Fairchild Reference Design RD-406

This reference design supports design of 600 V Motion SPM® 3 ver.5 series. It should be used in conjunction with the 600 V Motion SPM 3 series datasheets as well as Fairchild’s application note AN-9085. For more information, please visit Fairchild’s website at http://www.fairchildsemi.com.

<table>
<thead>
<tr>
<th>Application</th>
<th>Fairchild Device</th>
<th>IGBT Rating</th>
<th>Motor Rating(^{(1)})</th>
<th>Isolation Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air Conditioner</td>
<td>FSBB30CH60D</td>
<td>30 A / 600 V</td>
<td>3 KW / 220 V(_{AC})</td>
<td>V(<em>{ISO} = 2500) V(</em>{RMS})</td>
</tr>
<tr>
<td>Industrial Motor</td>
<td>FSBB20CH60D(^{(2)})</td>
<td>(20 A / 600 V)</td>
<td>(2 KW / 220 V(_{AC}))</td>
<td></td>
</tr>
<tr>
<td></td>
<td>FSBB15CH60D(^{(2)})</td>
<td>(15 A / 600 V)</td>
<td>(1.5 KW / 220 V(_{AC}))</td>
<td></td>
</tr>
</tbody>
</table>

Notes
1. This motor rating is a typical value and may change depending on the operating conditions.
2. In development; not released to production as of this publication.

Key Features

- 600 V 15 A / 20 A / 30 A 3-Phase IGBT Inverter Including Control ICs for Gate Driving and Protections
- Very Low Thermal Resistance by Adopting DBC Substrate
- Easy PCB Layout due to Built-in Bootstrap Diodes
- Divided Negative DC-Link Terminals for Inverter Three-Leg Current Sensing
- Single-Grounded Power Supply due to Built-in HVICs and Bootstrap Operations
- Built-in Temperature Sensing Unit of IC
- Isolation Rating of 2500 V\(_{RMS}\)/min
1. Block Diagram

Figure 1. Schematic
Figure 2. Schematic of Reference Design for 3-Phase Inverter Part (One Shunt Solution)
3. Key Parameter Design

3.1. Selection of Bootstrap Capacitance ($C_{BS}$)

The bootstrap capacitor value can be calculated by:

$$C_{BS} = \frac{I_{Leak} \times \Delta t}{\Delta V_{BS}}$$

(1)

where:

- $\Delta t$ = maximum ON-pulse width of high-side IGBT;
- $\Delta V_{BS}$ = the allowable discharge voltage of the CBS (voltage ripple);
- $I_{Leak}$ = maximum discharge current of the CBS consisting of:
  - Gate charge for turning the high-side IGBT on
  - Quiescent current to the high-side circuit in the IC
  - Level-shift charge required by level-shifters in IC
  - Leakage current in the bootstrap diode
  - $C_{BS}$ capacitor leakage current (can be ignored for non-electrolytic capacitors)
  - Bootstrap diode reverse recovery charge

Practically, 4 mA of $I_{Leak}$ is recommended for 600 V Motion SPM® 3 FSBB30CH60D (I_{PBS}, operating $V_{BS}$ supply current at 20 kHz, is max. 4.5 mA in the datasheet).

✔ Calculation examples of $C_{BS}$:

$$I_{Leak} = 4 \text{ mA}$$
$$\Delta V_{BS} = 1.0 \text{ V} \text{ (recommended value)}$$
$$\Delta t = 5 \text{ ms} \text{ (depends on user system)}$$

$$C_{BS\_min} = \frac{I_{Leak} \times \Delta t}{\Delta V_{BS}} = \frac{4 \text{ mA} \times 5 \text{ ms}}{1.0 \text{ V}} = 20 \times 10^{-6}$$

More than 2~3times $\rightarrow$ 40~60 μF $\rightarrow$ standard nominal capacitance 47~100 μF

Notes:

3. In case of trapezoidal control for BLDC motor or 2-phase modulation, long ON time periods of the high-side IGBT may exist. Attention should be paid to the bootstrap supply voltage drop.
4. The above result is only a calculation example. It is recommended that actual PWM patterns and lifetime of components should be considered in the design.
3.2. Selection of Shunt Resistor (One Shunt Solution)

The value of shunt resistor is calculated by the following equations.

Maximum Short-Circuit (SC) current trip level (depend on user selection):

\[ I_{SC(max)} = 1.5 \times I_{C(max)} \]

SC Trip Reference Voltage (depends on datasheet):

\[ V_{SC} = \text{min. } 0.45 \text{ V}, \text{typ. } 0.50 \text{ V}, \text{max. } 0.55 \text{ V} \]

Shunt Resistance:

\[ I_{SC(max)} = \frac{V_{SC(max)}}{R_{SHUNT(min)}} \rightarrow R_{SHUNT(min)} = \frac{V_{SC(max)}}{I_{SC(max)}} \]

If the Deviation of the Shunt Resistor is Limited below ±5%:

\[ R_{SHUNT(typ)} = \frac{R_{SHUNT(min)}}{0.95}, \quad R_{SHUNT(max)} = R_{SHUNT(typ)} \times 1.05 \]

Actual SC Trip Current Level becomes:

\[ I_{SC(typ)} = \frac{V_{SC(typ)}}{R_{SHUNT(typ)}}, \quad I_{SC(min)} = \frac{V_{SC(min)}}{R_{SHUNT(max)}} \]

Inverter Output Power:

\[ P_{OUT} = \frac{\sqrt{3}}{2} \times MI \times V_{DC\_Link} \times I_{RMS} \times PF \]

where:

- \( MI \) = Modulation Index;
- \( V_{DC\_Link} \) = DC Link Voltage;
- \( I_{RMS} \) = Maximum load current of inverter; and
- \( PF \) = Power Factor

Average DC Current

\[ I_{DC\_AVG} = \frac{V_{DC\_Link}}{(P_{out} \times Eff)} \]

where:

- \( Eff \) = Inverter Efficiency

The power rating of shunt resistor is calculated by the following equation:

\[ P_{SHUNT} = \left( I_{DC\_AVG}^2 \times R_{SHUNT} \times \text{Margin} \right) / \text{Derating Ratio} \]

where:

- \( R_{SHUNT} \) = Shunt resistor typical value at \( T_C = 25^\circ \text{C} \)
- \( \text{Derating Ratio} \) = Derating ratio of shunt resistor at \( T_{SHUNT} = 100^\circ \text{C} \)

(From datasheet of shunt resistor); and

- \( \text{Margin} \) = Safety margin (determined by user)

✓ Shunt Resistor Calculation Examples

Calculation Conditions:

- DUT: FSBB30CH60D
- Tolerance of shunt resistor: ±5%
- SC Trip Reference Voltage:
  - $V_{SC(min)} = 0.45 \, \text{V}$, $V_{SC(typ)} = 0.50 \, \text{V}$, $V_{SC(max)} = 0.55 \, \text{V}$
- Maximum Load Current of Inverter ($I_{RMS}$): 21 A
- Maximum Peak Load Current of Inverter ($I_{C(max)}$): 45 A
- Modulation Index (MI): 0.9
- DC Link Voltage ($V_{DC\_Link}$): 300 V
- Power Factor (PF): 0.8
- Inverter Efficiency (Eff): 0.95
- Shunt Resistor Value at $T_C = 25^\circ \text{C}$ ($R_{SHUNT}$): 11.0 mΩ
- Derating Ratio of Shunt Resistor at $T_{SHUNT} = 100^\circ \text{C}$: 70%
- Safety Margin: 20%

### Calculation Results:

- $I_{SC(max)}$: $1.5 \times I_{C(max)} = 1.5 \times 30 \, \text{A} = 45 \, \text{A}$
- $R_{SHUNT(typ)}$: $V_{SC(typ)} / I_{SC(max)} = 0.50 \, \text{V} / 45 \, \text{A} = 11.0 \, \text{mΩ}$
- $R_{SHUNT(max)}$: $R_{SHUNT(typ)} \times 1.05 = 11.0 \, \text{mΩ} \times 1.05 = 11.55 \, \text{mΩ}$
- $R_{SHUNT(min)}$: $R_{SHUNT(typ)} \times 0.95 = 11.0 \, \text{mΩ} \times 0.95 = 10.45 \, \text{mΩ}$
- $I_{SC(min)}$: $V_{SC(min)} / R_{SHUNT(max)} = 0.45 \, \text{V} / 11.55 \, \text{mΩ} = 38.96 \, \text{A}$
- $I_{SC(max)}$: $V_{SC(typ)} / R_{SHUNT(min)} = 0.55 \, \text{V} / 10.45 \, \text{mΩ} = 52.6 \, \text{A}$
- $P_{OUT} = \sqrt{3} / \sqrt{2} \times \text{MI} \times V_{DC\_Link} \times I_{RMS} \times PF = \sqrt{3} / \sqrt{2} \times 0.9 \times 300 \times 21 \times 0.8 = 5,555 \, \text{W}$
- $I_{DC\_AVG} = (P_{OUT}/Eff) / V_{DC\_Link} = 19.49 \, \text{A}$
- $P_{SHUNT} = (I_{DC\_AVG} \times R_{SHUNT} \times \text{Margin}) / \text{Derating Ratio} = (19.49^2 \times 0.012 \times 1.2) / 0.7 = 7.8 \, \text{W}$

(Therefore, the proper power rating of shunt resistor is over 8.0 W)

When over-current events are detected, 600 V Motion SPM 3 ver.5 series shuts down all low-side IGBTs and sends out the fault-out ($F_O$) signal. Fault-out pulse width is fixed; minimum value is 50 μsec (in datasheet).

To prevent malfunction, it is recommended that an RC filter be inserted at the $C_{SC}$ pin. To shut down IGBTs within 2 μs when over-current situation occurs, a time constant of 1.5 ~ 2 μs is recommended.

Table 1 Shows the sense resistance and minimum short-circuit protection current.

### Table 1. Over-Current (OC) Protection Trip Level

<table>
<thead>
<tr>
<th>Device</th>
<th>$R_{SHUNT}$</th>
<th>OC Trip Level</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>FSBB30CH60D</td>
<td>11 mΩ</td>
<td>45 A</td>
<td>Shunt resistor are typical value</td>
</tr>
<tr>
<td>FSBB20CH60D(5)</td>
<td>16 mΩ</td>
<td>30 A</td>
<td></td>
</tr>
<tr>
<td>FSBB15CH60D(5)</td>
<td>22 mΩ</td>
<td>22.5 A</td>
<td></td>
</tr>
</tbody>
</table>

**Note:**

5. In development; not released to production as of this publication.
3.3. Thermal Sensing Unit (TSU)

600 V Motion SPM® 3 ver.5 series products include a thermal sensing unit (TSU). However it is temperature of LVIC (see Figure 3, blue area is LVIC location). If the customer wants to use the thermal sensing unit, they should make adjustment in real operation conditions.

![Internal Structure of 600 V SPM3 ver.5 Series](image)

![Curve of Thermal Sensing Unit (TSU) in 600 V SPM3 ver.5 Series](image)
4. PCB Layout Guidance

① It is recommended to connect control GND and Power GND at only a point. (Not copper pattern and don’t make a close loop in GND pattern) And this wiring should be as short as possible.

② Place sunbber capacitor between P and N, and closely to terminals W, N, U, N, V, and shunt resistor should be as short as possible.

③ The capacitor between Vc and COM should be placed to SPM as close as possible.

④ Connect Csc filter's capacitor to control GND(not to power GND).

⑤ Wiring between N, N, N, and shunt resistor should be as short as possible.

⑥ The capacitor and Zener diode should be located closely to terminals of SPM.

Isolation distance between high voltage block and low voltage block should be kept.

CFOD
600V SPM3 Design for PCB Layout

Figure 5. PCB Layout Guidance
5. Related Resources

FSBB30CH60D – 600V SPM® 3 - Product Folder
AN-9085 – 600V Motion SPM3 ver.5 Series Application notes
AN-9086 - SPM 3 Series Mounting Guidance

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