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ON Semiconductor®

April 2017

# FNF51560TD1

## Motion SPM® 55 Series

### Features

- UL Certified No. E209204 (UL1557)
- 600 V - 15 A 3-Phase IGBT Inverter Including Control IC for Gate Drive and Protections
- Low-Loss, Short-Circuit Rated IGBTs
- Built-In Bootstrap Diodes in HVIC
- Separate Open-Emitter Pins from Low-Side IGBTs for Three-Phase Current Sensing
- Active-HIGH interface, works with 3.3 / 5 V Logic, Schmitt-trigger Input
- HVIC for Gate Driving, Under-Voltage and Short-Circuit Current Protection
- Fault Output for Under-Voltage and Short-Circuit Current Protection
- Inter-Lock Function to Prevent Short-Circuit
- Shut-Down Input
- HVIC Temperature-Sensing Built-In for Temperature Monitoring
- Optimized for 15 kHz Switching Frequency
- Isolation Rating: 1500 V<sub>rms</sub> / min.

### Applications

- Motion Control - Home Appliance / Industrial Motor

### Related Resources

- [AN-9096 - Smart Power Module, Motion SPM® 55 Series User's Guide](#)
- [AN-9097 - SPM® 55 Packing Mounting Guidance](#)

### General Description

FNF51560TD1 is a Motion SPM 55 module providing a fully-featured, high-performance inverter output stage for AC Induction, BLDC, and PMSM motors. These modules integrate optimized gate drive of the built-in IGBTs to minimize EMI and losses, while also providing multiple on-module protection features including under-voltage lockouts, inter-lock function, over-current shutdown, thermal monitoring of drive IC, and fault reporting. The built-in, high-speed HVIC requires only a single supply voltage and translates the incoming logic-level gate inputs to the high-voltage, high-current drive signals required to properly drive the module's robust short-circuit-rated IGBTs. Separate negative IGBT terminals are available for each phase to support the widest variety of control algorithms.



Figure 1. 3D Package Drawing  
(Click to Activate 3D Content)

### Package Marking and Ordering Information

| Device      | Device Marking | Package   | Packing Type | Quantity |
|-------------|----------------|-----------|--------------|----------|
| FNF51560TD1 | FNF51560TD1    | SPMFA-A20 | RAIL         | 13       |

## Integrated Power Functions

- 600 V - 15 A IGBT inverter for three phase DC / AC power conversion (Please refer to Figure 3)

## Integrated Drive, Protection and System Control Functions

- For inverter high-side IGBTs: gate drive circuit, high-voltage isolated high-speed level shifting control circuit Under-Voltage Lock-Out (UVLO) protection
- For inverter low-side IGBTs: gate drive circuit, Short-Circuit Protection (SCP) control supply circuit Under-Voltage Lock-Out (UVLO) protection
- Fault signaling: corresponding to UVLO (low-side supply) and SC faults
- Input interface: High-active interface, works with 3.3 / 5 V logic, Schmitt trigger input
- Built in Bootstrap circuitry in HVIC

## Pin Configuration

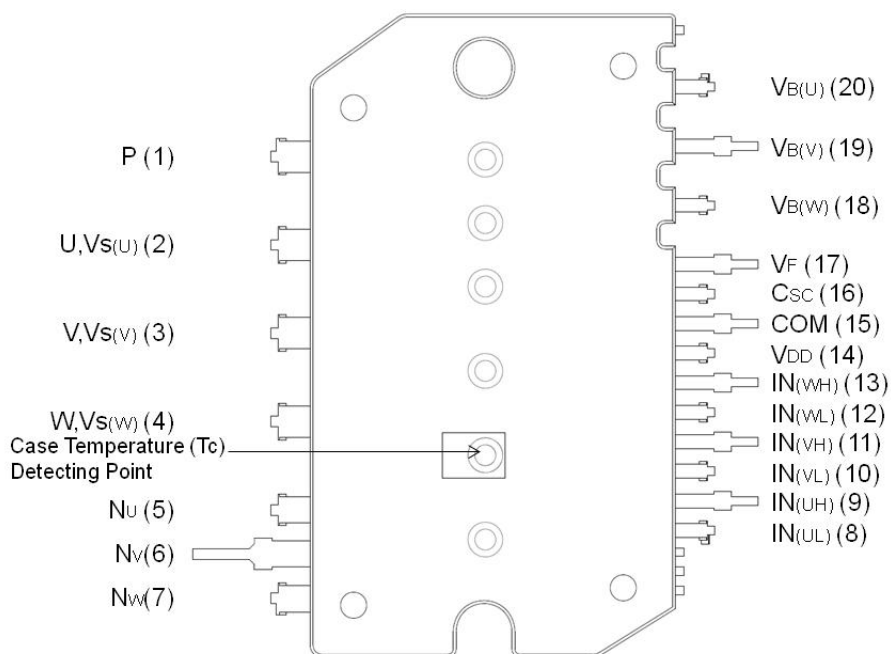
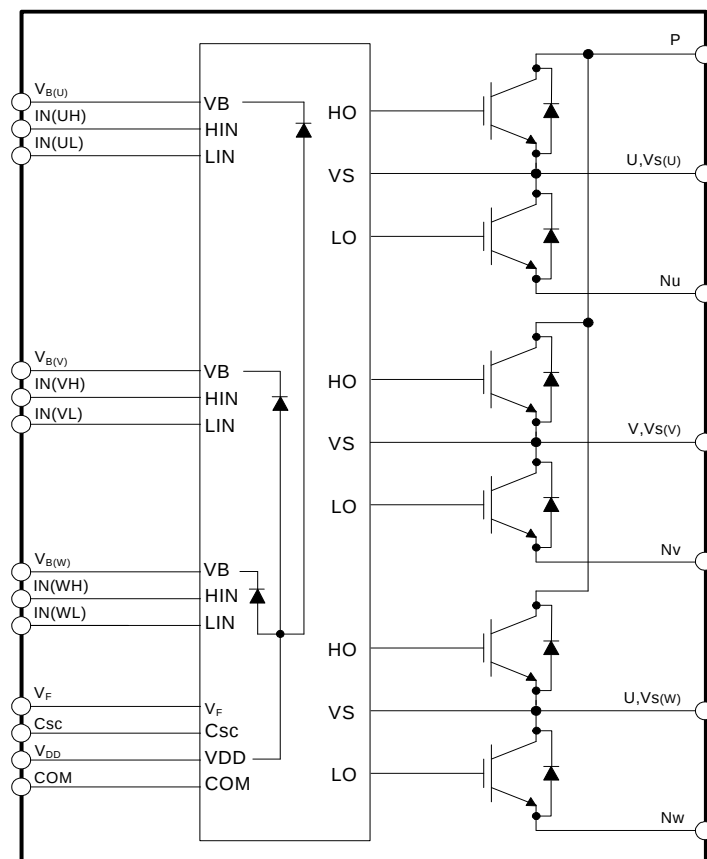


Figure 2. Top View

## Pin Descriptions

| Pin Number | Pin Name    | Pin Description                                                       |
|------------|-------------|-----------------------------------------------------------------------|
| 1          | P           | Positive DC-Link Input                                                |
| 2          | U, $V_S(U)$ | Output for U Phase                                                    |
| 3          | V, $V_S(V)$ | Output for V Phase                                                    |
| 4          | W, $V_S(W)$ | Output for W Phase                                                    |
| 5          | $N_U$       | Negative DC-Link Input for U Phase                                    |
| 6          | $N_V$       | Negative DC-Link Input for V Phase                                    |
| 7          | $N_W$       | Negative DC-Link Input for W Phase                                    |
| 8          | $IN_{(UL)}$ | Signal Input for Low-Side U Phase                                     |
| 9          | $IN_{(UH)}$ | Signal Input for High-Side U Phase                                    |
| 10         | $IN_{(VL)}$ | Signal Input for Low-Side V Phase                                     |
| 11         | $IN_{(VH)}$ | Signal Input for High-Side V Phase                                    |
| 12         | $IN_{(WL)}$ | Signal Input for Low-Side W Phase                                     |
| 13         | $IN_{(WH)}$ | Signal Input for High-Side W Phase                                    |
| 14         | $V_{DD}$    | Common Bias Voltage for IC and IGBTs Driving                          |
| 15         | COM         | Common Supply Ground                                                  |
| 16         | $C_{SC}$    | Capacitor (Low-Pass Filter) for Short-circuit Current Detection Input |
| 17         | $V_F$       | Fault Output, Shut-Down Input, Temperature Output of Drive IC         |
| 18         | $V_{B(W)}$  | High-Side Bias Voltage for W-Phase IGBT Driving                       |
| 19         | $V_{B(V)}$  | High-Side Bias Voltage for V-Phase IGBT Driving                       |
| 20         | $V_{B(U)}$  | High-Side Bias Voltage for U-Phase IGBT Driving                       |

## Internal Equivalent Circuit and Input/Output Pins



**Figure 3. Internal Block Diagram**

**Note:**

1. Inverter high-side is composed of three IGBTs, freewheeling diodes, and one control IC for each IGBT.
2. Inverter low-side is composed of three IGBTs, freewheeling diodes, and one control IC for each IGBT. It has gate drive and protection functions.
3. Single drive IC has gate driver for six IGBTs and protection functions.
4. Inverter power side is composed of four inverter DC-link input terminals and three inverter output terminals.

**Absolute Maximum Ratings** ( $T_J = 25^\circ\text{C}$ , unless otherwise specified.)**Inverter Part**

| Symbol                 | Parameter                          | Conditions                                                                    | Rating    | Unit             |
|------------------------|------------------------------------|-------------------------------------------------------------------------------|-----------|------------------|
| $V_{PN}$               | Supply Voltage                     | Applied between P - $N_U$ , $N_V$ , $N_W$                                     | 450       | V                |
| $V_{PN(\text{Surge})}$ | Supply Voltage (Surge)             | Applied between P - $N_U$ , $N_V$ , $N_W$                                     | 500       | V                |
| $V_{CES}$              | Collector - Emitter Voltage        |                                                                               | 600       | V                |
| $* \pm I_C$            | Each IGBT Collector Current        | $T_C = 25^\circ\text{C}$ , $T_J < 150^\circ\text{C}$                          | 15        | A                |
| $* \pm I_{CP}$         | Each IGBT Collector Current (Peak) | $T_C = 25^\circ\text{C}$ , $T_J < 150^\circ\text{C}$ , Under 1 ms Pulse Width | 30        | A                |
| $* P_C$                | Collector Dissipation              | $T_C = 25^\circ\text{C}$ per Chip                                             | 22        | W                |
| $T_J$                  | Operating Junction Temperature     | (Note 5)                                                                      | -40 ~ 150 | $^\circ\text{C}$ |

**Note:**

5. The maximum junction temperature rating of the power chips integrated within the Motion SPM® 55 product is  $150^\circ\text{C}$ .

**Control Part**

| Symbol   | Parameter                      | Conditions                                                                                              | Rating                | Unit |
|----------|--------------------------------|---------------------------------------------------------------------------------------------------------|-----------------------|------|
| $V_{DD}$ | Control Supply Voltage         | Applied between $V_{DD}$ - COM                                                                          | 20                    | V    |
| $V_{BS}$ | High-Side Control Bias Voltage | Applied between $V_{B(U)}$ - $V_{S(U)}$ , $V_{B(V)}$ - $V_{S(V)}$ , $V_{B(W)}$ - $V_{S(W)}$             | 20                    | V    |
| $V_{IN}$ | Input Signal Voltage           | Applied between $IN_{(UH)}$ , $IN_{(VH)}$ , $IN_{(WH)}$ , $IN_{(UL)}$ , $IN_{(VL)}$ , $IN_{(WL)}$ - COM | -0.3 ~ $V_{DD} + 0.3$ | V    |
| $V_F$    | Fault Supply Voltage           | Applied between $V_F$ - COM                                                                             | -0.3 ~ $V_{DD} + 0.3$ | V    |
| $* I_F$  | Fault Current                  | Sink Current at $V_F$ pin                                                                               | 5                     | mA   |
| $V_{SC}$ | Current Sensing Input Voltage  | Applied between $C_{SC}$ - COM                                                                          | -0.3 ~ $V_{DD} + 0.3$ | V    |

**Total System**

| Symbol                | Parameter                                                                  | Conditions                                                                                                    | Rating    | Unit             |
|-----------------------|----------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------|-----------|------------------|
| $V_{PN(\text{PROT})}$ | Self Protection Supply Voltage Limit (Short Circuit Protection Capability) | $V_{DD} = V_{BS} = 13.5 \sim 16.5 \text{ V}$<br>$T_J = 150^\circ\text{C}$ , Non-Repetitive, $< 2 \mu\text{s}$ | 400       | V                |
| $T_{STG}$             | Storage Temperature                                                        |                                                                                                               | -40 ~ 125 | $^\circ\text{C}$ |
| $V_{ISO}$             | Isolation Voltage<br>Connect Pins to Heat Sink Plate                       | AC 60 Hz, Sinusoidal, 1 Minute                                                                                | 1500      | $V_{rms}$        |

**Thermal Resistance**

| Symbol         | Parameter                                    | Conditions                            | Min. | Typ. | Max. | Unit                        |
|----------------|----------------------------------------------|---------------------------------------|------|------|------|-----------------------------|
| $R_{th(j-c)Q}$ | Junction to Case Thermal Resistance (Note 7) | Inverter IGBT part (per 1 / 6 module) | -    | -    | 5.6  | $^\circ\text{C} / \text{W}$ |
| $R_{th(j-c)F}$ |                                              | Inverter FWD part (per 1 / 6 module)  | -    | -    | 6.9  | $^\circ\text{C} / \text{W}$ |

**Note:**

6. For Marking " \* ", These Value had been made an acquisition by the calculation considered to design factor.

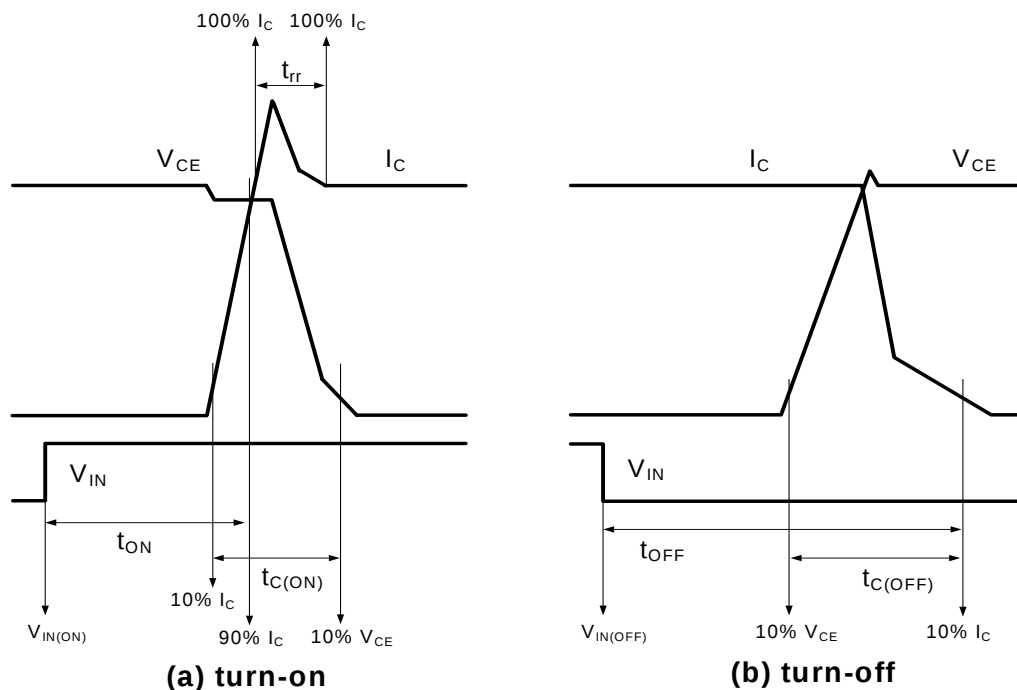
7. For the measurement point of case temperature ( $T_C$ ), please refer to Figure 2.

**Electrical Characteristics** ( $T_J = 25^\circ\text{C}$ , unless otherwise specified.)**Inverter Part**

| Symbol        | Parameter                              | Conditions                                                                                                                                                                                   | Min. | Typ. | Max. | Unit |
|---------------|----------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|------|------|------|
| $V_{CE(SAT)}$ | Collector - Emitter Saturation Voltage | $V_{DD} = V_{BS} = 15\text{ V}$<br>$V_{IN} = 5\text{ V}$<br>$I_C = 10\text{ A}$                                                                                                              | -    | 1.9  | 2.2  | V    |
|               |                                        | $T_J = 150^\circ\text{C}$                                                                                                                                                                    | -    | 2.4  | -    | V    |
| $V_F$         | FWDI Forward Voltage                   | $V_{IN} = 0\text{ V}$<br>$I_F = 10\text{ A}$                                                                                                                                                 | -    | 2.0  | 2.45 | V    |
|               |                                        | $T_J = 150^\circ\text{C}$                                                                                                                                                                    | -    | 1.9  | -    | V    |
| HS            | $t_{ON}$                               | $V_{PN} = 400\text{ V}$ , $V_{DD} = V_{BS} = 15\text{ V}$ , $I_C = 15\text{ A}$<br>$T_J = 25^\circ\text{C}$<br>$V_{IN} = 0\text{ V} \leftrightarrow 5\text{ V}$ , Inductive load<br>(Note 8) | 0.40 | 0.60 | 0.80 | us   |
|               | $t_{C(ON)}$                            |                                                                                                                                                                                              | -    | 0.20 | 0.30 | us   |
|               | $t_{OFF}$                              |                                                                                                                                                                                              | -    | 0.50 | 0.70 | us   |
|               | $t_{C(OFF)}$                           |                                                                                                                                                                                              | -    | 0.10 | 0.20 | us   |
|               | $t_{rr}$                               |                                                                                                                                                                                              | -    | 0.04 | -    | us   |
| LS            | $t_{ON}$                               | $V_{PN} = 400\text{ V}$ , $V_{DD} = V_{BS} = 15\text{ V}$ , $I_C = 15\text{ A}$<br>$T_J = 25^\circ\text{C}$<br>$V_{IN} = 0\text{ V} \leftrightarrow 5\text{ V}$ , Inductive load<br>(Note 8) | 0.40 | 0.60 | 0.80 | us   |
|               | $t_{C(ON)}$                            |                                                                                                                                                                                              | -    | 0.20 | 0.30 | us   |
|               | $t_{OFF}$                              |                                                                                                                                                                                              | -    | 0.50 | 0.70 | us   |
|               | $t_{C(OFF)}$                           |                                                                                                                                                                                              | -    | 0.10 | 0.20 | us   |
|               | $t_{rr}$                               |                                                                                                                                                                                              | -    | 0.04 | -    | us   |
| $I_{CES}$     | Collector - Emitter Leakage Current    | $V_{CE} = V_{CES}$                                                                                                                                                                           | -    | -    | 1    | mA   |

**Note:**

8.  $t_{ON}$  and  $t_{OFF}$  include the propagation delay of the internal drive IC.  $t_{C(ON)}$  and  $t_{C(OFF)}$  are the switching time of IGBT itself under the given gate driving condition internally. For the detailed information, please see Figure 4.

**Figure 4. Switching Time Definition**

## Control Part

| Symbol               | Parameter                                | Conditions                                                                                                                                        |                                                                                                                       | Min. | Typ. | Max. | Unit |
|----------------------|------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------|------|------|------|------|
| I <sub>QDD</sub>     | Quiescent V <sub>DD</sub> Supply Current | V <sub>DD</sub> = 15 V, IN <sub>(UH,VH,WH,UL,VL,WL)</sub> = 0 V                                                                                   | V <sub>DD</sub> - COM                                                                                                 | -    | 1.5  | 2.0  | mA   |
| I <sub>PDD</sub>     | Operating V <sub>DD</sub> Supply Current | V <sub>DD</sub> = 15 V, f <sub>PWM</sub> = 20 kHz, duty = 50%, applied to one PWM signal input                                                    | V <sub>DD</sub> - COM                                                                                                 | -    | 1.8  | 2.5  | mA   |
| I <sub>QBS</sub>     | Quiescent V <sub>BS</sub> Supply Current | V <sub>BS</sub> = 15 V, IN <sub>(UH, VH, WH)</sub> = 0 V                                                                                          | V <sub>B(U)</sub> - V <sub>S(U)</sub> , V <sub>B(V)</sub> - V <sub>S(V)</sub> , V <sub>B(W)</sub> - V <sub>S(W)</sub> | -    | 30   | 55   | μA   |
| I <sub>PBS</sub>     | Operating V <sub>BS</sub> Supply Current | V <sub>DD</sub> = V <sub>BS</sub> = 15 V, f <sub>PWM</sub> = 20 kHz, duty = 50%, applied to one PWM signal input for high - side                  | V <sub>B(U)</sub> - V <sub>S(U)</sub> , V <sub>B(V)</sub> - V <sub>S(V)</sub> , V <sub>B(W)</sub> - V <sub>S(W)</sub> | -    | 330  | 450  | μA   |
| V <sub>FH</sub>      | Fault Output Voltage                     | V <sub>SC</sub> = 0 V, V <sub>F</sub> Circuit: 10 kΩ to 5 V Pull-up                                                                               |                                                                                                                       | 4.5  | -    | -    | V    |
| V <sub>FL</sub>      |                                          | V <sub>SC</sub> = 1 V, V <sub>F</sub> Circuit: 10 kΩ to 5 V Pull-up                                                                               |                                                                                                                       | -    | -    | 0.5  | V    |
| V <sub>SC(ref)</sub> | Short-Circuit Trip Level                 | V <sub>DD</sub> = 15 V (Note 4)                                                                                                                   |                                                                                                                       | 0.45 | 0.5  | 0.55 | V    |
| UV <sub>DDD</sub>    | Supply Circuit Under-Voltage Protection  | Detection level                                                                                                                                   |                                                                                                                       | 10.7 | 11.4 | 12.1 | V    |
| UV <sub>DDR</sub>    |                                          | Reset level                                                                                                                                       |                                                                                                                       | 11.2 | 12.3 | 13.0 | V    |
| UV <sub>BSD</sub>    |                                          | Detection level                                                                                                                                   |                                                                                                                       | 10.1 | 10.8 | 11.5 | V    |
| UV <sub>BSR</sub>    |                                          | Reset level                                                                                                                                       |                                                                                                                       | 10.7 | 11.4 | 12.1 | V    |
| I <sub>FT</sub>      | HVIC Temperature Sensing Current         | V <sub>DD</sub> = V <sub>BS</sub> = 15 V, T <sub>HVIC</sub> = 25°C                                                                                |                                                                                                                       | 68   | 81   | 95   | μA   |
| V <sub>FT</sub>      | HVIC Temperature Sensing Voltage         | V <sub>DD</sub> = V <sub>BS</sub> = 15 V, T <sub>HVIC</sub> = 25°C, 10 kΩ to 5 V Pull-up (Figure. 5)                                              |                                                                                                                       | 4.05 | 4.19 | 4.32 | V    |
| t <sub>FOD</sub>     | Fault-Out Pulse Width                    |                                                                                                                                                   |                                                                                                                       | 40   | 120  | -    | μs   |
| V <sub>FSDR</sub>    | Shut-down Reset level                    | Applied between V <sub>F</sub> - COM                                                                                                              |                                                                                                                       | -    | -    | 2.4  | V    |
| V <sub>FSDD</sub>    | Shut-down Detection level                |                                                                                                                                                   |                                                                                                                       | 0.8  | -    | -    | V    |
| V <sub>IN(ON)</sub>  | ON Threshold Voltage                     | Applied between IN <sub>(UH)</sub> , IN <sub>(VH)</sub> , IN <sub>(WH)</sub> , IN <sub>(UL)</sub> , IN <sub>(VL)</sub> , IN <sub>(WL)</sub> - COM |                                                                                                                       | -    | -    | 2.4  | V    |
| V <sub>IN(OFF)</sub> | OFF Threshold Voltage                    |                                                                                                                                                   |                                                                                                                       | 0.8  | -    | -    | V    |

## Note:

9. Short-circuit protection is functioning for all six IGBTs.

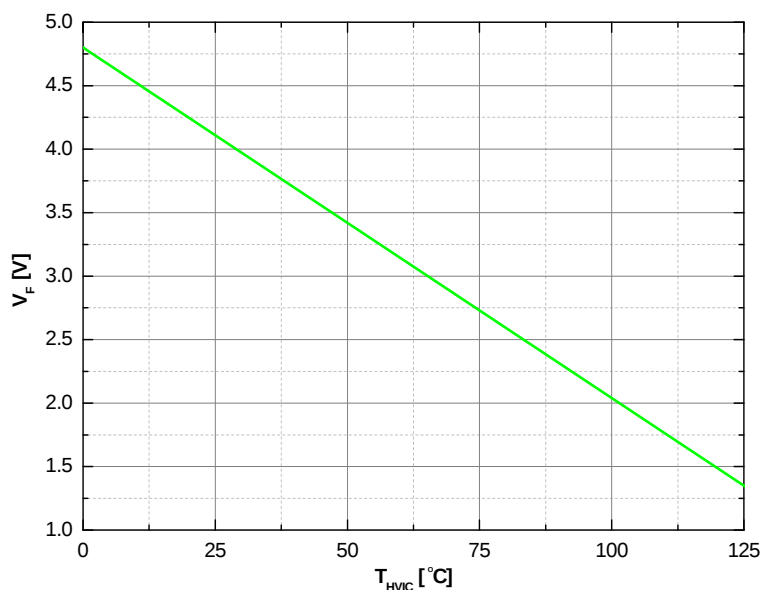


Figure. 5. V-T Curve of Temperature Output of IC (5V pull-up with 10kohm)

## Bootstrap Diode Part

| Symbol   | Parameter                 | Conditions                        | Min. | Typ. | Max. | Unit     |
|----------|---------------------------|-----------------------------------|------|------|------|----------|
| $R_{BS}$ | Bootstrap Diode Resitance | $V_{DD} = 15V, T_J = 25^{\circ}C$ | -    | 280  | -    | $\Omega$ |

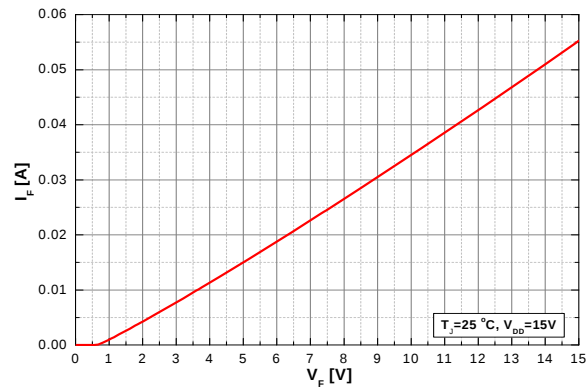


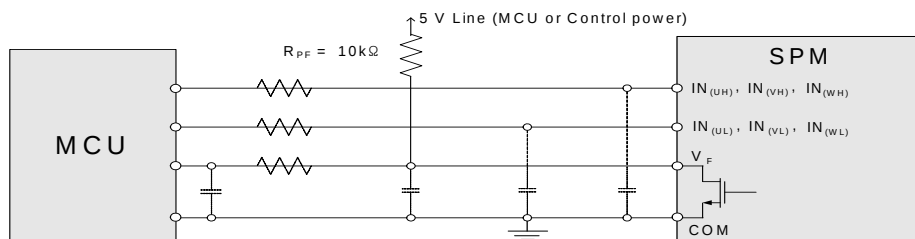
Figure 6. Built-In Bootstrap Diode Charaterstics

## Recommended Operating Conditions

| Symbol                       | Parameter                                | Conditions                                                                      | Min. | Typ. | Max. | Unit        |
|------------------------------|------------------------------------------|---------------------------------------------------------------------------------|------|------|------|-------------|
| $V_{PN}$                     | Supply Voltage                           | Applied between P - $N_U, N_V, N_W$                                             | -    | 300  | 400  | V           |
| $V_{DD}$                     | Control Supply Voltage                   | Applied between $V_{DD}$ - COM                                                  | 14.0 | 15   | 16.5 | V           |
| $V_{BS}$                     | High - Side Bias Voltage                 | Applied between $V_{B(U)} - V_{S(U)}, V_{B(V)} - V_{S(V)}, V_{B(W)} - V_{S(W)}$ | 13.0 | 15   | 18.5 | V           |
| $dV_{DD} / dt, dV_{BS} / dt$ | Control Supply Variation                 |                                                                                 | -1   | -    | 1    | V / $\mu s$ |
| $t_{dead}$                   | Blanking Time for Preventing Arm - Short | For each input signal                                                           | 0.5  | -    | -    | $\mu s$     |
| $f_{PWM}$                    | PWM Input Signal                         | $-40^{\circ}C < T_J < 150^{\circ}C$                                             | -    | -    | 20   | kHz         |
| $V_{SEN}$                    | Voltage for Current Sensing              | Applied between $N_U, N_V, N_W$ - COM (Including surge voltage)                 | -4   |      | 4    | V           |
| $P_{WIN(ON)}$                | Minimum Input Pulse Width                | (Note 10)                                                                       | 0.7  | -    | -    | $\mu s$     |
| $P_{WIN(OFF)}$               |                                          |                                                                                 | 0.7  | -    | -    |             |

### Note:

10. This product might not make response if input pulse width is less than the recommended value.



### Note:

11. RC coupling at each input (parts shown dotted) might change depending on the PWM control scheme used in the application and the wiring impedance of the application's printed circuit board. The input signal section of the SPM 55 product integrates 10 k $\Omega$  (typ.) pull-down resistor. Therefore, when using an external filtering resistor, please pay attention to the signal voltage drop at input terminal.

Figure 7. Recommended MCU I/O Interface Circuit

## Mechanical Characteristics and Ratings

| Parameter       | Conditions                            |                         | Min. | Typ. | Max. | Unit          |
|-----------------|---------------------------------------|-------------------------|------|------|------|---------------|
| Device Flatness | See Figure 8                          |                         | -50  | -    | 100  | $\mu\text{m}$ |
| Mounting Torque | Mounting Screw: - M3<br>Note Figure 9 | Recommended 0.7 N • m   | 0.6  | 0.7  | 0.8  | N • m         |
|                 |                                       | Recommended 7.1 kg • cm | 5.9  | 6.9  | 7.9  | kg • cm       |
| Weight          |                                       |                         | -    | 6.0  | -    | g             |

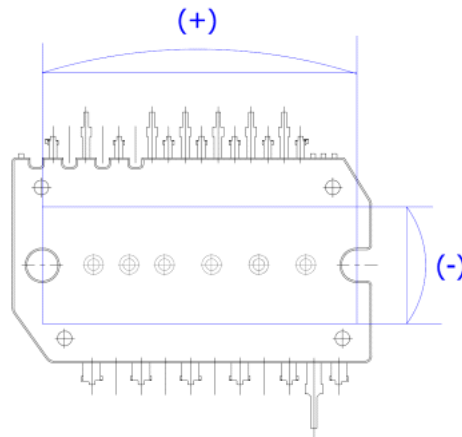


Figure 8. Flatness Measurement Position

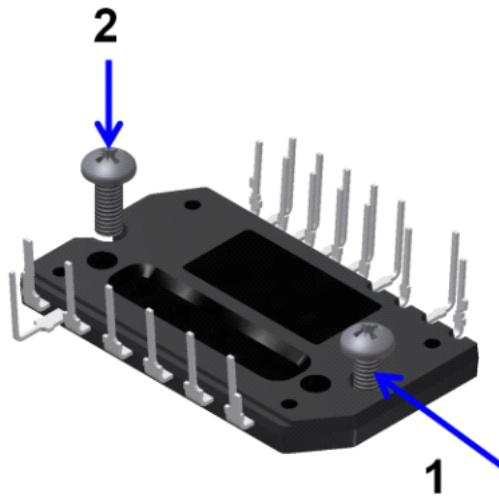
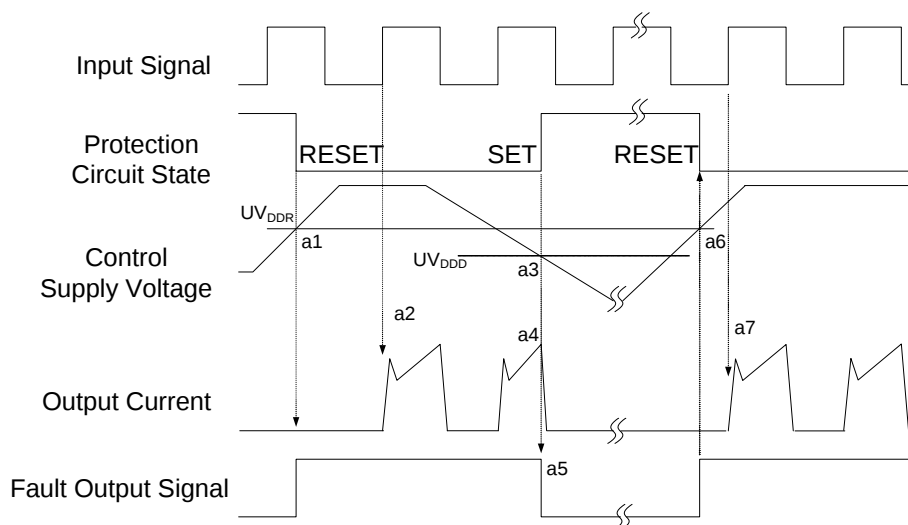


Figure 9. Mounting Screws Torque Order

**Note:**

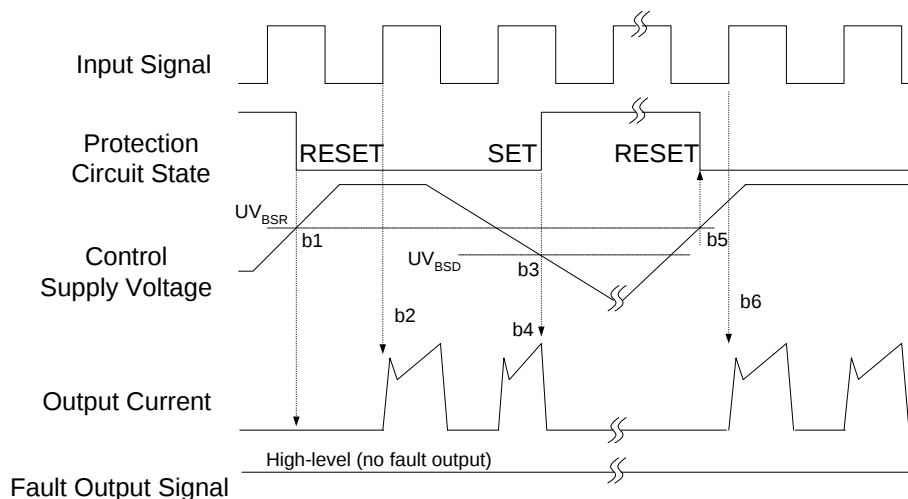
12. Do not make over torque when mounting screws. Much mounting torque may cause package cracks, as well as bolts and Al heat-sink destruction.
13. Avoid one side tightening stress. Figure 11 shows the recommended torque order for mounting screws. Uneven mounting can cause the ceramic substrate of the Motion SPM 55 product to be damaged. The Pre-screwing torque is set to 20 ~ 30 % of maximum torque rating.

## Time Charts of Protective Function



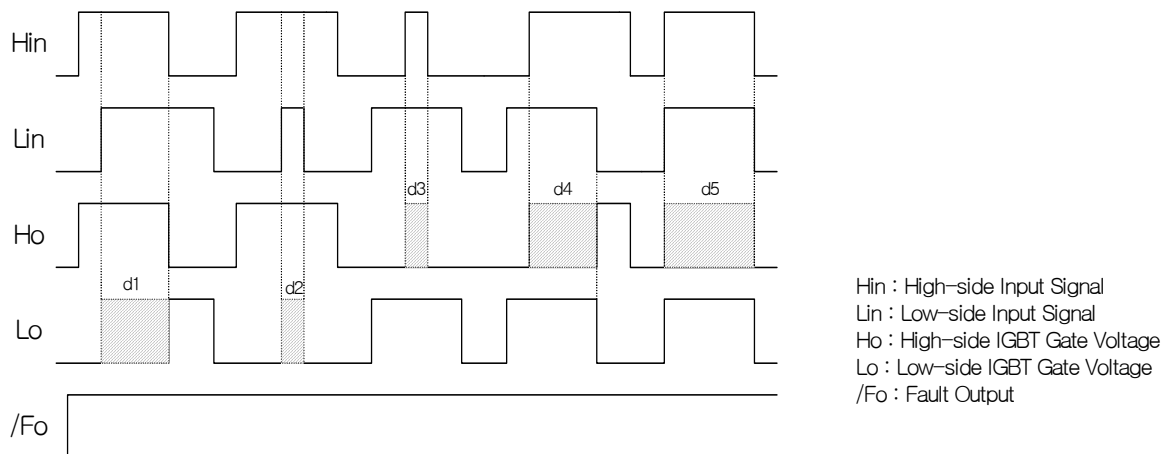
- a1 : Control supply voltage rises: After the voltage rises  $UV_{DDR}$ , the circuits start to operate when next input is applied.
- a2 : Normal operation: IGBT ON and carrying current.
- a3 : Under voltage detection ( $UV_{DD\bar{D}}$ ).
- a4 : IGBT OFF in spite of control input condition.
- a5 : Fault output operation starts.
- a6 : Under voltage reset ( $UV_{DDR}$ ).
- a7 : Normal operation: IGBT ON and carrying current.

**Figure 10. Under-Voltage Protection (Low-Side)**



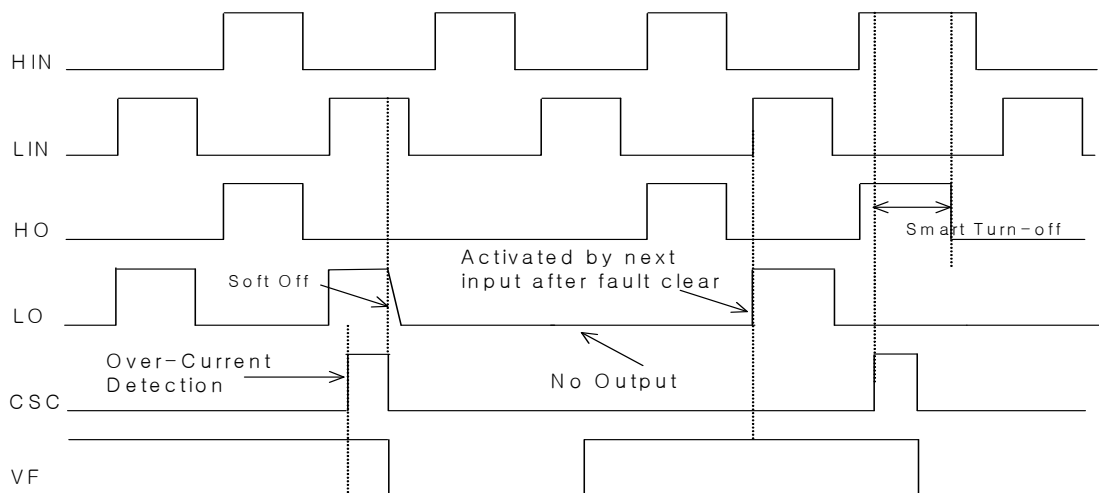
- b1 : Control supply voltage rises: After the voltage reaches  $UV_{BSR}$ , the circuits start to operate when next input is applied.
- b2 : Normal operation: IGBT ON and carrying current.
- b3 : Under voltage detection ( $UV_{BSD}$ ).
- b4 : IGBT OFF in spite of control input condition, but there is no fault output signal.
- b5 : Under voltage reset ( $UV_{BSR}$ )
- b6 : Normal operation: IGBT ON and carrying current

**Figure 11. Under-Voltage Protection (High-Side)**

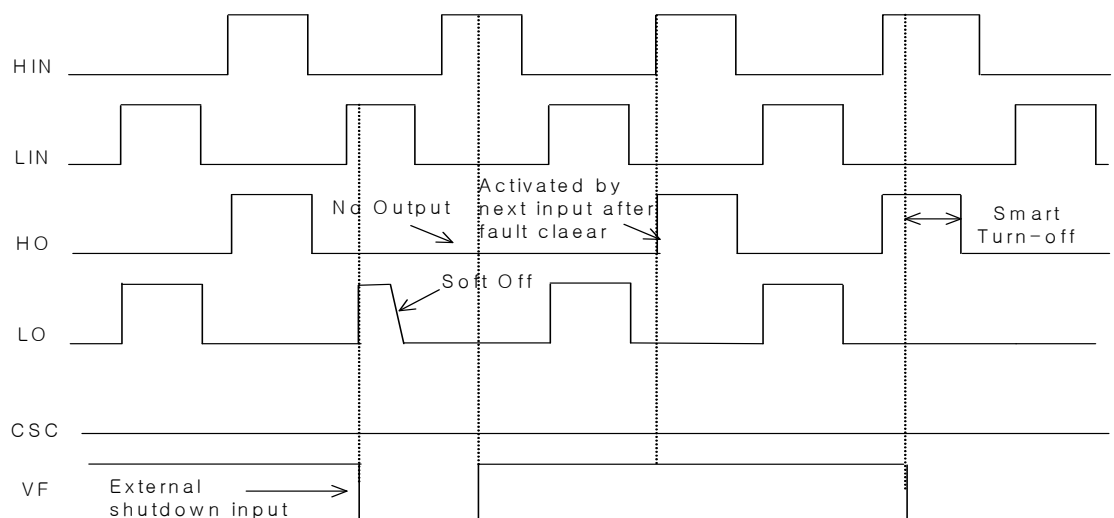


- d1 : High Side First - Input - First - Output Mode
- d2 : Low Side Noise Mode : No Lo
- d3 : High Side Noise Mode : No Ho
- d4 : Low Side First - Input - First - Output Mode
- d5 : In - Phase Mode : No Ho

**Figure 12. Inter-Lock Function**



**Figure 13. Fault-Out Function By Over Current Protection**



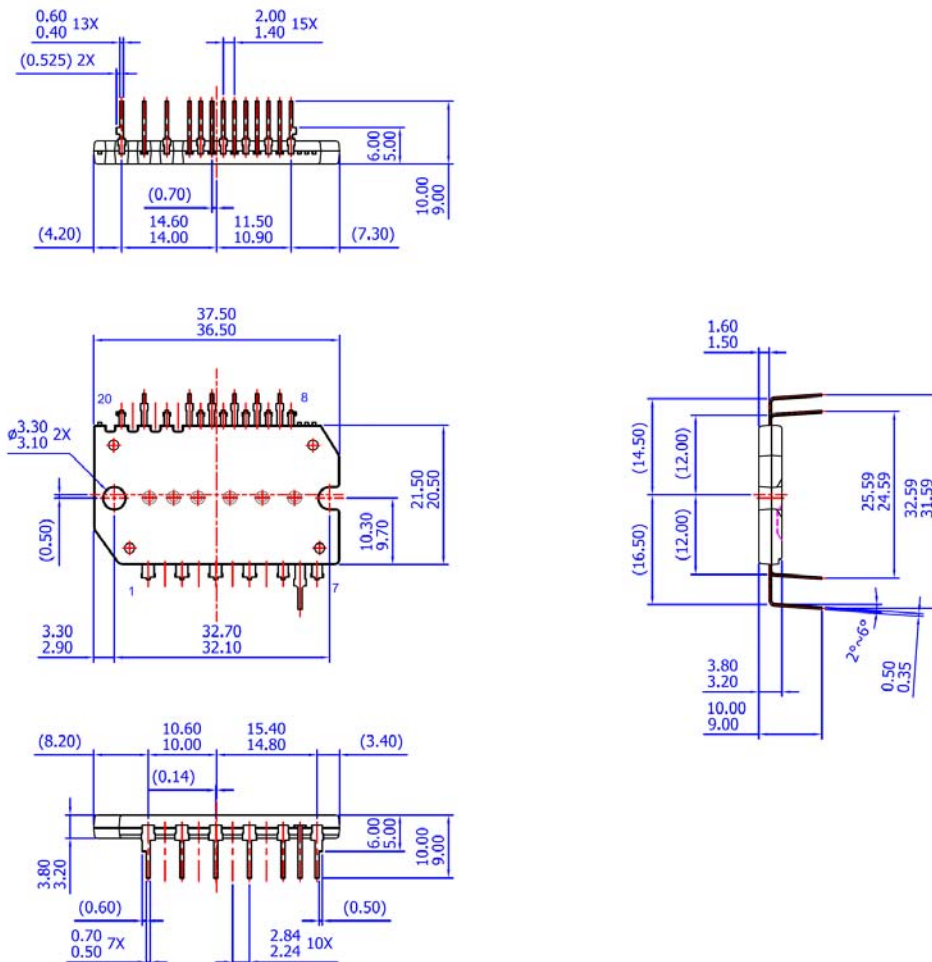
HIN : High-side Input Signal  
 LIN : Low-side Input Signal  
 HO : High-Side Output Signal  
 LO : Low-Side Output Signal  
 CSC : Over Current Detection Input  
 VF : Shutdown Input Function

**Figure 14. Shutdown Input Function By External Command**



- ### Figur15. Typical Application Circuit

## Detailed Package Outline Drawings (FNF51560TD1, Short Lead)



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