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October 2016

# FAM65V05DF1
# Auto SPM® Series
# Automotive 3-Phase IGBT Smart Power Module

## Features

- 27 pin Auto SPM® module
- 650 V-50 A 3-phase IGBT module with low loss IGBTs and soft recovery diodes optimized for motor control applications
- Integrated gate drivers with Internal $V_S$ connection, Under Voltage lockout, Over-current shutdown, Temperature Sensing Unit and Fault reporting
- Electrically isolated AlN substrate with low Rthjc
- Module serialization for full traceability
- Pb-Free and RoHS compliant
- UL Certified No. E209204 (UL 1557)
- Automotive qualified

## Applications and Benefits

Automotive high voltage auxiliary motors such as air conditioning compressor and oil pump

- Compact design
- Simplified PCB layout and low EMI
- Simplified Assembly
- High reliability

## General Description

FAM65V05DF1 is an advanced Auto SPM® module providing a fully-featured high-performance auxiliary inverter output stage for hybrid and electric vehicles. These modules integrate optimized gate drive of the built-in IGBTs to minimize EMI and losses, while also providing various protection features, in a compact 12cm$^2$ footprint.

## Applications Note

AN-8422` – *650 V Auto SPM® Series; Automotive 3-Phase IGBT Smart Power Module User's Guide*

**Top View**



**Bottom View**



**Figure 1.** Package view

## Ordering Information

| Part Number | Marking | Package | Packing Method | Qty. per tube | Qty. per box |
|---|---|---|---|---|---|
| FAM65V05DF1 | FAM65V05DF1 | APM27-CAA | Tube | 10 | 60 |

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## Pin Configuration

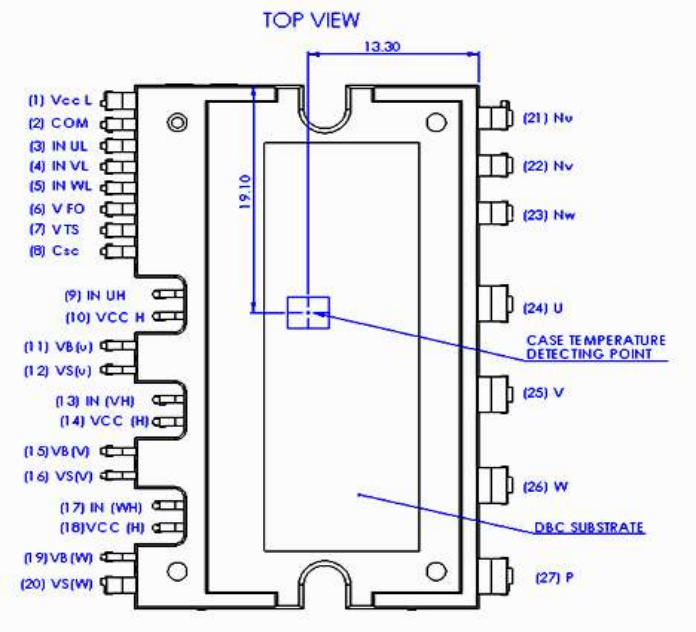



**Figure 2.** Pin configuration

## Pin Description

| Pin Number | Pin | Pin Function Description |
|---|---|---|
| 1 | VCC(L) | Low-side Common Bias Voltage for IC and IGBTs Driving |
| 2 | COM | Common Supply Ground |
| 3 | IN (UL) | Signal Input for Low-side U Phase |
| 4 | IN (VL) | Signal Input for Low-side V Phase |
| 5 | IN (WL) | Signal Input for Low-side W Phase |
| 6 | VFO | Fault Output |
| 7 | VTS | Output for LVIC temperature sense |
| 8 | CSC | Capacitor (Low-pass Filter) for Short-Current Detection Input |
| 9 | IN (UH) | Signal Input for High-side U Phase |
| 10 | VCC(H) | High-side Common Bias Voltage for IC and IGBTs Driving |
| 11 | VB(U) | High-side Bias Voltage for U Phase IGBT Driving |
| 12 | VS(U) | High-side Bias Voltage Ground for U Phase IGBT Driving |
| 13 | IN(VH) | Signal Input for High-side V Phase |
| 14 | VCC(H) | High-side Common Bias Voltage for IC and IGBTs Driving |
| 15 | VB(V) | High-side Bias Voltage for V Phase IGBT Driving |
| 16 | VS(V) | High-side Bias Voltage Ground for V Phase IGBT Driving |
| 17 | IN(WH) | Signal Input for High-side W Phase |
| 18 | VCC(H) | High-side Common Bias Voltage for IC and IGBTs Driving |
| 19 | VB(W) | High-side Bias Voltage for W Phase IGBT Driving |
| 20 | VS(W) | High-side Bias Voltage Ground for W Phase IGBT Driving |
| 21 | NU | Negative DC–Link Input for U Phase |
| 22 | NV | Negative DC–Link Input for V Phase |
| 23 | NW | Negative DC–Link Input for W Phase |
| 24 | U | Output for U Phase |
| 25 | V | Output for V Phase |
| 26 | W | Output for W Phase |
| 27 | P | Positive DC–Link Input |

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## Internal Equivalent Circuit and Input/Output Pins

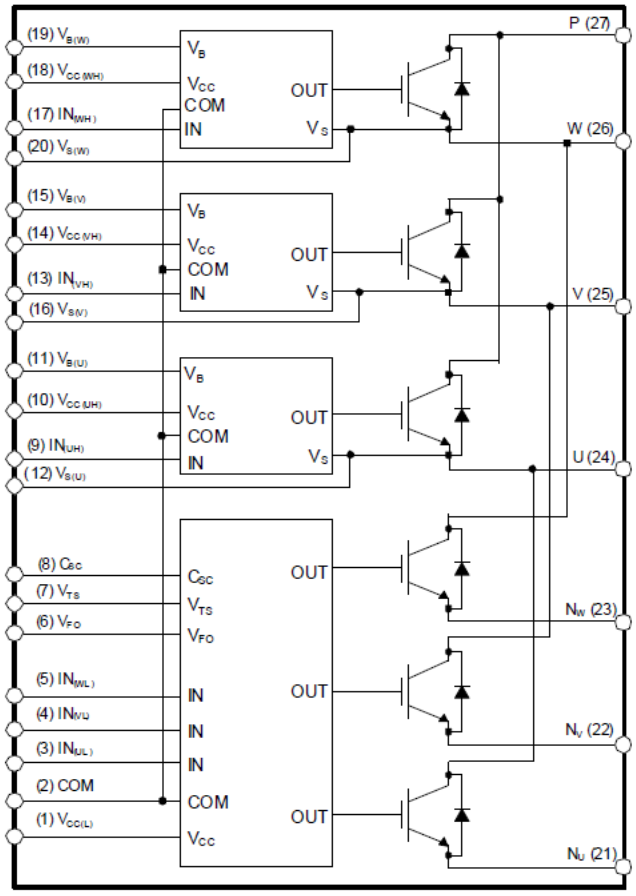



**Figure 3.** Schematic

## Gate drivers block diagram

High side gate driver (x3 single channel):

- Control circuit under-voltage (UV) protection
- 3.3/5 V CMOS/LSTTL compatible, Schmitt trigger input

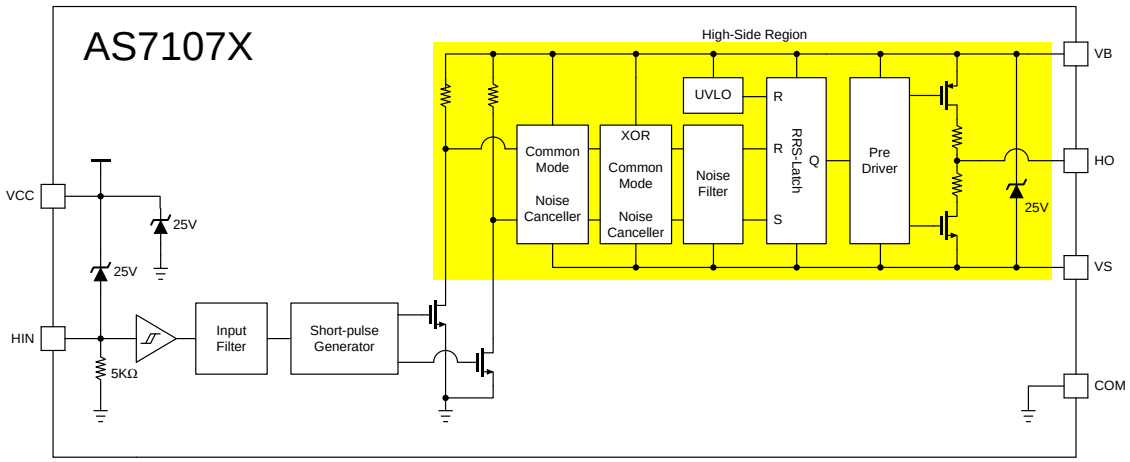



**Figure 4.** High Side gate drivers (block diagram)

Low side gate driver (x1 monolithic three-channel):

- Control circuit under-voltage (UV) protection
- Short circuit protection (SC)
- Temperature sensing unit
- Fault Output
- 3.3/5 V CMOS/LSTTL compatible, Schmitt trigger input

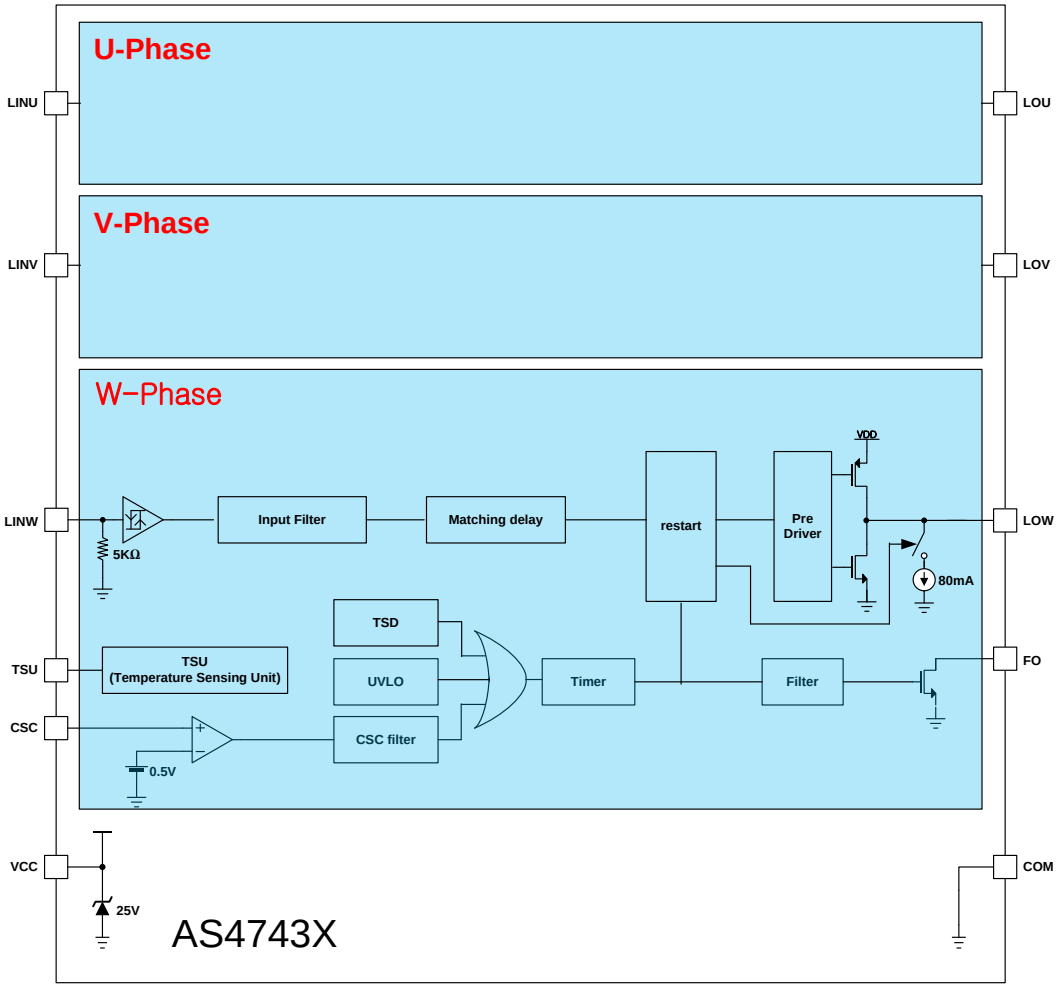



**Figure 5.** Low Side gate drivers (block diagram)

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## Absolute Maximum Ratings ($T_J$ = 25°C, Unless Otherwise Specified)

Stresses exceeding the Absolute Maximum Ratings may damage the device. The device may not function or be operable above the recommended operating conditions and stressing the parts to these levels is not recommended. In addition, extended exposure to stresses above the recommended operating conditions may affect device reliability.

### Inverter Part

| Symbol | Parameter | Condition | Rating | Unit |
|---|---|---|---|---|
| $V_{PN}$ | Supply voltage | Applied between P- $N_U$, $N_V$, $N_W$ | 500 | V |
| $V_{PN(Surge)}$ | Supply Voltage (surge) | Applied between P- $N_U$, $N_V$, $N_W$<br>dI/dt ≤ 3A/ns | 575 | V |
| $V_{CES}$ | Collector-emitter Voltage at the IGBT/diode | $T_J$=25°C | 650 | V |
| ± $I_C$ | IGBT continuous collector current | $T_C$ = 100°C, $T_{Jmax}$=175°C (Note1) | 50 | A |
| ± $I_{CP}$ | IGBT peak collector pulse current | $T_C$ = 25°C, $T_{Jmax}$=175°C,<br>$V_{CC}$=$V_{BS}$=15V, less than 1ms (Note 6) | 150 | A |
| $P_C$ | Collector Dissipation | $T_C$ = 25°C per IGBT | 333 | W |
| $T_J$ | Junction Temperature | IGBT/Diode | -40 ~ +175 | °C |
| | | Driver IC | -40 ~ +150 | °C |

### Control Part

| Symbol | Parameter | Condition | Rating | Unit |
|---|---|---|---|---|
| $V_{CC}$ | Control Supply Voltage | Applied between $V_{CC(H)}$, $V_{CC(L)}$ - 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 ~ $V_{CC}$+0.3 | V |
| $V_{FO}$ | Fault Output Supply Voltage | Applied between $V_{FO}$ - COM | -0.3 ~ $V_{CC}$+0.3 | V |
| $I_{FO}$ | Fault Output Current | Sink Current at $V_{FO}$ Pin | 5 | mA |
| $V_{SC}$ | Current Sensing Input Voltage | Applied between $C_{SC}$ - COM | -0.3 ~ $V_{CC}$+0.3 | V |
| $V_{TS}$ | Temperature sense unit | | -0.3 ~ 2/3 x $V_{CC}$) | V |

### Total System

| Symbol | Parameter | Condition | Rating | Unit |
|---|---|---|---|---|
| $T_{STG}$ | Storage Temperature | | -40 ~ 125 | °C |
| $V_{ISO}$ | Isolation Voltage | 60Hz, Sinusoidal, AC 1 minute, Connection Pins to heat sink plate | 2500 | $V_{rms}$ |
| $T_{LEAD}$ | Max lead temperature at the base of the package during pcb assembly | No remelt of internal solder joints | 200 | °C |

### Package Characteristics

| Symbol | Parameter | Conditions | Typ. | Max. | Units |
|---|---|---|---|---|---|
| $R_{th(j-c)Q}$ | Junction to Case Thermal Resistance (2) | Inverter IGBT part (per IGBT) | - | 0.45 | °C/W |
| $R_{th(j-c)F}$ | | Inverter FWD part (per DIODE) | - | 0.85 | °C/W |
| $L_\sigma$ | Package Stray Inductance | P to $N_U$, $N_V$, $N_W$ (3) | 24 | - | nH |

**Notes:**

1. Current limited by package terminal, defined by design
2. Case temperature measured below the package at the chip center, compliant with MIL STD 883-1012.1 (single chip heating), DBC discoloration allowed, please refer to application note **AN-9190** *(Impact of DBC Oxidation on SPM® Module Performance)*
3. Stray inductance per phase measured per IEC 60747-15

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## Electrical Specifications

### Inverter part ($T_J$ as specified)

| Symbol | | Parameters | Conditions | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|---|
| $V_{CE(SAT)}$ | | Collector-Emitter Saturation Voltage | $V_{CC}$ = $V_{BS}$ = 15 V, $V_{IN}$ = 5 V<br>$I_C$ = 50 A, $T_J$ = 25°C | - | 1.65 | - | V |
| | | | $V_{CC}$ = $V_{BS}$ = 15 V, $V_{IN}$ = 5 V<br>$I_C$ = 50 A, $T_J$ = 125°C | - | 1.9 | 2.4 | V |
| $V_F$ | | FWD Forward Voltage | $V_{IN}$ = 0 V, $I_F$ = 30 A, $T_J$ = 25°C | - | 2.1 | - | V |
| | | | $V_{IN}$ = 0 V, $I_F$ = 30 A, $T_J$ = 125°C | | 1.9 | 2.5 | V |
| HS | $t_{ON}$ | High Side Switching Times | $V_{PN}$ = 300 V, $V_{CC}$ = $V_{BS}$ = 15 V<br>$I_C$ = 50 A<br>$V_{IN}$ = 0 V ↔ 5V, Ls=55 nH, Inductive Load<br>$T_J$= 25°C (4 , 5) | - | 0.73 | - | µs |
| | $t_{C(ON)}$ | | | - | 0.12 | - | |
| | $t_{OFF}$ | | | - | 0.80 | - | |
| | $t_{C(OFF)}$ | | | - | 0.14 | - | |
| | $t_{rr}$ | | | - | 0.10 | - | |
| | $t_{ON}$ | High Side Switching Times | $V_{PN}$ = 300 V, $V_{CC}$ = $V_{BS}$ = 15 V<br>$I_C$ = 50 A<br>$V_{IN}$ = 0 V ↔ 5V, Ls=55 nH, Inductive Load<br>$T_J$= 125°C (4, 5) | - | 0.70 | - | µs |
| | $t_{C(ON)}$ | | | - | 0.15 | - | |
| | $t_{OFF}$ | | | - | 0.87 | - | |
| | $t_{C(OFF)}$ | | | - | 0.19 | - | |
| | $t_{rr}$ | | | - | 0.20 | - | |
| LS | $t_{ON}$ | Low Side Switching Times | $V_{PN}$ = 300 V, $V_{CC}$ = $V_{BS}$ = 15 V<br>$I_C$ = 50 A<br>$V_{IN}$ = 0 V ↔ 5 V, Ls=55 nH, Inductive Load<br>$T_J$= 25°C (4, 5) | - | 0.68 | - | µs |
| | $t_{C(ON)}$ | | | - | 0.20 | - | |
| | $t_{OFF}$ | | | - | 0.86 | - | |
| | $t_{C(OFF)}$ | | | - | 0.19 | - | |
| | $t_{rr}$ | | | - | 0.14 | - | |
| | $t_{ON}$ | Low Side Switching Times | $V_{PN}$ = 300 V, $V_{CC}$ = $V_{BS}$ = 15 V<br>$I_C$ = 50 A<br>$V_{IN}$ = 0 V ↔ 5 V, Ls=55 nH, Inductive Load<br>$T_J$= 125°C (4,5) | - | 0.64 | - | µs |
| | $t_{C(ON)}$ | | | - | 0.24 | - | |
| | $t_{OFF}$ | | | - | 0.88 | - | |
| | $t_{C(OFF)}$ | | | - | 0.23 | - | |
| | $t_{rr}$ | | | - | 0.20 | - | |
| SCWT | | Short Circuit withstand time (6) | $V_{CC}$ = $V_{BS}$ = 15 V, $V_{PN}$= 450 V,<br>$T_J$= 25°C, Non-repetitive | - | 5 | - | µs |
| $I_{CES}$ | | Collector-Emitter Leakage Current for IGBT and diode in parallel | $T_J$= 25°C, $V_{CE}$ = 650 V | - | 3 | - | µA |
| | | | $T_J$= 125°C, $V_{CE}$ = 650 V | - | 150 | 1500 | µA |

**Notes:**

4. $t_{ON}$ and $t_{OFF}$ include the propagation delay time of the internal drive IC. $t_{C(ON)}$ and $t_{C(OFF)}$ are the switching times of IGBT itself under the given gate driving condition internally. Refer to Figure 6 for detailed information
5. Stray inductance Ls is sum of stray inductance of module & setup
6. Verified by design and bench-testing only

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**Control Part** ($T_J$ = -40°C to 150°C, unless otherwise specified, typical values specified at $T_J$=125°C)

| Symbol | Parameters | Conditions | | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|---|
| $I_{QCCL}$ | Quiescent $V_{CC}$ Supply Current | $V_{CC}$ = 15 V, $IN_{(UL, VL, WL)}$ = 0 V | $V_{CC(L)}$ – COM | - | - | 5 | mA |
| $I_{QCCH}$ | | $V_{CC}$ = 15 V, $IN_{(UH, VH, WH)}$ = 0 V | $V_{CC(H)}$ – COM | - | - | 150 | µA |
| $I_{PCCH}$ | Operating $V_{CC}$ Supply Current | $V_{CC(UH, VH, WH)}$ = 15 V $f_{PWM}$ = 20 kHz Duty=50%, applied to one PWM signal input for high-side | $V_{CC(UH)}$ – COM $V_{CC(VH)}$ – COM $V_{CC(WH)}$ – COM | - | - | 0.30 | mA |
| $I_{QCCL}$ | | $V_{CC(UH, VH, WH)}$ = 15 V $f_{PWM}$ = 20 kHz Duty=50%, applied to one PWM signal input for low-side | $V_{CC(L)}$ – COM | - | - | 8.5 | mA |
| $I_{QBS}$ | Quiescent $V_{BS}$ Supply Current | $V_{BS}$ = 15 V, $IN_{(UH, VH, WH)}$ = 0V | $V_{B(U)}$ - $V_{S(U)}$ $V_{B(V)}$ -$V_{S(V}$ $V_{B(W)}$ - $V_{S(W)}$ | - | - | 150 | µA |
| $I_{PBS}$ | Operating $V_{BS}$ Supply Current | $V_{CC}$=VBC=15 V $IN_{(UH, VH, WH)}$ = 0 V | $V_{B(U)}$ - $V_{S(U)}$ $V_{B(V)}$ -$V_{S(V}$ $V_{B(W)}$ - $V_{S(W)}$ | - | - | 4.5 | mA |
| $V_{FOH}$ | Fault Output Voltage | $V_{SC}$ = 0 V, $V_{FO}$ Circuit: 4.7 kΩ to 5 V Pull-up | | 4.5 | - | - | V |
| $V_{FOL}$ | | $V_{SC}$ = 1 V, $V_{FO}$ Circuit: 4.7 kΩ to 5 V Pull-up | | - | - | 0.5 | V |
| $V_{SC(ref)}$ | Short-Circuit Trip Level | $V_{CC}$ = 15 V (7) | $C_{SC}$-COM | 0.45 | 0.52 | 0.59 | V |
| $UV_{CCD}$ | Supply Circuit Under-Voltage Protection | Detection Level, $T_J$= 125°C | | 10.6 | - | 13.2 | V |
| $UV_{CCR}$ | | Reset Level, $T_J$= 125°C | | 11.0 | - | 13.8 | V |
| $UV_{BSD}$ | | Detection Level, $T_J$= 125°C | | 10.5 | - | 13 | V |
| $UV_{BSR}$ | | Reset Level, $T_J$= 125°C | | 10.8 | - | 13.3 | V |
| $t_{FOD}$ | Fault-out Pulse Width | | | - | 60 | - | µs |
| $V_{TS}$ | LVIC Temperature Sensing Voltage Output | $V_{CC(L)}$ = 15 V, $T_{LVIC}$ =125˚C (8) | | - | 2.4 | - | V |
| $V_{IN(ON)}$ | ON Threshold Voltage | Applied between $IN_{(UH)}$, $IN_{(VH)}$, $IN_{(WH)}$, $IN_{(UL)}$, $IN_{(VL)}$, $IN_{(WL)}$ – COM | | - | 2.6 | 3.1 | V |
| $V_{IN(OFF)}$ | OFF Threshold Voltage | | | 0.9 | 1.2 | - | V |

**Notes:**

7. Short-circuit current protection is functional only for low side
8. $T_{LVIC}$ is the junction temperature of the LVIC itself

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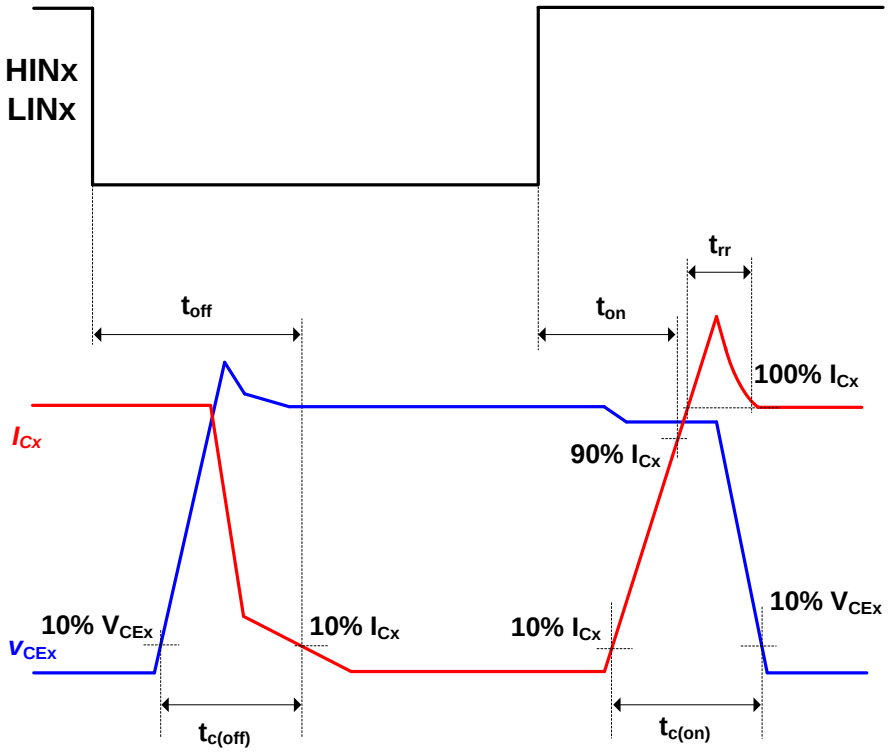



**Figure 6a.** Switching Time Definition

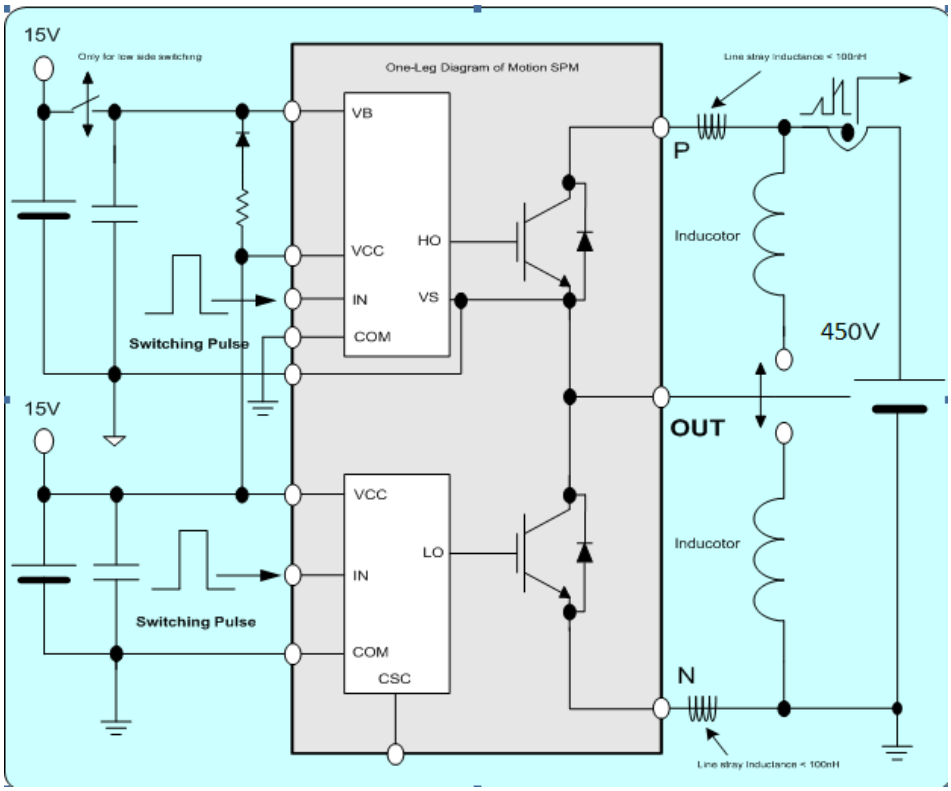



**Figure 7b.** Switching Evaluation Circuit

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## Recommended Operating Conditions

The Recommended Operating Conditions table defines the conditions for actual device operation. Recommended Operating Conditions are specified to ensure optimal performance to the datasheet specifications. Fairchild does not recommend exceeding them or designing to Absolute Maximum Ratings.

| Symbol | Parameters | Conditions | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|
| $V_{PN}$ | Supply Voltage | Applied between P - $N_U$, $N_V$, $N_W$ | - | 450 | 500 | V |
| $V_{CC}$ | Control Supply Voltage | Applied between $V_{CC(H)}$, $V_{CC(L)}$ - COM | 13.5 | 15 | 16.5 | V |
| $V_{BS}$ | High-side Bias Voltage | Applied between $V_{B(U)}$ - $V_{S(U)}$, $V_{B(V)}$ - $V_{S(V)}$, $V_{B(W)}$ - $V_{S(W)}$ | 13.3 | 15 | 18.5 | V |
| $dV_{CC}/dt$, $dV_{BS}/dt$ | Control supply variation | | -1 | - | 1 | V/µs |
| $t_{dead}$ | Blanking Time for Preventing Arm-short | For Each Input Signal | 1.0 | - | - | µs |
| $f_{PWM}$ | PWM Input Signal | $T_C$= 125°C | - | - | 20 | kHz |
| $V_{SEN}$ | Voltage for Current Sensing | Applied between $N_U$, $N_V$, $N_W$ – COM (Including surge voltage) | -4 | - | 4 | V |
| $T_J$ | Junction temperature | | -40 | - | 150 | °C |

## Mechanical Characteristics and Ratings

| Parameter | Conditions | Conditions | Limits | | | Units |
|---|---|---|---|---|---|---|
| | | | Min. | Typ. | Max. | |
| Mounting Torque | Mounting Screw: - M3 | Recommended 0.62N•m | 0.51 | 0.62 | 0.80 | N•m |
| Device Flatness | | | | | +150 | µm |
| Weight | | | | 15 | | g |

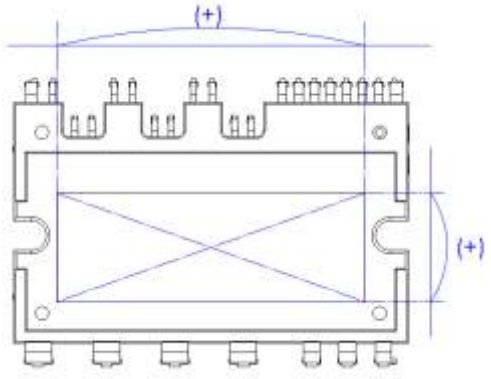



**Figure 8**. Flatness Measurement Position

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## Typical Inverter Characteristics

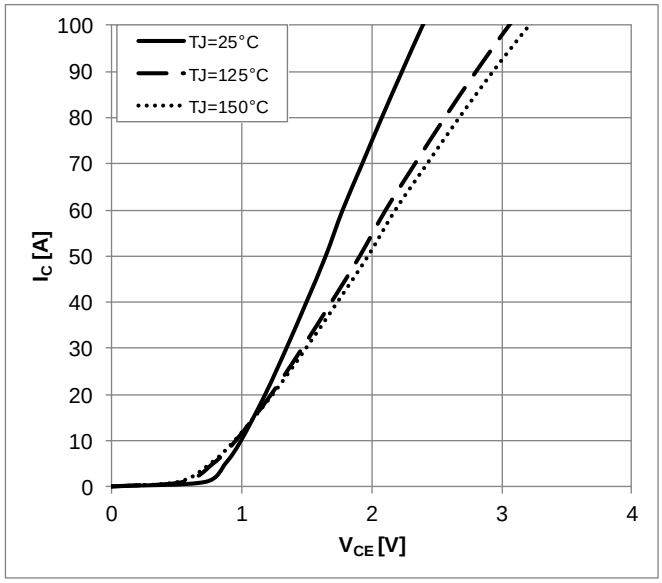



**Figure 9. Output characteristics IGBT inverter (typical)**
$V_{CC}$ = $V_{BS}$ = 15 V, $V_{IN}$=5 V

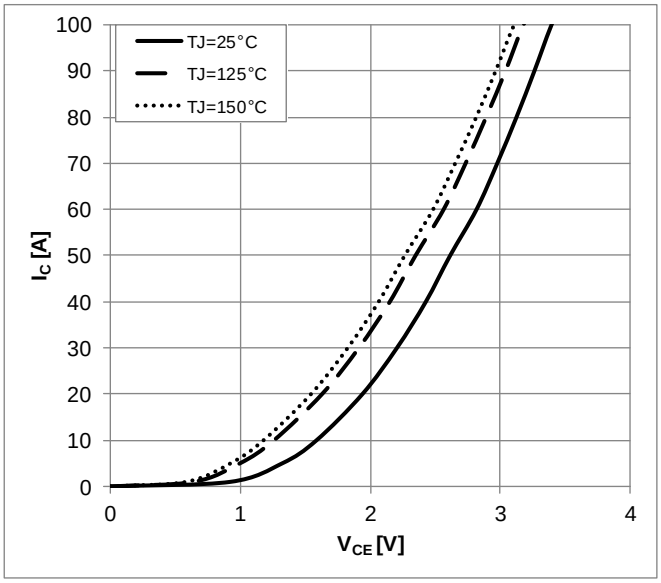



**Figure 10. Forward characteristics DIODE inverter (typical)**
$V_{IN}$=0 V

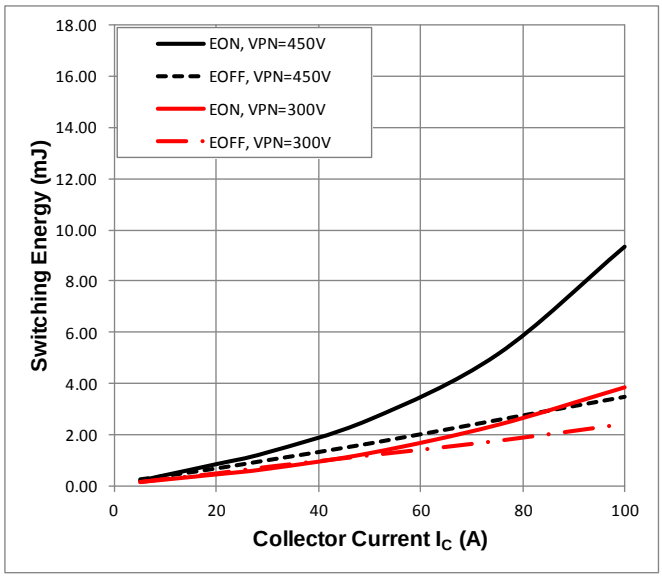



**Figure 11. Switching losses IGBT inverter High-Side (typical) versus collector current**
VCC = VBS = 15 V
VIN = 0 V ↔ 5 V, Ls=55 nH, Inductive Load, $T_J$=125°C

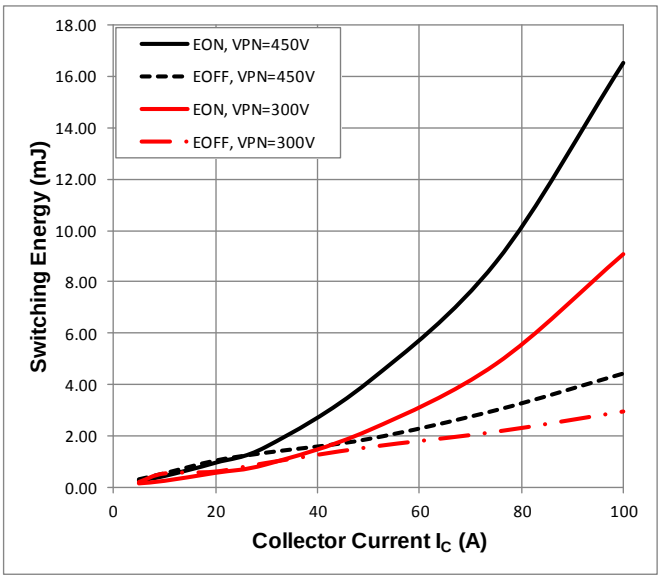



**Figure 12. Switching losses IGBT inverter Low-Side (typical) versus collector current**
VCC = VBS = 15 V
VIN = 0 V ↔ 5 V, Ls=55 nH, Inductive Load, $T_J$=125°C

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## Typical Inverter Characteristics

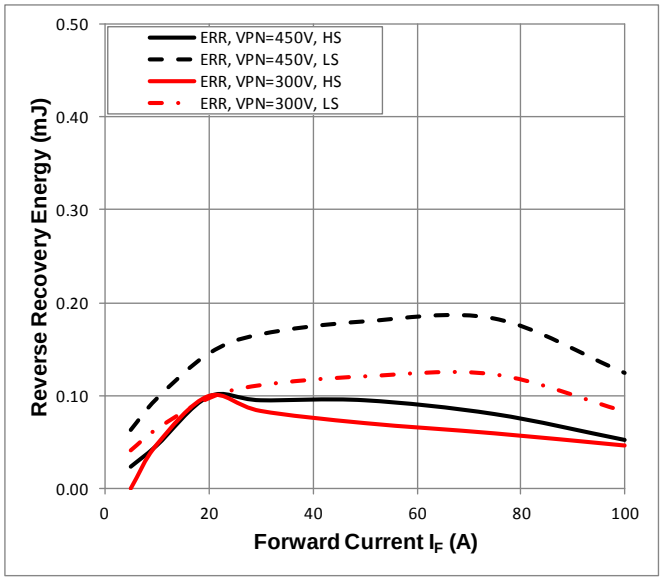



**Figure 13. Reverse recovery energy DIODE inverter (typical) versus forward current**
VCC = VBS = 15 V
VIN = 0 V ↔ 5 V, Ls=55nH, Inductive Load, $T_J$=125°C

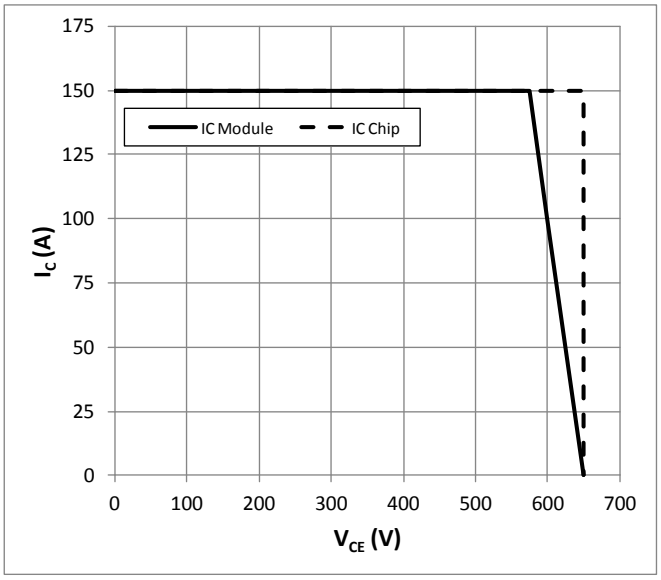



**Figure 14. Reverse Bias Safe Operating Area IGBT (RBSOA) inverter**
$V_{CC}$ = $V_{BS}$ = 15 V, Tj=150°C

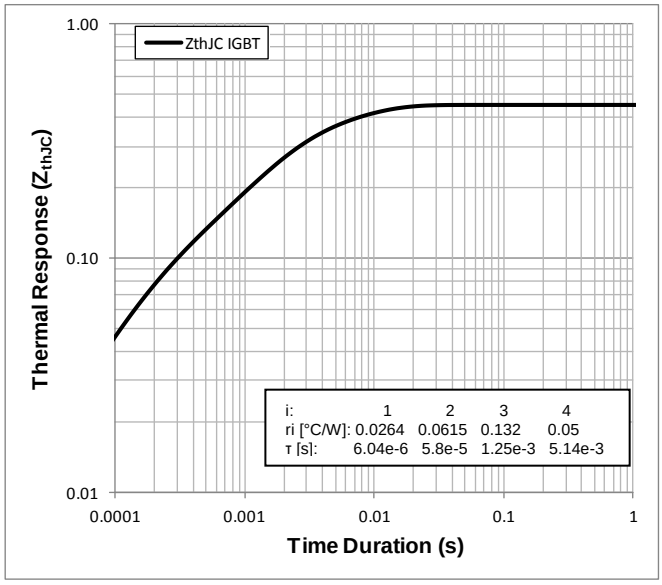



**Figure 15. Transient thermal impedance IGBT inverter**

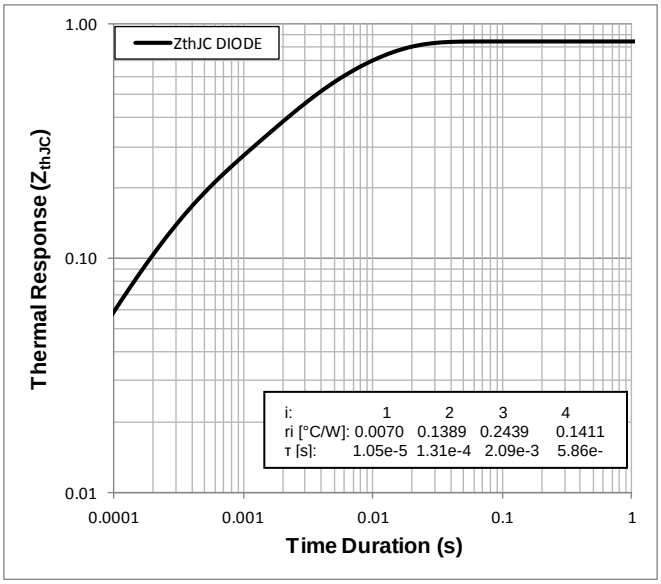



**Figure 16. Transient thermal impedance DIODE inverter**

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## Typical Controller Characteristics

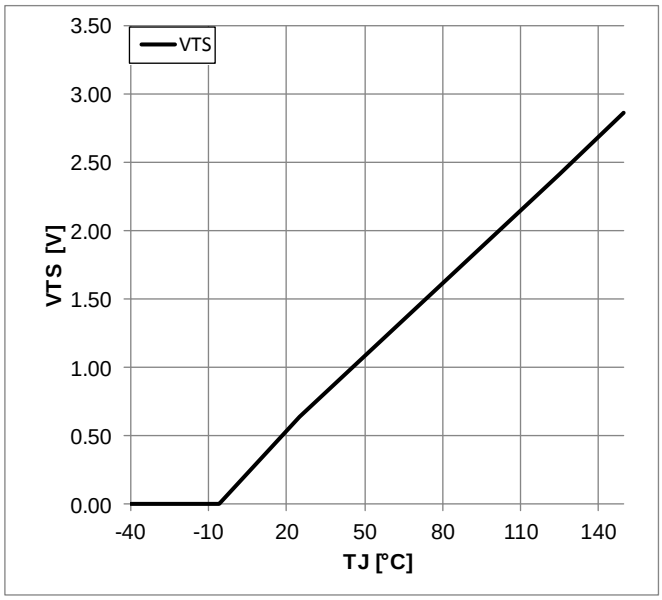



**Figure 17. Temperature profile of $V_{TS}$ (typical)**

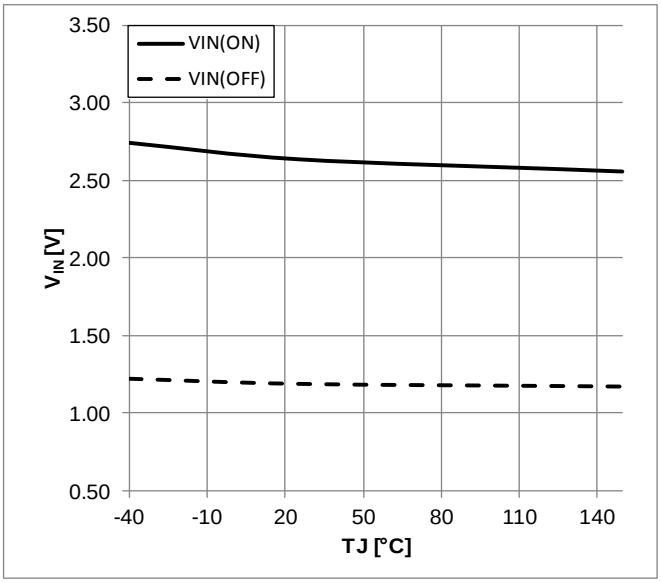



**Figure 18. Threshold voltage versus temperature**

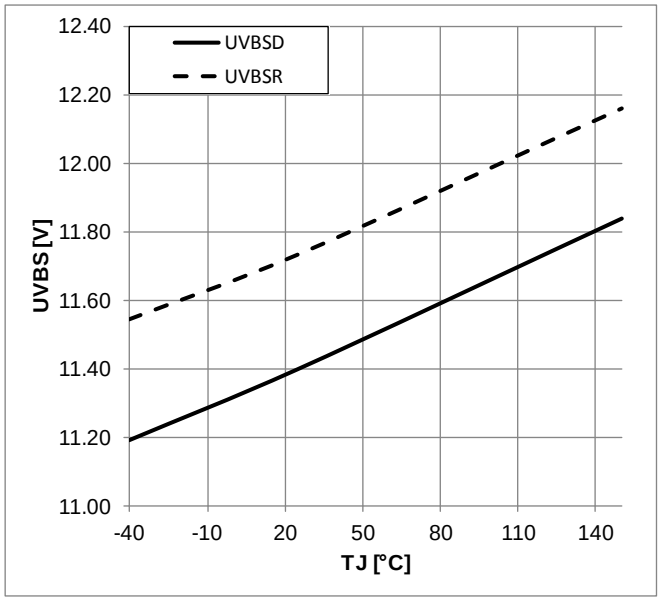



**Figure 19. Supply under-voltage protection high-side (typical)**

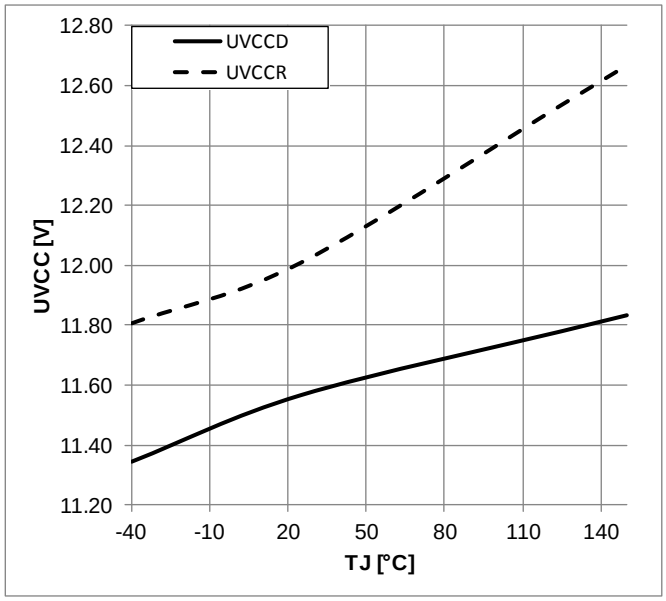
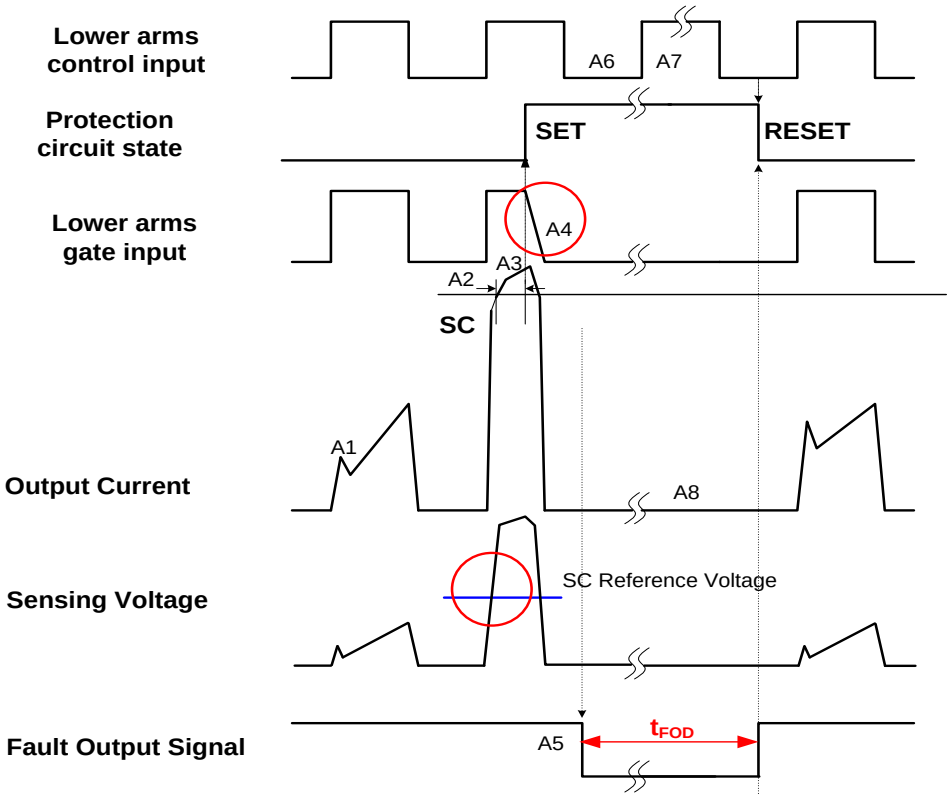



**Figure 20. Supply under-voltage protection low-side (typical)**

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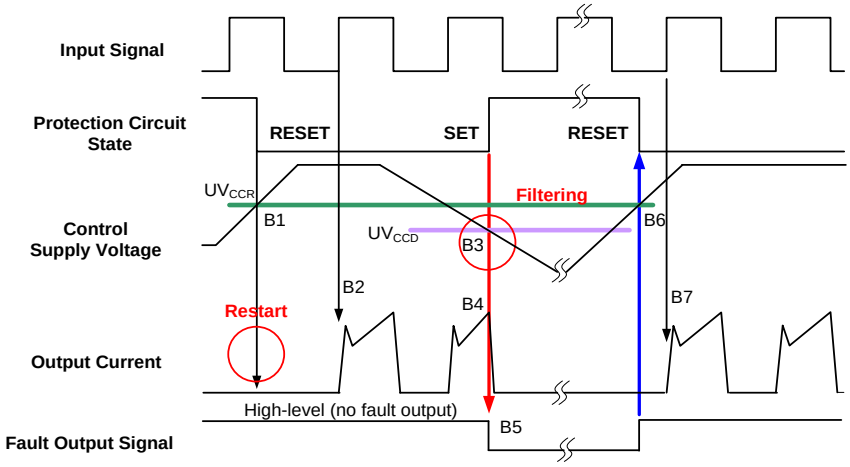
## Timing Chart Protective Functions




| Step | Description |
|---|---|
| A1 | Normal operation. IGBT on and carrying current |
| A2 | Short-circuit current threshold reached |
| A3 | Protection function triggered |
| A4 | IGBT turns off with soft turn-off |
| A5 | Fault output activated (initial delay 2 μs, $t_{FOD}$ min. 50μs) |
| A6 | IGBT “LO” input |
| A7 | IGBT “HI” input is ignored |
| A8 | Current stays at zero during fault state |

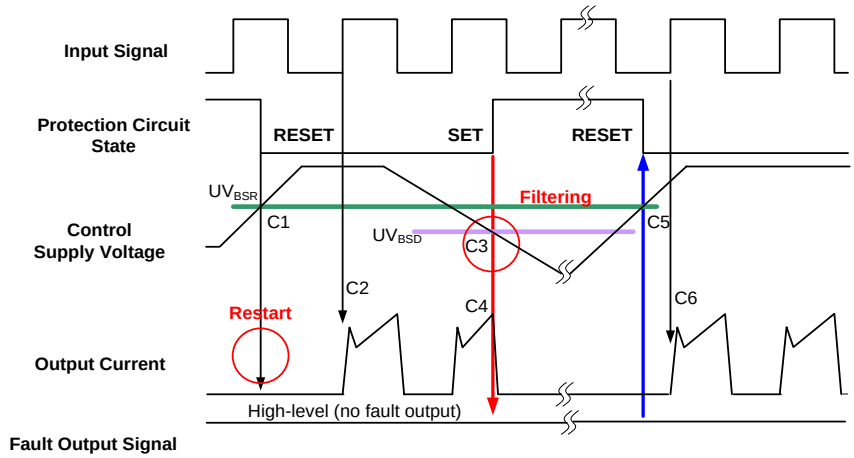
**Figure 21.** Short-Circuit Current Protection

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| Step | Description |
|---|---|
| B1 | Control supply voltage rises above reset voltage $UV_{CCR}$ |
| B2 | Normal operation. IGBT on and carrying current |
| B3 | Control supply voltage falls below detection voltage $UV_{CCD}$ |
| B4 | Filtered supply voltage falls below $UV_{CCD}$ and IGBT turns off |
| B5 | Fault output activated (initial delay 2 μs, $t_{FOD}$ min. 50μs) |
| B6 | Control supply voltage rises above reset voltage $UV_{CCR}$ |
| B7 | IGBT “HI” input is followed after fault output duration and supply voltage rise |

**Figure 22**. Under-Voltage Protection (Low-side)

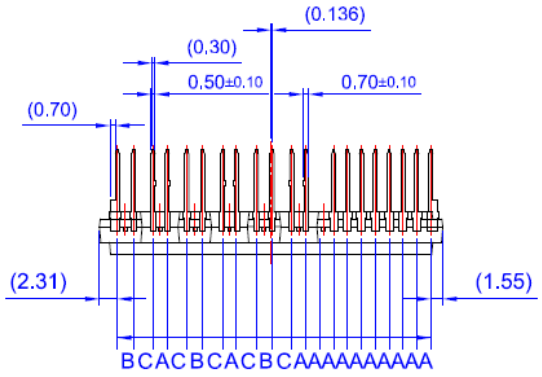



| Step | Description |
|---|---|
| C1 | Control supply voltage rises above reset voltage $UV_{CCR}$ |
| C2 | Normal operation. IGBT on and carrying current |
| C3 | Control supply voltage falls below detection voltage $UV_{CCD}$ |
| C4 | Filtered supply voltage falls below $UV_{CCD}$ and IGBT turns off |
| C5 | Control supply voltage rises above reset voltage $UV_{CCR}$ |
| C6 | IGBT “HI” input is followed after supply voltage rise |

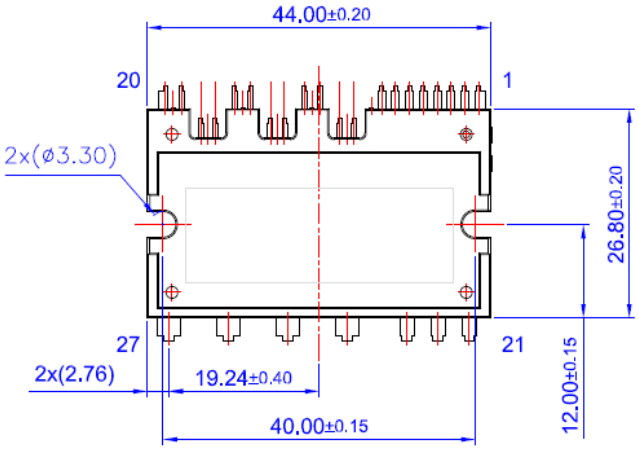
**Figure 23** Under-Voltage Protection (High-side)

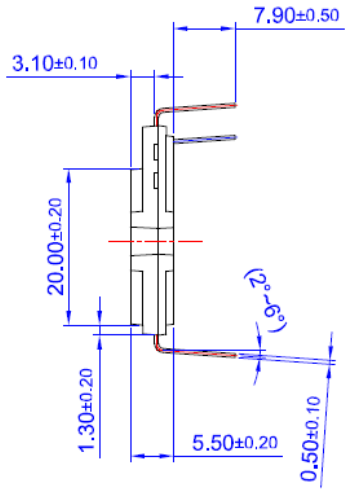
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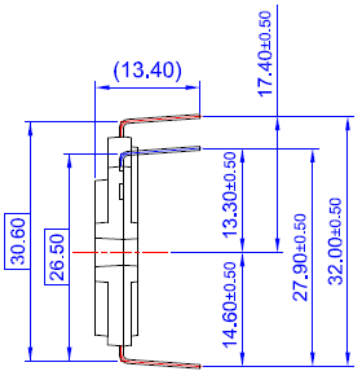
## Physical Dimensions Dimension is in millimeter unless otherwise noted.

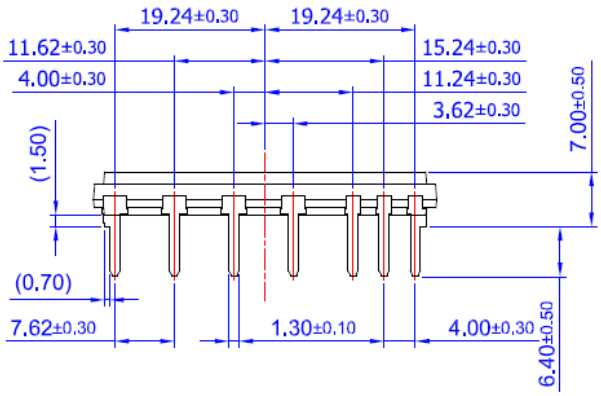



LEAD PITCH (TOLERANCE : ±0,30)
A : 1.778
B : 2.050
C : 2.531



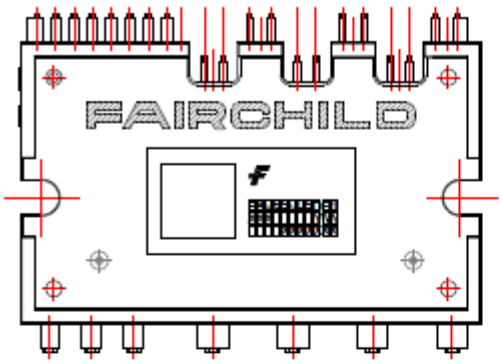




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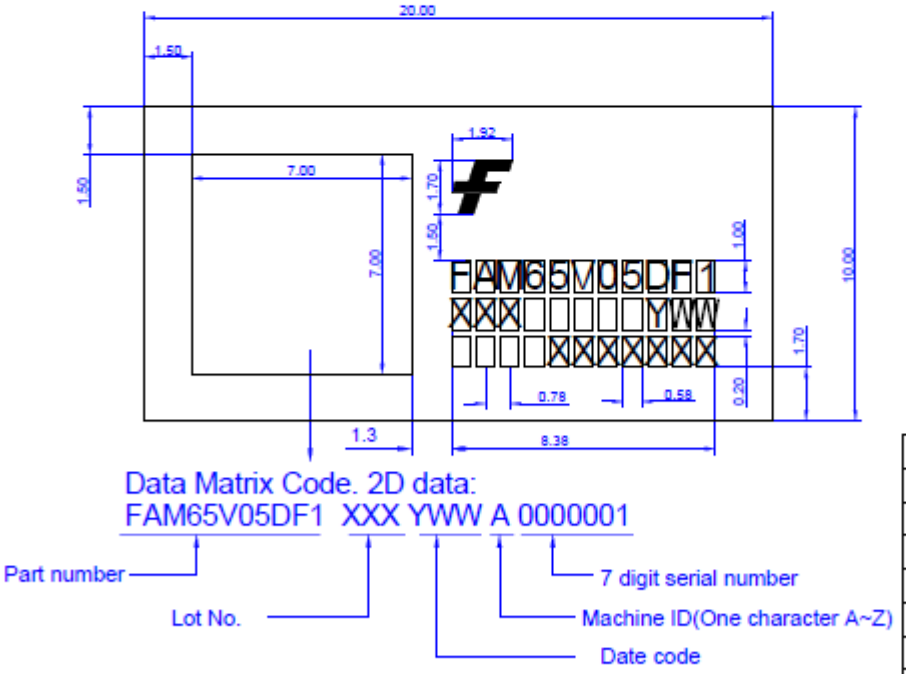
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## Physical Dimensions

### * MARKING LAY-OUT




### * MARKING DIMENSION




| X | Alphabet |
|---|---|
| 2010 | A |
| 2011 | B |
| 2012 | C |
| 2013 | D |
| 2014 | E |
| 2015 | F |
| 2016 | G |
| 2017 | H |
| 2018 | J |
| 2019 | K |
| 2020 | A |

*Note: Marking pattern shown for final production version, which slightly differ from previous engineering versions.*

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