FAIRCHILD SEMICONDUCTOR®

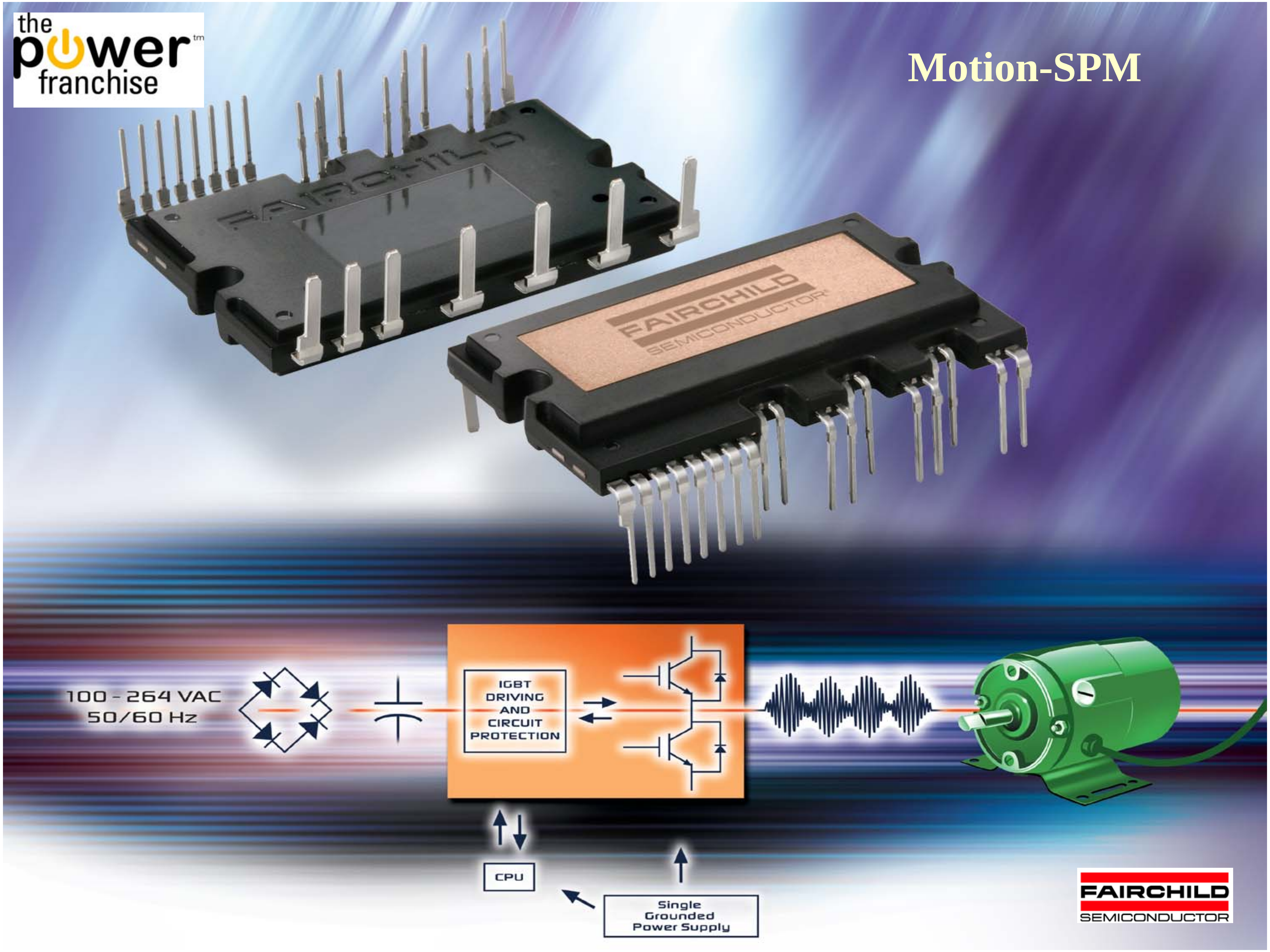
Introduction
of
Smart Power Modules

March 2006

Motion Control System Team
HV Functional Power Group

www.fairchildsemi.com

the power franchise™


the power franchise
Motion-SPM
100 - 264 VAC
50/60 Hz
IGBT DRIVING AND CIRCUIT PROTECTION
CPU
Single Grounded Power Supply
FAIRCHILD SEMICONDUCTOR

Terminology

A/C	Air-Conditioner	NTC	Negative Temperature Coefficient
BLDC	Brush-less DC	OCP	Over Voltage Protection
BS	Boot Strap	PFC	Power Factor Correction
CAN	Controller Area Network	PKG	Package
CPM	Compact Power Module	PSC	Partial Power Factor Correction Switching Converter
CIB	Converter Inverter Brake	PWM	Pulse Width Modulation
DBC	Direct Bonding Copper	PROT	Protection
DIP	Dual In-line Package	PCB	Printed Circuit Board
EMI	Electro-Magnetic Interference	QA	Quality Assurance
EMC	Electro-Magnetic Compatibility	SPM	Smart Power Module
ESR	Equivalent Series Resistance	SPIU	Smart Power Integrated Unit
FCS	Fairchild Semiconductor	SPIM	Smart Power Integrated Module
FOC	Field Oriented Control	SEER	Seasonal Energy Efficiency Rating
FRD	Fast Recovery Diode	SC	Short Circuit
FWD	Free-Wheeling Diode	SRM	Switched Reluctance Motor
F/F	Flip Flop	SIP	Single In-Line Package
FRFET	Fast Recovery body diode MOSFET	SMD	Surface Mounted Device
FPS	Fairchild Power Switch	SOA	Safe Operating Area
HVIC	High Voltage gate driver IC	SCWT	Short Circuit Withstands Time
IM	Induction Motor	UV	Under Voltage
IGBT	Insulated Gate Bipolar Transistor	UVP	Under Voltage Protection
INV	Inverter	UVLO	Under Voltage Lock-Out
LVIC	Low Voltage gate driver IC	VVVF	Variable Voltage Variable Frequency
MI	Modulation Index	VSD	Variable Speed Drive
MCU	Micro Controller Unit	1N	One Separate Negative Rail Emitter
MFG	Manufacturing	3N	Three Separate Negative Rail Emitter

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Contents

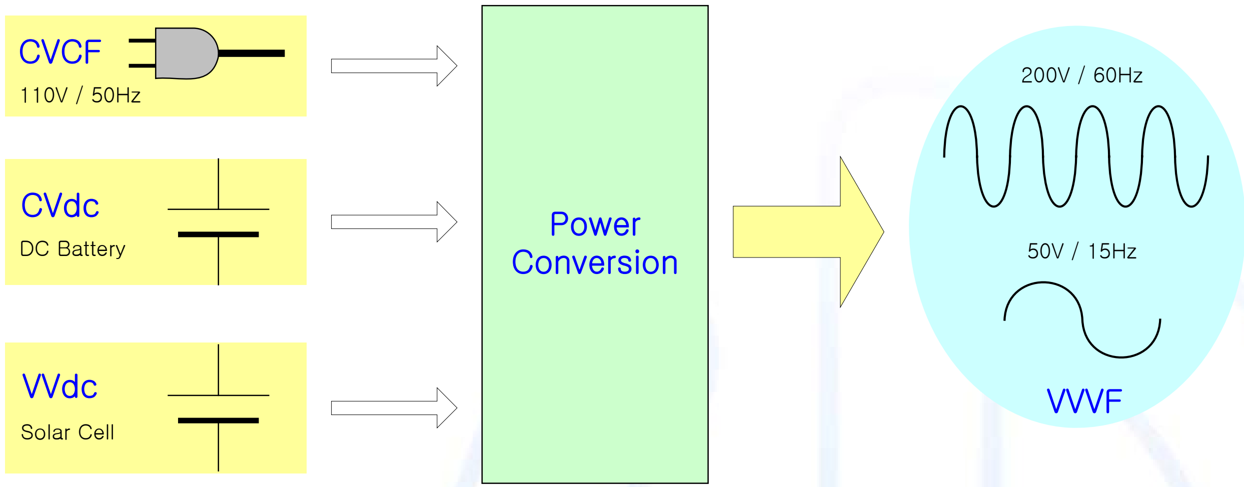
Chapter 1. Why Motor Drives

Why/How Motion Control ?

WHY:

- Speed Control → Energy Savings
- Speed and Torque Control → High Efficiency and Performance
- Speed and Position Control → High Efficiency and Performance

HOW: by Variable Voltage and Variable Frequency in 3-phase ac motor configuration



Trend of Motor Technology

Trend is Inverter-driven Motion !!

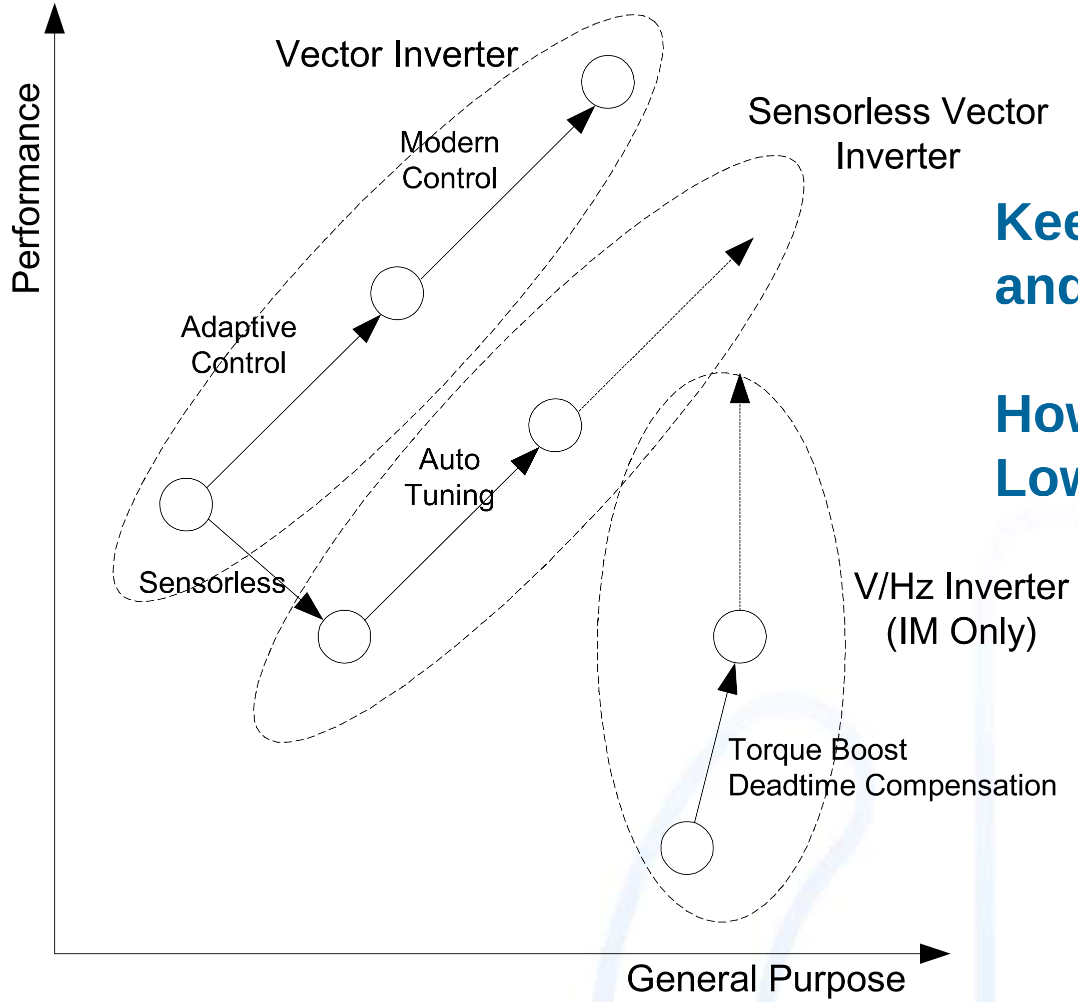
- DC Motor
- AC Motor
  - Induction Motor
  - Synchronous Motor
    - Permanent Magnet (BLDC) *Broad sense*
      - Brushless DC (BLDC) *Narrow sense*
      - Surface Mounted Permanent Magnet (SMPMM)
      - Interior Permanent Magnet (IPMM)
    - Reluctance
      - Synchronous Reluctance (SynRM)
      - Switched Reluctance (SRM)

Interior Permanent Magnet (IPMM) + Synchronous Reluctance (SynRM) → Permanent Magnet Assisted SynRM (PMA-SynRM)

Trend goes to higher efficiency and better performance

- Use of VVVF, FOC Inverter
- High-speed operation enhances total efficiency of entire system
- Faster & better torque & speed control
- Wide-speed operation
- Additional functions that give comfort & reliability

Inverter Technology Trend



Keeping Higher performance and Efficiency !

How to achieve Lower Cost Solution !!

Higher Efficiency to Meet New Regulations

- The U.S. Department of Energy announced on April 2nd that it will enforce a seasonal energy efficiency rating **(SEER) standard of 13** for residential central air conditioners starting in January 2006.
- This represents a **30 percent increase in energy efficiency** compared to the previous10 SEER standard.
- New regulations from government agencies within the European Community
- Japan government has announced the need of 20% higher efficiency than present efficiency level in order to meet Kyoto Protocol from 2010, particularly in Air-conditioners and Refrigerators

Chapter 2. SPM Introduction

Summary of SPM Portfolio

		Basic Structure
SPIU	> 10kW (600V 450A)	6-IGBT/FRD with thermal sensor + Gate Driver + Protection + DC/DC Converter + CAN MCU + I/O
SPIM	< 10kW (600V 100A 1200V 50A)	6-IGBT/FRD for inverter + Inverter Gate Driver + PFC + PFC controller + Thermistor + Protection + MCU
CPM	< 10kW (600V 100A 1200V 50A	6-IGBT/FRD for inverter + Rectifier + Dynamic brake + Thermistor
SPM1	< 10kW (600V 100A 1200V 50A	6-IGBT or MOSFET / FRD for inverter + Gate driver with Protection + Thermistor
SPM2	< 5kW (600V 75A)	6-IGBT / FRD for inverter + Gate driver with Protection (SC, UV, Soft Shut down) + Thermistor
SPM3	< 2.2kW (600V 30A)	6-IGBT / FRD for inverter + Gate driver with Protection (SC, UV, Soft Shut down) + Thermistor
SPM4	< 1kW (600V 15A)	6-IGBT / FRD for inverter + Gate driver with Protection (SC, UV, Soft Shut down) + Thermistor
SPM5	< 0.1kW (500V 3A)-MOSFET	6-MOSFET for inverter + Gate driver with Protection (UV) + Thermistor

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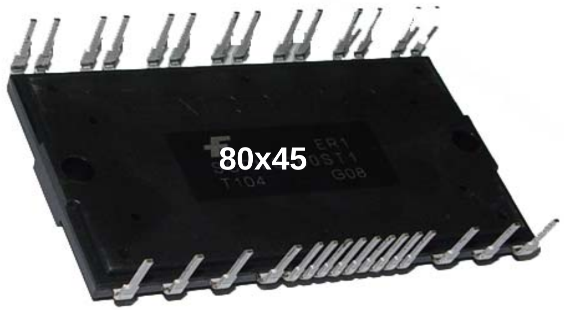
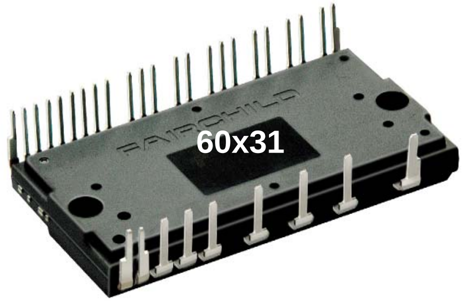
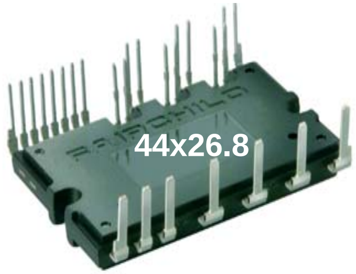
External View of SPM Product Group



CPM/SPM1 Series



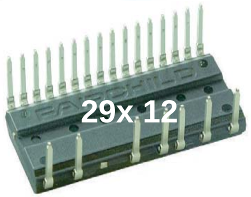
SPM2 Series



SPM3 Series

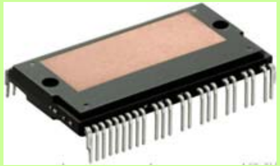
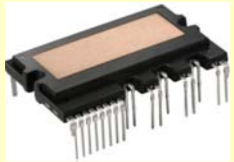
SPM4 SIP1 Series

SPM4 SIP2 Series

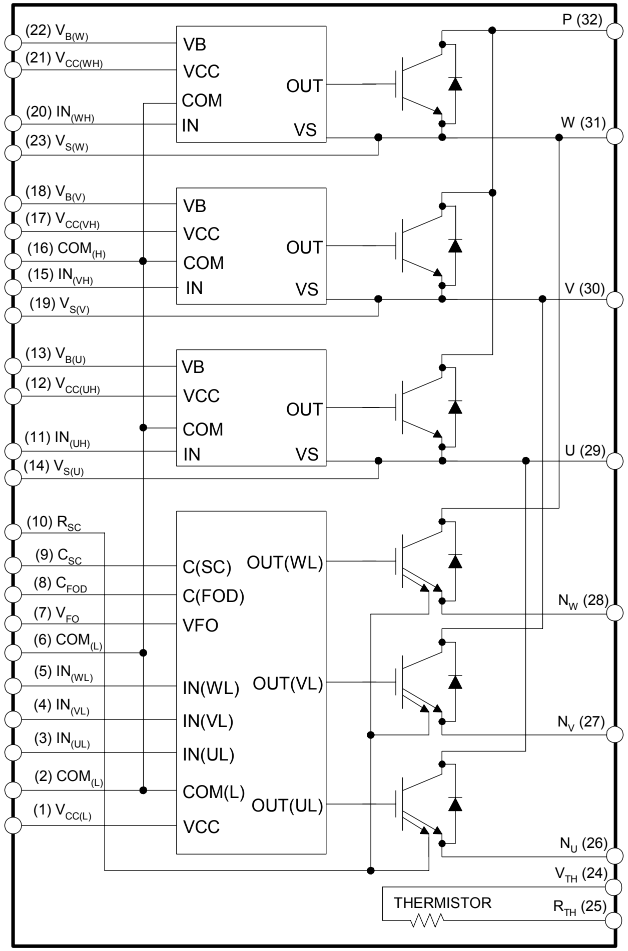


SPM5 Series

Overview of SPM2 and SPM3 Products

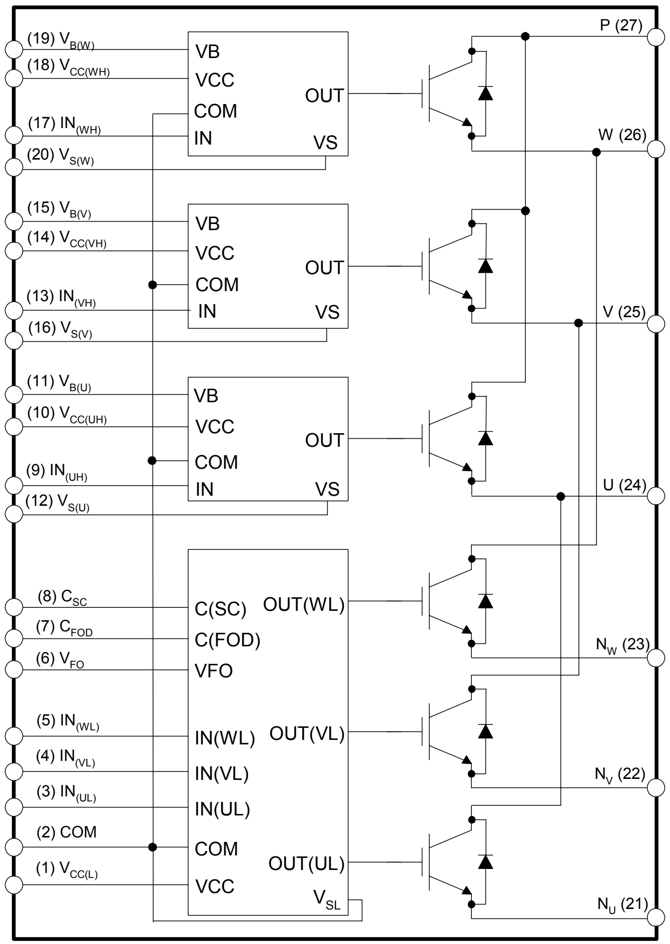
	 60x31	 60x31	 44x26.8	 44x26.8
PKG	**SPM2 PKG with Ceramic substrate**	**SPM2 PKG with DBC substrate**	**SPM3 PKG with Ceramic substrate**	**SPM3 PKG with DBC substrate**
Developed	**SPM2** **600V-10/15/20/30A**	**SPM2** **600V-50A, 75A**	**V2 SPM3** **600V-3/5/10/15A** **MOSFET SPM3** **500V-5/6A**	**V2 SPM3** **600V-15/20/30A** **SRM-SPM : 600V-50A** **PSC-SPM : 600V-20A** **PFC-SPM : 600V-20/30/50A**
Developing			**V3 SPM3** **600V-3/5/10/15A**	**V3 SPM3** **600V-15/20/30A**

Details of SPM2 Series



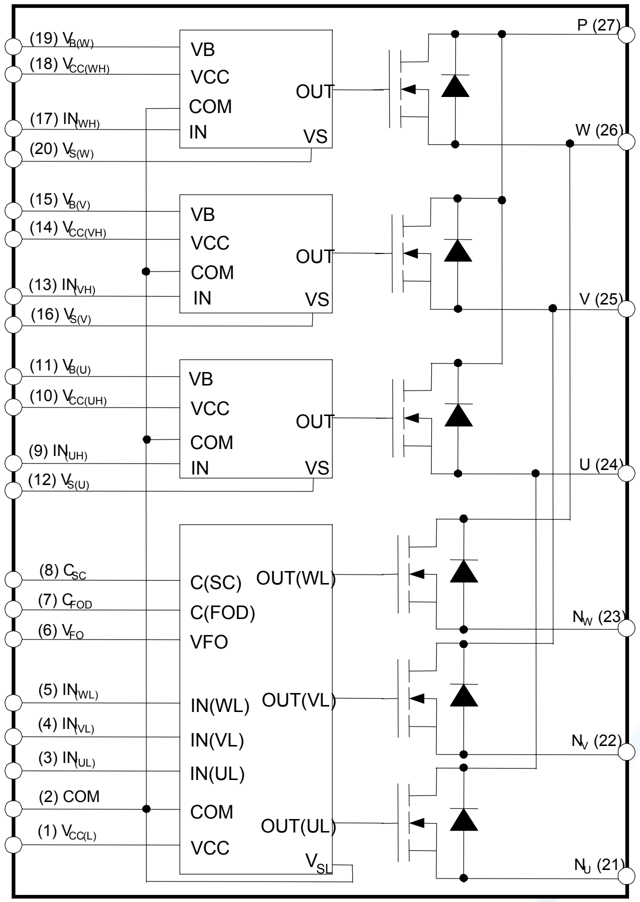
- Line-up – SPM2 :
  - 600V/10A, 15A, 20A, 30A – with Ceramic Substrate
  - 600V/50A, 75A – with DBC Substrate
- Major Applications :
  - Consumer appliance inverters (Air conditioner, Treadmill)
  - Low power industrial inverters
- Feature :
  - Built-in thermistor (NTC)
  - Short-circuit protection with soft shut- down control using sense-IGBTs
  - Good thermal resistance and isolation capacity with ceramic/DBC substrate
  - 3 N-terminals for low-cost current sensing

Details of SPM3 Series



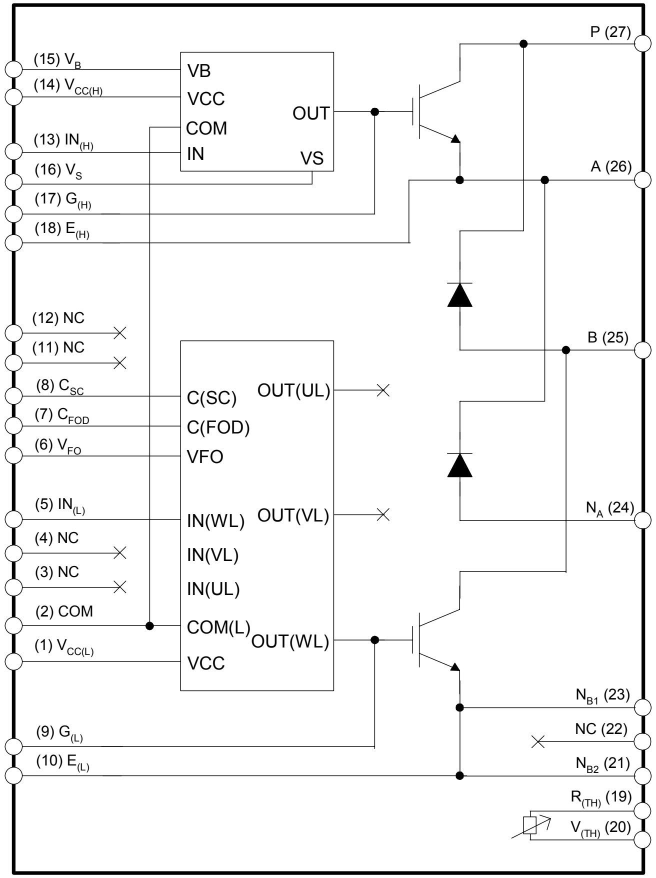
- **Line-up - V2 SPM3 :**
  - **- 600V/3A, 5A, 10A, 15A –with ceramic**
  - **- 600V/15A, 20A, 30A –with DBC**
- **Line-up - V3 SPM3 (under development) :**
  - **- 600V/3A, 5A, 10A, 15A – V3 SPM3 with ceramic**
  - **- 600V/15A, 20A, 30A – V3 SPM3 with DBC**
  - **- V3 SPM3 = enhanced IGBT**
- **Major Applications :**
  - **- Consumer appliance inverters**
    (Air conditioner, Washing machine, Refrigerator, etc)
  - **- Low power industrial inverters**
    (Industrial inverter, Water pump, Treadmill, Elevator door, etc)
- **Feature :**
  - **- Good thermal resistance**
  - **- Small size & Large pin-to-pin spacing with zigzag package structure**
  - **- 3 N-terminals for low-cost current sensing**

Details of MOSFET-SPM3



- **Line-up :**
  - **- 500V/ 5A (1.35Ω(typ.)), 6A (1.15Ω(typ))**
- **Major Applications :**
  - **- Low power consumer appliance inverters (Refrigerator, Fan)**
- **Feature :**
  - **- 3-phase MOSFET inverter with driver IC**
  - **- Good thermal resistance**
  - **- Small size & Large pin-to-pin spacing with zigzag package structure**
  - **- 3 N-terminals for low-cost current sensing**

Details of SRM-SPM3



- **Line-up :**
  - **600V/50A - SPM3 package with DBC**
- **Major Applications :**
  - **Single-phase SRM drives (Vacuum cleaner)**
- **Feature :**
  - **Good thermal resistance**
  - **IGBT switching speed control with external capacitor**
  - **Built-in thermistor (NTC)**
  - **Small size & Large pin-to-pin spacing with zigzag package structure**
  - **Divided N-terminals for low-cost current sensing**

Details of PFC-SPM3

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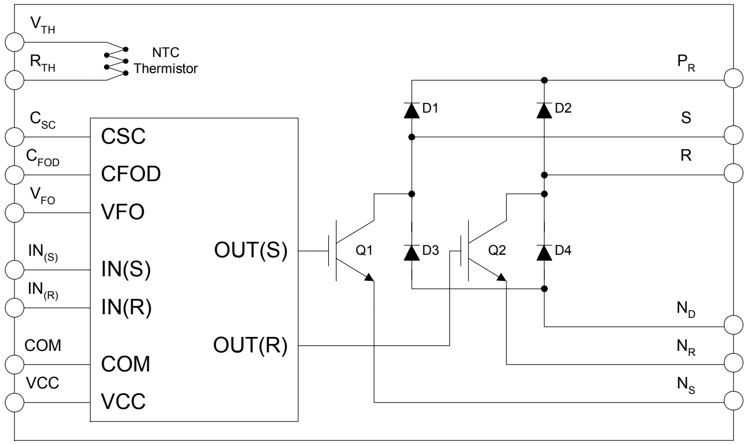

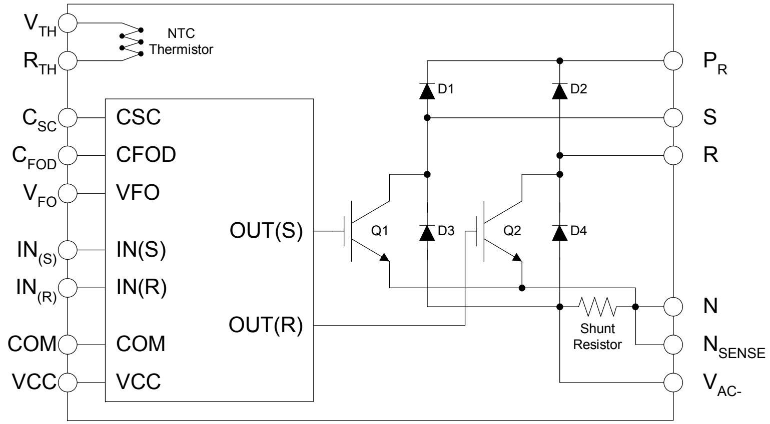

PSC-SPM(Partial switching PFC)

- **Line-up :**
  - **600V/20A - SPM3 package with DBC**
- **Major Applications :**
  - **Low/Medium power consumer appliances such as Room air conditioner**
- **Feature :**
  - **Good thermal resistance**
  - **Same package as SPM3**
  - **Built-in thermistor for temperature sensing**
  - **LVIC with UVP, OCP**

PFC-SPM(Full switching PFC)

- **Line-up :**
  - **600V/20A,30A, 50A - SPM3 package with DBC**
- **Major Applications :**
  - **Medium/high power consumer appliance such as Package/System air conditioner**
- **Feature :**
  - **Good thermal resistance**
  - **Built-in shunt resistor**
  - **Same package as SPM3**
  - **Built-in thermistor for temperature sensing**
  - **LVIC with UVP, OCP**

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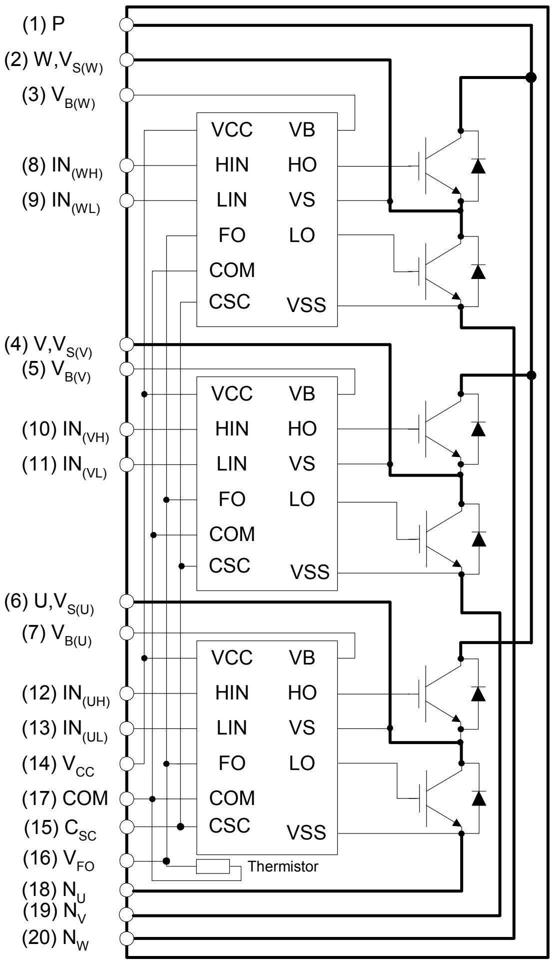
Overview of SPM4, SPM5 and CPM Products

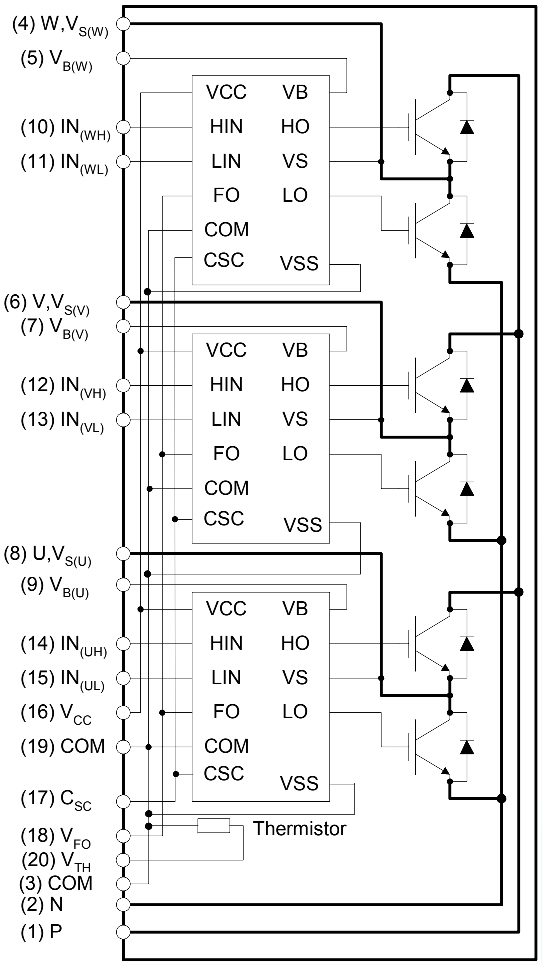
	 54x29.5	 45x28	   29x12	 80x45
PKG	**SPM4 SIP1 PKG**	**SPM4 SIP2 PKG**	**SPM5 PKG**	**CPM PKG**
Developed			**V1 SPM5 DIP** **500V** **2A** (3.3 Ω(typ)), **3A** (1.9 Ω(typ)) **250V 3A** (1.4 Ω(typ))	
Developing	**SPM4** **600V-3/5/8/10/12/15A**	**SPM4** **600V-3/5/8/10/12/15A** **MOSFET SPM4** **500V- 5/6/9A**	**V2 SPM5 SMD** **500V- 2 / 3A** **250V - 3A** **LV-SPM5 DIP, SMD** **60V 40mΩ(typ)**	**600V / 1200V CPM CIB** **1200V- 15A, 25A** **600V - 30A, 50A** **600V / 1200V CPM Inv.** **1200V- 25A, 35A, 50A** **600V- 50A, 75A, 100A** **600V/1200V SPM1** **600V- 50A, 75A, 100A** **1200V- 10A, 15A, 25A**

Details of SPM4-SIP1

A option – 3N

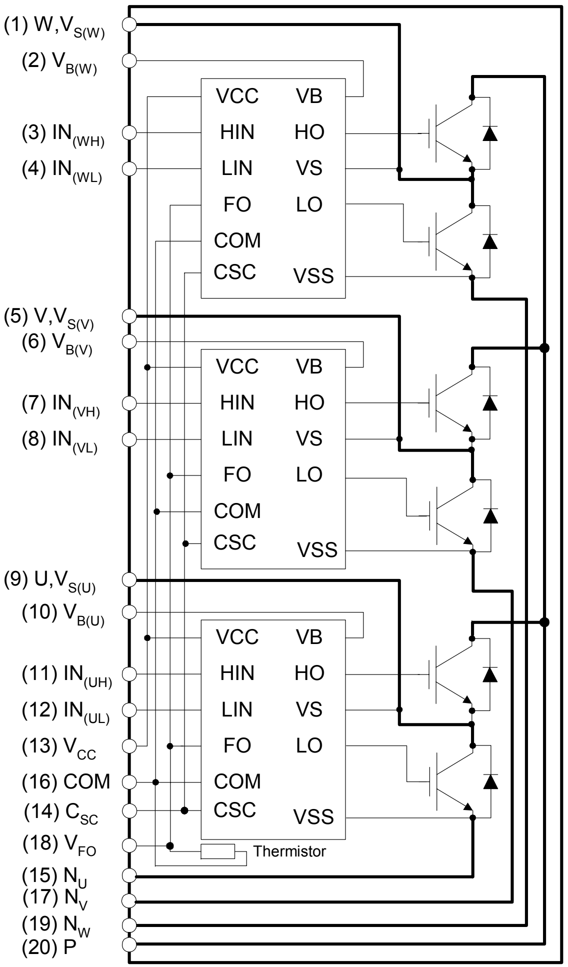


B option – 1N



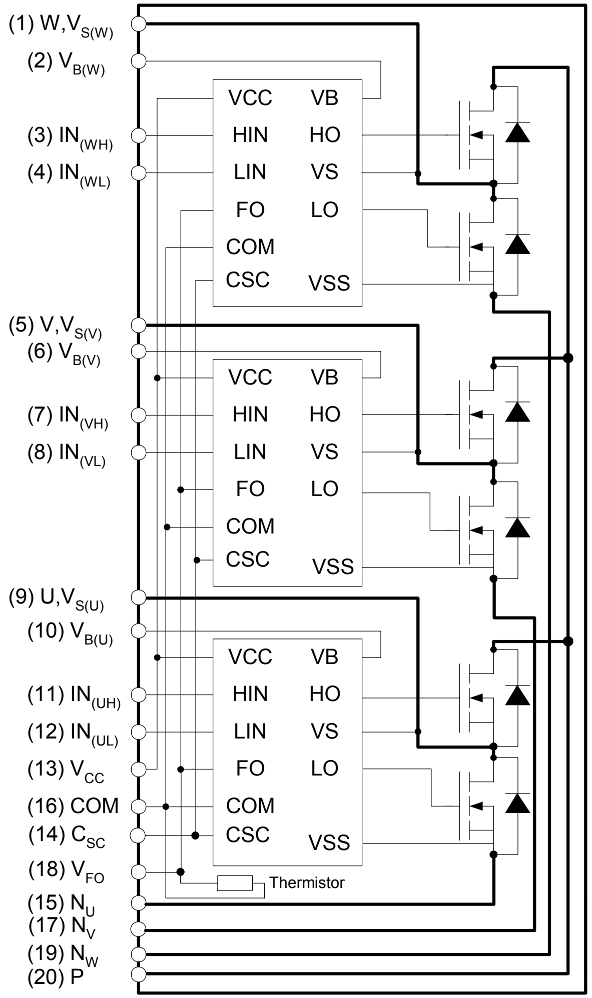
- **Line-up (under development) :**
- **- 600V/3A, 5A, 8A, 10A, 12A, 15A**
  1N / 3N terminal
- **Major Applications :**
  - **- Consumer appliance inverters**
    (Air conditioner, Washing machine, Refrigerator, Water pump, etc)
  - **- Low power industrial inverters**
    (Fan Motor, Industrial Inverter, etc)
- **Feature :**
  - **- Cross-Conduction Prevention Logic**
  - **- Large pin spacing and signal/power pins separation**
  - **- Single-In-Line package**
  - **- 3 N-terminals for low-cost current sensing**
  - **- Built-in thermistor**

Details of SPM4-SIP2



- Line-up **(under development)** :
  - 600V/3A, 5A, 8A, 10A, 12A, 15A
- Major Applications :
  - Consumer appliance inverters
    (Air conditioner, Washing machine, Refrigerator, Water pump, etc)
  - Low power industrial inverters
- Feature :
  - Single-In-Line package
  - 3 N-terminals for low-cost current sensing
  - Built-in thermistor

Details of MOSFET-SPM4-SIP2



- Line-up (under development) :
  - 500V / 5A(1.35Ω(typ.)), 6A(1.15Ω(typ)), 9A(0.8Ω(typ))
- Major Applications :
  - Low power consumer appliance inverters (Refrigerator, Fan)
- Feature :
  - 3phase MOSFET inverter
  - Single-In-Line package
  - 3 N-terminals for low-cost current sensing
  - Built-in thermistor

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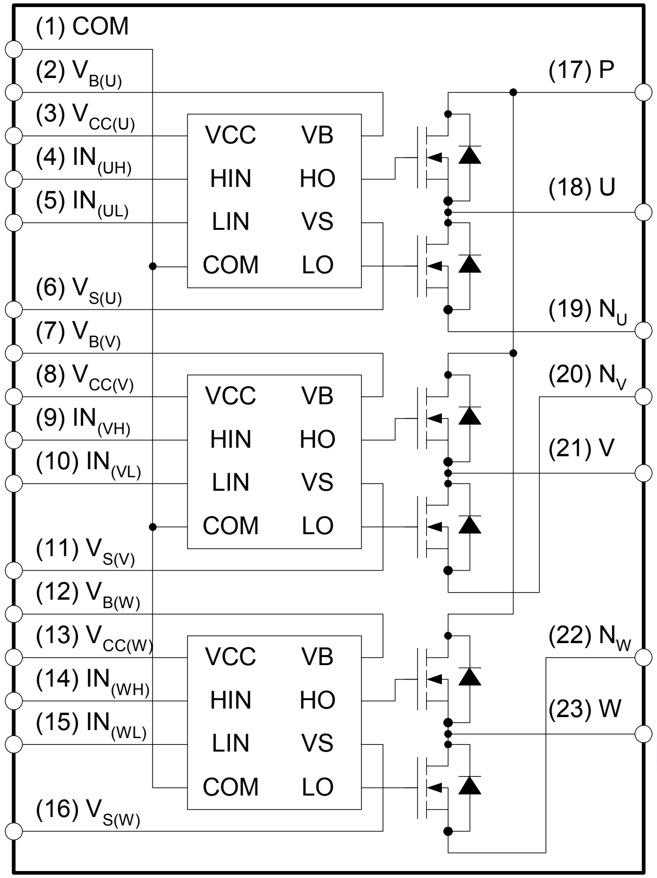
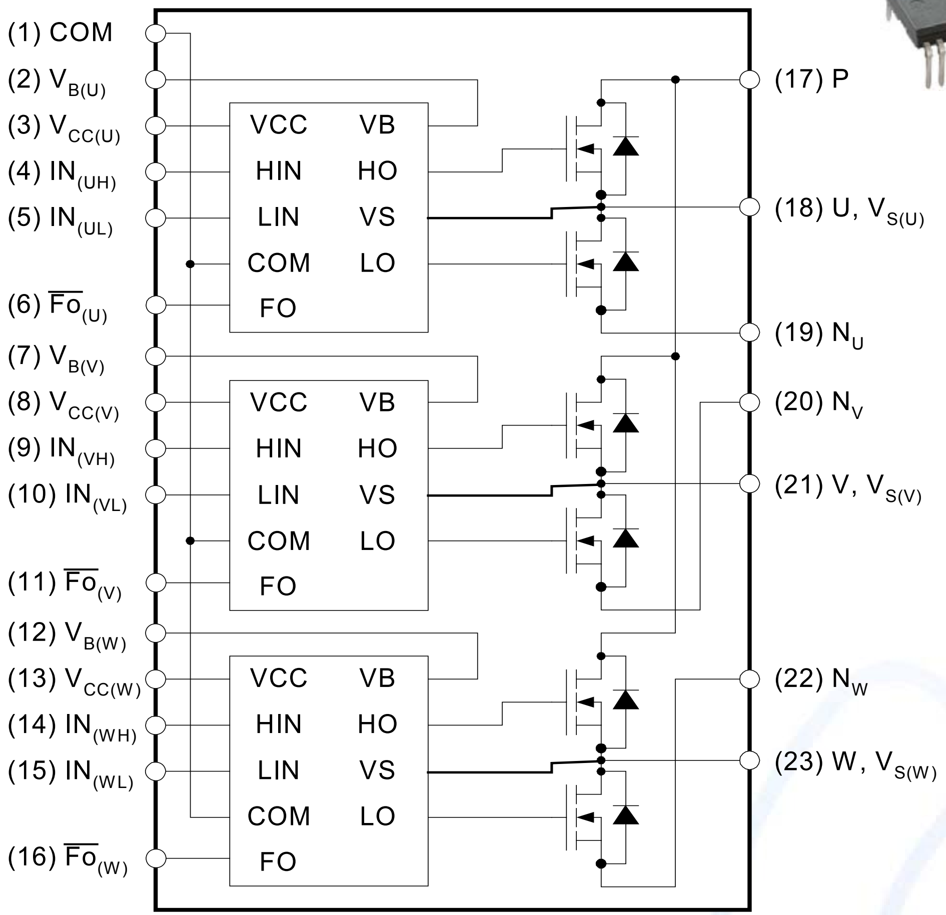
Details of SPM5 V1 Series



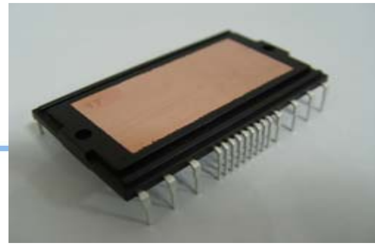
- **Line-up :**
  - **V1 SPM5 DIP: 500V 2A (3.3Ω(typ)), 3A(1.9Ω(typ)) & 250V 3A(1.4 Ω(typ))**
  - **V1 SPM5 SMD: 500V 2, 3A & 250V 3A (under development)**
  - **Transfer-molded full-pack package**
- **Major Applications :**
  - **Fan motor, water pump, etc.**
  - **Small motor applications up to 150W**
- **Feature :**
  - **High power density compared to small package**
  - **Ruggedness (Switching and short-circuit)**
  - **Low conducted and radiated EMI (Slow dV/dt & dI/dt)**
  - **HVIC with UVP**

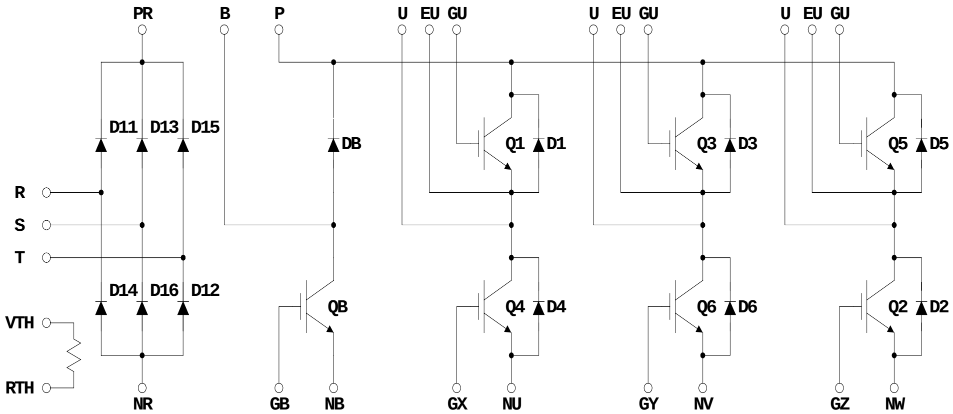
Details of SPM5 V2 Series



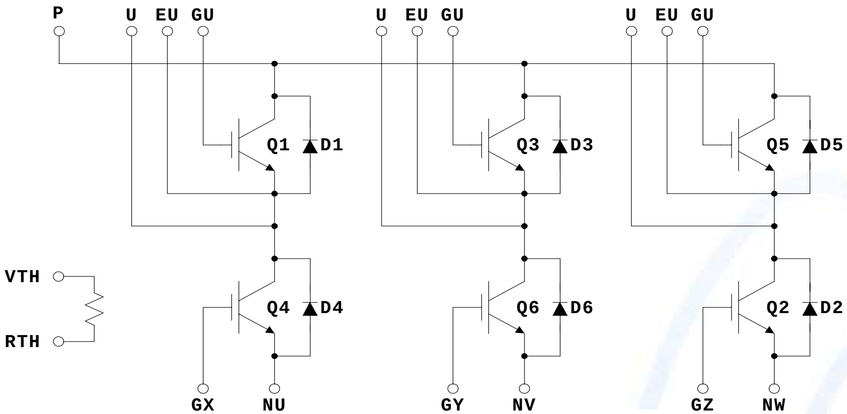
- **Line-up (under development)**
  - **V2 SPM5 DIP and SMD : 500V 2A (3.3Ω(typ)), 3A(1.9Ω(typ))**
    & 250V 3A(1.4 Ω(typ))
  - **LV-SPM5 DIP and SMD : 60V 40mΩ(typ)**
  - **Transfer-molded full-pack package with SMD**
- **Major Applications :**
  - **Fan motor, water pump, etc.**
  - **Small motor applications up to 150W**
- **Feature :**
  - **High power density compared to small package**
  - **Ruggedness (Switching and short-circuit)**
  - **Low conducted and radiated EMI**
    (Slow dV/dt & dI/dt)
  - **HVIC with UVP**

Details of CPM Series





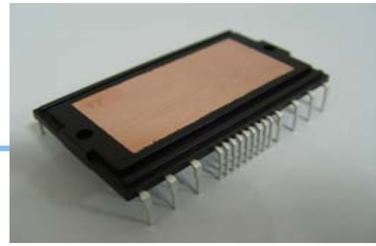
CPM CIB(1200V/25A)

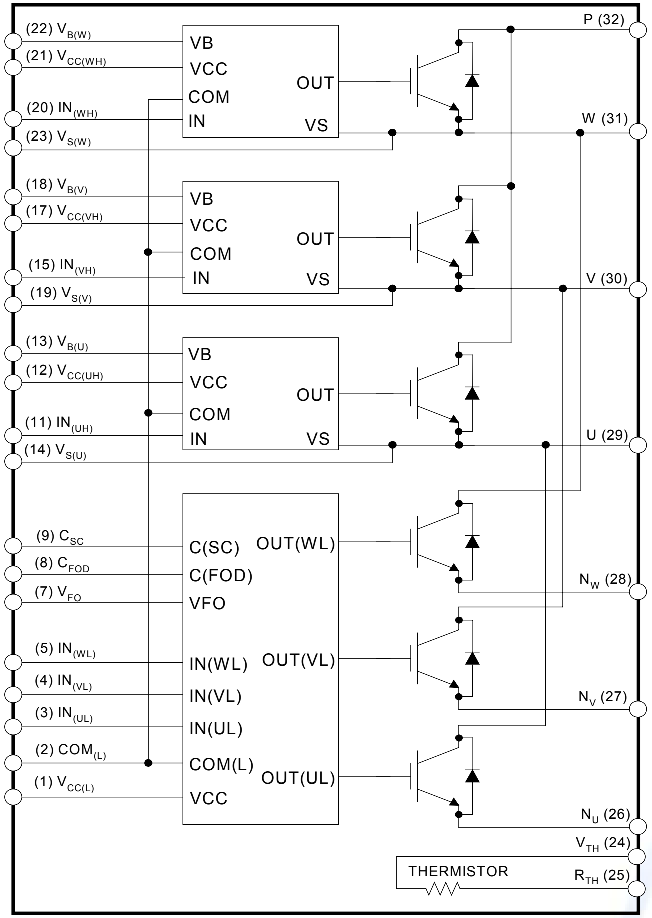


CPM Inv. (1200V-50A, 600V-75A/100A)

- **Line-up (Under Development) :**
  - **CPM CIB : 600V/30A, 50A**
    1200V/15A, 25A
  - **CPM Inverter : 600V 50A, 75A, 100A**
    1200V 25A, 35A, 50A
  - **Transfer-molded DBC package**
- **Major Applications :**
  - **Industrial Inverter, System A/C**
- **Feature :**
  - **High power density in a small package**
  - **3-phase Rectifier and IGBT inverter (CIB)**
  - **3-phase IGBT inverter (Inverter Only)**
  - **Built-in Thermistor for temperature sensing**
  - **Good thermal resistance**
  - **3 N-terminals for low-cost current sensing**
  - **Various other topologies may be considered on demand**

Details of SPM1 Series



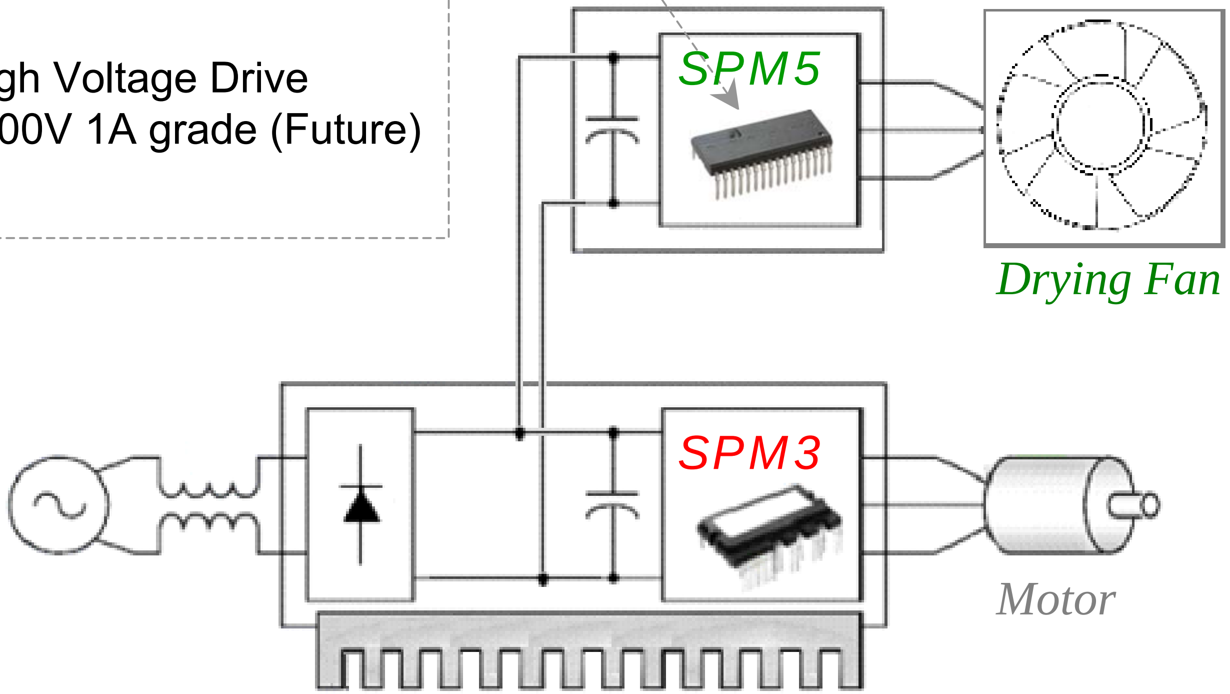


- **Line-up – SPM1 (under development) :**
  - **600V/50A, 75A, 100A**
  - **1200V/10A, 15A, 25A**
- **Major Applications :**
  - **Industrial Inverter, System A/C**
- **Feature :**
  - **High power density in a small package**
  - **3-phase IGBT inverter**
  - **Built-in Thermistor for temperature sensing**
  - **Good thermal resistance**
  - **3 N-terminals for low-cost current sensing**

Application Example - Washing Machines

* Low Voltage Drive
  under 40V (Currently)

* High Voltage Drive
  500V 1A grade (Future)



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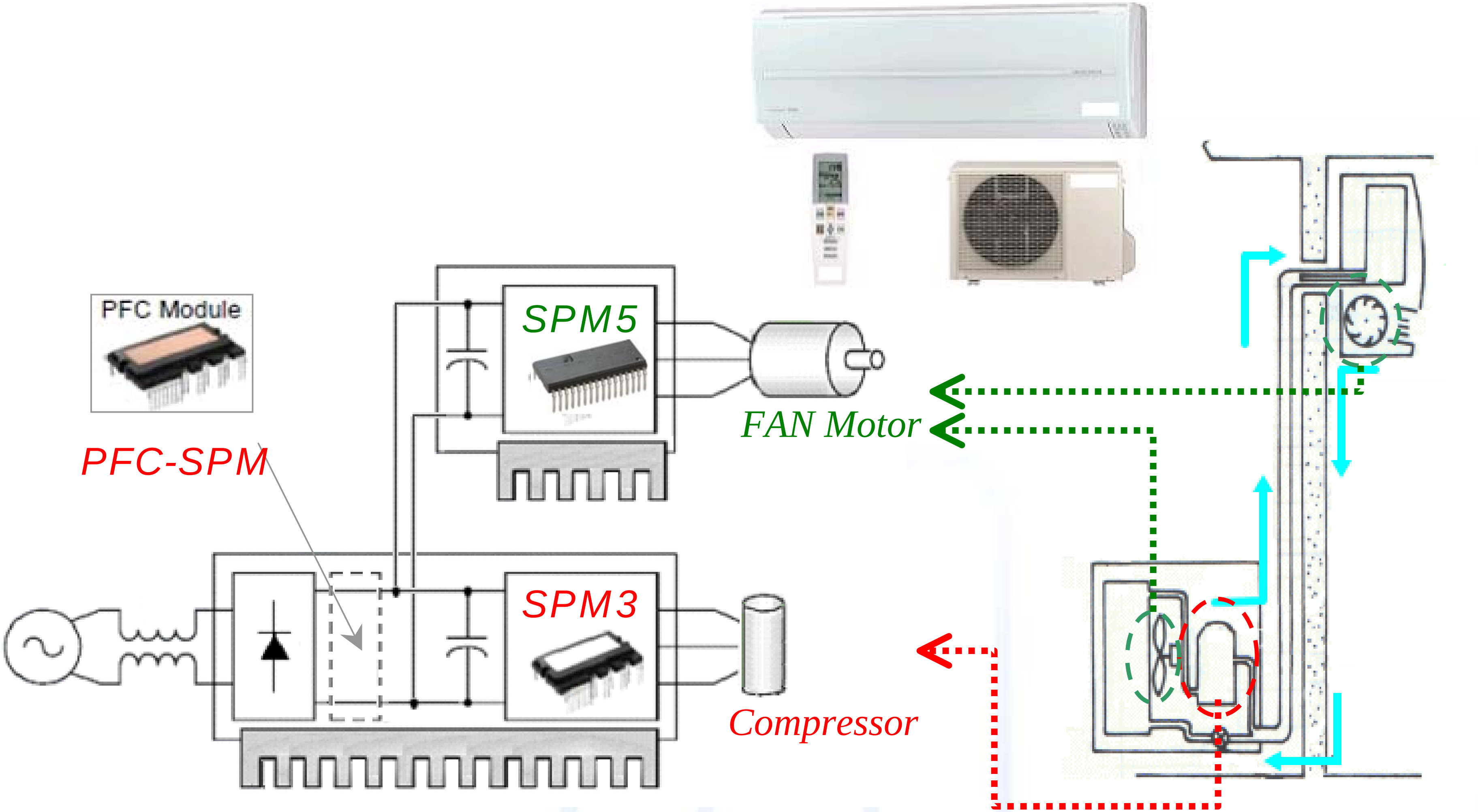
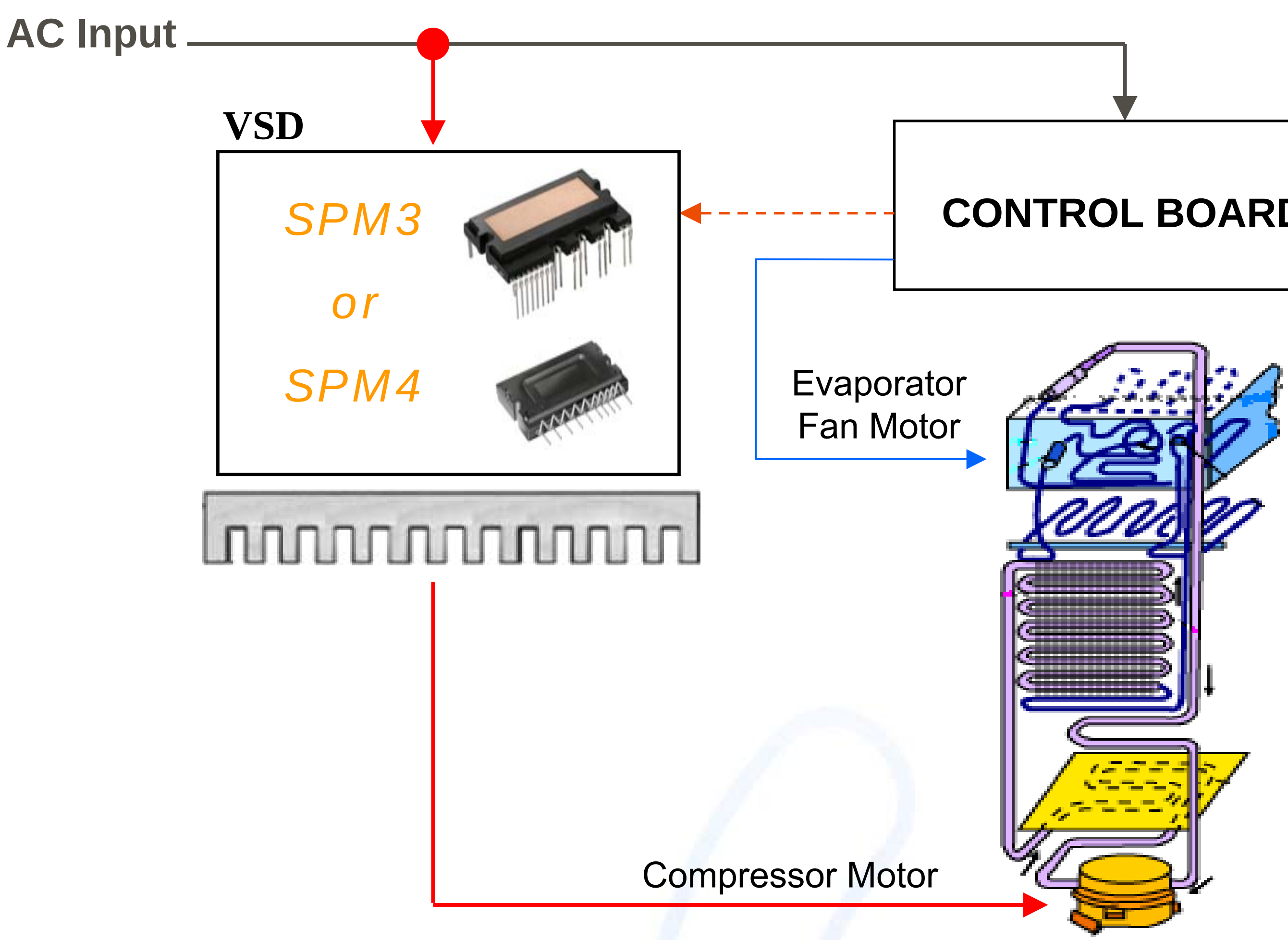
Application Example - Air Conditioners



Application Example - Refrigerators



Chapter 3. SPM Design Considerations

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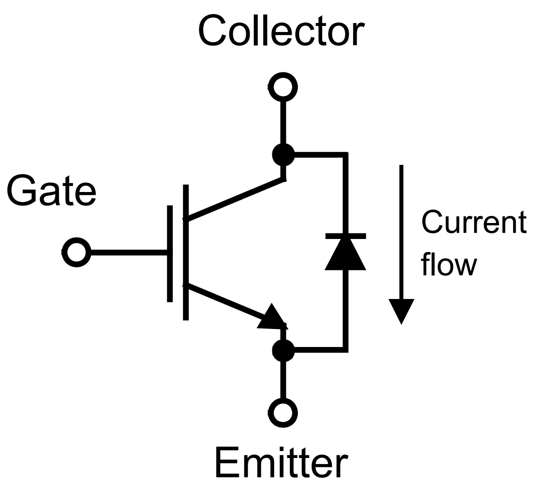
IGBT



- Insulated Gate Bipolar Transistor
- Voltage controlled
- Conducts current from collector to emitter when a positive voltage is applied from the gate to the emitter
- Modules include a free-wheeling diode (FWD)
- Fundamental Parameters
  - V_{CES} Collector-emitter voltage rating
  - I_C Collector current rating

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Key Parameters & Definitions

- $V_{CE(SAT)}$ – IGBT saturation voltage; On-state collector to emitter voltage drop while conducting current.
- $R_{TH(j\text{-}c)}$ – Thermal resistance; Specifies the resistance to heat flow from chip to base plate(Junction to Case).
- $E_{SW(on)}$ – Turn-on switching energy; Energy dissipated during turn-on.
- $E_{SW(off)}$ – turn-off switching energy; Energy dissipated during turn-off.
- Total Loss – (Watts) = (conduction losses + switching losses)

  = (duty factor* $V_{CE(SAT)}$ * I_C) + (($E_{SW(on)}$ + $E_{SW(off)}$) * frequency).

  The total power dissipated in the device.

  Used to determine heat sink size and junction temperature rise.

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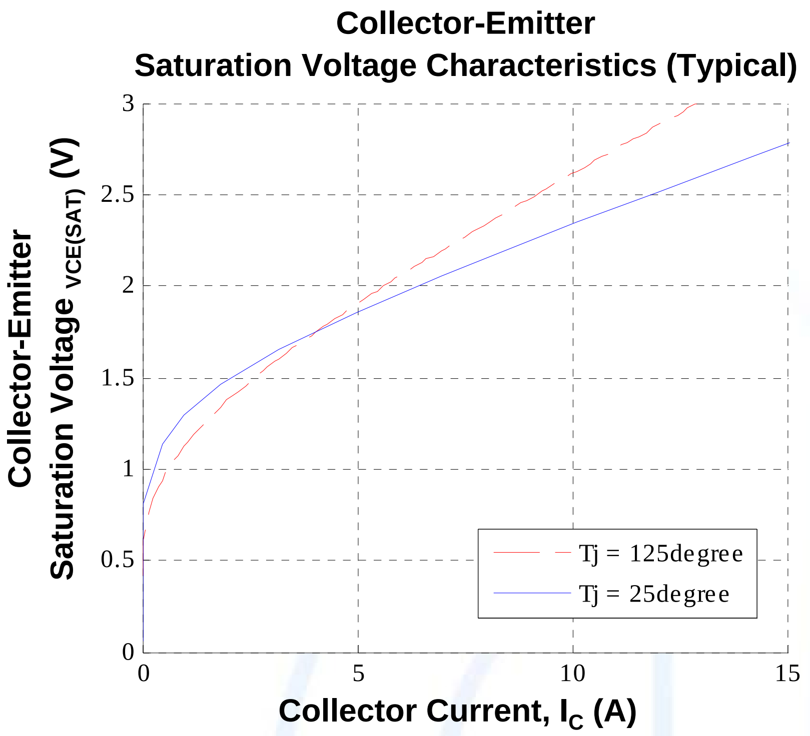
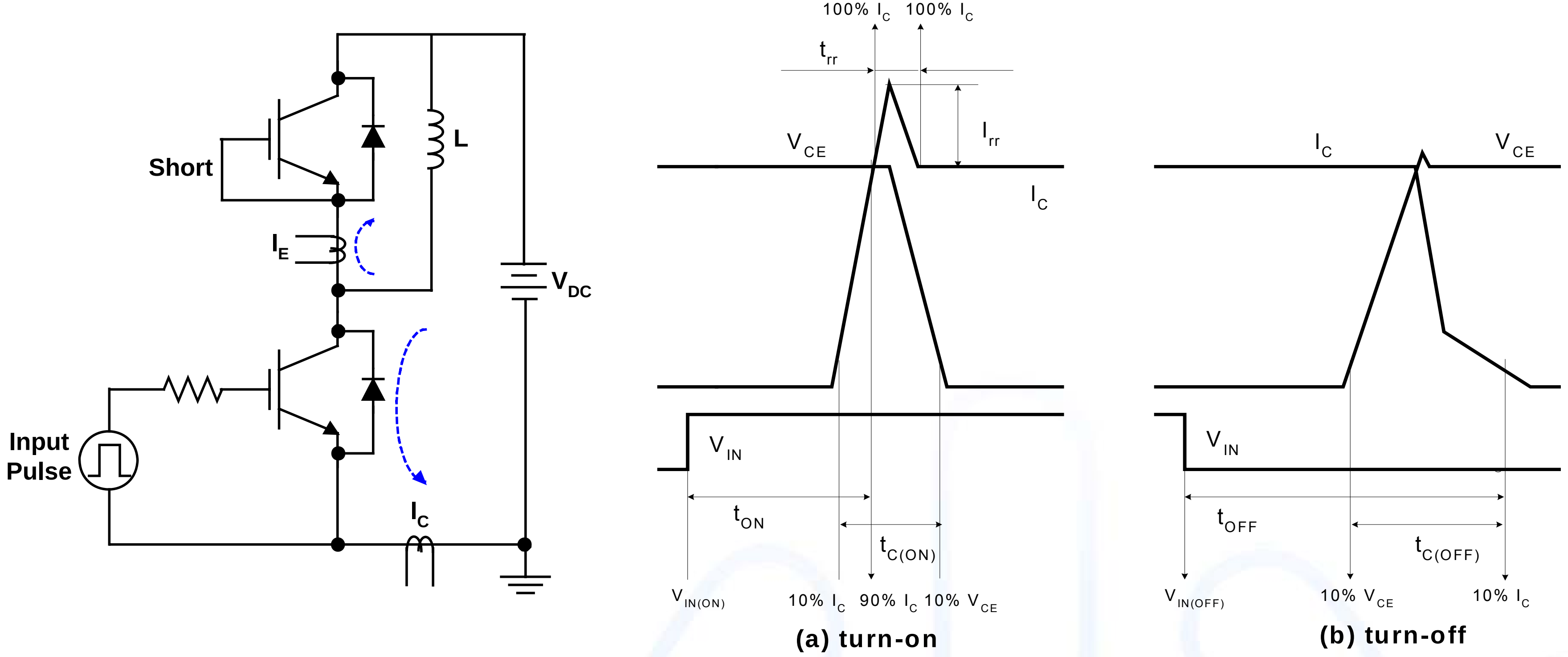
$V_{CE(SAT)}$ Specification

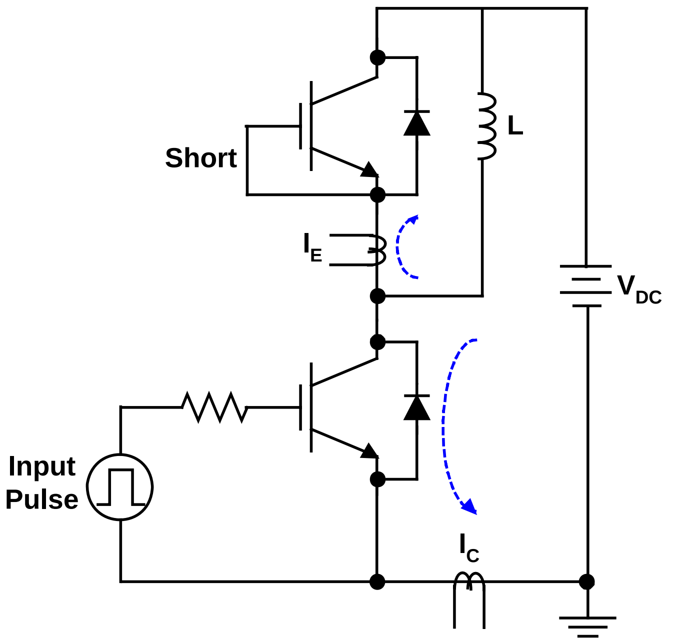
Characteristics	Symbol	Test Conditions	Min.	Typ.	Max.	Units
Collector–Emitter Saturation Voltage	$V_{CE(SAT)}$	V_{CC} = V_{BS} = 15V, V_{IN} = 5V I_C =20A, T_J = 25°C	–	–	2.3	V

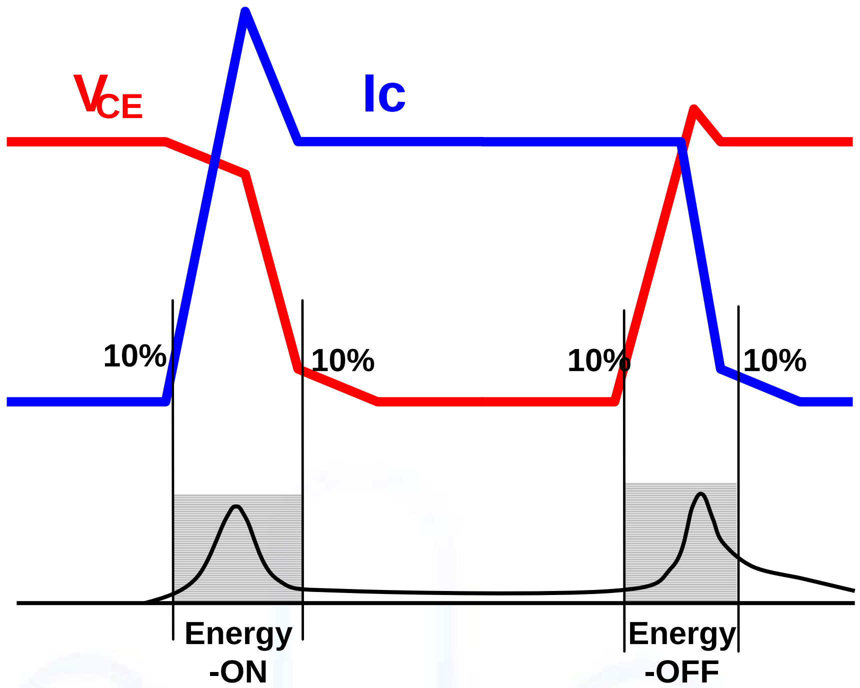


Switching Time



Switching Energy (E_{SW})





Turn-on and Turn-off Switching Losses

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Nameplate Current Rating

Is the rating that is used in the device part number.
For example, the nameplate rating of FSBS10CH60 is 10A.

Many manufactures use a so called “i_{DC}” rating for their nameplate. An i_{DC} rating is the DC current that will cause the IGBT chip junction temperature to reach Tj(max) with the module’s base plate held at a constant arbitrary temperature Tc.

The i_{DC} “rated” current can be computed from:

$$i_{DC} = [T_j(max) – T_c] / [V_{ce}(@i_T) \times R_{TH(j-c)}]$$

Where:
i_{DC} = DC current rating
Vce(@iT) = Collector to emitter Voltage at i_T
Tj(max) = Maximum junction temperature
R_{TH}(j-c) = Junction to case thermal impedance
Tc = Arbitrarily selected case temperature

The current rating (i_{DC}) depends on the following:

- Selection of Tc - Lower Tc gives higher i_{DC} rating
- Selection of Tj(max) - Some manufacturers use a conservative 125C while others use 150C. Higher Tj(max) gives higher i_{DC} rating
- Measurement method for R_{TH}(j-c) - Using the under chip method gives lower thermal impedance and higher i_{DC} rating

Nameplate Current Rating

Fairchild does not use i_{DC} ratings as a basis for nameplate current ratings.
However many manufacturers use this method for rating their modules.
Please see the following table for examples of how these ratings can be misleading.

Comments on i_{DC} ratings :

- i_{DC} ratings are generally useless for device selection
  (These ratings consider DC loss only and ignore switching losses and SOA)
- i_{DC} ratings are generally useless for comparing devices from different manufacturers
  (Rating is influenced by selection of Tc, Tj(max) and thermal impedance measurement point)

To properly select a device you should consider:

- On State Conduction (DC) Losses
- Switching Losses
- Thermal Impedance R_{TH}(j-c)
- Available heat sink/cooling method
- Maximum ambient temperature
- Turn-off switching SOA
- Free Wheel Diode Utilization

IGBT Module i_T Rating Comparison

Module with Nameplate rating 75A, 1200V	Maximum Vce(sat) (V) Ic=75A Tj=125C	Maximum Rth(j-c)(C/W) Tc under Chip	i_T(A) Tj(max)=150C Tc=25C	i_T(A) Tj(max)=150C Tc=80C
Brand A	2.5	0.22	**168**	**112**
Brand B	4.0	0.2	**124**	**84**
Brand C	3.1	0.21	**147**	**98**
Brand D	3.6	0.27	**107**	**73**
Brand F	3.0	0.25	**130**	**88**
Brand A (50A)	2.9	0.31	**115**	**75**

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Key Points 1

- When comparing devices, the specific electrical characteristics (Vce(sat), Esw(on&off), **Rth**) must be evaluated. → **At Actual Operating Conditions** !!
- These parameters must be compared under the same test conditions, as most manufacturers spec these under varying conditions.
- These can usually be obtained from the data sheet values or performance curves.
- When comparing thermal impedance the case temperature (Tc) measurement point is very important.
- An under chip measurement point yields a considerably lower value for thermal impedance than the edge of base plate value for Rth.

Key Points 2

- <u>There are different methods to calculate power losses</u>.
- One method uses a basic/general formula to estimate total loss.
- The sinusoidal loss calculation provides a more realistic value for total inverter loss.
- Both are intended for comparison purposes only.
- <u>Actual loss values are dependant on the specific application.</u>
- ΔTj is found by multiplying losses and Rth.
- The change in junction temperature helps in determining which device runs cooler.
- Of course the lower the ΔTj the more reliable the system or the less heat sinking is required.

Power Loss Calculation !!
ΔTj Calculation !!

FAIRCHILD SEMICONDUCTOR

Loss and Allowable Tc - Example

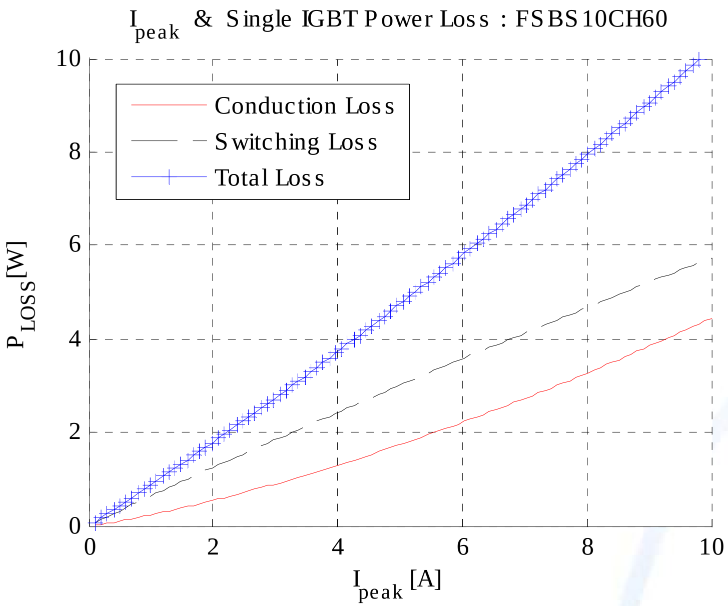
Device : FSBS10CH60

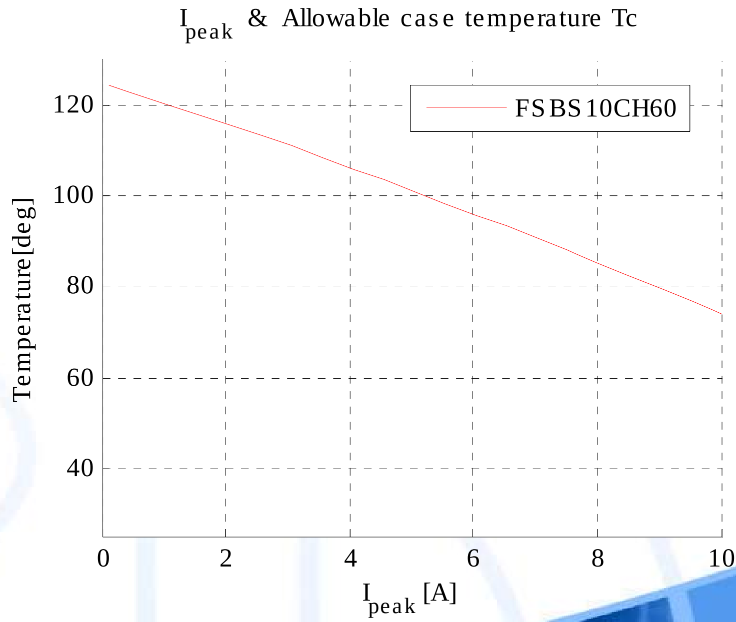
Vdc = 300V, Vcc = Vbs = 15V, Fsw = 15kHz,

Output Current Frequency >= 60Hz, Rth(j-c) = max,

3-phase Sine-PWM, Power Factor = 0.95, Modulation Index = 0.8

$V_{CE(sat)}$ = Typical, Switching loss = Typical, Tj = 125°C





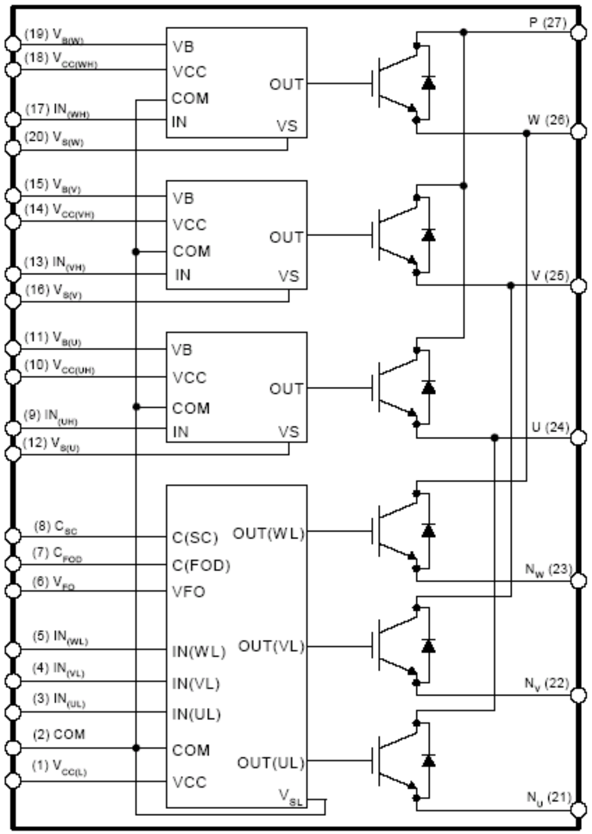
Structure

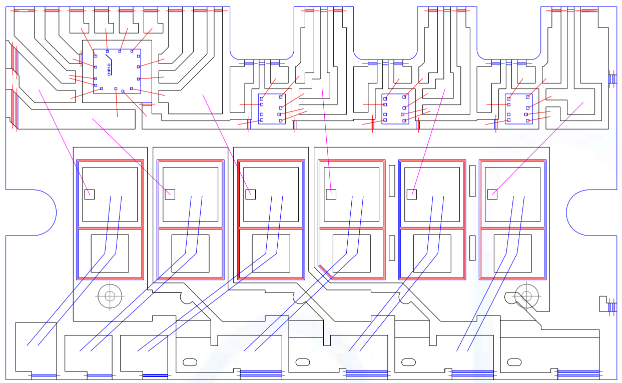
<u>SPM = Power device + Driver IC + Package</u> → **Performance & Protection & Reliability**

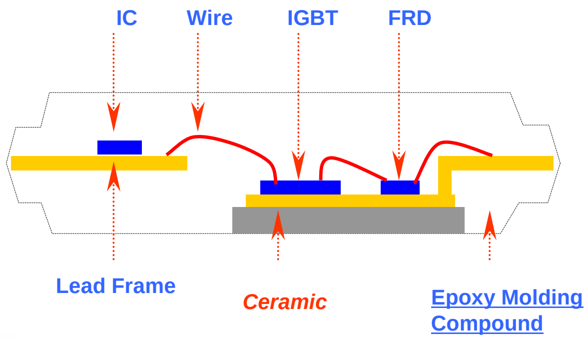
Power device = IGBT with FRD (or MOSFET)

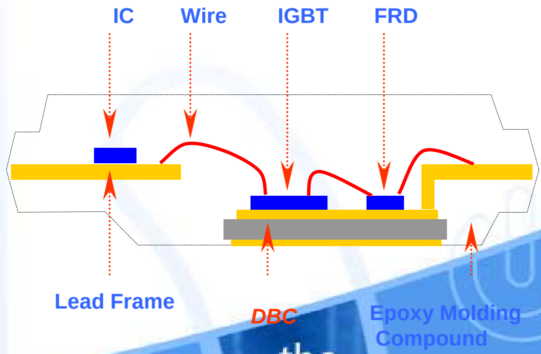
Driver IC = HVIC & LVIC

Package = Transfer Molding with Ceramic or DBC









Performance

Target :

Low conduction/switching loss

Long short-circuit withstand time

Low switching noise

IGBT Trade-offs:

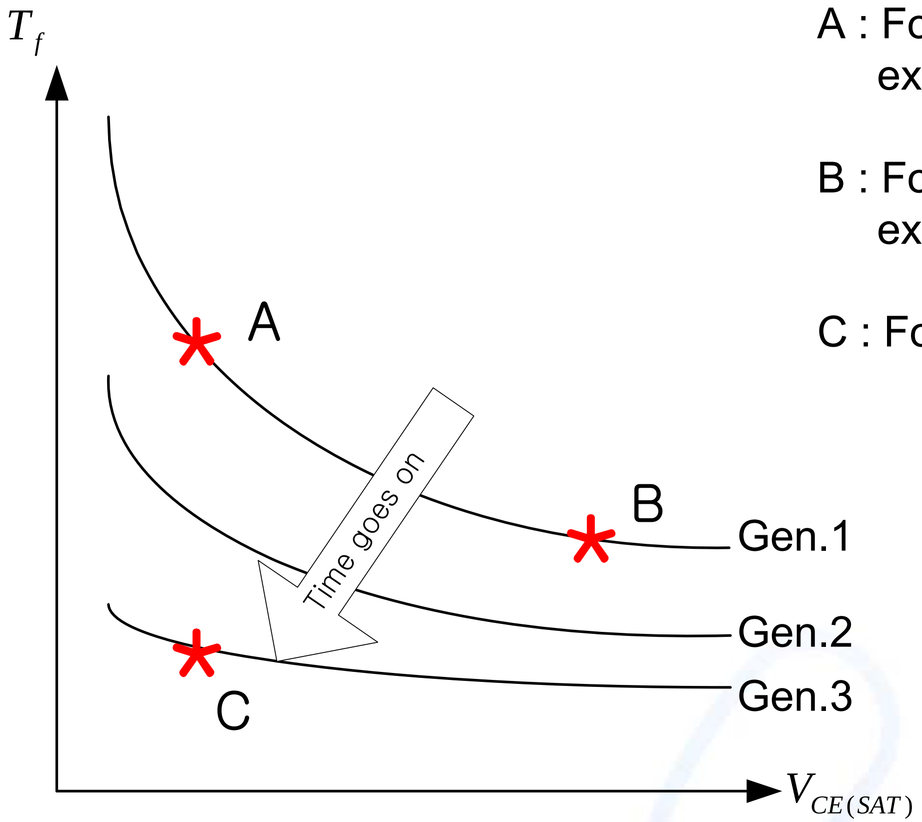
Low conduction loss ↔ low OFF-switching loss

Low conduction loss ↔ long short-circuit withstand time

System Design Trade-offs

Low switching noise ↔ low ON-switching loss

Performance

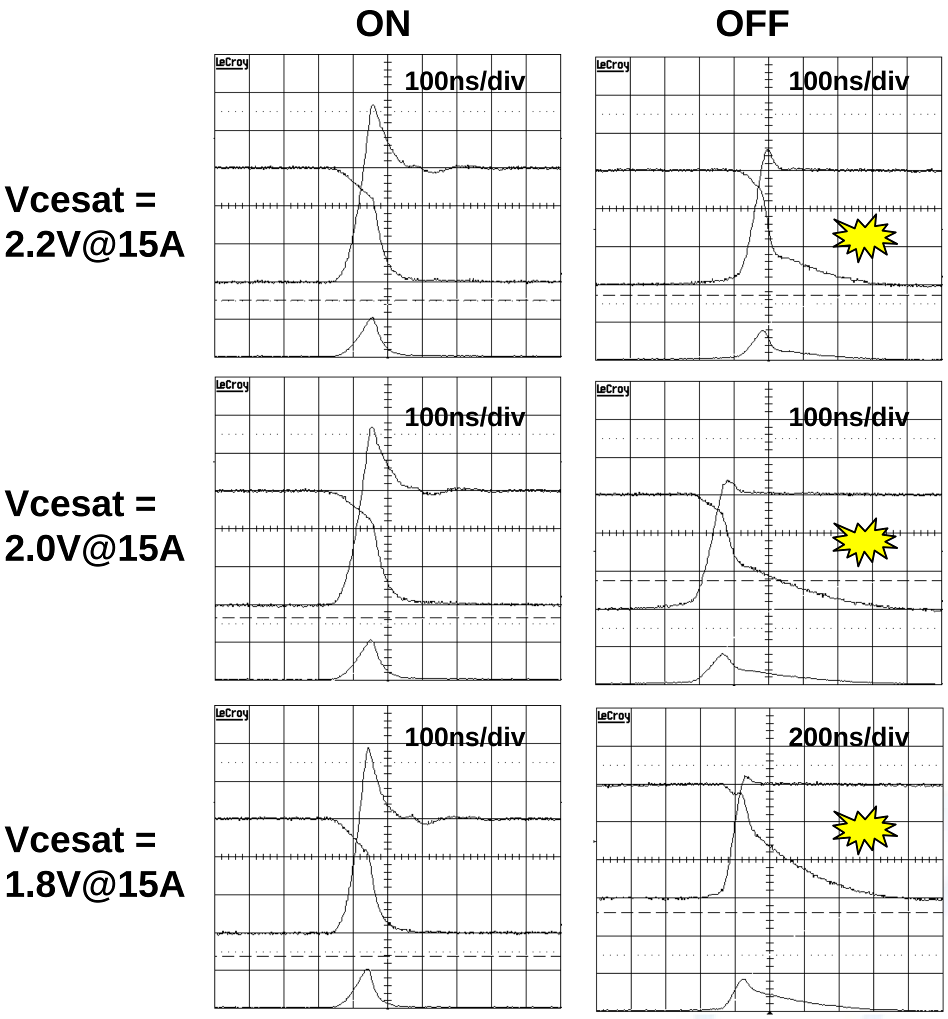


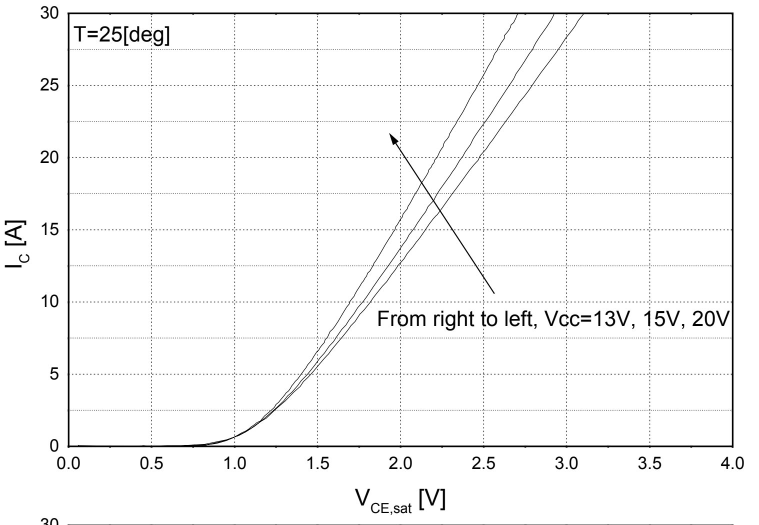
A : For low switching frequency applications
example. Air conditioner (fsw = 5KHz)

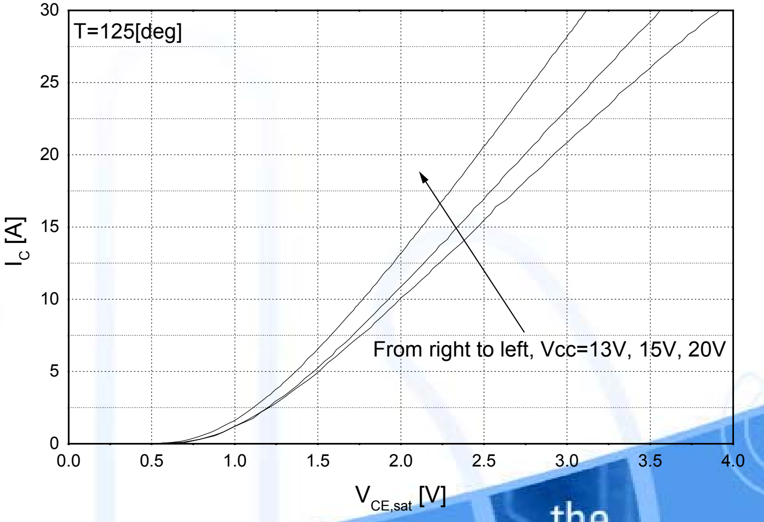
B : For high switching frequency applications
example. Washing machine (fsw = 15KHz)

C : For all applications

IGBT $V_{ce(sat)}$ (on-drop voltage) : Trade-off with T_f

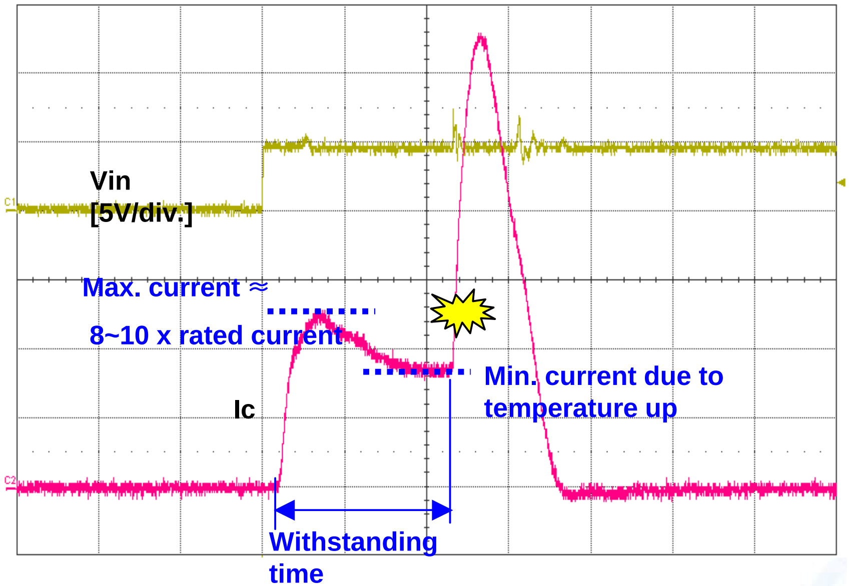


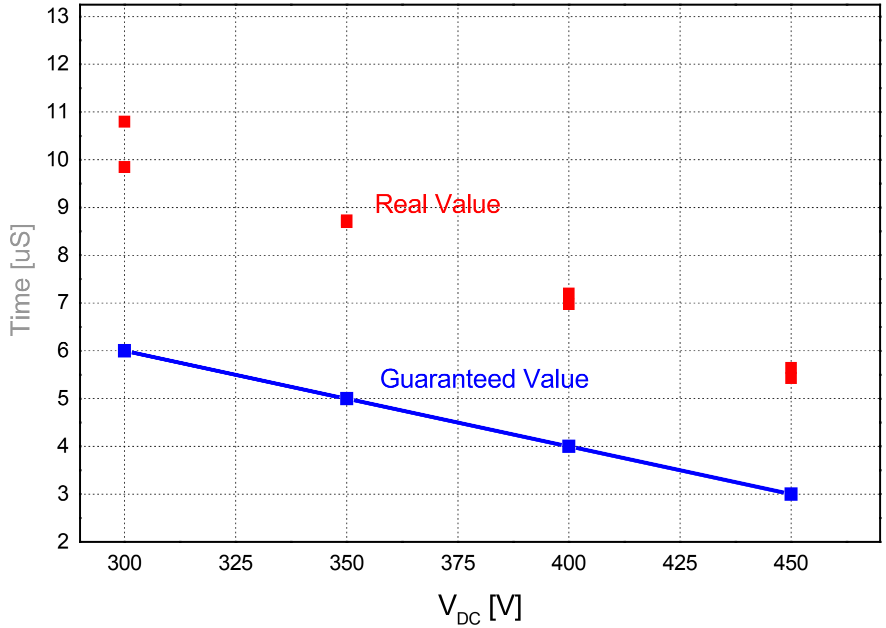




IGBT Short-circuit Endurance

- Worst case : High Vcc (High Ic), High Vdc

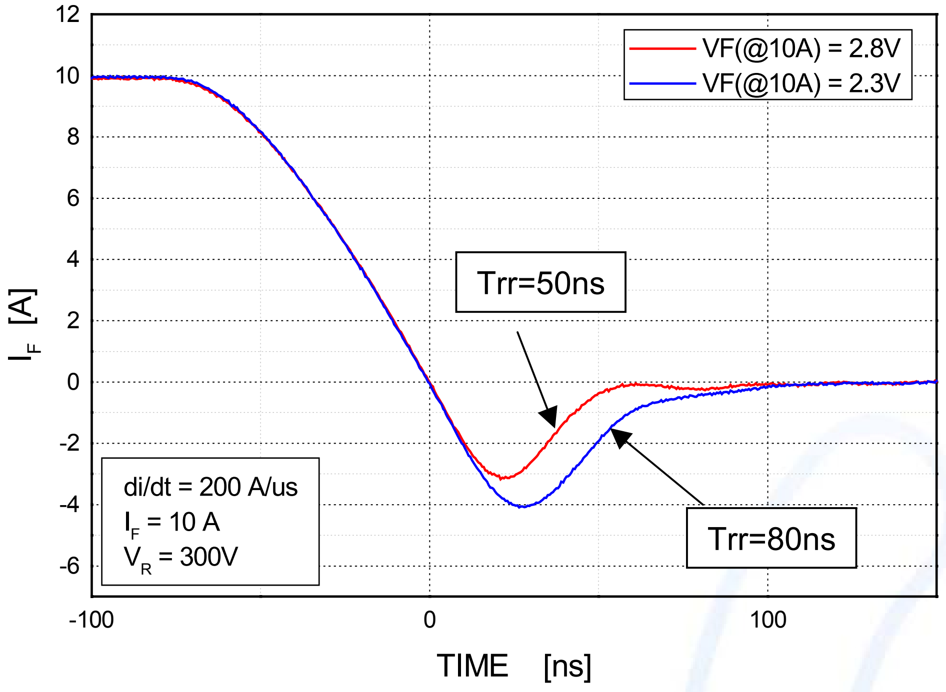


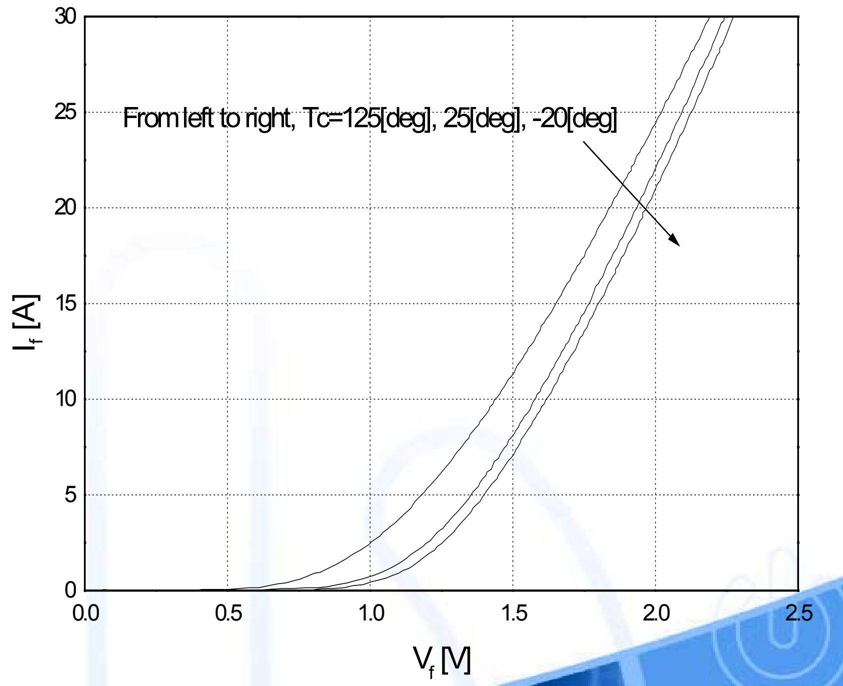


* **Test conditions:** **Worst, Vcc=20V, Tc=125℃**

Diode

- Fast Recovery Diode
- Small I_{rr} and T_{rr} and soft recovery (tb/ta) →Low loss and good dv/dt
- Trade-off between V_f and T_{rr}

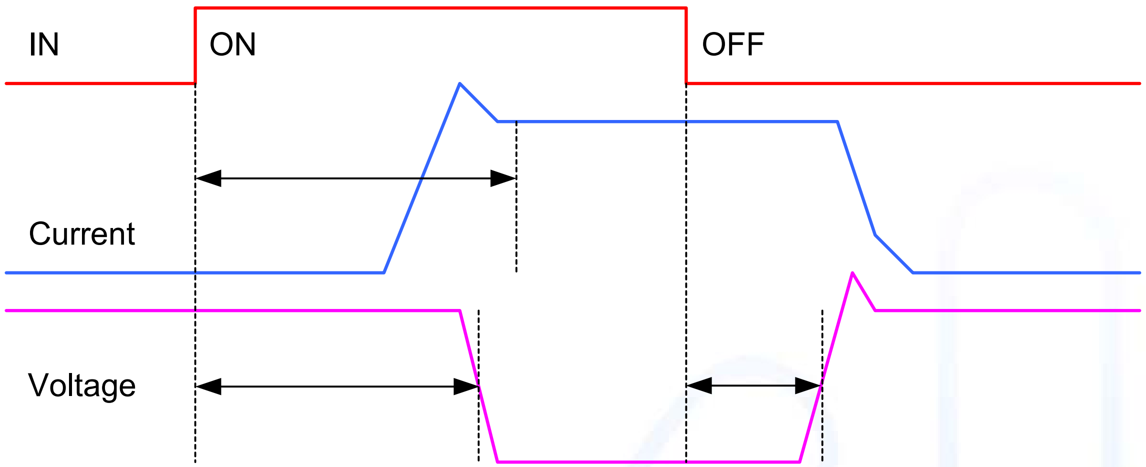




Switching Parameters

1. Current Measuring using shunt resistor
→ Key time : ON command to current build-up

2. Voltage Generation for sensorless control
→ Key time : ON command to 50% voltage transient
→ Key time : OFF command to 50% voltage transient



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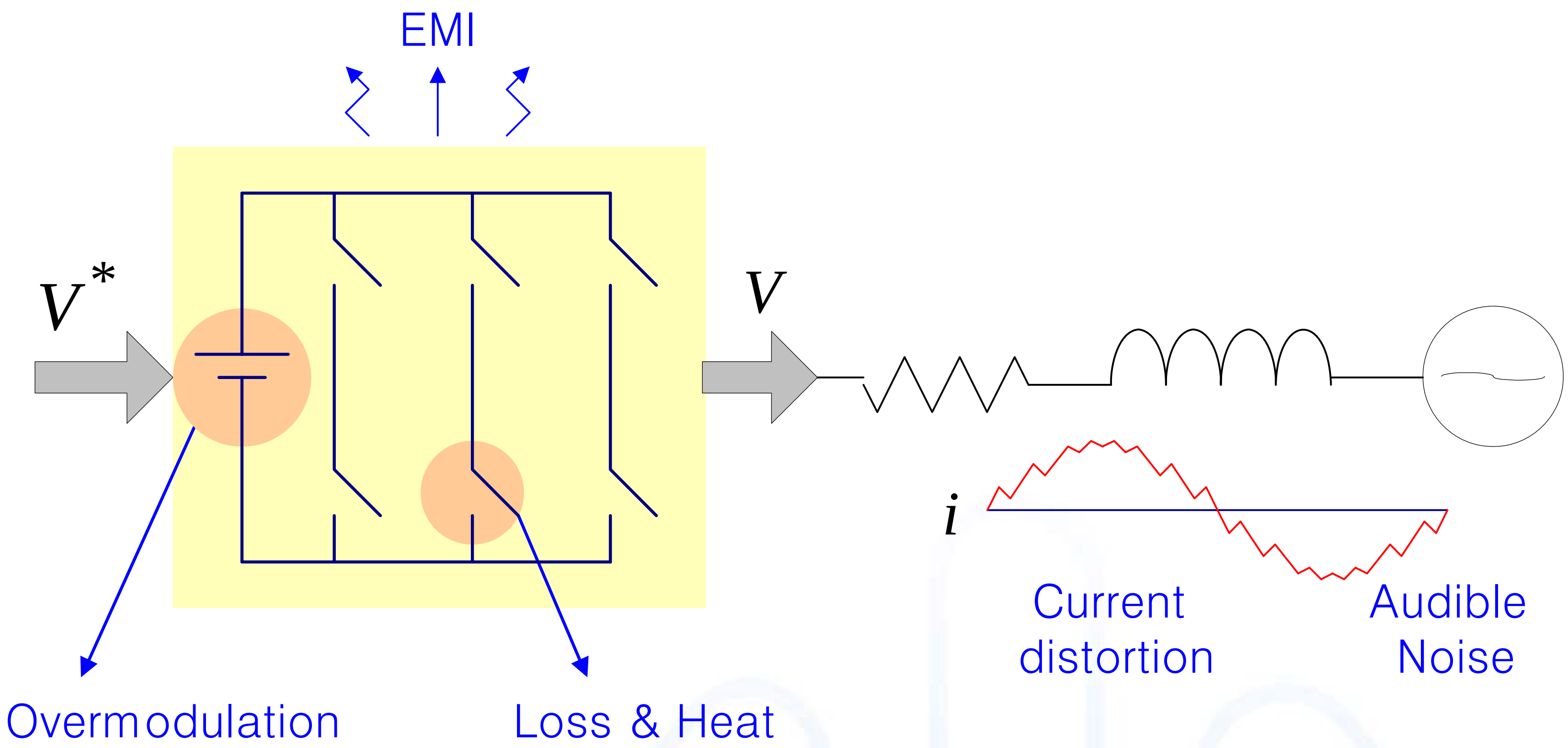
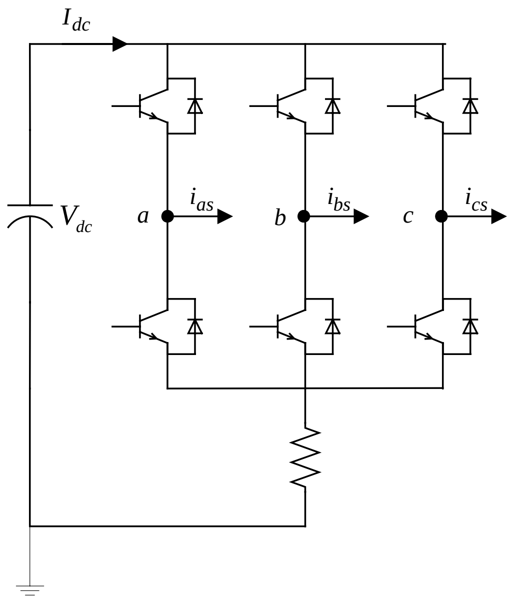
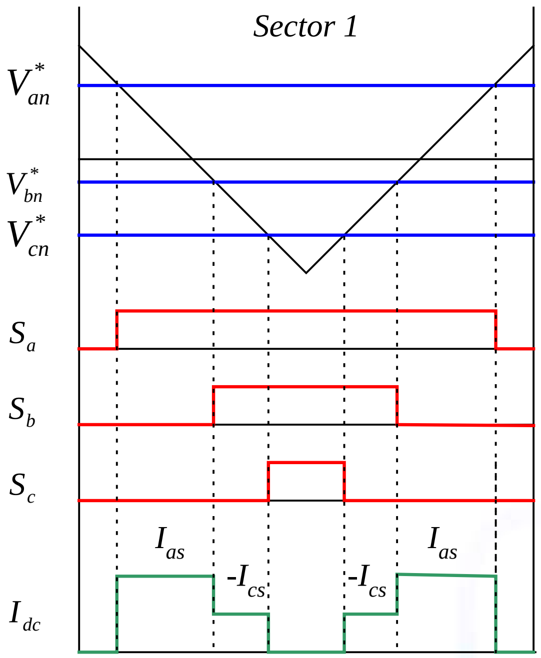
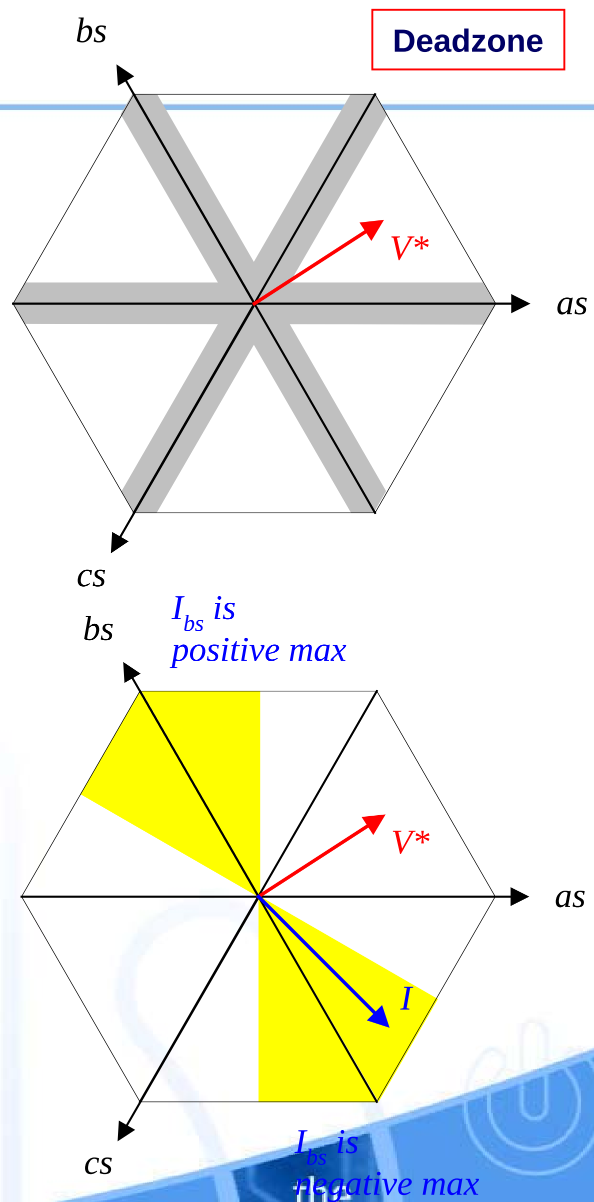
PWM Considerations



Current Measurement

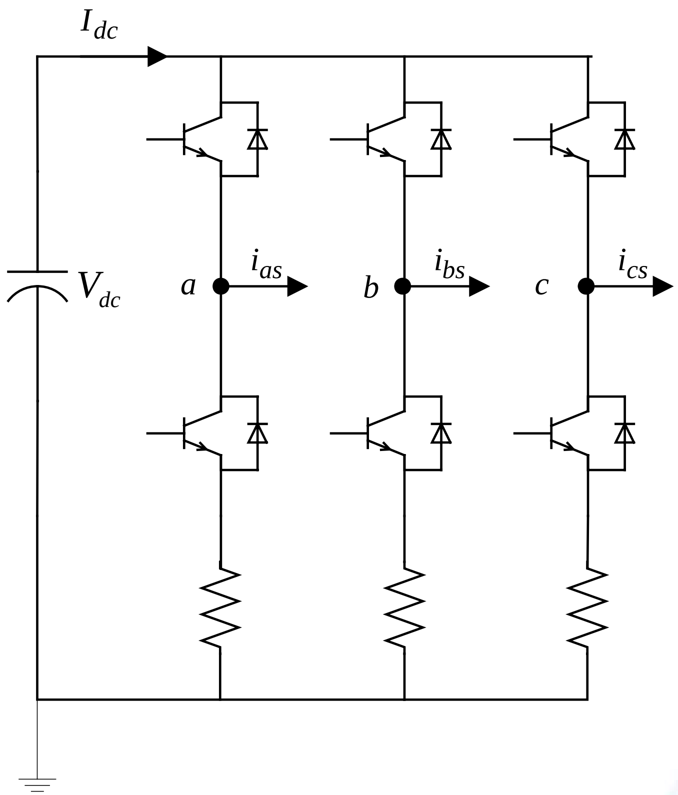






Low cost & simple to detect over-current
Idc = 0 in zero-vector period
Phase-current detection in effective-vector period
→ complex
→ impossible when voltage gets small esp. at high Fsw

Current Measurement



Phase-current = voltage drop on resistor when low-side IGBT is turn-on

Complex to detect over-current

FAIRCHILD SEMICONDUCTOR

Loss Calculation

- **SPM Loses = Conduction + Switching + Leakage (negligible)**
- **Conduction Loss = almost same for all kinds of PWM methods**
- **Switching Loss = 66% in case of discontinuous PWM**
- **Leakage Loss = negligible**

- **by Linear Approximation,**

$$v_T = V_T + R_T \times i\,[V]$$

$$v_D = V_D + R_D \times i\,[V]$$

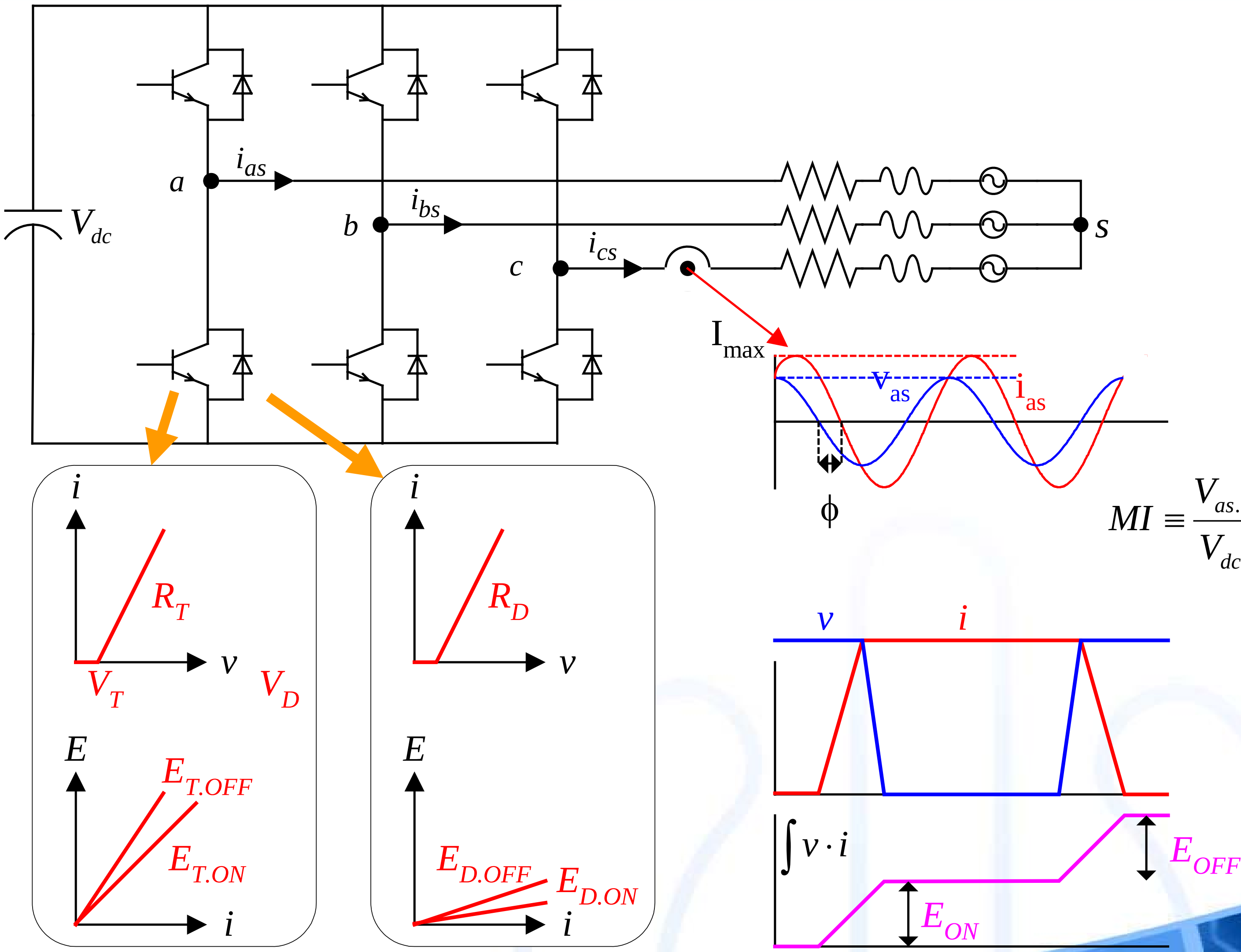
$$IGBT\ On\ loss\ energy = E_{T.ON} \times \mathrm{i}\ [J]$$

$$IGBT\ Off\ loss\ energy = E_{T.OFF} \times \mathrm{i}\ [J]$$

$$diode\ \ On\ loss\ energy = E_{D.ON} \times \mathrm{i}\ [J]$$

$$diode\ \ Off\ loss\ energy = E_{D.OFF} \times \mathrm{i}\ [J]$$

Loss Calculation



$$MI \equiv \frac{V_{as.peak}}{V_{dc}/2}$$

Loss Calculation

losses[W] in one IGBT and one diode are as below in case of continuous PWMs. Total SPM losses are six fold.

$$P_{con.T} = \frac{I_{\max}}{2\pi} V_T + \frac{I_{\max}}{8} V_T MI \cos\phi + \frac{I_{\max}^2}{8} R_T + \frac{I_{\max}^2}{3\pi} R_T MI \cos\phi$$

$$P_{con.D} = \frac{I_{\max}}{2\pi} V_D - \frac{I_{\max}}{8} V_D MI \cos\phi + \frac{I_{\max}^2}{8} R_D - \frac{I_{\max}^2}{3\pi} R_D MI \cos\phi$$

$$P_{sw.T} = \frac{(\mathrm{E}_{\mathrm{T.ON}} + \mathrm{E}_{\mathrm{T.OFF}}) f_{sw} I_{\max}}{\pi}$$

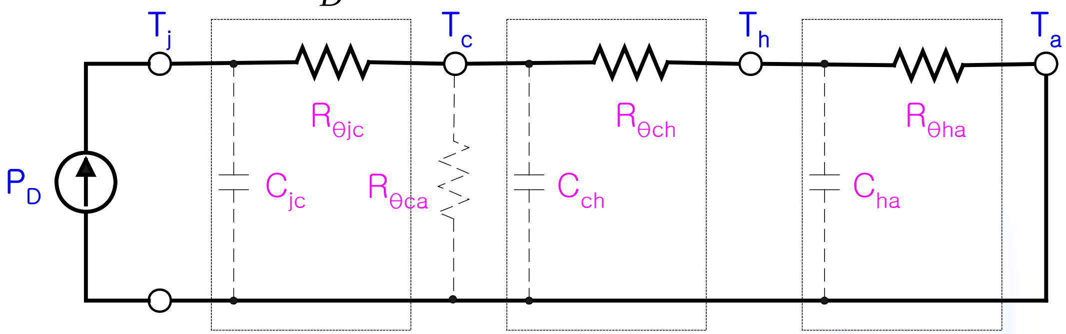
$$P_{sw.D} = \frac{(\mathrm{E}_{\mathrm{D.ON}} + \mathrm{E}_{\mathrm{D.OFF}}) f_{sw} I_{\max}}{\pi}$$

FAIRCHILD SEMICONDUCTOR

Tj Calculation

- Thermal Equivalent Circuit
  - Tj : Junction temperature. Can't be over guaranteed value.
  - Rθjc : Thermal resistance (junction to case) [deg/W]
  - Zθjc : Thermal impedance (junction to case) [deg/W]

$$R_{\theta jc} = \frac{T_j - T_c}{P_D}$$



Only Rθjc

Thermal Resistance

Symbol	Parameter	Condition	Min.	Typ.	Max.	Units
$R_{th(j-c)Q}$	Junction to Case Thermal Resistance	Inverter IGBT part (per 1/6 module)	-	-	1.63	°C/W
$R_{th(j-c)F}$		Inverter FWD part (per 1/6 module)	-	-	2.55	°C/W

Note:

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

Tj Calculation

⦿Tj Calculation with Rθjc

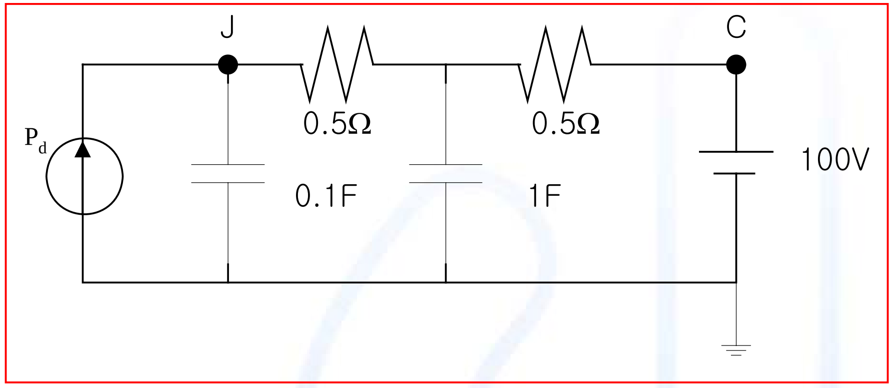
Tc = measured value, Rθjc = max value from datasheet, Pd = calculated value

$$T_j = T_c + R_{\theta jc} \cdot P_D$$

Ex) Tc=100°C when Pd=10W is consumed with Rθjc=1deg/W,

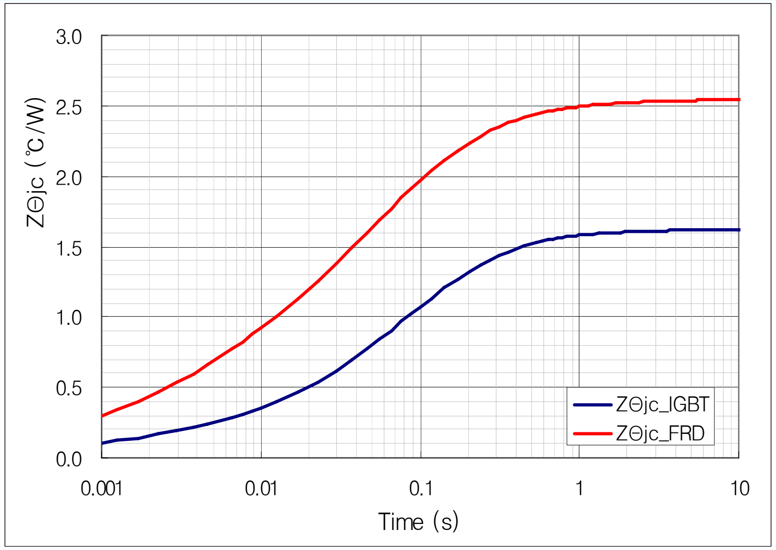
$$T_j = T_c + R_{\theta jc} \cdot P_D = 110^{\circ} C$$

←Average junction temperature using average Pd and steady-state thermal impedance

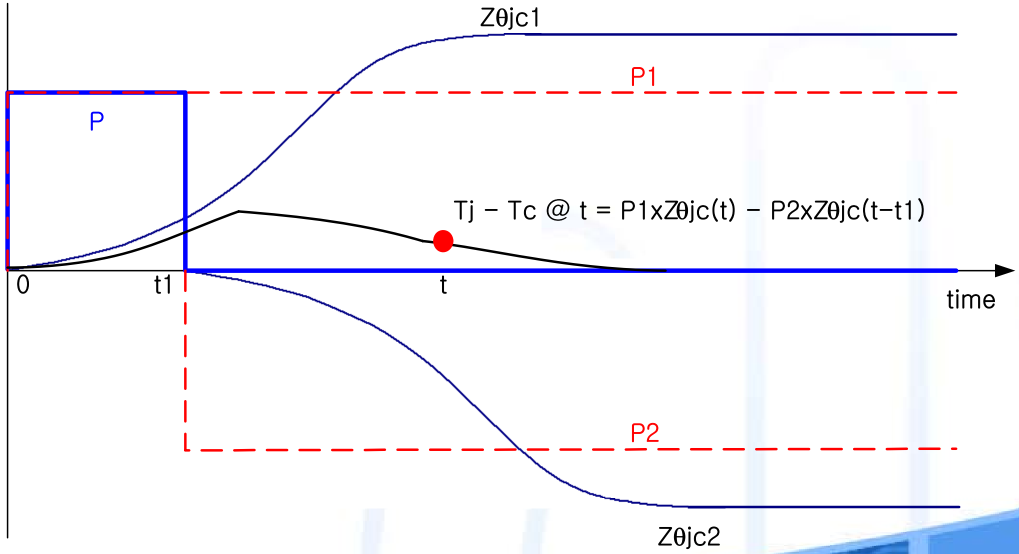


Tj Calculation

Confidential

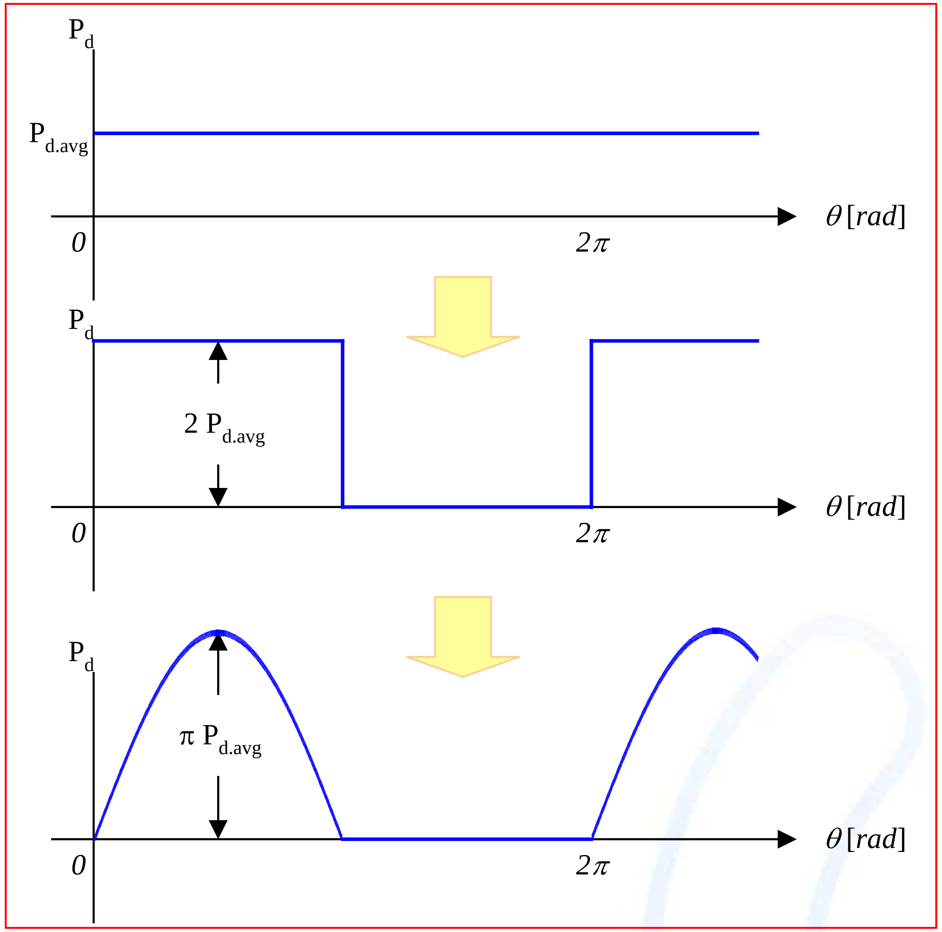


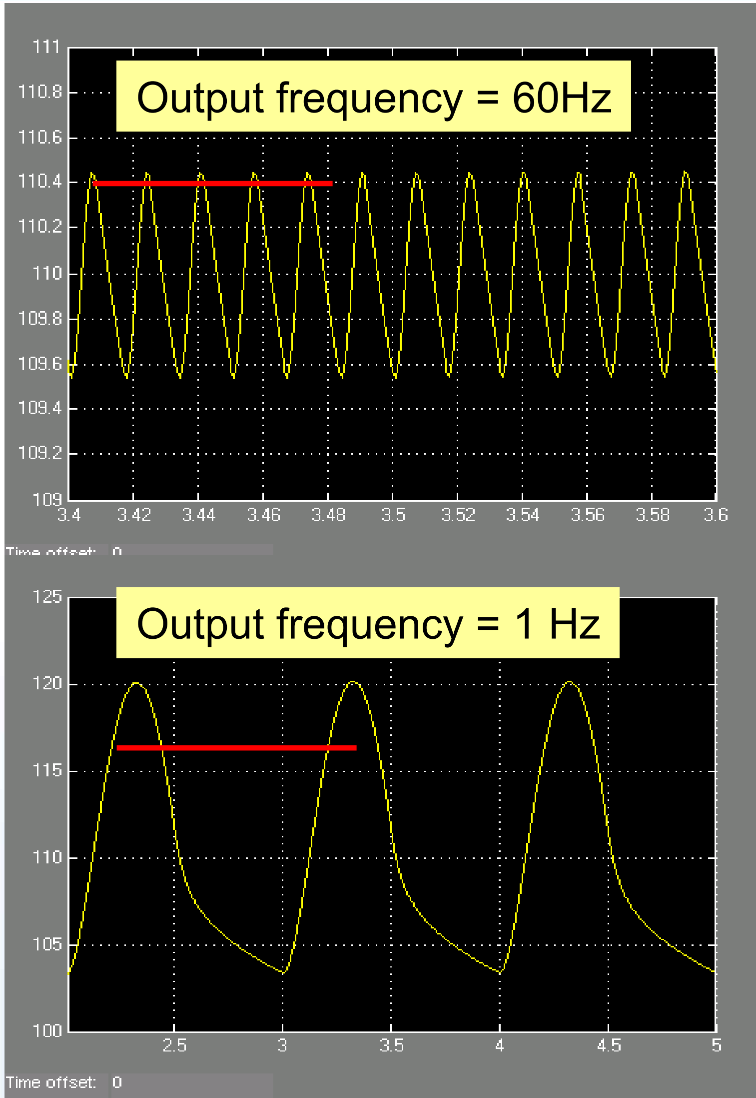
Rθjc is steady-state value of Zθjc



Tj Calculation

- ⦿Tj Calculation with Zθjc
- Using actual Pd and Zθjc





Life-time Calculation

Power Cycle Test

power device is heated and cooled repeatedly by external current injection under specific temperature and time. The change in ΔTca should be less than 10deg (water cooling is used). Test variable is ΔTjc and the number of cycles.

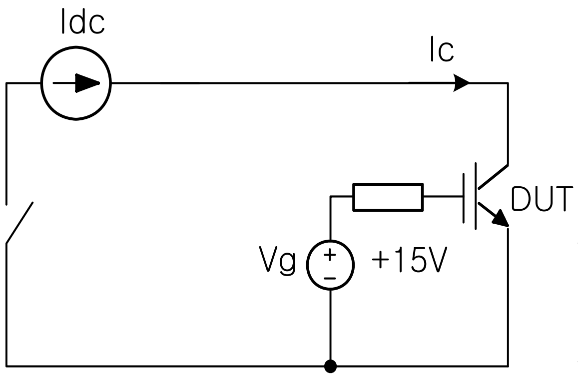


Fig.1. Basic circuit for power cycle test.

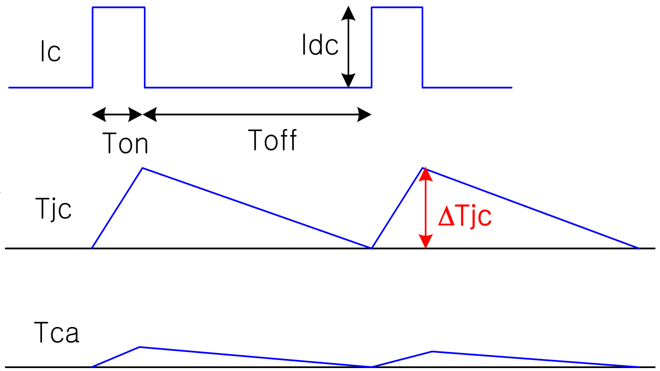


Fig.2. Pulse duty of current for power cycle test

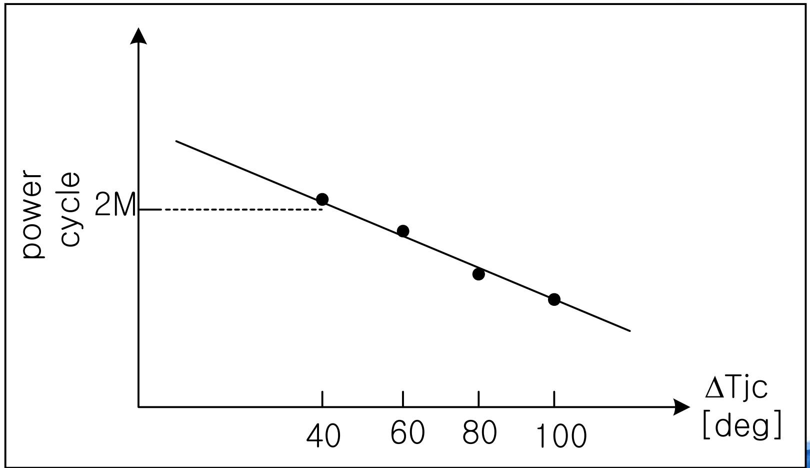


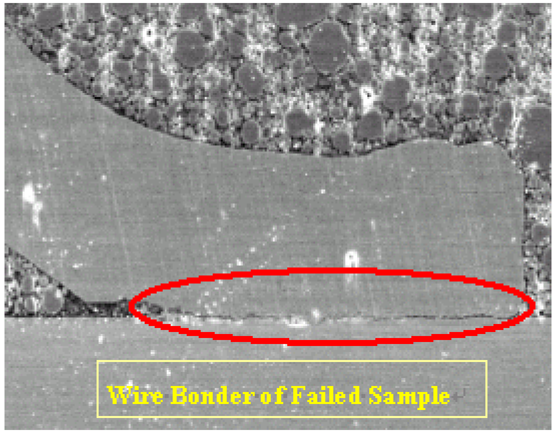
Fig.3. Example plot of power cycle test

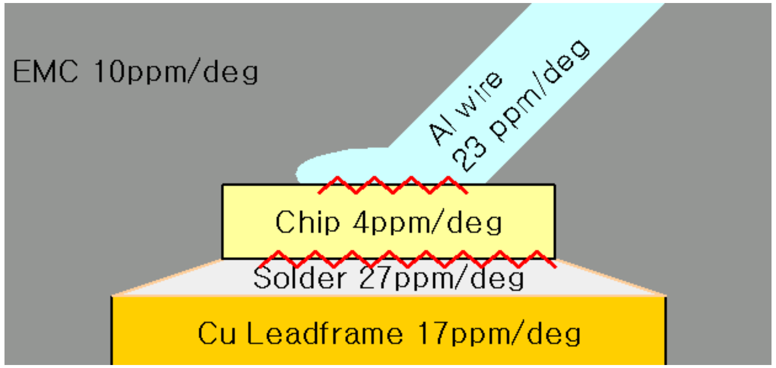
Main Failure Mechanism

Main Failure Mechanism

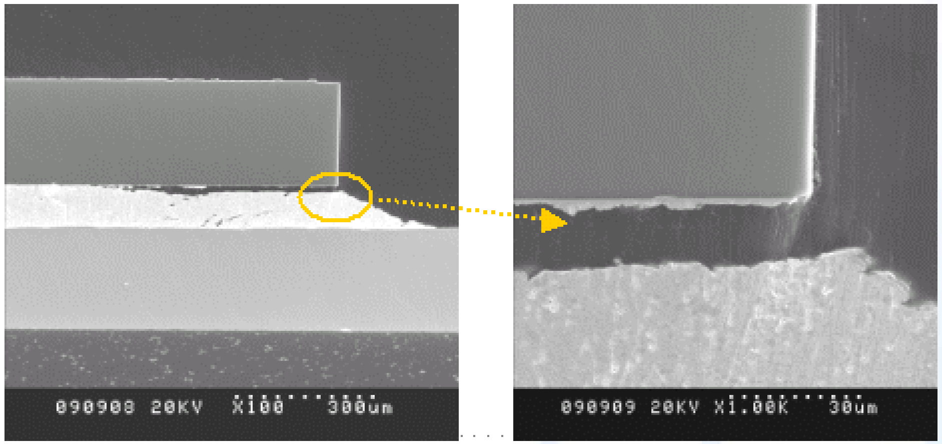
= Difference in thermal expansion coeff. between two adjacent materials

Bonding Worn out





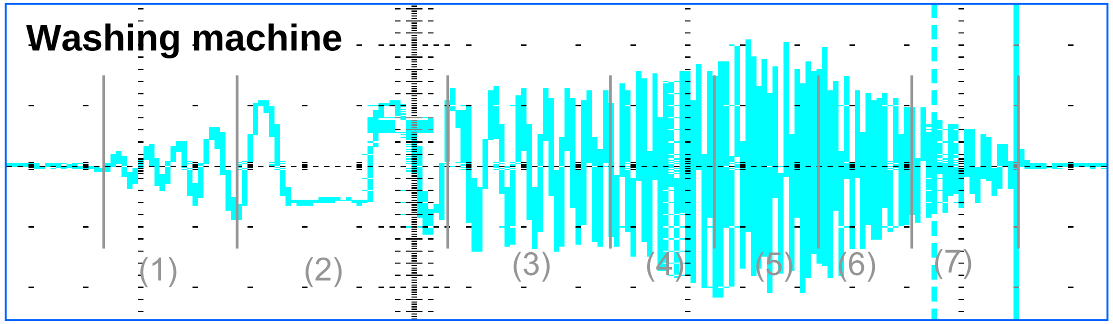
Solder Crack



FAIRCHILD SEMICONDUCTOR

Power Cycle Consideration

Step-1 : Divide period so that Imax is same from typical load pattern



Step-2 : Calculate ΔTjc

Tc is measured value and assumed to be constant

$$\Delta Tjc = P_1 \times Z_{\theta jc}(t_1 + t_2 + \ldots t_7) - P_1 \times Z_{\theta jc}(t_2 + t_3 + .. t_7)$$
$$+ P_2 \times Z_{\theta jc}(t_2 + t_3 + .. t_7) - P_2 \times Z_{\theta jc}(t_3 + t_4 + .. t_7) \ \ldots \ + P_7 \times Z_{\theta jc}(t_7)$$

P_n from loss calculation

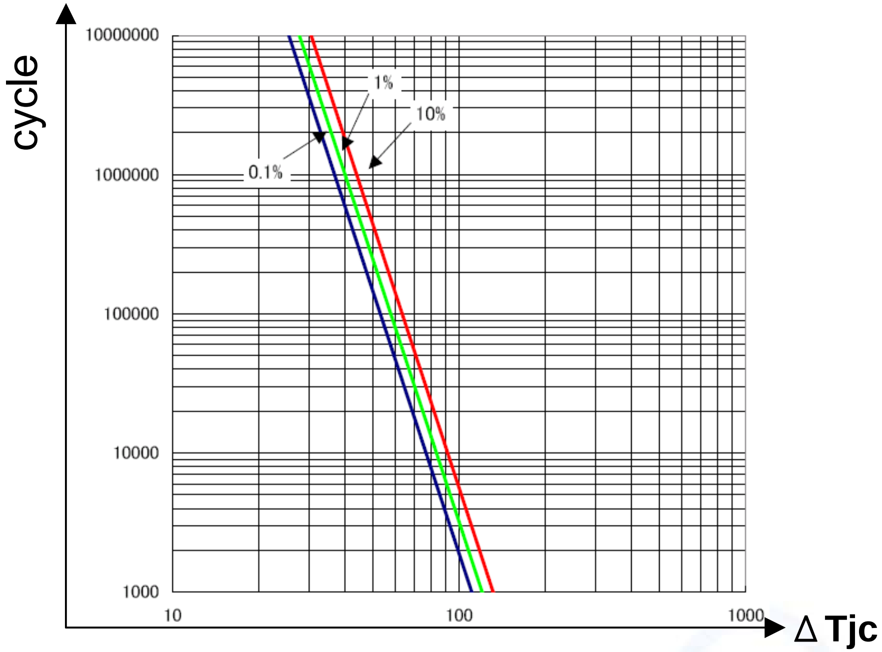
$Z_{\theta jc}$ from thermal impedance

n	Imax	Pn	t n	tn+..+t7	Zθjc(tn+..+t7)	ΔT
1	1.9	2.2	1.71	5.87	2.66	0.2
2	7.8	9.6	1.46	4.16	2.57	1.4
3	9.1	11.3	1.04	2.7	2.42	1.6
4	11.2	14.0	0.68	1.66	2.28	2.0
5	14.1	18.9	0.53	0.98	2.14	2.7
6	9.8	13.1	0.3	0.45	2.00	4.5
7	5.9	6.8	0.15	0.15	1.65	11.2
					ΔTjc =	23.5

Power Cycle Consideration

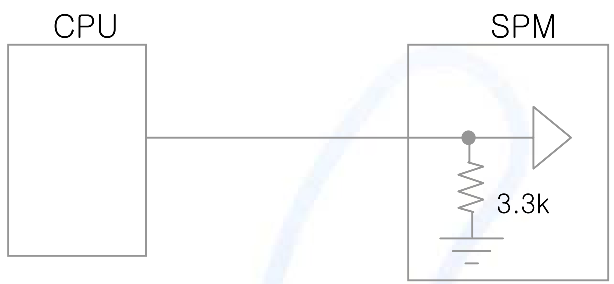
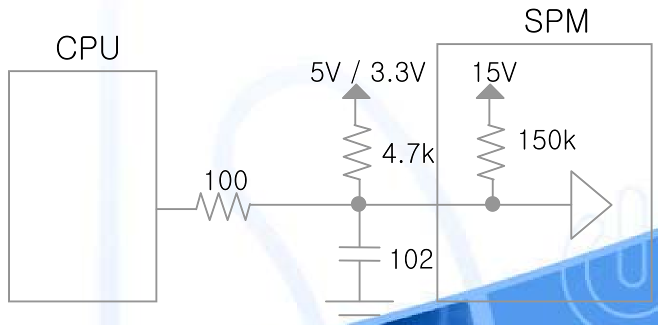
Step-3 : Calculate Life-time

From power-cycle graph provided by maker



$$10Mcyc \cdot \frac{1opr}{500cyc} \cdot \frac{1day}{1.5opr} \cdot \frac{1year}{365day} = 36.5year$$

Input Interface

ITEM	Active HIGH	Active LOW
Power Supply Turn-on/off Sequence	Fail safe sequence	Power on/off sequence must be: ON : CPU 5V → SPM 15V → Power 300V OFF : Reverse Order
5V/ 3.3V Compatibility & Simple Interface Circuit & Low noise acceptability	Internal R pull-down = 3.3 ~ 5 KΩ	Internal V pull-up = 15V or 6.2V Internal R pull-up = 150KΩ or 50KΩ
	No need for external pull-down resistor due to built-in one. Low Noise Acceptability with 3.3KOhm internal pull-down resistor	Needs another pull-up resistor to limit the MCU output.
Photo-coupler Interface	Needs Inverter	
Interface Circuitry		

FAIRCHILD SEMICONDUCTOR

Maximum Ratings

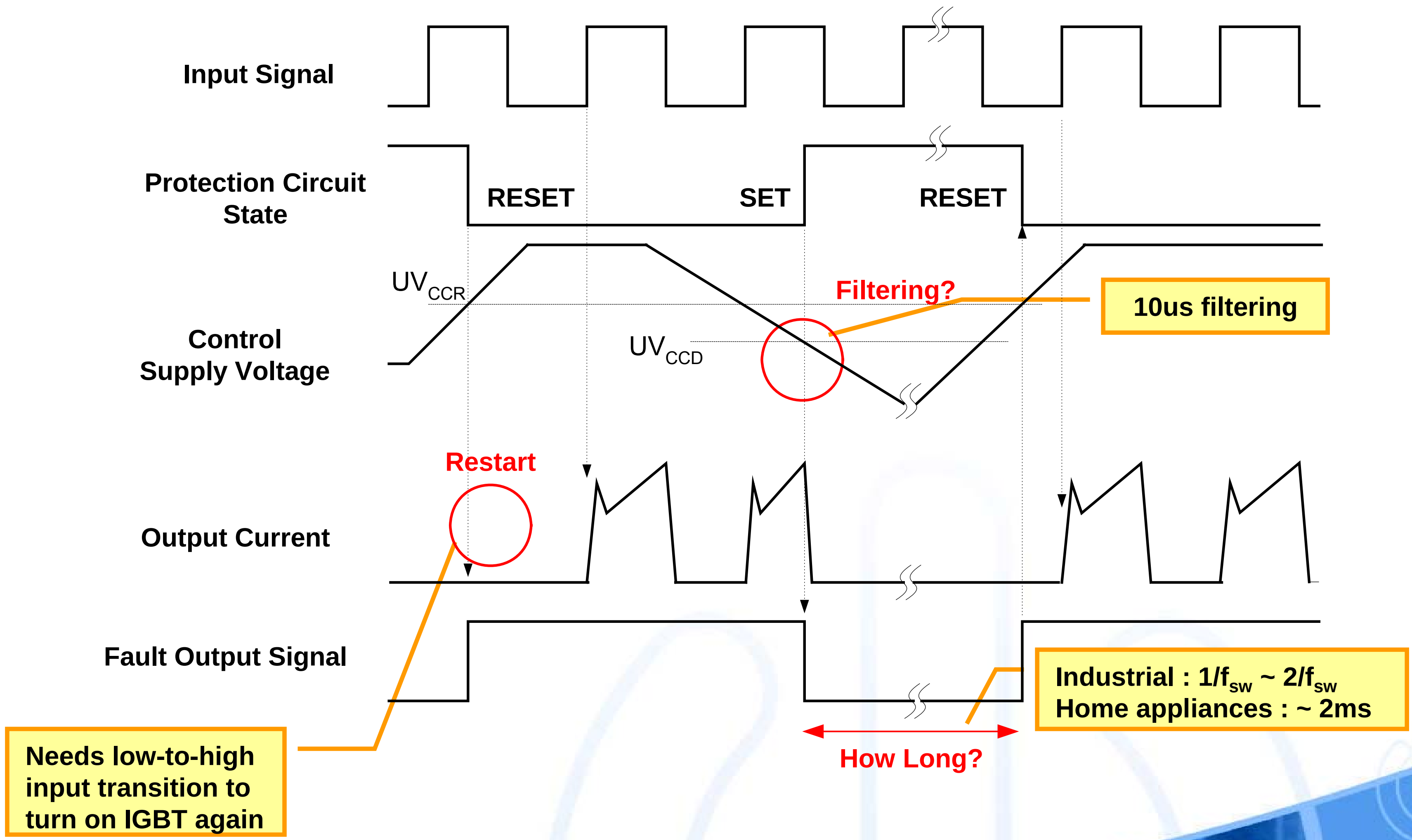
T_j=25˚C

Item	Symbol	Rating	Description
Supply Voltage	V_{PN}	450V	The maximum steady-state (non-switching mode) voltage between P-N. A brake circuit is necessary if P-N voltage exceeds this value.
Supply Voltage (surge)	$V_{PN(surge)}$	500V	The maximum surge voltage (non-switching mode) between P-N. A snubber circuit is necessary if P-N surge voltage exceeds this value.
Collector-emitter voltage	V_{CES}	600V	The sustained collector-emitter voltage of built-in IGBTs.
Each IGBT Collector current	$\pm I_C$	10A	The maximum allowable DC continuous IGBT collector current at Tc=25˚C.
Junction Temperature	T_J	-20 ~ 125°C	The maximum junction temperature rating of the power chips integrated within SPM is 150˚C. However, to insure safe operation, the average junction temperature should be limited to 125˚C. Although IGBT and FRD chips will not fail immediately at TJ = 150°C, they may be degraded by repetitive operation at this temperature.
Self Protection Supply Voltage Limit (Short Circuit Protection Capability)	$V_{PN(PROT)}$	400V	Under the conditions of Vcc=13.5V ~ 16.5V, non-repetitive, less than 2µs. The maximum supply voltage for safe IGBT turn off under SC “Short Circuit” or OC “Over Current” condition. The power chip may be damaged if supply voltage exceeds this specification.

Bias Voltage

Control Voltage Range [V]	SPM Function Operations
0 ~ 4	Control IC does not operate. Under voltage lockout and fault output do not operate. dV/dt noise on the main P-N supply might trigger the IGBTs.
4 ~ 12.5	Control IC starts to operate. As the under voltage lockout is set, control input signals are blocked and a fault signal Fo is generated.
12.5 ~ 13.5	Under voltage lockout is reset. IGBTs will be operated in accordance with the control gate input. Driving voltage is below the recommended range so $V_{CE(sat)}$ and the switching loss will be larger than those under normal condition.
13.5 ~ 16.5	Normal operation. This is the recommended operating condition.
16.5 ~ 20	IGBTs are still operated. Because driving voltage is above the recommended range, IGBTs' switching is faster. It causes increasing system noise. And peak short circuit current might be too large for proper operation of the short circuit protection.
Over 20	Control circuit in the SPM may be damaged.

Protection : UVLO



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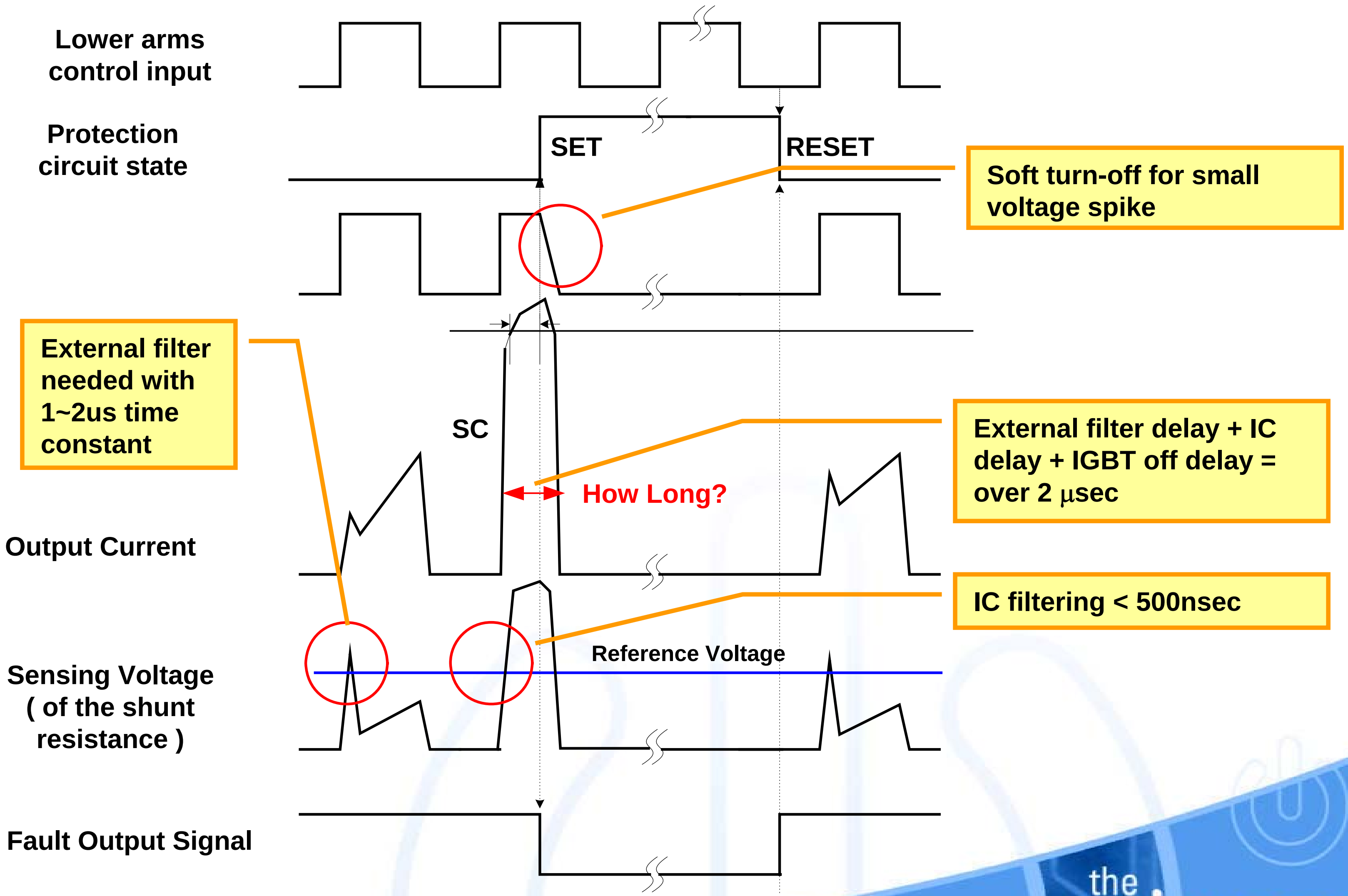
Protection : SC



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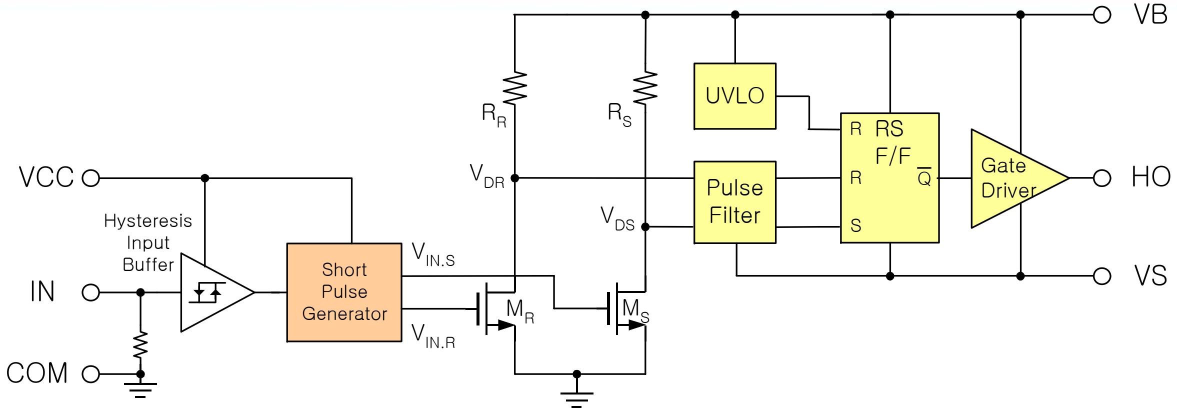
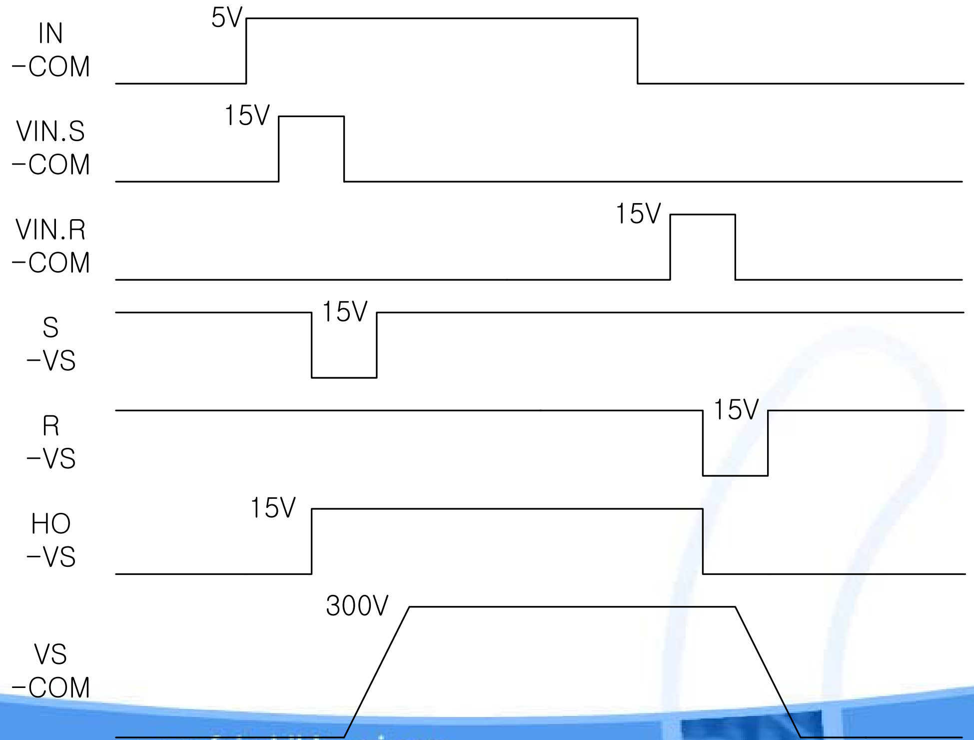
HVIC : General Structure





-Function :

IN signal can be transferred to HO

-Merit :

Short propagation delay (short deadtime)

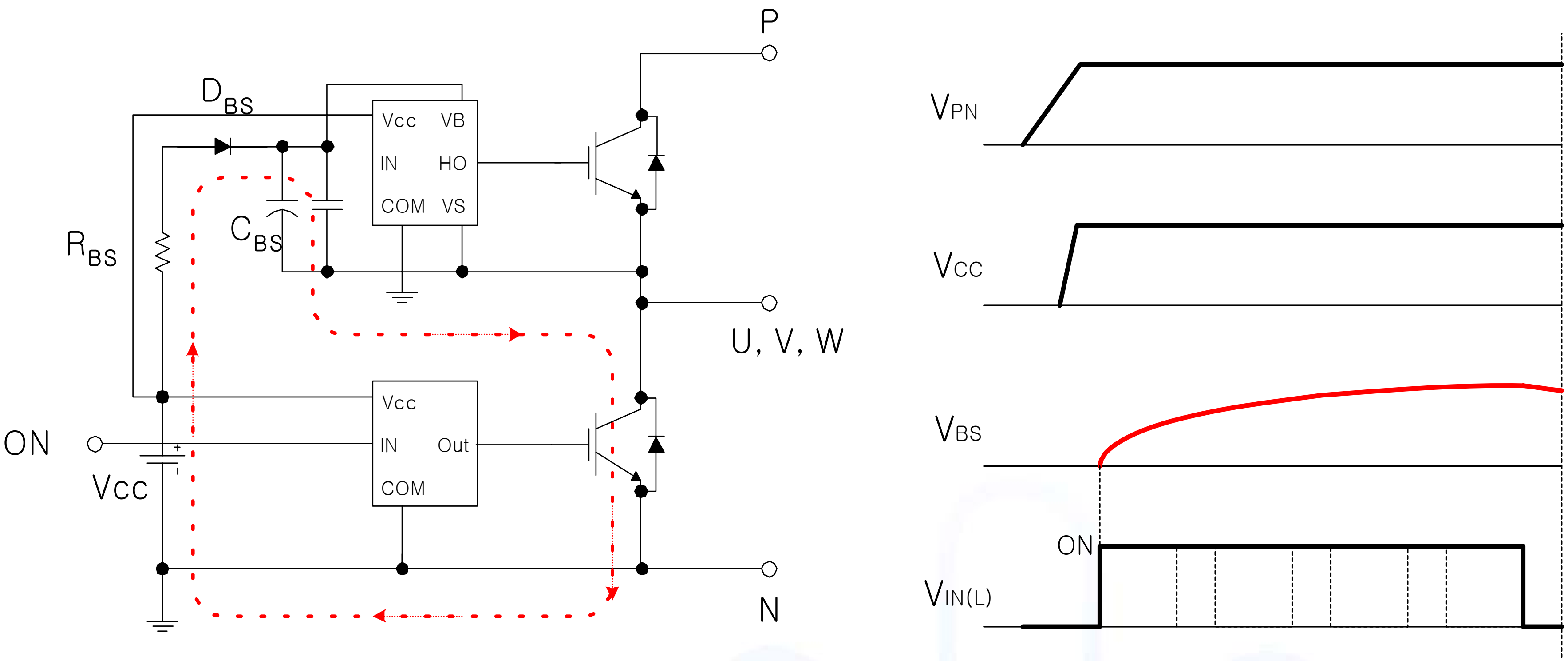
Long lifetime & Low cost

-Demerit :

No signal transfer when VS is negative

Poor noise immunity due to edge-trigger and F/F structure

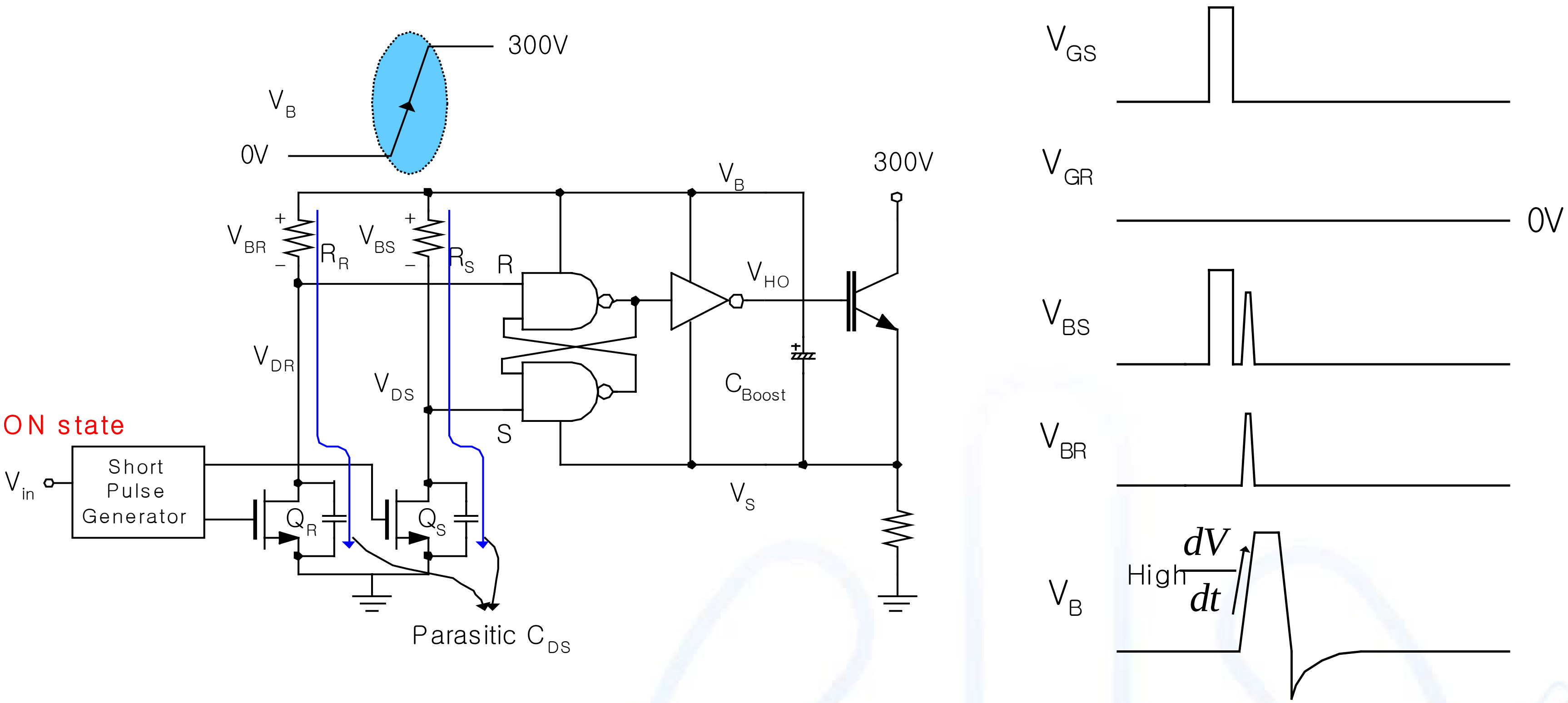
HVIC : Bootstrap



C_{BS} : Close to the pins as possible. At least one low ESR capacitor should be used to provide good local de-coupling.
D_{BS} : Withstand voltage more than 600V. Fast recovery (recovery time < 100ns) device to minimize the reverse charge.
R_{BS} : Slow down the dV_{BS}/dt. Determines the time to charge the bootstrap capacitor.

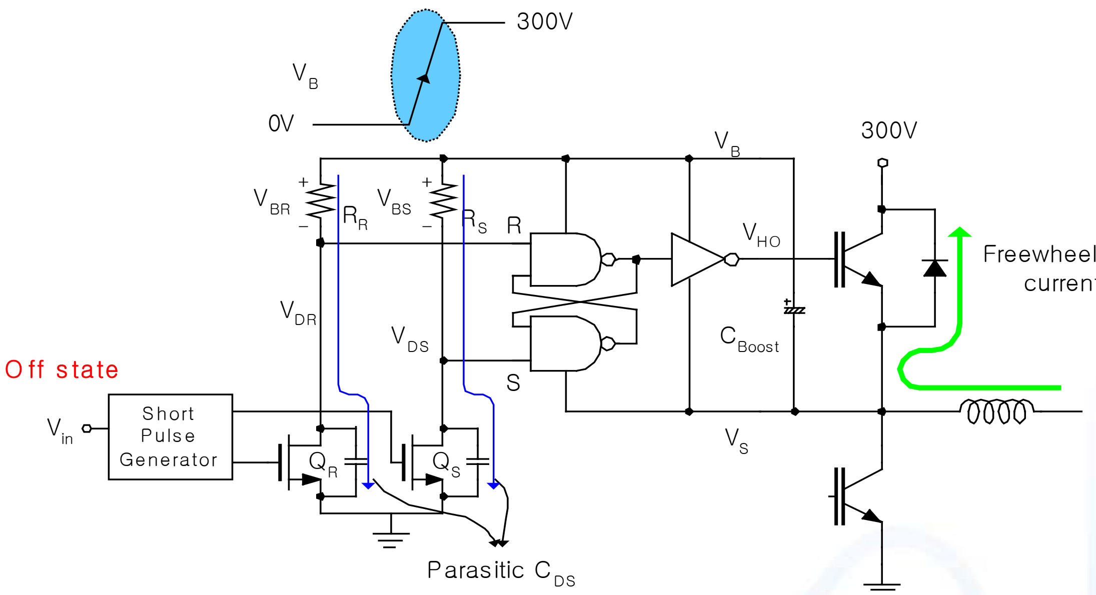
HVIC : Latch-off

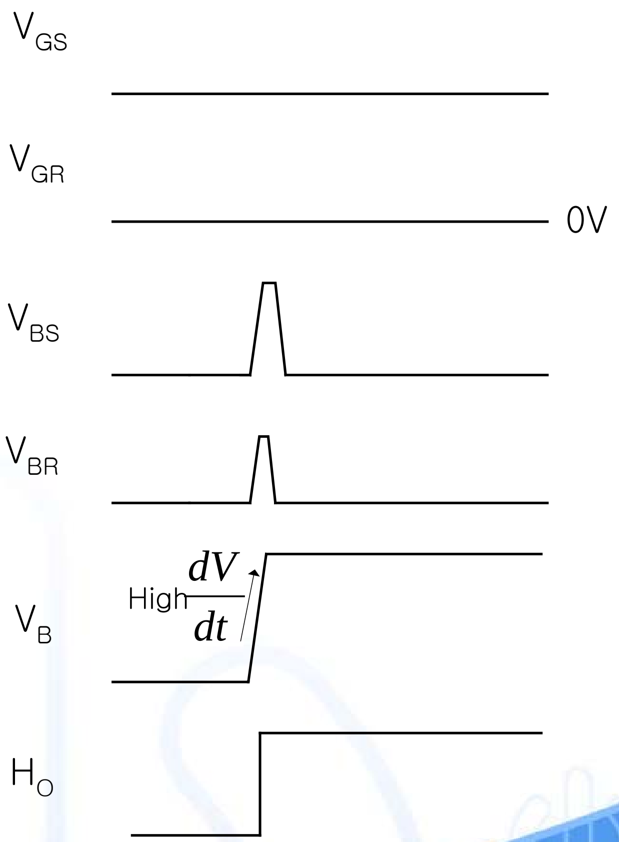
❑Turned off shortly after turning on



HVIC : Latch-on

❑Turned on when freewheeling current occurs in the off state

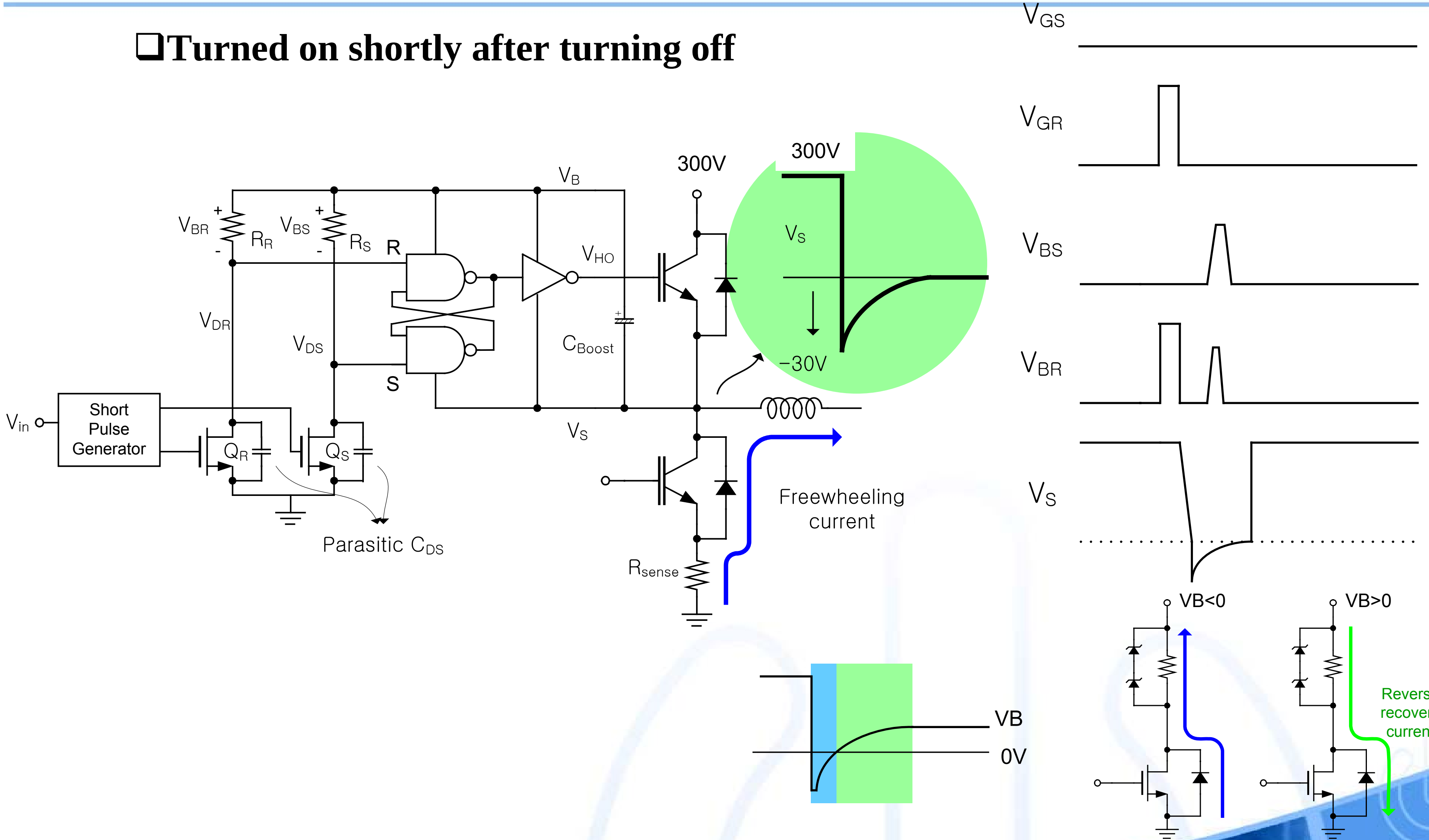




FAIRCHILD SEMICONDUCTOR

HVIC : Latch-on

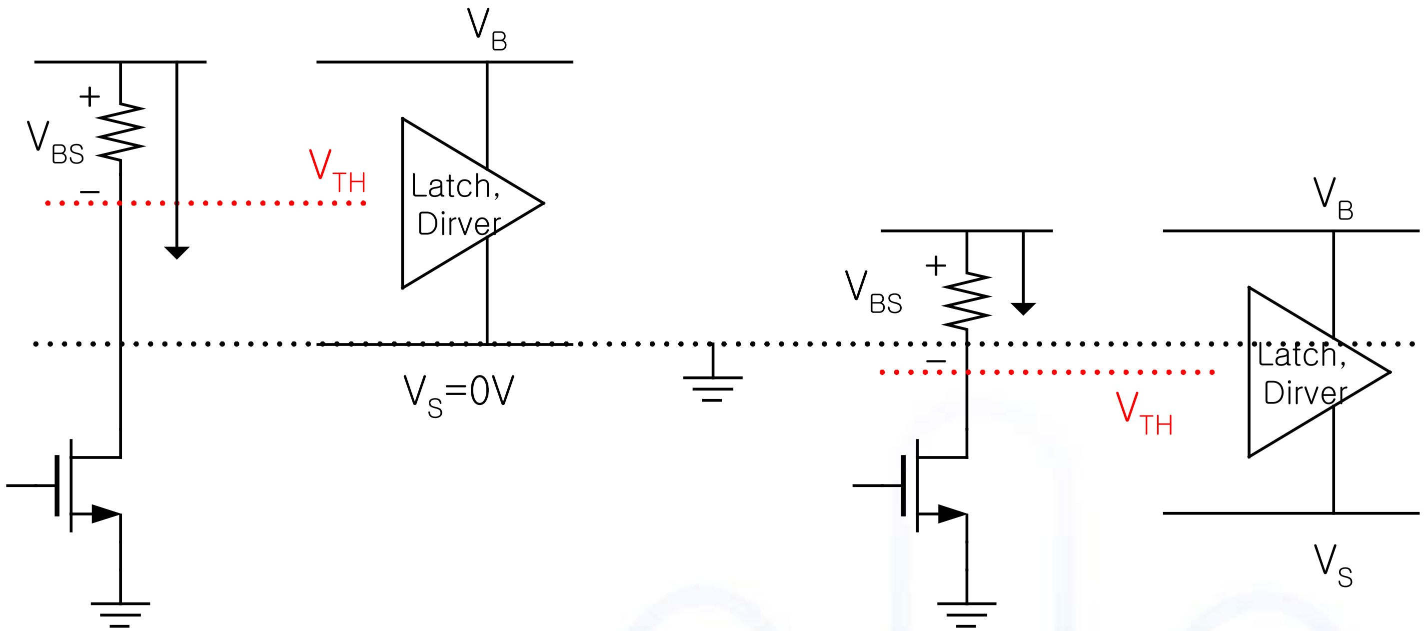
- Turned on shortly after turning off



the power franchise

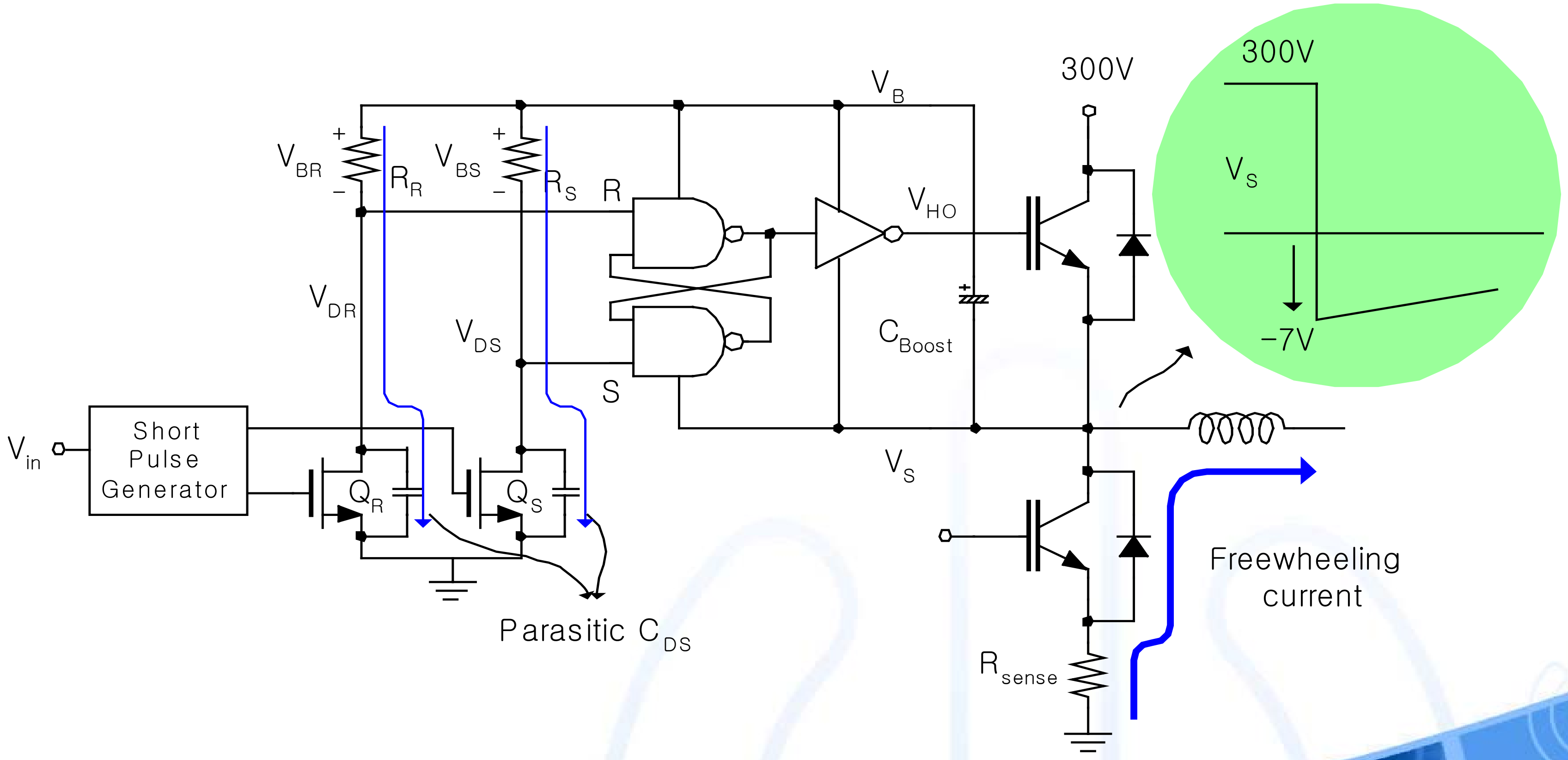
HVIC : Latch-up

❑ **No response to input (note : -Vs level in datasheet)**

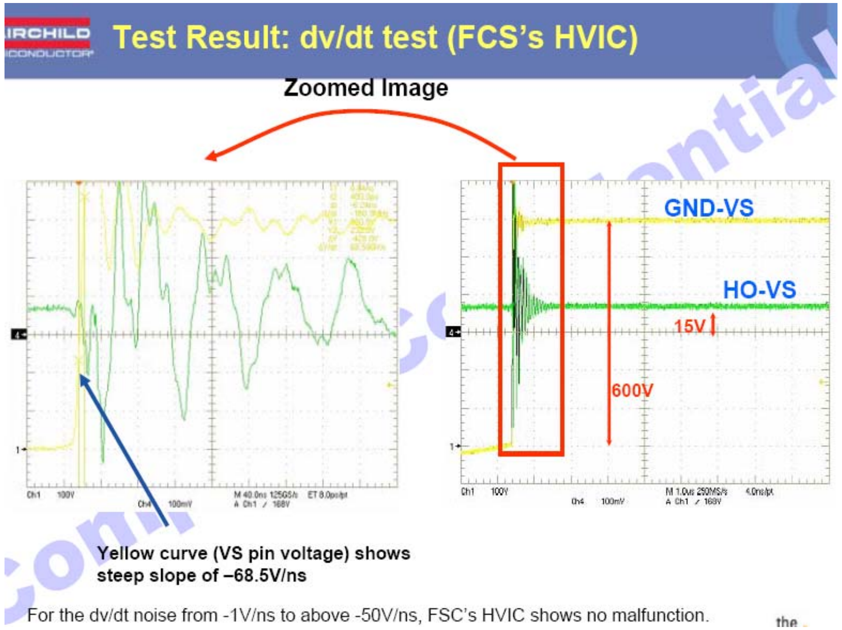


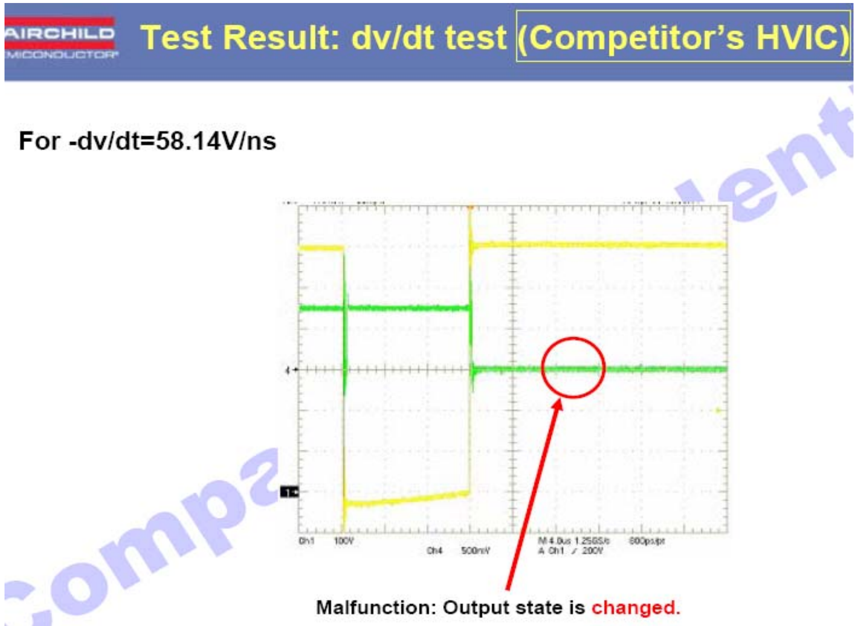
HVIC : Latch-off

❑ **input off-signal is very narrow**
(Minimum off-pulse width > 1us recommended)



HVIC : dv/dt immunity test





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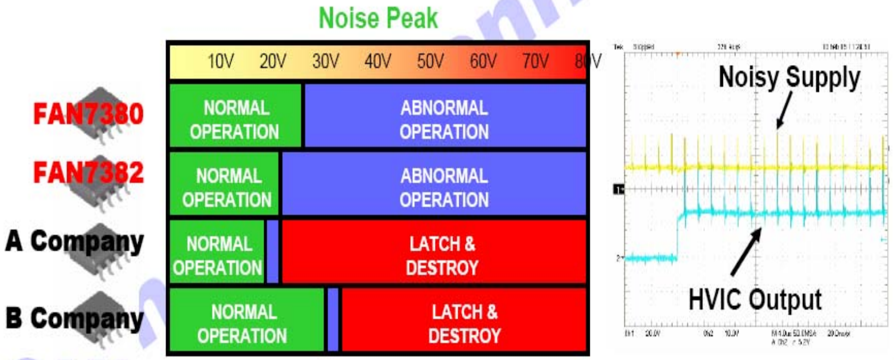
HVIC : Impulse noise immunity test

Positive Pulse Noise Test on VB

(A) Add Positive Noise on the supply of High-Side Driver

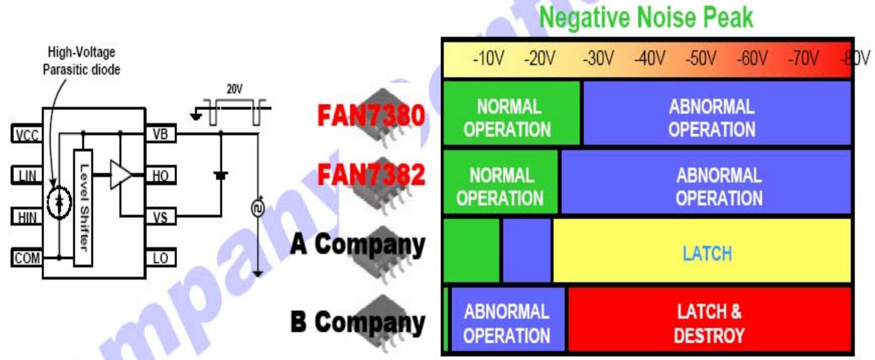
→ VBS = 15V(dc) + Positive Pulse Noise



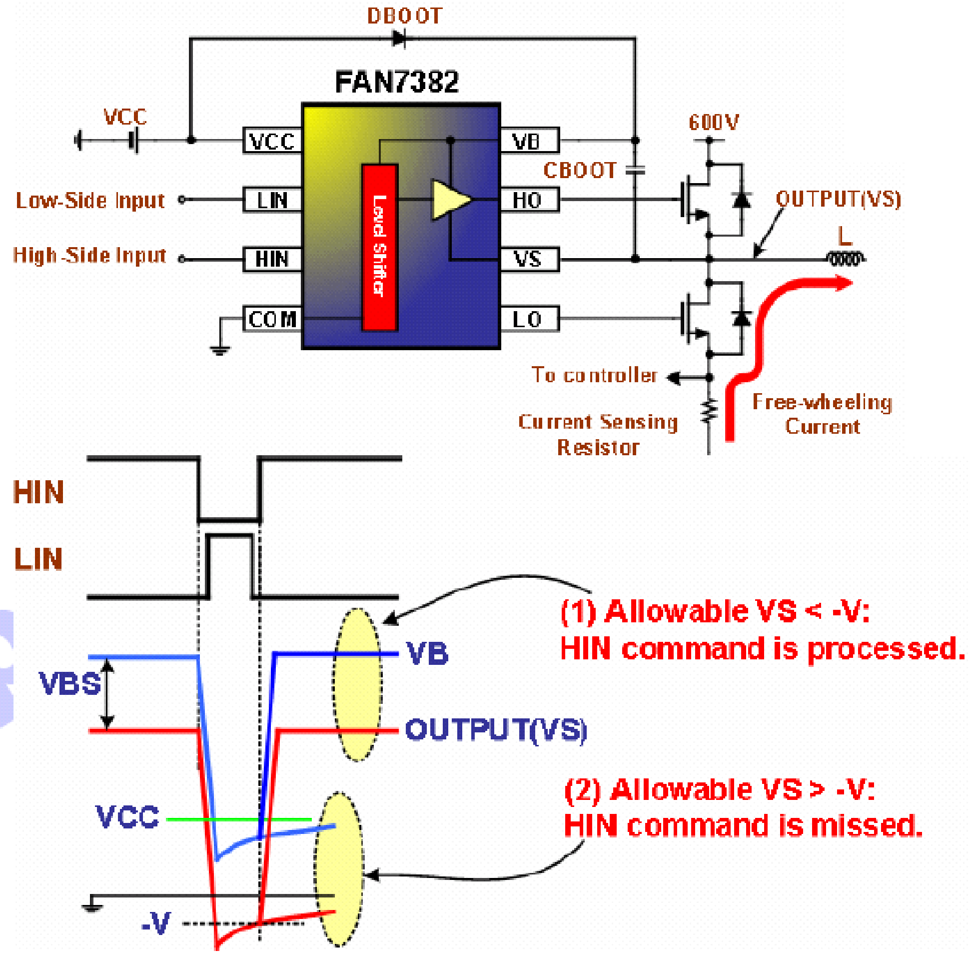
Negative Pulse Noise Test on VB

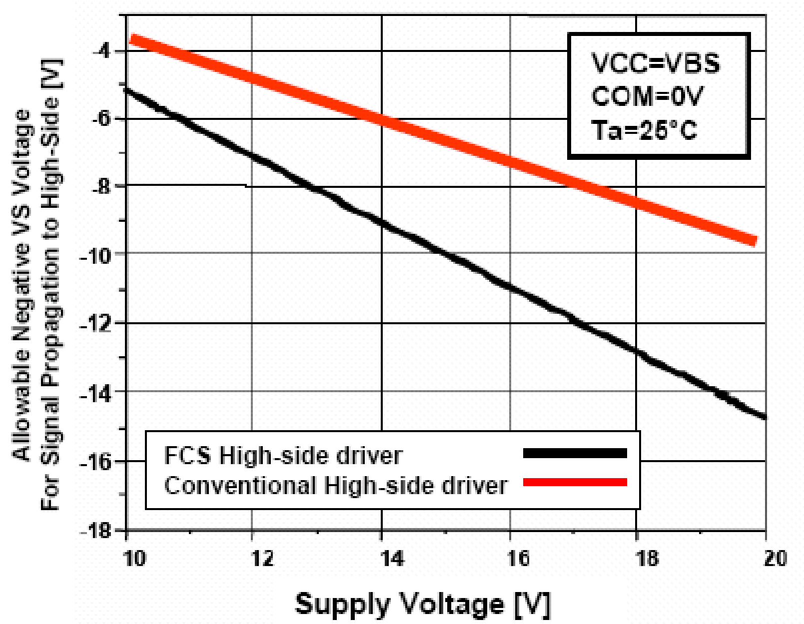
(B) Add Negative Noise on the supply of High-Side Driver

→ VBS=15V, VB= Negative Noise Pulse



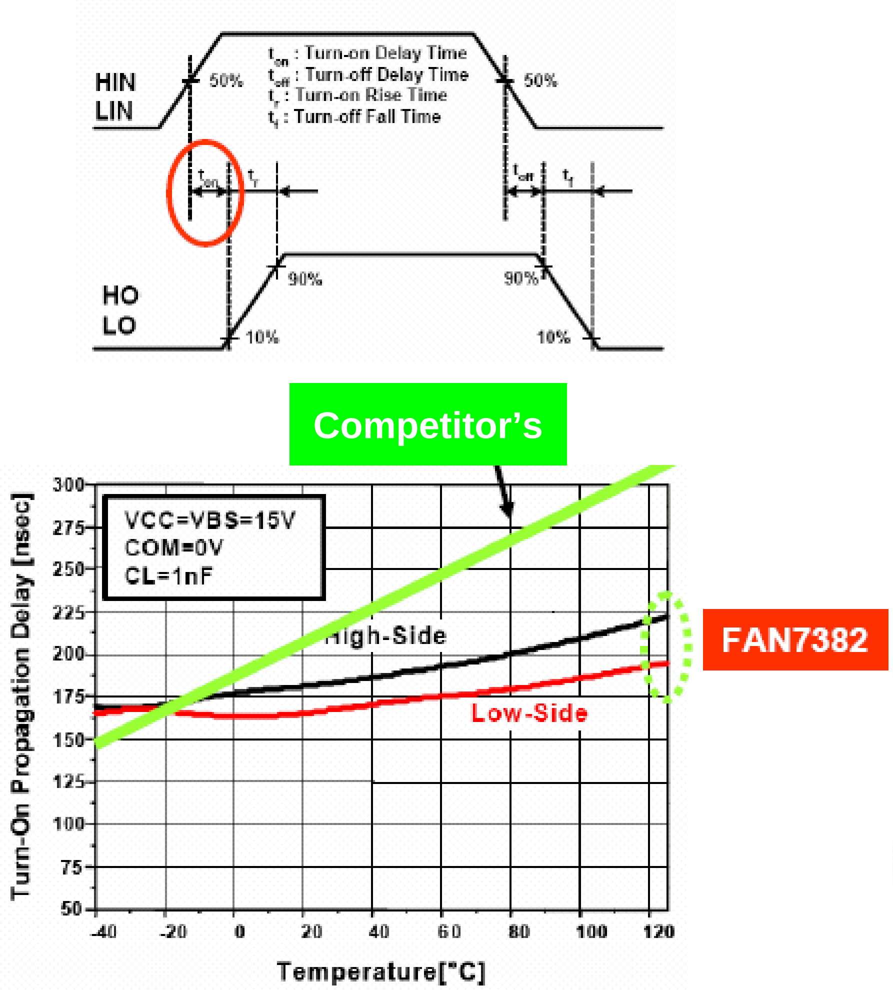
HVIC : Extended -Vs operation



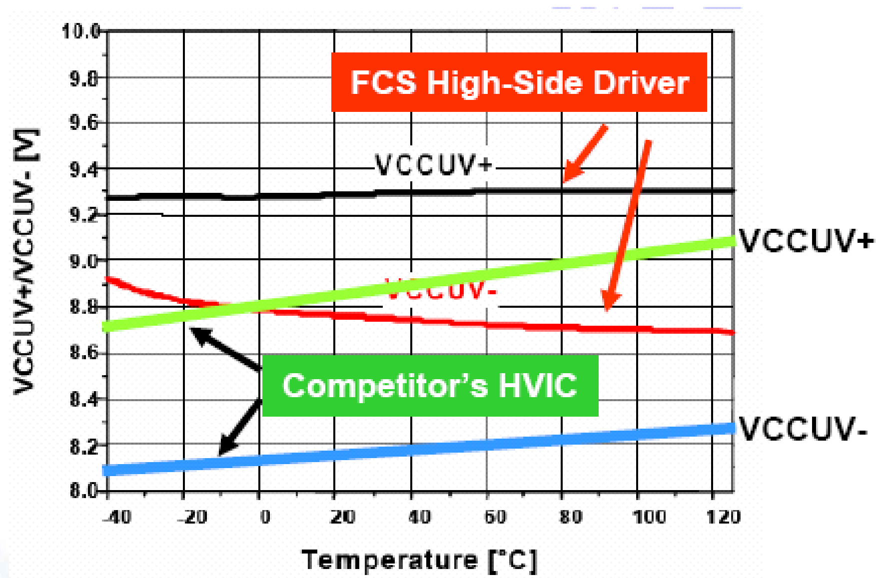


HVIC : Temperature Independency

Turn-on delay



UVLO Level



Chapter 4. SPM Values

Factors driving the need for SPM

1. Energy saving initiatives
   - forcing the adoption of newer and complex power drive stages.
   - forcing household appliance manufacturers to adopt energy saving motor solutions, requiring more complex electronic drive solutions.
2. Different types of appliances use different power drive solutions
   - different devices can be successfully integrated into one SPM to satisfy these diverse needs.
3. The increased rate of technological advances in the consumer appliance industry
   - forcing a strong reduction of time to market on companies.
   - designers of these controls face enormous pressure to provide cost-effective solutions in the shortest possible time.

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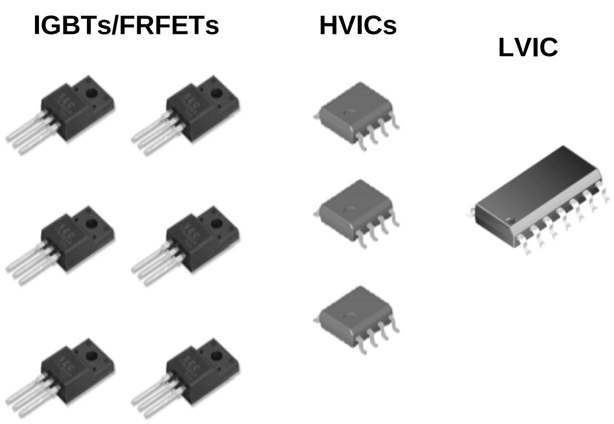
Integration of analog, discrete and package technology

Integration of discrete components



A protection circuit using analog components causes time delays and noise

SPM's built-in HVIC and LVIC with protection circuit

Design Considerations

Needs optimization for switching and short-circuit dynamics using external components

SPM optimizes driving characteristics for built-in power devices

Assembling these parts may increase manufacturing time and cause low yields.

SPM, which integrates all diverse components, enhances productivity while simplifying manufacturing

Manufacturing Impact

- -reduced total system cost
- -reduced development time
- -easy management
- -optimized control flexibility
- -higher reliability

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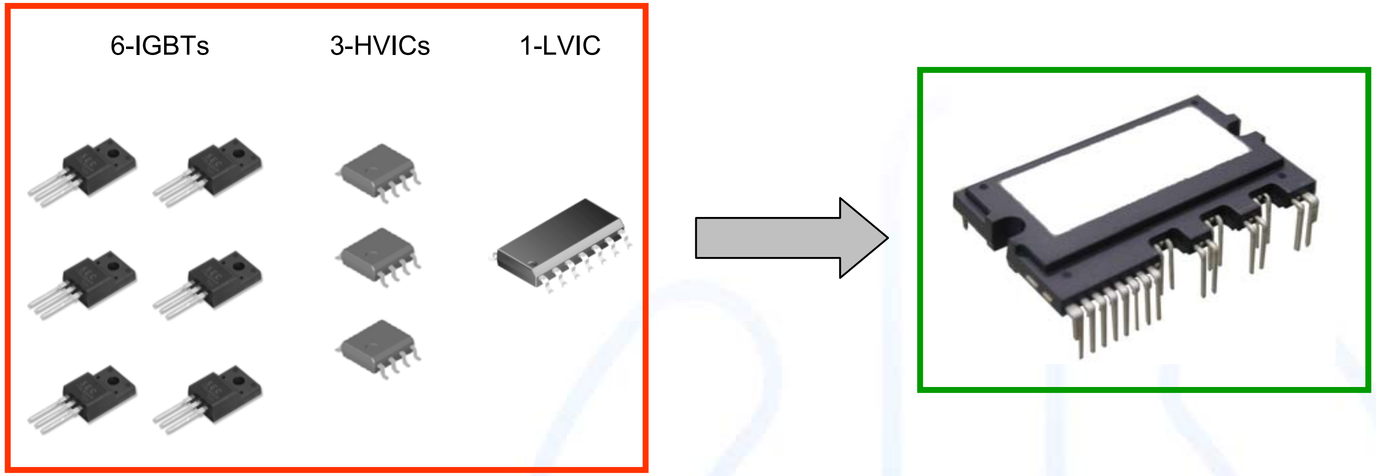
SPM Effect

Impact of using SPM on…	BOM cost	System cost	Time to market	0h failures	Failures in time
Reduced number of components	+	+	++	++	++
High performance	++	++	+	0	0
Increased reliability	0	0	+	++	+++
Less board space or application volume	++	+++	++	0	0
Easier and faster design	+	++	+++	+	++
Reproducible performance	++	+++	++	+	+

- Using SPM is in line with modern application trends (smaller, more efficient, better performance)
- Increased reliability and improved time to market are added benefits

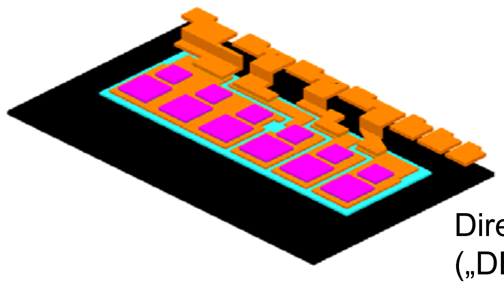
Reduced number of components

- Biggest impact is in saving mounting cost
  - Production time saved for hand-assembly / heatsink to 1 component instead of 6 heatsinks
- Reduced logistics and purchasing efforts
- Fairchild Semiconductor is a proven, high-volume power semi supplier with excellent quality

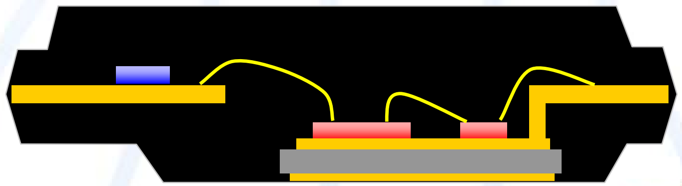


High performance

- Performance criteria are:
  - Power density – how large is the system for a given output power?
  - EMI behaviour – shielding / filtering efforts?
  - Thermals – how complicated / expensive is cooling the system?
- With Fairchild SPM, power density can be the highest
- Power switches and drivers are precisely matched, improving EMI
- Switching speed can be changed externally, improving EMI – no flexibility lost over discrete solution
- The Thermal resistance from devices to case and case to heatsink is very low
- DIP package allows easy mounting in standard production lines



Direct bond to copper („DBC“)



Increased reliability

- All devices in a module are tested together at the end of production
  - Fairchild performs reliability and quality engineering on the modules
  - For discrete solutions, the customer needs to perform QA eng.
- Protection functions are close to the power devices
  - Built-in and tested, no external components
- Lower thermal resistance results in lower temperature change over a load cycle, increasing reliability
- Standardized high-power wiring is optimized
  - Less parasitic components
  - Better control of peak voltages

Less board space or application volume

- Smaller system size has many advantages
  - System is less expensive (PCB space, system volume, mounting efforts)
  - New options for system design (e.g. adding the inverter to the panel controller)
- Motion-SPM in mini-DIP package: 44mm x 27mm
- Height 7mm vs 19mm for TO220
  - However, heatsink to be considered
- Discrete solution is considerably larger
  - Must respect minimum distances between components

Ultra-compact, low height complete control board with Motion-SPM in SMP3, auxiliary supply with FPS, and microcontroller

Easier and faster design

- Time to market is a significant success factor
  - Bringing innovation to end market yields higher margins – the earlier, the better
  - Shortening the design time improves time to market significantly
  - Consider manufacturing / ramp-up impact – reduced number of issues using modules
- High-power wiring can be standardized
  - Added flexibility – for different output power: (One SPM package size covers 3A to 30A designs)
  - Standardized PCB layout will comply with layout rules
  - Remove interaction between devices in a discrete solution

Excerpt from Motion-SPM product portfolio in SMP3 package – Adapt application easily across wide power range

Substrate	Rating	Part Number
Ceramic	3A/600V	FSBS3CH60
	5A/600V	FSBS5CH60
	10A/600V	FSBS10CH60
	15A/600V	FSBS15CH60
DBC	15A/600V	FSBB15CH60
	20A/600V	FSBB20CH60
	30A/600V	FSBB30CH60

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Reproducible performance

- Performance variations are much more under control, accomplished within the module, 100% tested
  - Gate drivers are fine tuned to switches
  - Large impact on efficiency, EMI and safe operation
- Reduce the amount of effort elsewhere in the system to compensate (potentially cumulative) device variations
  - Larger bus capacitors, stronger input rectifiers, snubber circuits – less effort required
- Overall, system cost can be reduced through less variation of system performance

More than the sum of their parts

Simplified Design:		Streamlined Mfg:		Higher Value Solution:
- Fewer components to choose and lay out - Highest power efficiency - Lowest radiated and conducted EMI - Rapid time-to-market	+	- Reduced board space - Lower number of inserts and solder joints - Reduced test and visual inspection time	=	- Leading edge technology - Optimized system performance - Quick design cycles - Highest quality and reliability

- SPMs are rich in features and customer benefits
- The value is uniquely defined by the customer's design, manufacturing and business needs

Why Customers Choose SPM Inverters - by Application

- Many new designs now in production or qualification
- Broad spectrum of customers and applications
- Each design takes advantage of a unique combination of SPM configuration and associated features/benefits

Advantage	End Product				
	Air Conditioner	Washing Machine	Refrigerator	Fan Motor	Industrial Drive
Small Size				P	P
Higher Efficiency	P	s	P	P	
Reduced Noise	s	P	s	P	
Lower Mfg Cost	s	s	P	P	P
Higher Mfg Yield	P	P	P	P	P
Fewer Field Failures	P	P	P	P	P

P = Primary Choice Criteria
s = Secondary

Summary of SPM Benefits

- **Design and Development**
  - Save space
  - Compact design
  - Easier to meet efficiency & EMI regulations
  - Save development time
  - Reduce time to the market
- **Manufacturing: single component instead of several**
  - Easier procurement
  - Lower assembly cost (single placement, no special steps)
  - Higher yield (pre-tested, fewer connections)
- **The right technology for the future**
  - Cutting edge technology
  - Higher efficiency
  - High quality and reliability

To satisfy More Needs of Customers

Finding

a New Smart Power Module Solution

Welcome **Customized Module**

with Open Arms