  | 29   | –   | ns            |
| $t_a$       |   | $T_C = 25^\circ\text{C}$  | 16   | –   | ns            |
| $t_b$       |   | $T_C = 25^\circ\text{C}$  | 13   | –   | n             |
| $Q_{rr}$    |   | $T_C = 25^\circ\text{C}$  | 43   | –   | nC            |

### R<sub>DS(on)</sub>(T<sub>J</sub>) PROFILE FAM65HR51DS1/FAM65CR51DZ1

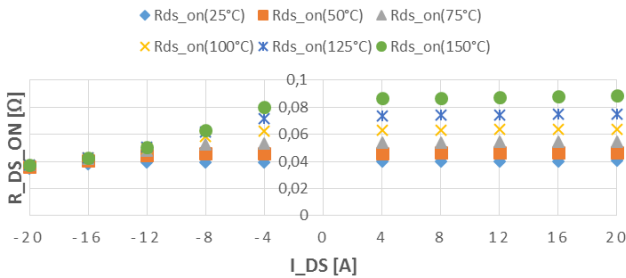


Figure 5. Simulation on  $R_{DS(on)}$  ( $T_J$ ) of the MOSFET Die

### Thermal Characteristics

For the thermal impedance measurement, 635  $\mu\text{m}$   $\text{Al}_2\text{O}_3$  DBC was applied and the thermal interface material (TIM) was assumed to have the thermal conductivity of 1.8 W/mK with 30  $\mu\text{m}$  of paste thickness.

### FAM65CR51DZ1 PFC MODULE

| Parameters                          | Min | Typ  | Max  | Unit |
|-------------------------------------|-----|------|------|------|
| $R_{\theta_{JC}}$ (per MOSFET chip) | –   | 0.66 | 0.92 | °C/W |
| $R_{\theta_{JS}}$ (per MOSFET chip) | –   | 1.32 | –    | °C/W |
| $R_{\theta_{JC}}$ (per DIODE chip)  | –   | 1.98 | 2.72 | °C/W |
| $R_{\theta_{JS}}$ (per DIODE chip)  | –   | 2.97 | –    | °C/W |

### FAM65HR51DS1 H-BRIDGE MODULE

| Parameters                          | Min | Typ  | Max  | Unit |
|-------------------------------------|-----|------|------|------|
| $R_{\theta_{JC}}$ (per MOSFET chip) | –   | 0.66 | 0.92 | °C/W |
| $R_{\theta_{JS}}$ (per MOSFET chip) | –   | 1.2  | –    | °C/W |

### Thermal Performance

Figure 6 shows the 6<sup>th</sup> order RC Foster thermal impedance network of the MOSFET and diode (FAM65CR51DZ1 only) die inside the module. Table 1 and Table 2 represent respectively the junction to heatsink thermal impedance,  $Z_{th_{js}}$  and the junction to case thermal impedance,  $Z_{th_{jc}}$  based on the 6<sup>th</sup> order thermal network.

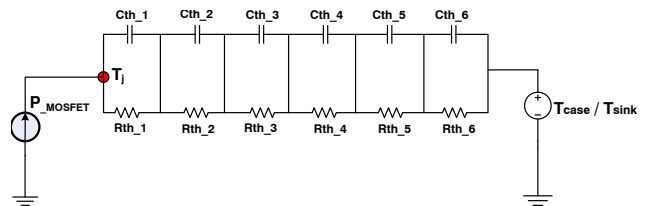


Figure 6. 6<sup>th</sup> order Foster Thermal Impedance Network of the MOSFET and Diode Die in the Module

**Table 1. THERMAL RESISTANCE ( $R_{TH}$ ) AND THERMAL CAPACITANCE ( $C_{TH}$ ) VALUES IN THE 6<sup>TH</sup> ORDER JUNCTION TO HEATSINK THERMAL IMPEDANCE ( $Z_{TH\_JS}$ ) NETWORK**

| $R_{th}$ [°C/W]  | $R_{th1}$ | $R_{th2}$ | $R_{th3}$ | $R_{th4}$ | $R_{th5}$ | $R_{th6}$ |
|------------------|-----------|-----------|-----------|-----------|-----------|-----------|
| FAM65CR51 MOSFET | 2 m       | 21 m      | 32 m      | 460 m     | 750 m     | 60 m      |
| FAM65CR51 Diode  | 8.6 m     | 92 m      | 233 m     | 1.47      | 1.05      | 104 m     |
| FAM65HR51 MOSFET | 2 m       | 22 m      | 34 m      | 450 m     | 650 m     | 53 m      |
| $C_{th}$ [J/°C]  | $C_{th1}$ | $C_{th2}$ | $C_{th3}$ | $C_{th4}$ | $C_{th5}$ | $C_{th6}$ |
| FAM65CR51 MOSFET | 2.3 m     | 4.7 m     | 68 m      | 100 m     | 700 m     | 34.8      |
| FAM65CR51 Diode  | 0.5 m     | 1.1 m     | 9.7 m     | 31.8 m    | 533 m     | 14.5      |
| FAM65HR51 MOSFET | 2.6 m     | 4.5 m     | 63 m      | 100 m     | 800 m     | 35        |

**Table 2. RTH AND CTH VALUES IN THE 6TH ORDER JUNCTION TO CASE THERMAL IMPEDANCE ( $Z_{TH\_JC}$ ) NETWORK**

| $R_{th}$ [°C/W]  | $R_{th1}$ | $R_{th2}$ | $R_{th3}$ | $R_{th4}$ | $R_{th5}$ | $R_{th6}$ |
|------------------|-----------|-----------|-----------|-----------|-----------|-----------|
| FAM65CR51 MOSFET | 2 m       | 23 m      | 140 m     | 475 m     | 19 m      | 3.7 m     |
| FAM65CR51 Diode  | 9.7 m     | 106 m     | 335 m     | 1.46      | 61 m      | 9 m       |
| FAM65HR51 MOSFET | 2 m       | 23 m      | 140 m     | 475 m     | 19 m      | 3.7 m     |
| $C_{th}$ [J/°C]  | $C_{th1}$ | $C_{th2}$ | $C_{th3}$ | $C_{th4}$ | $C_{th5}$ | $C_{th6}$ |
| FAM65CR51 MOSFET | 2.4 m     | 4.3 m     | 15 m      | 73 m      | 9.43      | 14.7      |
| FAM65CR51 Diode  | 0.3 m     | 0.7 m     | 4.8 m     | 19 m      | 3.79      | 13.6      |
| FAM65HR51 MOSFET | 2.4 m     | 4.3 m     | 15 m      | 73 m      | 9.43      | 14.7      |

Figure 7 shows the MOSFET junction temperature profile of FAM65HR51DS1 module in the worst case. The worst case is created from the LLC DC/DC converter operating condition in a 3.3 kW OBC system:  $P_{out} = 3.52$  kW,  $V_{out} = 220$  V,  $f_{sw} = 150$  kHz and  $I_{out} = 16$  A (maximum charging current). In the thermal simulation, the switching loss was calculated using the MOSFET current vs. switching energy curve and the conduction loss was obtained using the MOSFET current vs.  $R_{DS(on)}(T_j)$  curve.

In the worst case condition mentioned above, the peak junction temperature of the MOSFET die is 127.6°C.

Considering the maximum junction temperature is 150°C, the module has enough margin to maintain a good thermal condition through the entire operating range. Figure 8 represents the increase in  $R_{DS(on)}$  value in the worst case condition. At this condition,  $R_{DS(on)}$  (127.6°C)  $\approx 99.6$  mΩ. In this simulation,  $R_{DS(on)}$  (25°C) is assumed 51 mΩ, the worst case value (typical value: 44 mΩ). Figure 9 and Figure 10 shows respectively the  $T_j$  profile and  $R_{DS(on)}(T_j)$  profile of FAM65CR51DZ1 PFC module in the worst case condition,  $P_{out\_PFC} = 3.52$  kW,  $V_{out\_PFC} = 400$  V and  $I_{out\_PFC} = 8.8$  A.

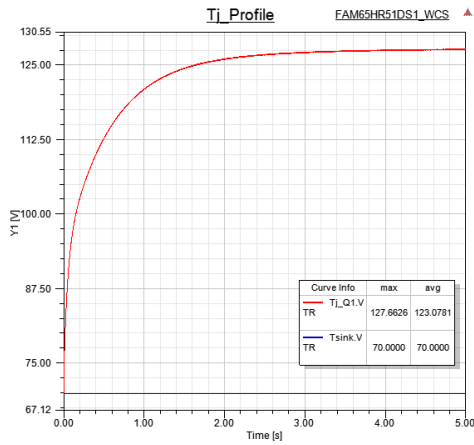


Figure 7.  $T_j$  Profile of FAM65HR51DS1 H-bridge Module for the worst Case

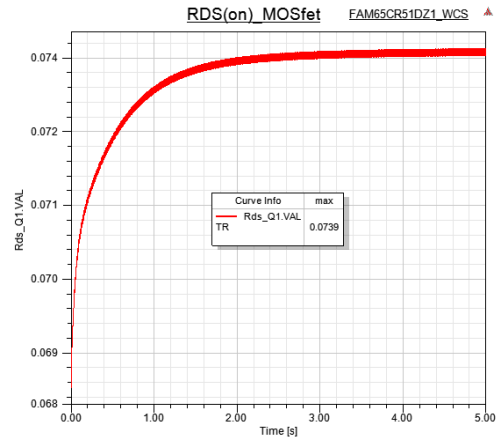


Figure 10.  $R_{DS(on)}(T_j)$  Profile of FAM65CR51DZ1 PFC Module for the worst Case

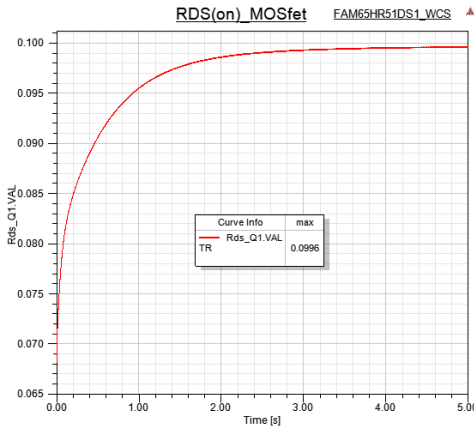


Figure 8.  $R_{DS(on)}(T_j)$  Profile of FAM65HR51DS1 H-bridge Module for the worst Case

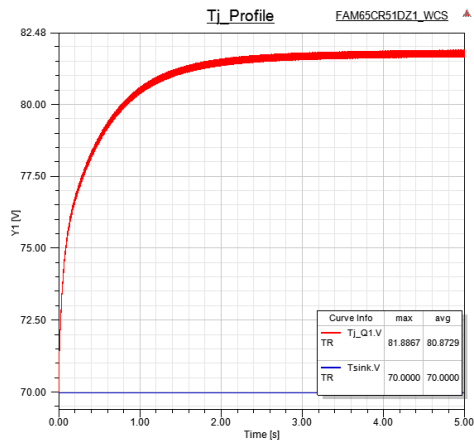


Figure 9.  $T_j$  Profile of FAM65CR51DZ1 PFC Module for the worst Case

### Short Circuit Withstand Time

Table 3 represents the result of the short circuit test based on AQG324 type 1 short circuit withstand time test procedure. The result shows that the module can survive over 13  $\mu$ sec of the short circuit period. Figure 11 illustrates the short circuit withstand time of FAM65HR51DS1 H-bridge module.

Table 3. SHORT CIRCUIT TEST RESULT

$T_{CASE} = 150^{\circ}\text{C}$  (MAX.  $T_j$ ),  $V_{DS} = 450\text{ V}$  AND  $V_{GS} = 10\text{ V}$

| Module | SC Peak Current | SC Energy | SC Withstand Time |
|--------|-----------------|-----------|-------------------|
| #1     | 320 A           | 1.59 J    | 13.8 $\mu$ sec    |
| #2     | 300 A           | 1.55 J    | 14.6 $\mu$ sec    |
| #3     | 316 A           | 1.56 J    | 13.8 $\mu$ sec    |
| #4     | 304 A           | 1.58 J    | 14.6 $\mu$ sec    |

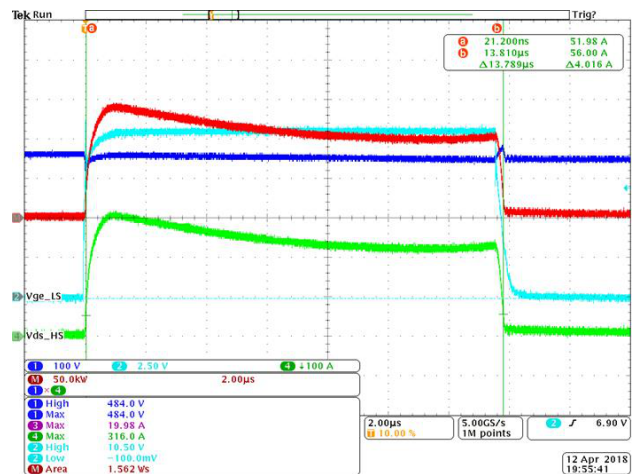


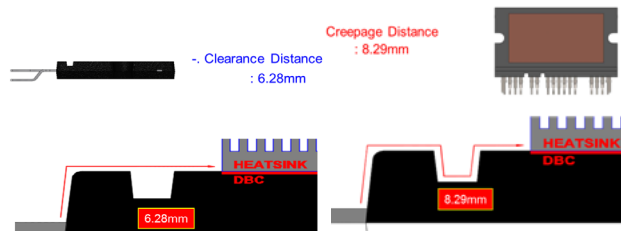
Figure 11. Waveforms in the Short Circuit Test

## Creepage and Clearance

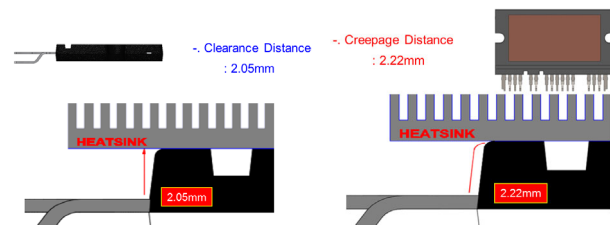
Electrical isolation is closely related to the safety and reliability of the module in an application. The distance between two conductive materials is defined as creepage and clearance in IEC61800-5-1. Creepage distance is the shortest distance along the surface of a solid insulating material between two conductive parts. The basis for the determination of a creepage distance is the rms value of the working voltage between the two conductive parts. Clearance is the shortest distance in air between two conductive parts to withstand transient overvoltage event that can cause an arc. Table 4 below represents the creepage and clearance distance of the two modules (Figure 14 and Figure 15) and Figure 12 and Figure 13 illustrates the clearance and creepage configuration of each module based on the restriction of the location of the edge of the heatsink.

**Table 4. CREEPAGE AND CLEARANCE OF THE MODULES**

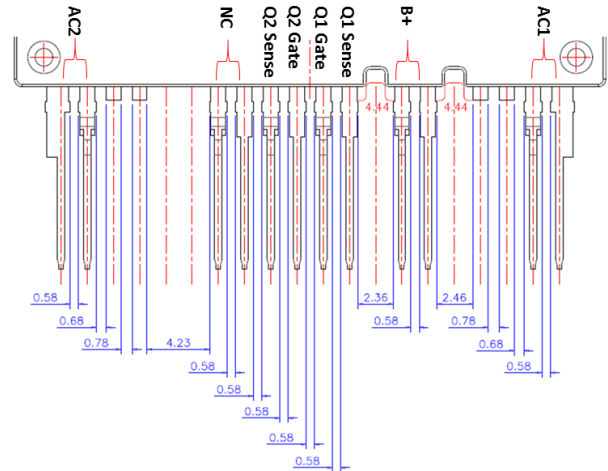
| Location  | Clearance [mm] | Creepage Distance [mm] |
|---|----------------|------------------------|
| Between Power leads<br>B+ and B-                          | 2.36           | 4.44                   |
| Between Signal leads                                      | 0.58           | 0.58                   |
| Between Power leads<br>and Signal leads                   | 2.36           | 4.44                   |
| Between leads &<br>heatsink: case 1 / 2<br>(Figure 12/13) | 6.28 / 2.05    | 8.29 / 2.22            |



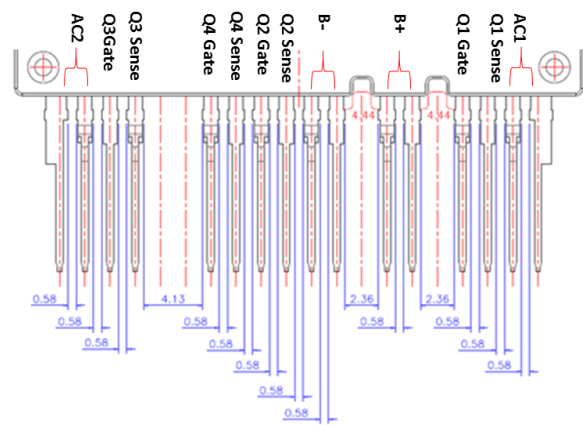
**Figure 12. Creepage and Clearance between Leads and Heatsink in Case 1: Restriction on the Location of the Edge of the Heatsink**



**Figure 13. Creepage and Clearance between Leads and Heatsink in case 2: No Restriction on the Location of the Edge of the Heatsink**



**Figure 14. Creepage and Clearance between the Leads in FAM65HR51DS1 Module**



**Figure 15. Creepage and Clearance between the Leads in FAM65CR51DZ1 Module**

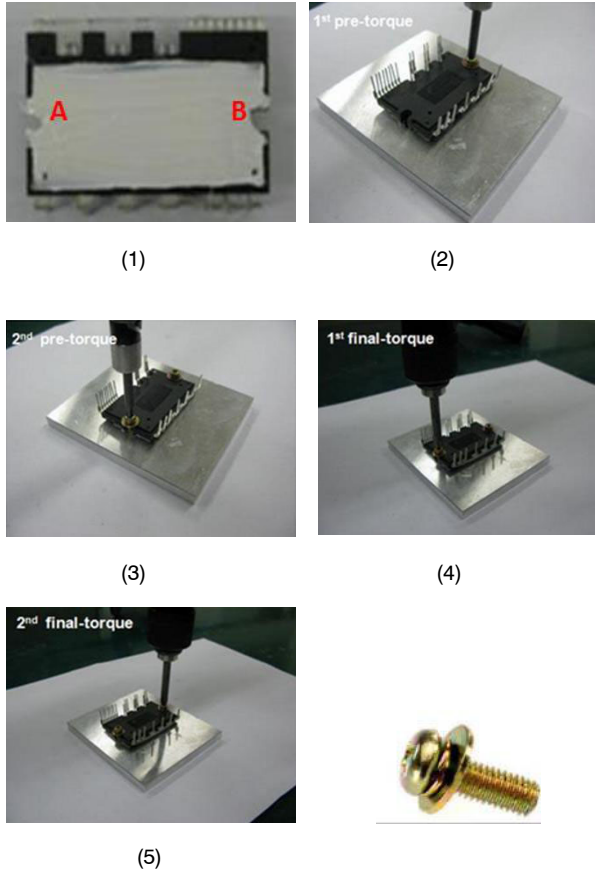
## Module Mounting Guide

### Heatsink Mounting Guide

For mounting the module to a heatsink, users should follow the ON Semiconductor's guideline (Table 6) to prevent the module from mechanical damage especially due to applying excessive torque to the mounting screw. With the specified torque application, the size of the drilling holes in the heatsink should be exactly matched to the specification and the surface of the heatsink should be smoothed by removing burrs and protrusion to satisfy the flatness and roughness requirement. The definition of flatness and roughness on heatsink surface are illustrated in Figure 17. Table 6 shows the guideline for the mounting torque, flatness in both the surface of the heatsink and DBC area and the roughness of the heatsink surface. The module mounting procedure is described as below and illustrated in Figure 16:



1. Thermal interface material (TIM) paste
2. Pre-screwing in side A  
(20% – 30% of maximum torque)
3. Pre-screwing in side B  
(20% – 30% of maximum torque)
4. Final screwing in side B (maximum torque)
5. Final screwing in side A (maximum torque)



**Figure 16. Example of Mounting Procedure of the Module to the Heatsink and SEMS Screw with 5.5 mm Spring Washer or over 6 mm flat washer**



**Figure 17. Flatness (a) and Roughness (b) of the Heatsink**

#### Thermal Interface Material (TIM) Application

TIM is applied between the heatsink and the module to reduce the contact thermal resistance. User should make sure that the TIM is applied thinly and evenly based on the TIM datasheet including the thickness [μm] and thermal

conductivity, [W/mK]. Only a small amount of compound is required to fill the gap space between the metal contact increasing the effective surface area for heat transfer. The recommended TIM is HTCP (Heat Transfer Compound Plus) thermal grease. HTCP is a non-curing, non-silicone heat transfer paste suitable for the application where silicones are prohibited, thus avoiding issues with silicone and low molecular weight siloxane migration. It is RoHS-2 compliant. Table 5 below shows the datasheet of HTCP.

**Table 5. HTCP Specifications**

|   |                           |
|---|---------------------------|
| Colour                                  | White                     |
| Base                                    | Blend of synthetic fluids |
| Thermo-conductive Component             | Powered metal oxides      |
| Density                                 | 3.0[g/mL]                 |
| Viscosity @ 1rpm                        | 101 – 112                 |
| Thermal Conductivity (Guided hot plate) | 2.5[W/m.K]                |
| Thermal Conductivity (Heat flow)        | 1.7[W/m.K]                |
| Temperature Range                       | –50°C ~ 130°C             |
| Permittivity @ 1 GHz                    | 4.2                       |
| Volume Resistivity                      | 1x10 <sup>14</sup> [Ω.cm] |
| Dielectric Strength                     | 42[kV/min]                |
| Flammability                            | UL94-0 equivalent         |

#### Screw Tightening Torque

Threaded fasteners should be tightened according to the specified fastening torque. Tightening beyond a certain limit causes the mechanical damage and does not provide any improvement in the contact thermal resistance. As shown in Table 6, the recommended range of screw torque is 0.4 N·m ~ 0.8 N·m.

**Table 6. MOUNTING TORQUE AND FLATNESS GUIDELINE**

| Item               | Limits |         |     | Unit |
|--------------------|--------|---------|-----|------|
|                    | Min    | Typical | Max |      |
| Mounting Torque    | 0.4    | 0.6     | 0.8 | N·m  |
| Module Flatness    | 0      | –       | 150 | μm   |
| Heatsink Flatness  | –100   | –       | 50  | μm   |
| Heatsink Roughness | 0      | –       | 10  | μm   |

#### Assembly Sequence

The assembly process can be done in two ways. One method is mounting the module to the heatsink first and then proceed with soldering. Alternatively, soldering can be done first and then mounting the module to the heatsink follows.



### Mounting the Module to the Heatsink before Soldering

Figure 18 shows the process for mounting before soldering. The process is as below:

1. Apply the TIM and place the module on the heatsink
2. Tighten up the module using M3 screw and washer
3. Place the PCB until the PCB surface touches the lead stopper
4. Solder the module lead to the PCB

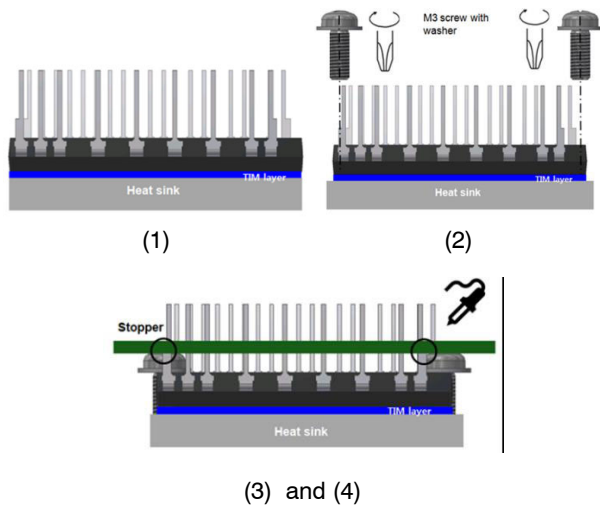


Figure 18. Module mounting before soldering

### Soldering to PCB before mounting

This method proceeds as below and Figure 19 illustrates the process:

1. Place the module on the PCB until the PCB surface touches the stopper
2. Solder the module to the PCB
3. Apply TIM and place the module on the heatsink
4. Tighten up the module using M3 screw and washer

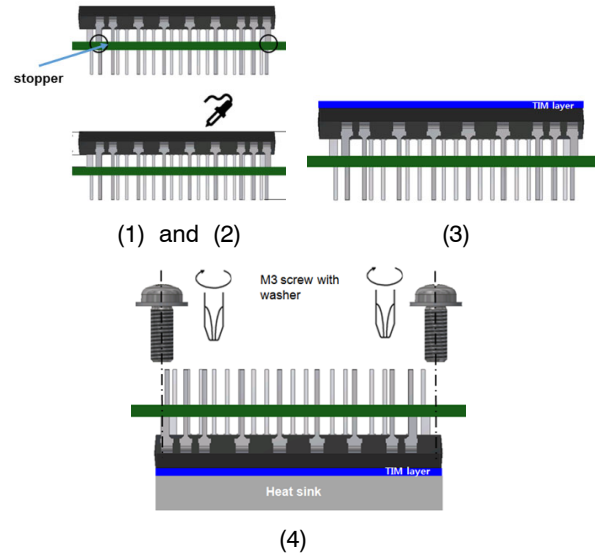



Figure 19. Mounting the module after soldering

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