

# Power Converter Systems

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## Graduate Course EE8407

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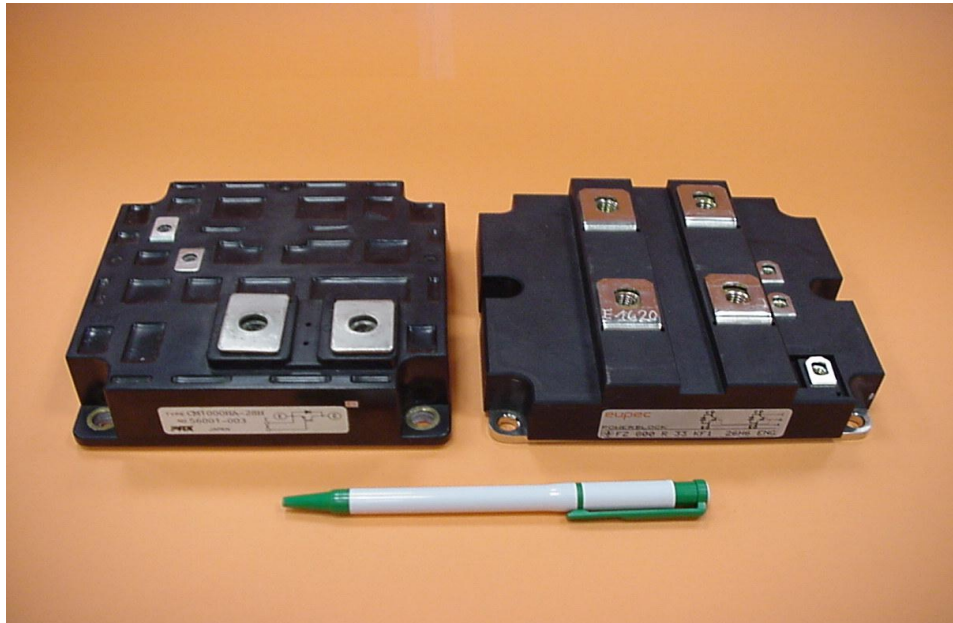


**Ryerson Campus**

## Topic 2

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# High-Power Semiconductor Devices



# High-Power Semiconductor Devices

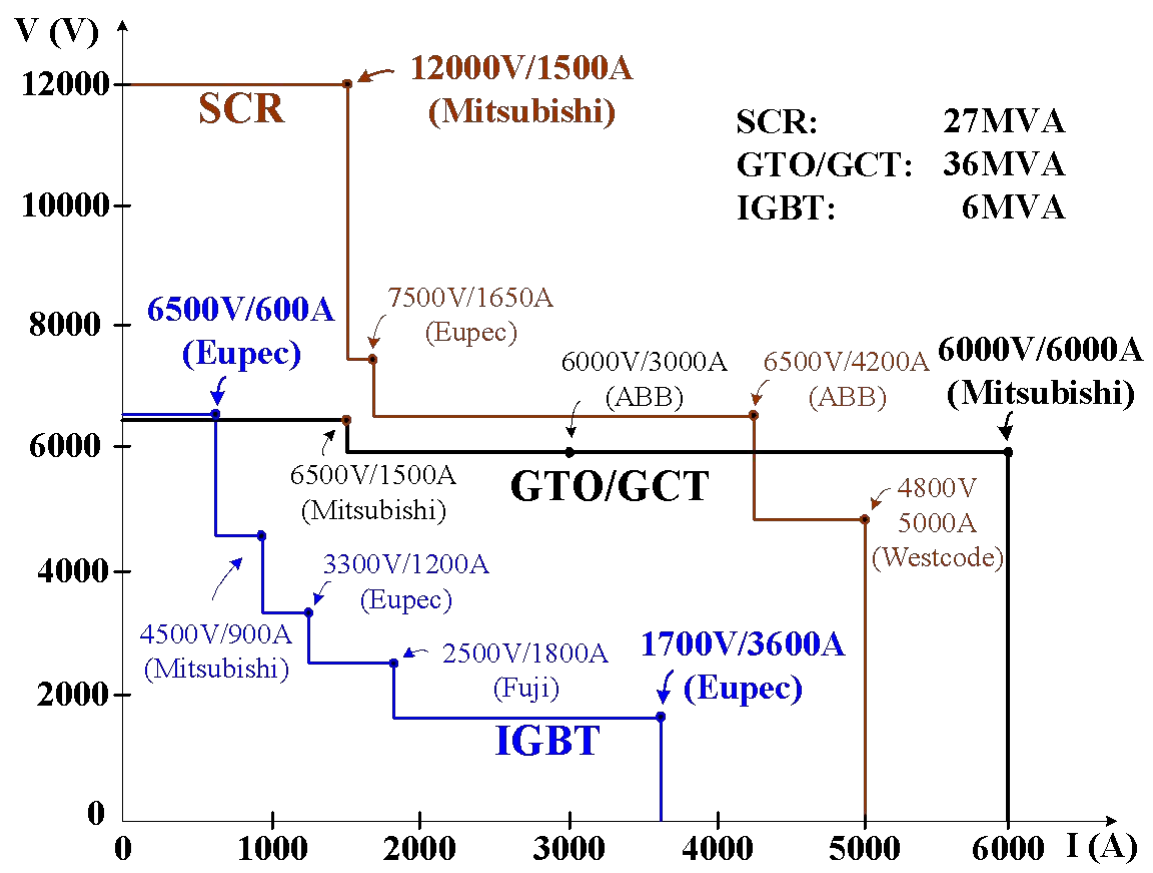
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## Lecture Topics

- Power Diode
- SCR Thyristor
- Gate Turn-Off Thyristor (GTO)
- Integrated Gate Commutated Thyristor (GCT)
- Insulated Gate Bipolar Transistor (IGBT)
- Switch Series Operation

# High-Power Semiconductor Devices

- Device Rating



# Power Diode

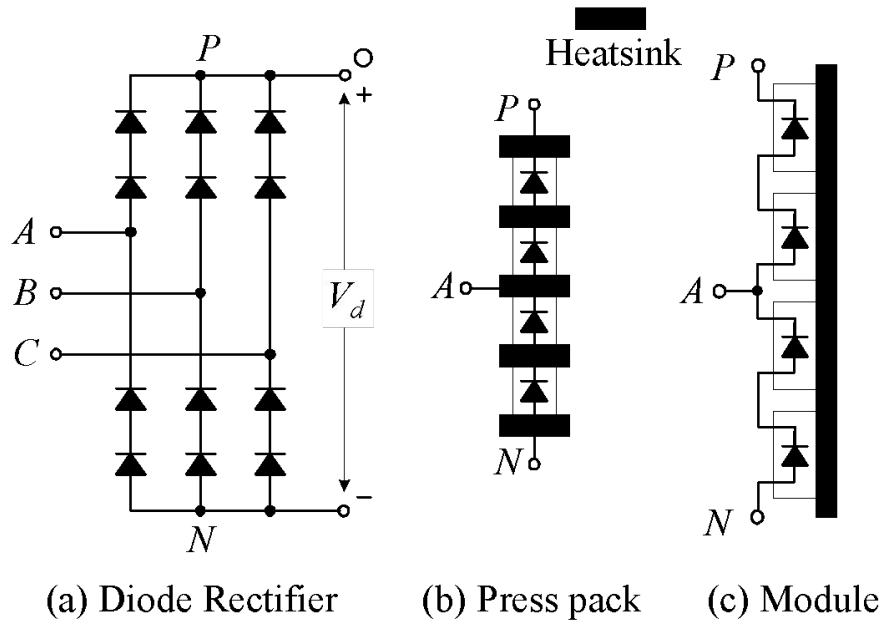
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**4500V/800A press pack and 1700V/1200A module diodes**

# Power Diode

## • Heatsink Assembly



### Press pack device:

- Double sided cooling
- Low assembly cost and high power density
- Preferred choice for high voltage high power applications

# SCR Thyristor

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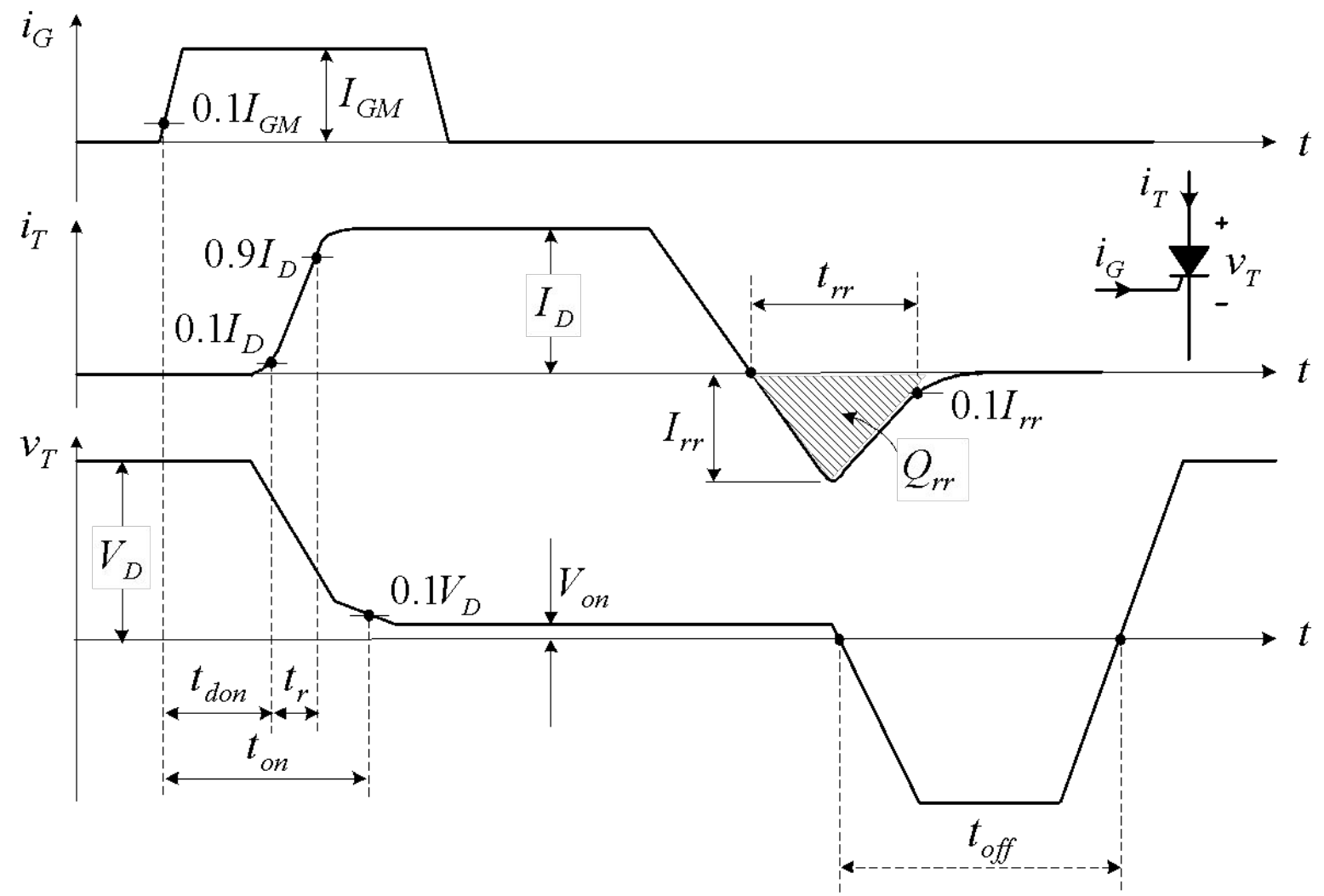


**4500V/800A and 4500V/1500A SCRs**



# SCR Thyristor

- Switching Characteristics





# SCR Thyristor

- Main Specifications

## 12000V/1500A SCR Thyristor

Maximum Rating	$V_{DRM}$	$V_{RRM}$	$I_{TAVM}$	$I_{TRMS}$	-
	12000V	12000V	1500A	2360A	-
Switching Characteristics	Turn-on Time	Turn-off Time	$di_T/dt$	$dv_T/dt$	$Q_{rr}$
	$t_{on} = 14\mu s$	$t_{off} = 1200\mu s$	$100A/\mu s$	$2000V/\mu s$	$7000\mu C$
$V_{DRM}$ – Repetitive peak off-state voltage			$V_{RRM}$ – Repetitive peak reverse voltage		
$I_{TAVM}$ – Maximum average on-state current			$I_{RRMS}$ – Maximum rms on-state current		
$Q_{rr} = \frac{t_{rr} I_{rr}}{2}$ – Reverse recovery Charge			Part number – FT1500AU-240 (Mitsubishi)		

# Gate Turn-Off (GTO) Thyristor

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**4500V/800A and 4500V/1500A GTOs**

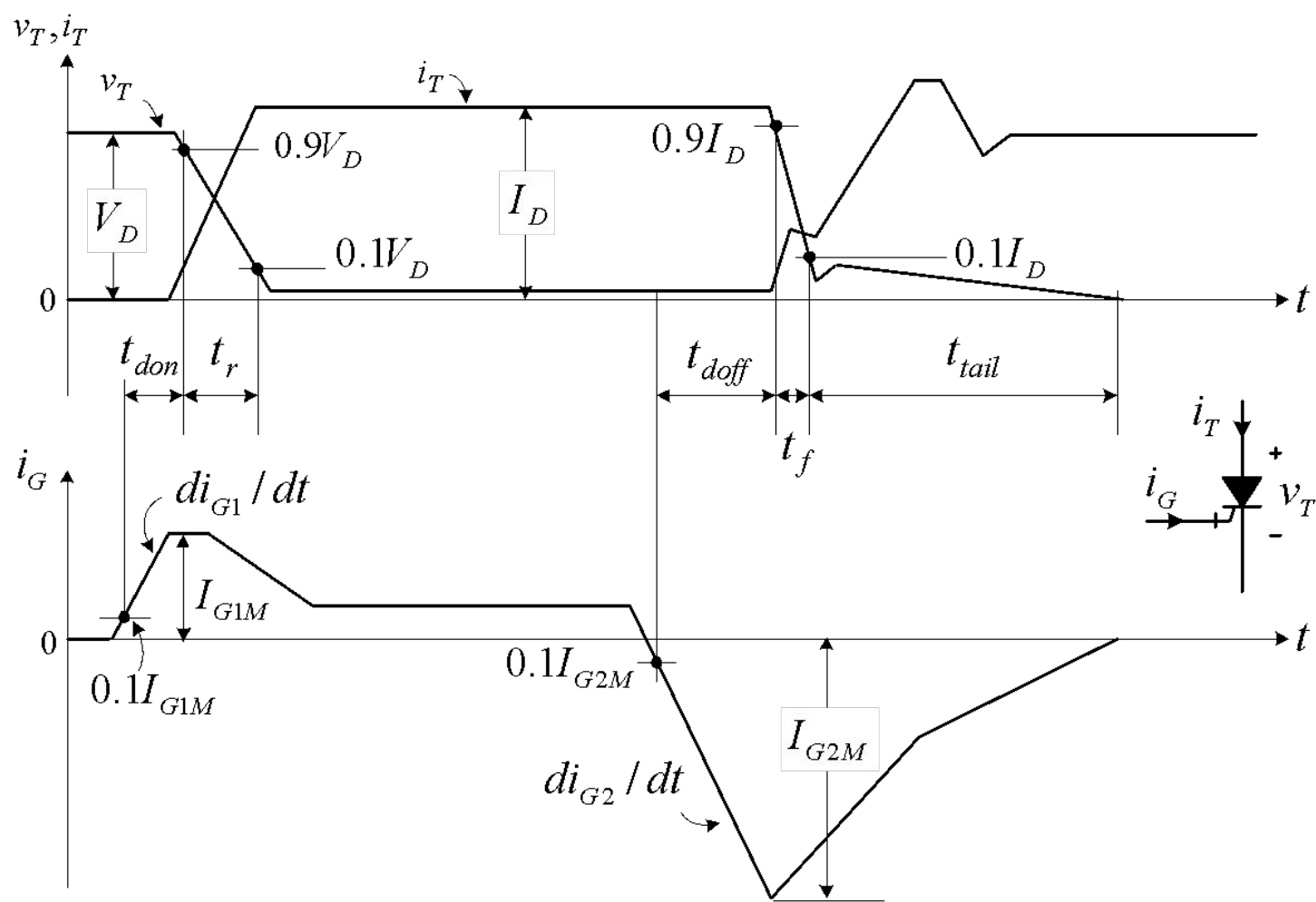
# Gate Turn-Off (GTO) Thyristor

- Symmetrical *versus* Asymmetrical GTOs

Type	Blocking Voltage	Example (6000V GTOs)	Applications
Asymmetrical GTO	$V_{RRM} \ll V_{DRM}$	$V_{DRM} = 6000V$ $V_{RRM} = 22V$	For use in voltage source inverters with anti-parallel diodes.
Symmetrical GTO	$V_{RRM} \approx V_{DRM}$	$V_{DRM} = 6000V$ $V_{RRM} = 6500V$	For use in current source inverters.
$V_{DRM}$ - Maximum repetitive peak (forward) off-state voltage $V_{RRM}$ - Maximum repetitive peak reverse voltage			

# Gate Turn-Off (GTO) Thyristor

- Switching Characteristics



# Gate Turn-Off (GTO) Thyristor

- Main Specifications

## 4500V/4000A Asymmetrical GTO Thyristor

Maximum Rating	$V_{DRM}$	$V_{RRM}$	$I_{TGQM}$	$I_{TAVM}$	$I_{TRMS}$	-
	4500V	17V	4000A	1000A	1570A	-
Switching Characteristics	Turn-on Switching	Turn-off Switching	$di_T/dt$	$dv_T/dt$	$di_{G1}/dt$	$di_{G2}/dt$
	$t_{don} = 2.5\mu s$ $t_r = 5.0\mu s$	$t_{doff} = 25.0\mu s$ $t_f = 3.0\mu s$	$500A/\mu s$	$1000V/\mu s$	$40A/\mu s$	$40A/\mu s$
On-state Voltage	$V_{T(on-state)} = 4.4V$ at $I_T = 4000A$					
$V_{DRM}$ - Repetitive peak off-state voltage			$V_{RRM}$ - Repetitive peak reverse voltage			
$I_{TGQM}$ - Repetitive controllable on-state current			$I_{TAVM}$ - Maximum average on-state current			
$I_{RRMS}$ - Maximum rms on-state current			Part number - 5SGA 40L4501 (ABB)			

# Integrated Gate Commutated Thyristor (GCT)

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**6500V/1500A Symmetrical GCT**

**GCT = Improved GTO + Integrated Gate + Anti-parallel Diode (optional)**

# Integrated Gate Commutated Thyristor

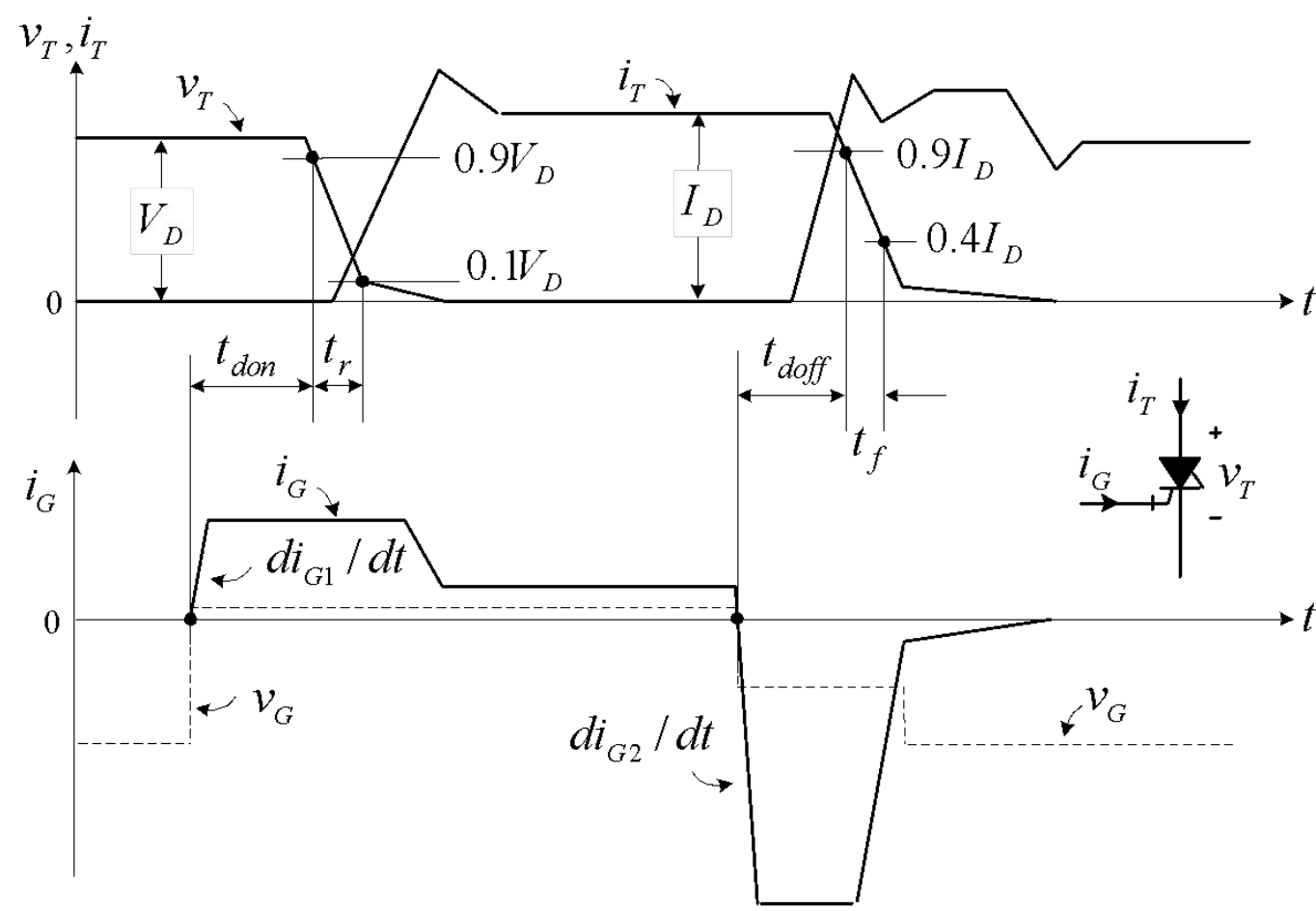
## • GCT Classifications

Type	Anti-parallel Diode	Blocking Voltage	Example (6000V GCT)	Applications
<b>Asymmetrical GCT</b>	Excluded	$V_{RRM} \ll V_{DRM}$	$V_{DRM} = 6000V$ $V_{RRM} = 22V$	For use in voltage source inverters with anti-parallel diodes.
<b>Reverse Conducting GCT</b>	Included	$V_{RRM} \approx 0$	$V_{DRM} = 6000V$	For use in voltage source inverters.
<b>Symmetrical GCT (Reverse Blocking)</b>	Not required	$V_{RRM} \approx V_{DRM}$	$V_{DRM} = 6000V$ $V_{RRM} = 6500V$	For use in current source Inverters.
$V_{DRM}$ - Maximum repetitive peak forward off-state voltage $V_{RRM}$ - Maximum repetitive peak reverse voltage				



# Integrated Gate Commutated Thyristor

- Switching Characteristics



# Integrated Gate Commutated Thyristor

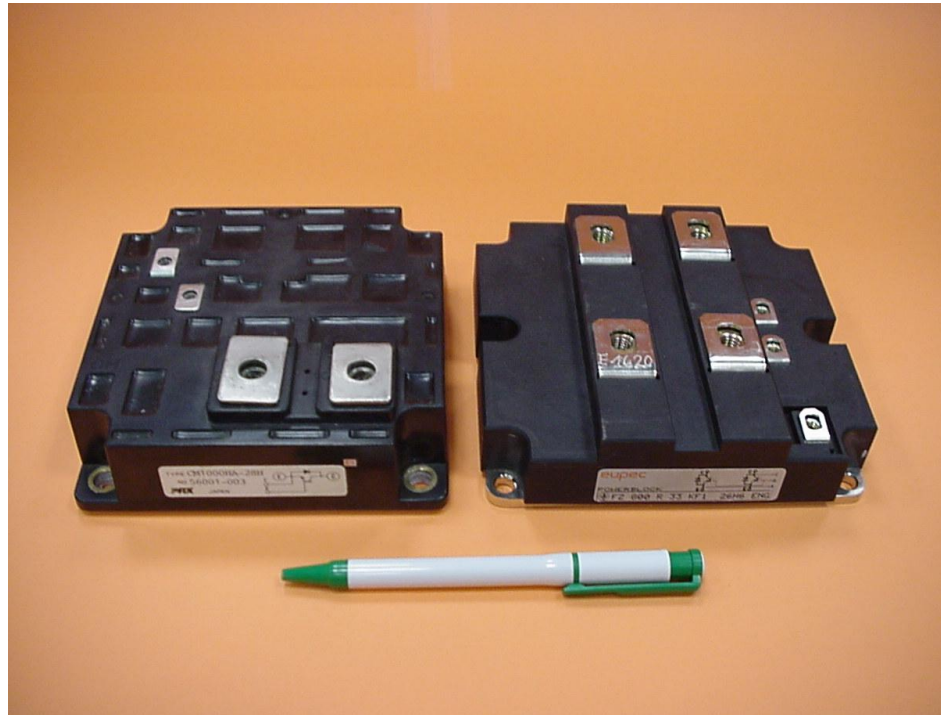
- Main Specifications

## 6000V/6000A Asymmetrical GCT

Maximum Rating	$V_{DRM}$	$V_{RRM}$	$I_{TQRM}$	$I_{TAVM}$	$I_{TRMS}$	-
	6000V	22V	6000A	2000A	3100A	-
Switching Characteristics	Turn-on Switching	Turn-off Switching	$di_T/dt$	$dv_T/dt$	$di_{G1}/dt$	$di_{G2}/dt$
	$t_{don} < 1.0\mu s$ $t_r < 2.0\mu s$	$t_{doff} < 3.0\mu s$ $t_f - N/A$	$1000A/\mu s$	$3000V/\mu s$	$200A/\mu s$	$10,000 A/\mu s$
On-state Voltage	$V_{T(on-state)} < 4V$ at $I_T = 6000A$					
$V_{DRM}$ - Repetitive peak off-state voltage			$V_{RRM}$ - Repetitive peak reverse voltage			
$I_{TGRM}$ - Repetitive controllable on-state current			$I_{TAVM}$ - Maximum average on-state current			
$I_{RRMS}$ - Maximum rms on-state current			Part number – FGC6000AX120DS (Mitsubishi)			

# Insulated Gate Bipolar Transistor (IGBT)

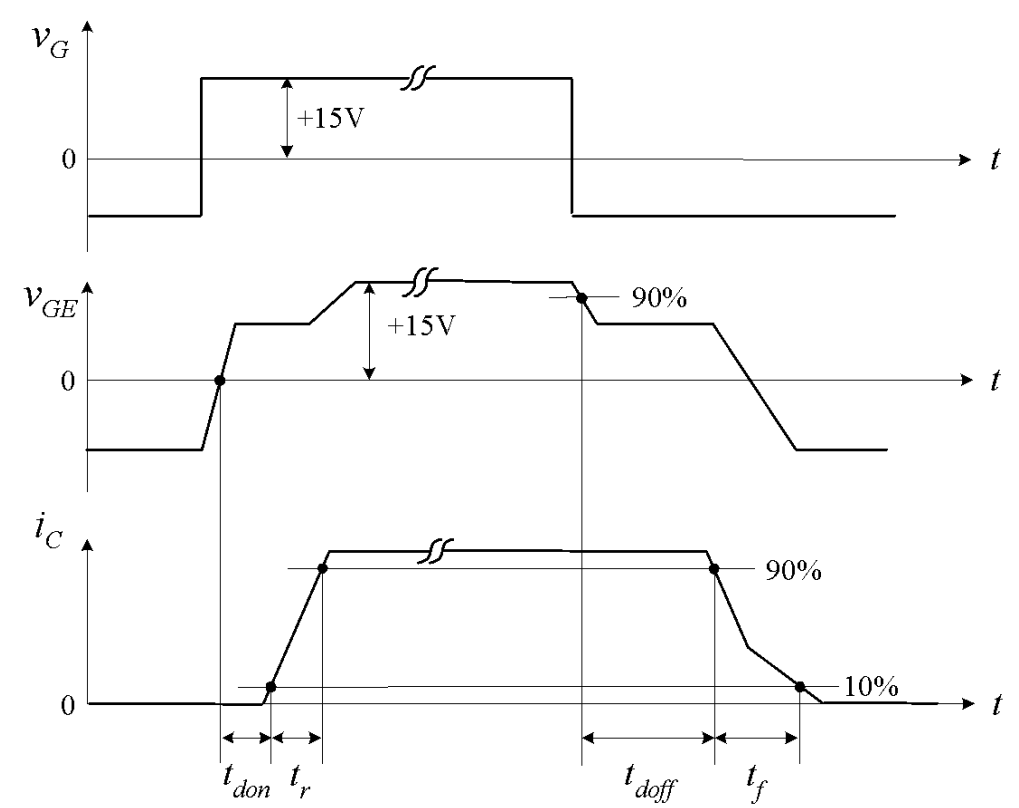
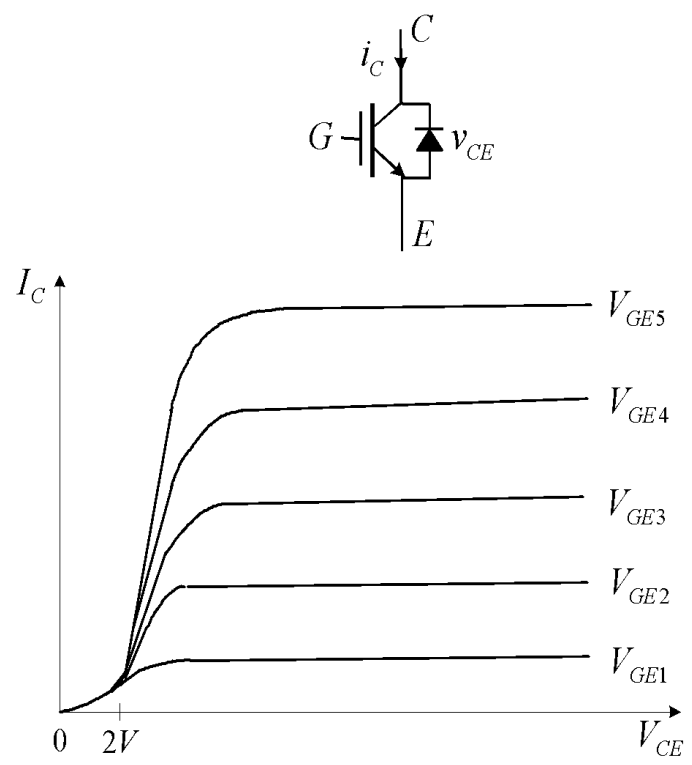
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**1700V/1200A and 3300V/1200A IGBT modules**

# Insulated Gate Bipolar Transistor (IGBT)

- IGBT Characteristics



Static V-I Characteristics

Switching characteristics

# Insulated Gate Bipolar Transistor (IGBT)

## • Main Specifications

### 3300V/1200A IGBT

Maximum Rating	$V_{CE}$	$I_C$	$I_{CM}$	-
	3300V	1200A	2400A	-
Switching Characteristics	$t_{don}$	$t_r$	$t_{doff}$	$t_f$
	$0.35 \mu s$	$0.27 \mu s$	$1.7 \mu s$	$0.2 \mu s$
Saturation Voltage	$I_{CE sat} = 4.3V$ at $I_C = 1200A$			

$V_{CE}$  - Rated collector-emitter voltage

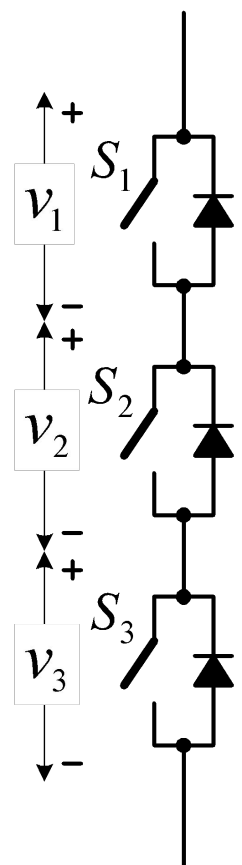
$I_C$  - Rated dc collector current

$I_{CM}$  - Maximum repetitive peak collector current

Part number – FZ1200 R33 KF2 (Eupec)

# Device Series Operation

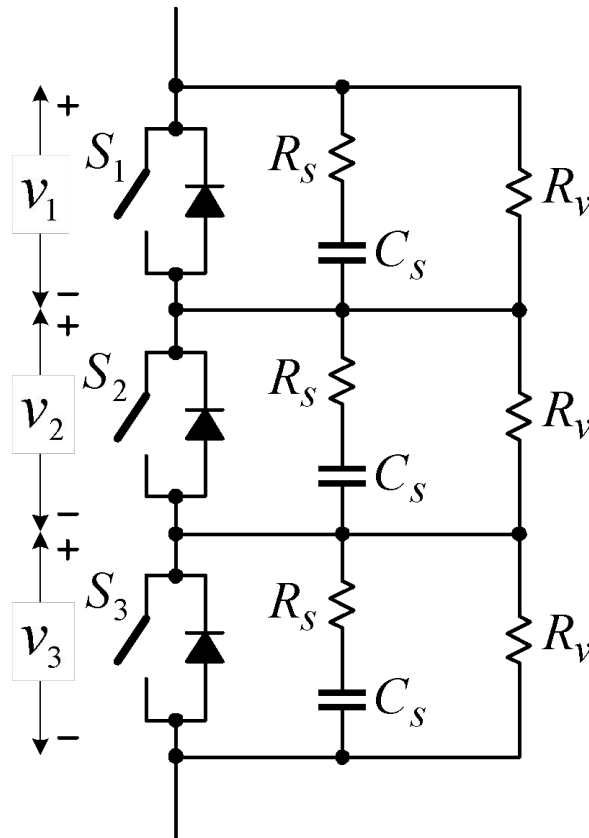
- Cause of Voltage Imbalance



Type	Causes of Voltage Imbalance	
Static Voltage Sharing	$\Delta I_{lk}$ – Device off-state leakage current $\Delta T_j$ – Junction temperature	
Dynamic Voltage Sharing	Device	$\Delta t_{don}$ – Turn-on delay time $\Delta t_{doff}$ – Turn-off delay time $\Delta Q_{rr}$ – Reverse recovery charge of anti-parallel diode $\Delta T_j$ – Junction temperature
	Gate Driver	$\Delta t_{GDon}$ – Gate driver turn-on delay time $\Delta t_{GDoff}$ – Gate driver turn-off delay time $\Delta L_{wire}$ – Wiring inductance between the gate driver and the device gate
	$\Delta$ – Differences between series connected devices.	

# Device Series Operation

## • Equal Voltage Sharing



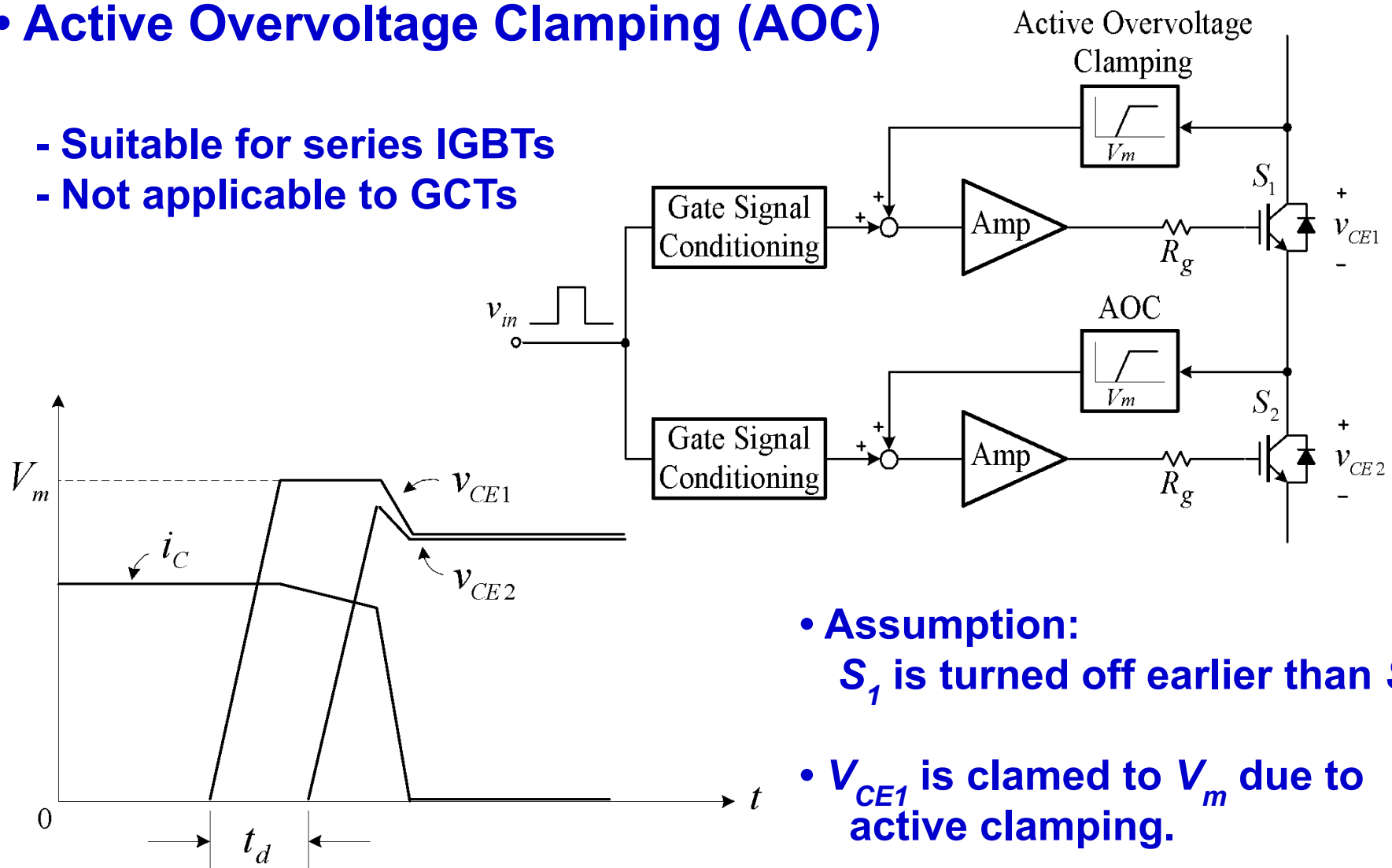
- $S_1, S_2, S_3$ :  
GTO, GCT or IGBT
- Voltage Sharing:  
 $V_1 = V_2 = V_3$  in steady state and transients
- Static Voltage Sharing:  
 $R_v$
- Dynamic Voltage Sharing:  
 $R_s$  and  $C_s$



# Device Series Operation

## • Active Overvoltage Clamping (AOC)

- Suitable for series IGBTs
- Not applicable to GCTs



- Assumption:  
 $S_1$  is turned off earlier than  $S_2$
- $V_{CE1}$  is clamped to  $V_m$  due to active clamping.

# Summary

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Item	GTO	IGCT	IGBT
<b>Maximum switch power (Device <math>V \times I</math>)</b>	<b>36MVA</b>	<b>36MVA</b>	<b>6MVA</b>
<b>Active di/dt and dv/dt control</b>	<b>No</b>	<b>No</b>	<b>Yes</b>
<b>Active short circuit protection</b>	<b>No</b>	<b>No</b>	<b>Yes</b>
<b>Turn-off (dv/dt) snubber</b>	<b>Required</b>	<b>Not required</b>	<b>No required</b>
<b>Turn-on (di/dt) snubber</b>	<b>Required</b>	<b>Required</b>	<b>No required</b>
<b>Parallel connection</b>	<b>No</b>	<b>No</b>	<b>Yes</b>
<b>Switching speed</b>	<b>Slow</b>	<b>Moderate</b>	<b>Fast</b>
<b>Behavior after destruction</b>	<b>Shorted</b>	<b>Shorted</b>	<b>Open in most cases</b>
<b>On-state losses</b>	<b>Low</b>	<b>Low</b>	<b>High</b>
<b>Switching losses</b>	<b>High</b>	<b>Low</b>	<b>Low</b>
<b>Gate Driver</b>	<b>Complex, separate</b>	<b>Complex, integrated</b>	<b>Simple, compact</b>
<b>Gate Driver Power Consumption</b>	<b>High</b>	<b>High</b>	<b>Low</b>



# Thanks