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AND9814/D

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

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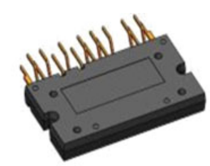
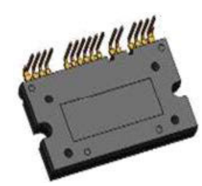
APPLICATION NOTE

(a) Bottom View



(b) Top View (Y−Form)



(c) Top View (L−Form)

Figure 1. FAM65CR51DZ1 Module

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.

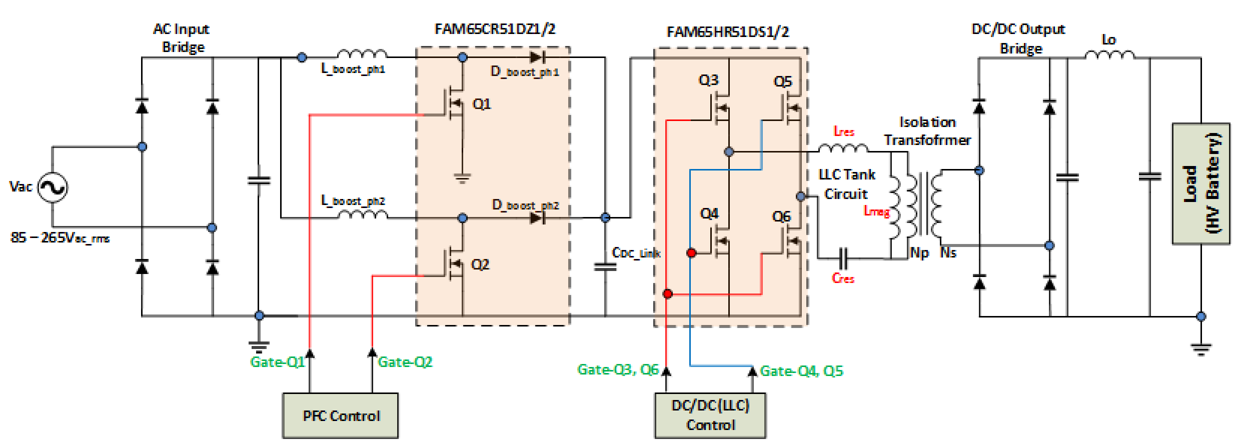
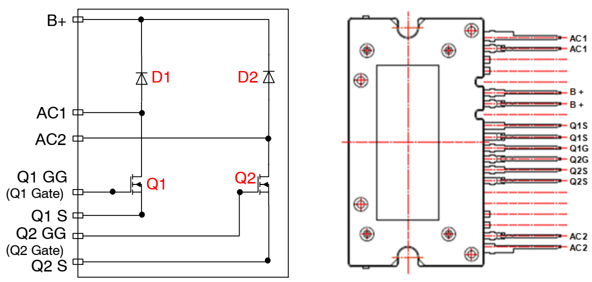
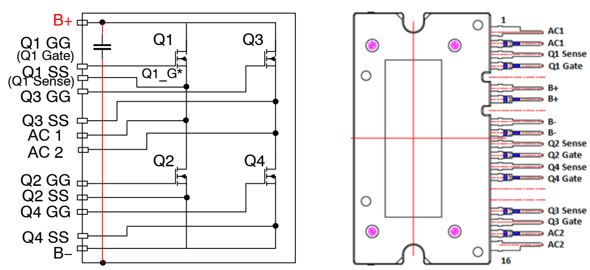


Figure 2. Typical Module Application in OBC System



a) b)

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



a) 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 mA V_{GS} = 0 V	650	−	−	V
$V_{GS(th)}$	$V_{GS} = V_{DS}$ I_D = 3.3 mA	3.0	−	5.0	V
$R_{DS(ON)}$	V_{GS} = 10 V I_D = 20 A	−	44	51	mΩ
$R_{DS(ON)}$	V_{GS} = 10V I_D = 20 A T_C=125°C	−	79	−	mΩ
g_{FS}	V_{DS} = 20 V, I_D = 20 A	−	30	−	S
I_{GSS}	V_{GS} = ±20 V, V_{DS} = 0 V	−100		+100	nA
I_{DSS}	V_{DS} = 650 V, V_{GS} = 0 V	−	−	10	μA

DYNAMIC CHARACTERISTICS

Symbol	Conditions	Min	Typ	Max	Unit
C_{iss}	V_{DS} = 400 V V_{GS} = 0 V f = 1 MHz	−	4864	−	pF
C_{oss}		−	109	−	pF
C_{rss}		−	16	−	pF
$C_{oss(eff)}$	V_{DS} = 0 to 520 V V_{GS} = 0 V	−	652	−	pF
R_g	f = 1MHz	−	2	−	Ω
$Q_{g(tot)}$	V_{DS} = 380 V I_D = 20 A V_{GS} = 0 to 10 V	−	123	−	nC
Q_{gs}		−	37.5	−	nC
Q_{gd}		−	49	−	nC

SWITCHING CHARACTERISTICS

Symbol	Conditions	Min	Typ	Max	Unit
t_{on}	V_{DS} = 400 V I_D = 20 A	−	60.5	−	μs
$t_{d(on)}$		−	50.5	−	μs
t_r		−	10	−	μs
t_{off}		−	241	−	μs
$t_{d(off)}$		−	117	−	μs
t_f		−	125	−	μs

BODY DIODE CHARACTERISTICS

Symbol	Conditions	Min	Typ	Ma-	Unit
V_{SD}	I_{SD} = 20 A, V_{GS} = 0 V	−	0.9 5	−	V
T_{rr}	V_{DS} = 520 V, I_D = 20 A, d_I/d_t = 100 A/μs	−	134	−	ns
Q_{rr}		−	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-bol	Test Conditions		Typ	Max	Unit
I_R	V_R = 600 V	T_C = 25°C	–	100	μA
		T_C = 125°C	–	1	mA
V_{FM}	I_F=15 A	T_C = 25°C	1.65	2.2	V
		T_C = 125°C	1.24	1.7	V
t_{rr}	I_F = 15 A	T_C = 25°C	29	–	ns
t_a	dI_F/dt = 200 A/μs	T_C = 25°C	16	–	ns
t_b	V_R = 390 V	T_C = 25°C	13	–	n
Q_{rr}		T_C = 25°C	43	–	nC

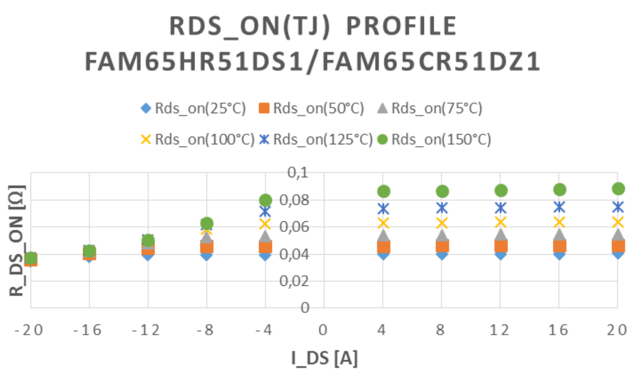


Figure 5. Simulation on $R_{DS(on)}$ (T_j) of the MOSFET Die

Thermal Characteristics

For the thermal impedance measurement, 635 μm Al_2O_3 DBC was applied and the thermal interface material (TIM) was assumed to have the thermal conductivity of 1.8 W/mK with 30 μm 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_{θ_JC} (per MOSFET chip)	–	0.66	0.92	°C/W
R_{θ_JS} (per MOSFET chip)	–	1.2	–	°C/W

Thermal Performance

Figure 6 shows the 6^{th} 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 im pedance, Z_{th_jc} based on the 6^{th} order thermal network.

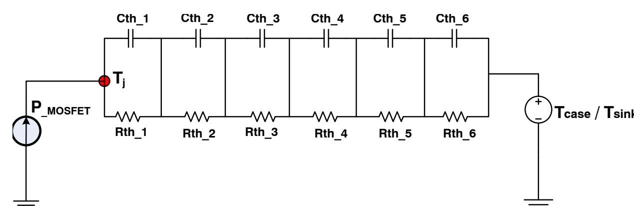


Figure 6. 6^{th} order Foster Thermal Impedance Netwotk of the MOSFET and Diode Die in the Module

Table 1. THERMAL RESISTANCE (R_{TH}) AND THERMAL CAPACITANCE (C_{TH}) VALUES IN THE 6^{TH} ORDER JUNCTION TO HEATSINK THERMAL IMPEDANCE (Z_{TH_JS}) NETWORK

Rth [°C/W]	$R_{th}1$	$R_{th}2$	$R_{th}3$	$R_{th}4$	$R_{th}5$	$R_{th}6$
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]	$C_{th}1$	$C_{th}2$	$C_{th}3$	$C_{th}4$	$C_{th}5$	$C_{th}6$
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 (ZTH_JC) NETWORK

Rth [°C/W]	$R_{th}1$	$R_{th}2$	$R_{th}3$	$R_{th}4$	$R_{th}5$	$R_{th}6$
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]	$C_{th}1$	$C_{th}2$	$C_{th}3$	$C_{th}4$	$C_{th}5$	$C_{th}6$
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} = 150kHz 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) ≈ 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 concition, P_{out_PFC} = 3.52 kW, V_{out_PFC} = 400 V and I_{out_PFC} = 8.8 A.

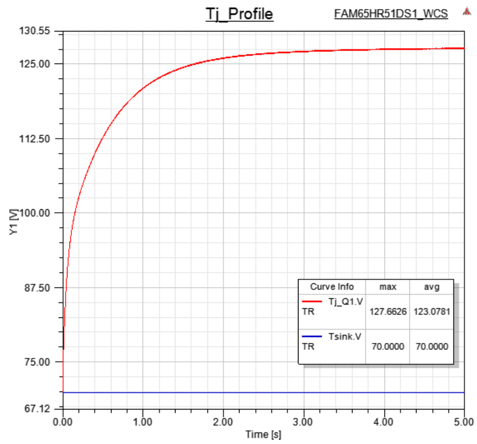


Figure 7. T_j Profile of FAM65HR51DS1 H−bridge Module for the worst Case

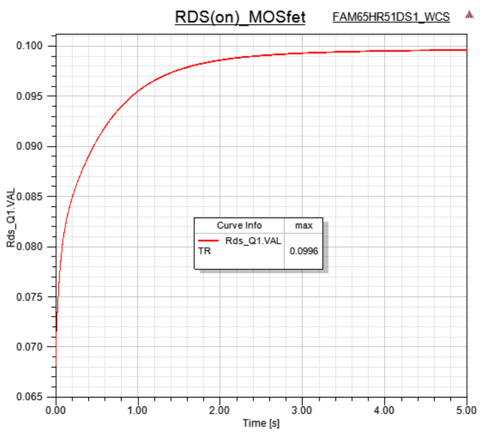


Figure 8. $R_{DS(on)}(T_j)$ Profile of FAM65HR51DS1 H−bridge Module for the worst Case

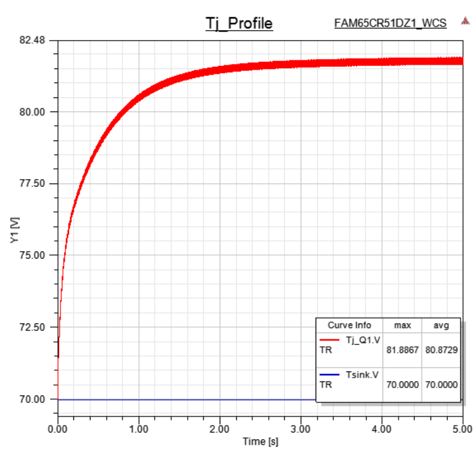


Figure 9. T_j Profile of FAM65CR51DZ1 PFC Module for the worst Case

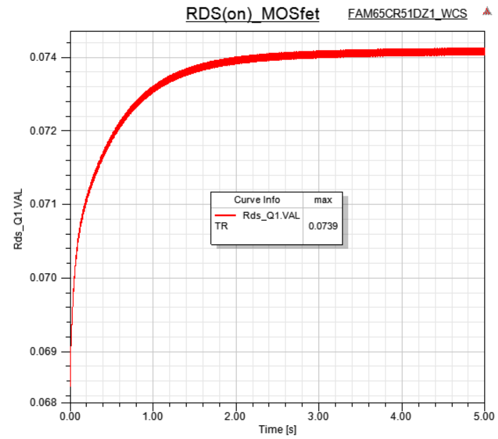


Figure 10. $R_{DS(on)}(T_j)$ Profile of FAM65CR51DZ1 PFC Module for the worst Case

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 μsec 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°C (MAX. T_J), V_{DS} = 450 V AND V_{GS} = 10 V

Module	SC Peak Current	SC Energy	SC Withstand Time
#1	320 A	1.59 J	13.8 μsec
#2	300 A	1.55 J	14.6 μsec
#3	316 A	1.56 J	13.8 μsec
#4	304 A	1.58 J	14.6 μsec

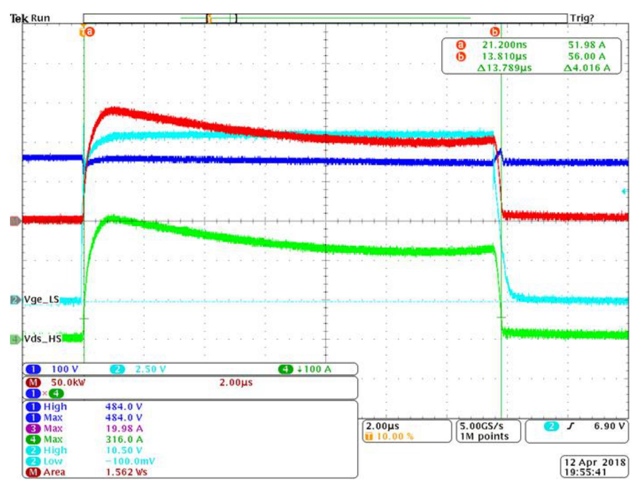


Figure 11. Waveforms in the Short Circuit Test

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 B+ and B−	2.36	4.44
Between Signal leads	0.58	0.58
Between Power leads and Signal leads	2.36	4.44
Between leads & heatsink: case 1 / 2 (Figure 12/13)	6.28 / 2.05	8.29 / 2.22

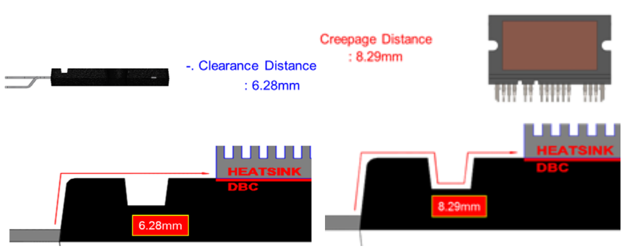


Figure 12. Creepage and Clearance between Leads and Heatsink in Case 1: Restriction on the Location of the Edge of the Heatsink

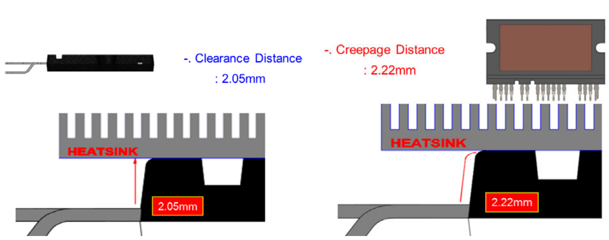


Figure 13. Creepage and Clearance between Leads and Heatsink in case 2: No Restriction on the Location of the Edge of the Heatsink

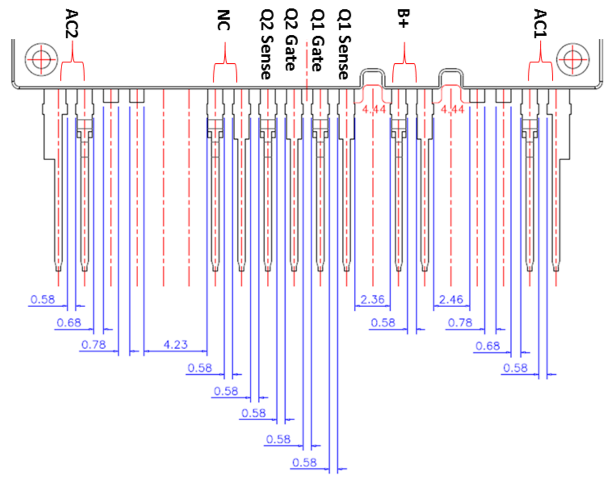


Figure 14. Creepage and Clearance between the Leads in FAM65HR51DS1 Module

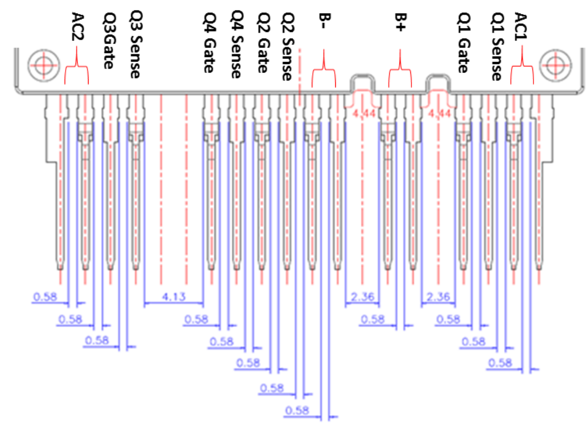


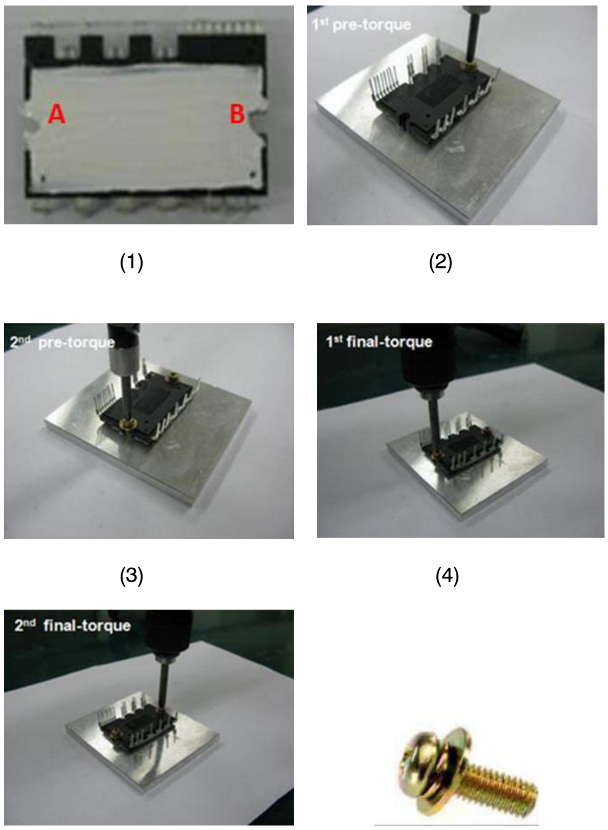
Figure 15. Creepage and Clearance between the Leads in FAM65CR51DZ1 Module

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 smoothened 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)



(1) (2) (3) (4) (5)

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

(a) (b)

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 recomended 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	1×10^{14}[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 recomended 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

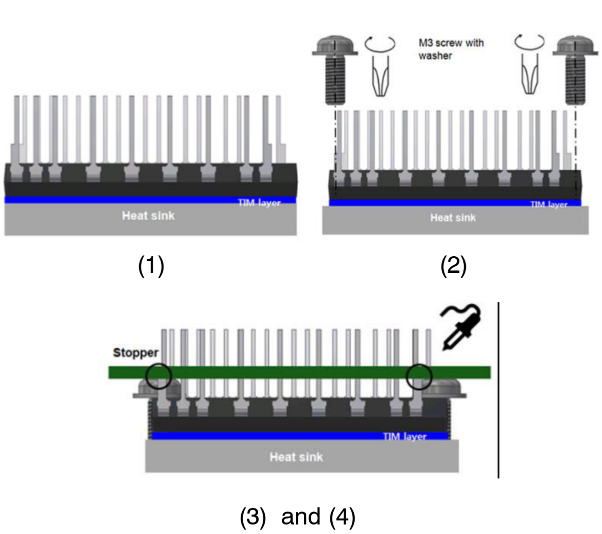


Figure 18. Module mounting before soldering

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

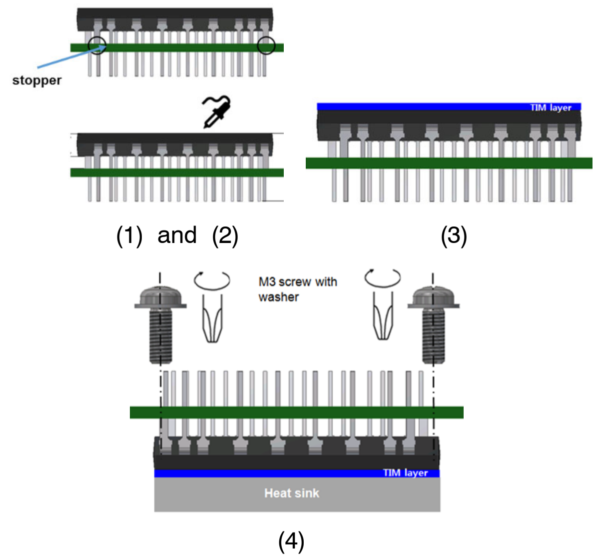


Figure 19. Mounting the module after soldering

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