Aalto University
School of Engineering

Power Electronics

ELEC-E8412 Power Electronics, 5 ECTS

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Course Objectives

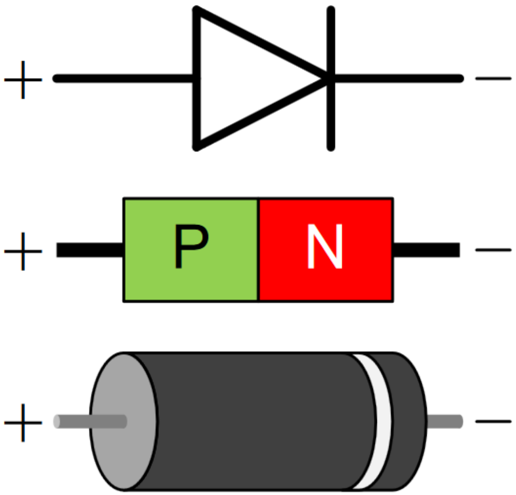
At the end of this chapter, you will be able to:

- Describe the operation of different Power Electronic Components (Diode, Thyristor (SCR), MOSTFET, and IGBT)
- Find the right component based on the application

Introduction of Power Electronic Devices

1. Diodes:

A diode is the simplest electronic switch. It is uncontrollable in that the ON and OFF conditions are determined by voltages and currents in the circuit.



- Comparing to Signal Diodes
  - More complicated structure
  - Much higher V and I ratings
- Used in power processing
  - Lower frequency response
  - Higher on-state voltage (forward voltage, VF)

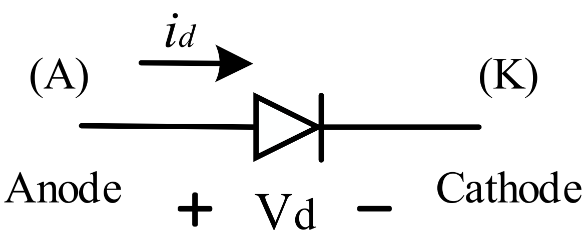


Figure 2-1: schematic diagram of an Ideal Diode.

Introduction of Power Electronic Devices

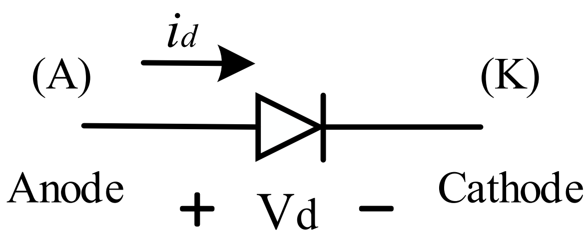
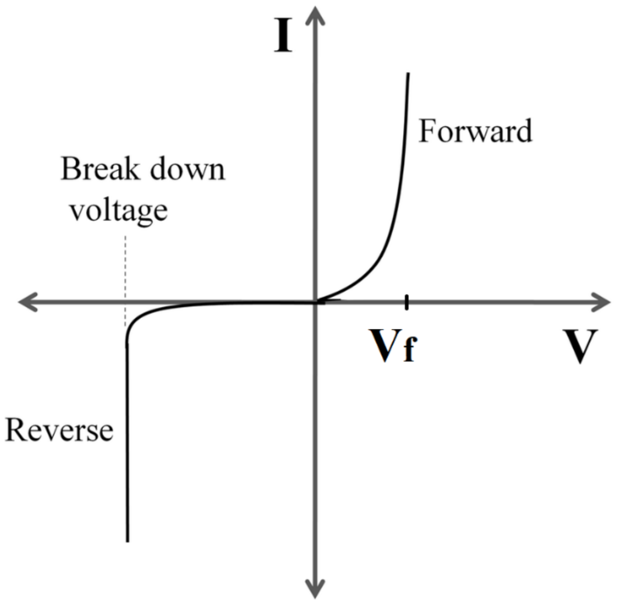
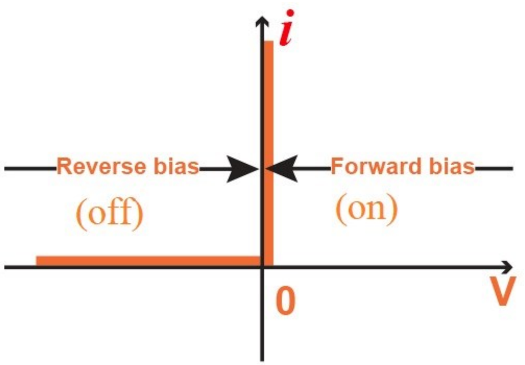


Figure 2-1: schematic diagram of an Ideal Diode.



(a)



(b)

$$\text{In an ideal diode } = \begin{cases} V_d = 0 \text{ if } i_d \geq 0 \\ i_d = 0 \text{ if } V_d \leq 0 \end{cases}$$

Figure 2-2: The current-voltage characteristic curve of: (a) non-ideal (real), (b) ideal diodes.

Introduction of Power Electronic Devices

2. Thyristor or SCR (Silicon Controlled Rectifier):

Thyristors are electronic switches used in some power electronic circuits where control of switch turn-on is required.

- Developed in 1960s
- Switched on by a short injecting gate current pulse
  - Firing or Triggering (**Triggering** means sending an impulse of current into the gate)
- Switched off when reverse biased
- Ratings up to 5kV and 4000A
  - Very high power applications
- Slow response
  - fs< 1kHz

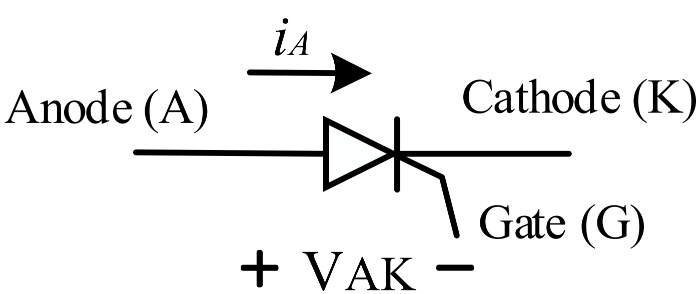
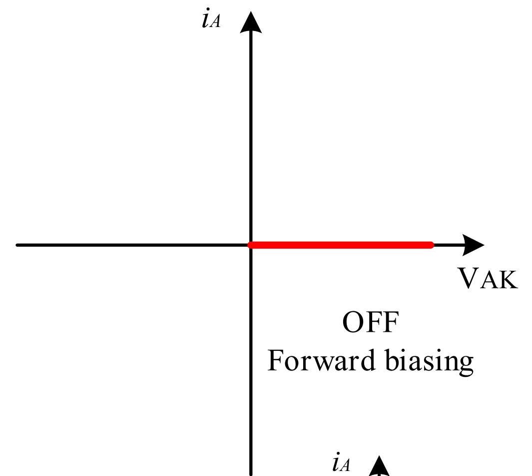
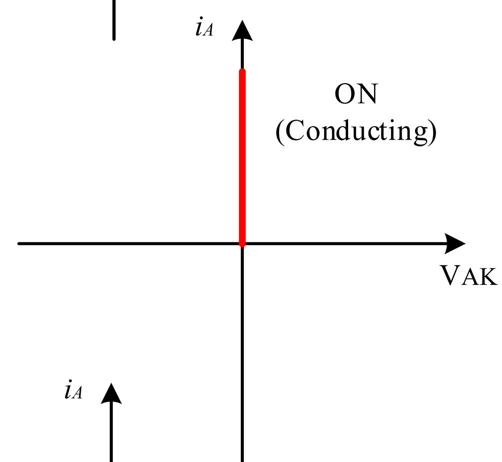


Figure 2-4: schematic diagram of Thyristor.

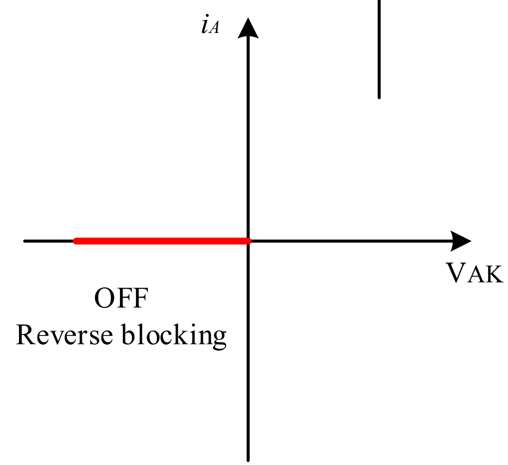
Introduction of Power Electronic Devices



- If we have not sent any signal to the gate (not triggered), Thyristor will be off and the current is zero. This region is called as forward biasing.



- If we send a signal to the gate (trigger), Thyristor will be ON and the voltage will be zero.

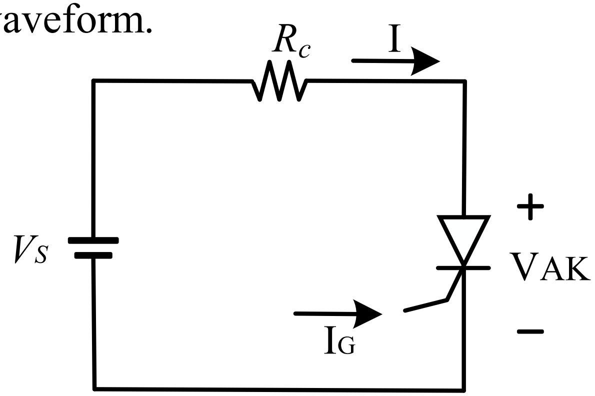


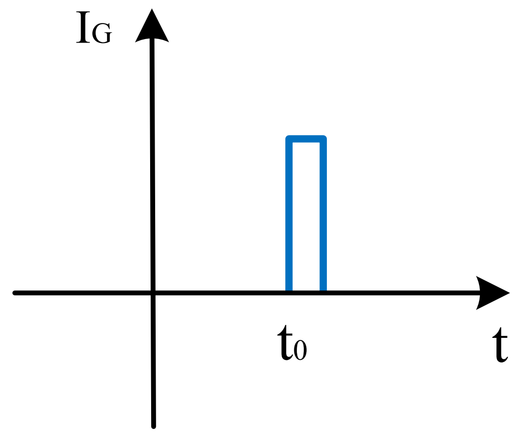
- If we do not apply any gate signal it can also block negative voltage.

❖ A Thyristor is going turn off when it's current is back to zero.

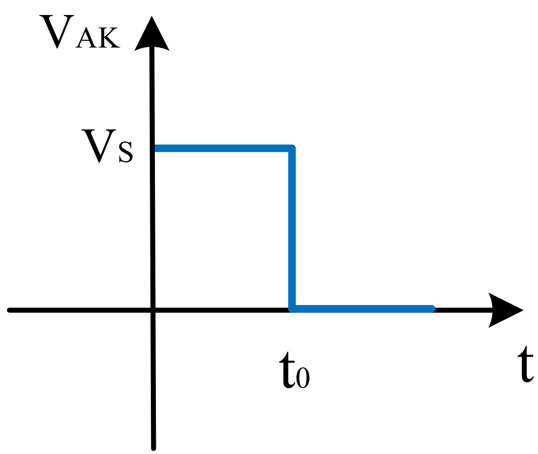
Introduction of Power Electronic Devices

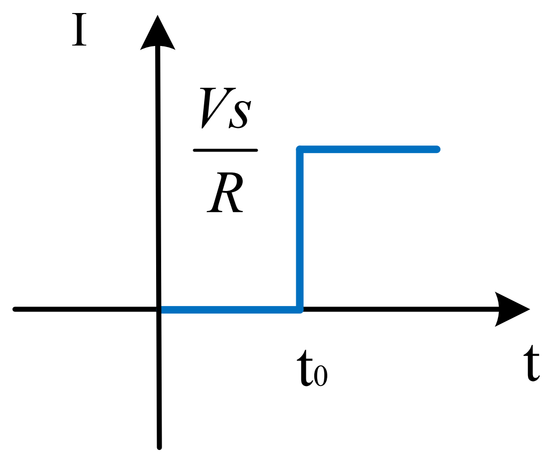
Example: At the following circuit, the gate was triggered at t_0. Draw the voltage and current waveform.





Solution:

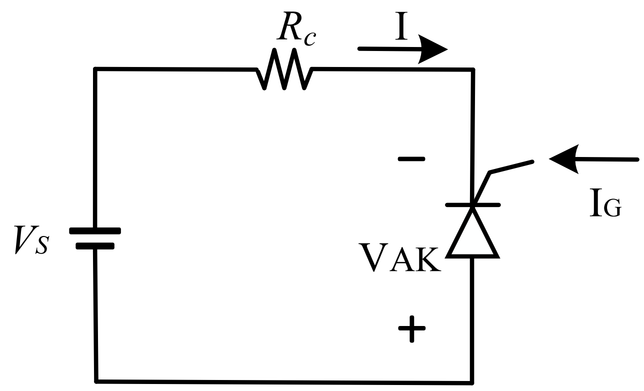


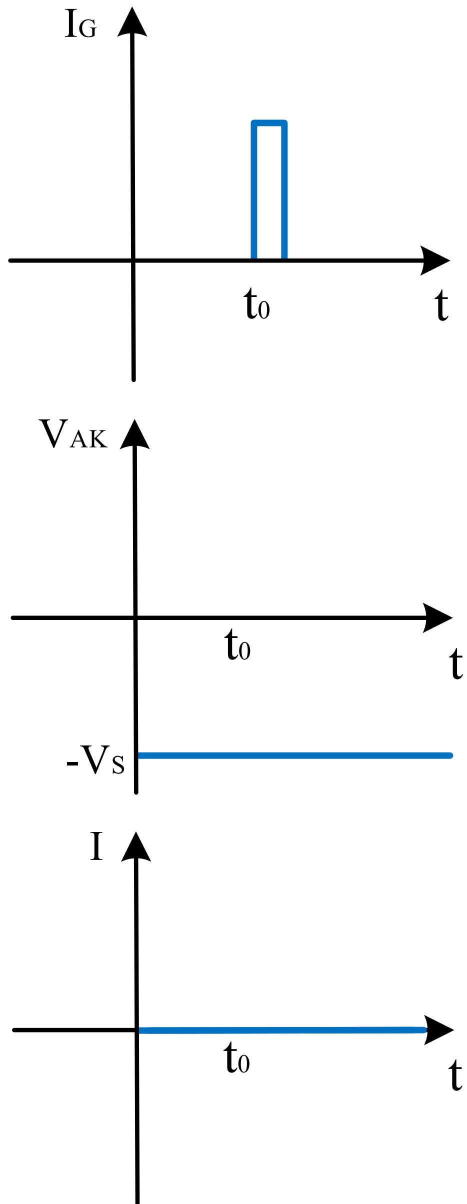


- ❖ As the source is a DC source, this will continue for ever without to have possibility to turn it off. In other word, if the current conducting positive, the conduction will continued for ever unless the situation change and current comes back to the zero value.

Introduction of Power Electronic Devices

Example: At the following circuit, the gate was triggered at t_0. Draw the voltage and current waveform.





Solution:

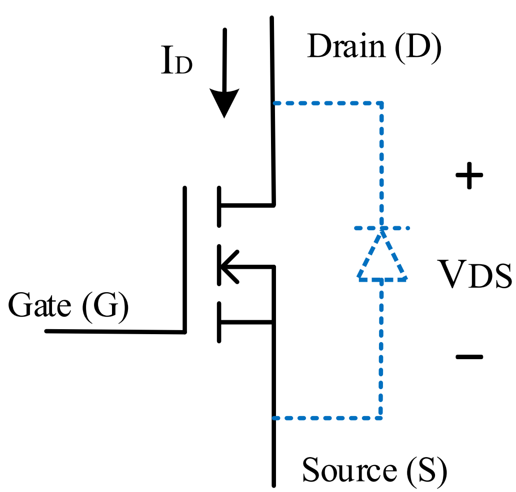
- Before t_0, Thyristor is off, and it is blocking some negative voltage. As it is in reverse blocking mode, it never turned on, therefore, V_{AK} will be always -Vs. In addition, the current will be always equal to zero.

- A Thyristor is turned on by applying a gate current while it is in the forward blocking state. Once Thyristor is turned on, the device continues to conduct even if the gating signal is removed. The Thyristor will continue to conduct as long as the current remains positive.

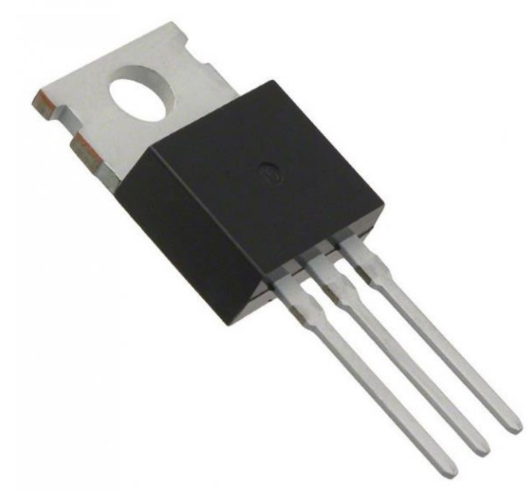
Power Transistors

3. Power MOSTFET:

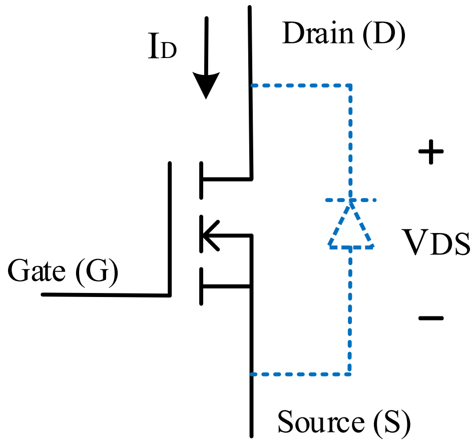
- Metal Oxide Silicon Field Effect Transistor
- Developed in early 1980s
- Controlled by gate-to-source voltage (VGS)
  - Gate Signal, 10V to 18V, typically 15V
- Ratings up to 1000V and 2000A
  - High current low voltage applications
  - SMPS, battery chargers
- Very fast response
  - fs < 1MHz, higher for soft-switching
- Bidirectional and resistive conduction characteristics

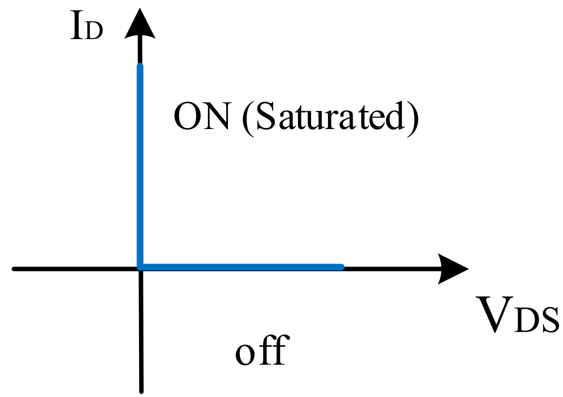


Schematic diagram of MOSTFET

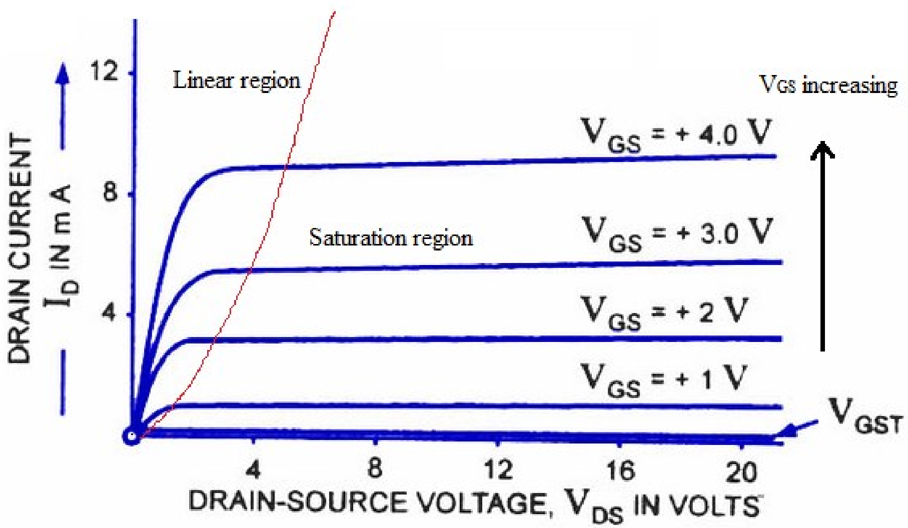


Power Transistors





Ideal MOSTFET



Real MOSTFET

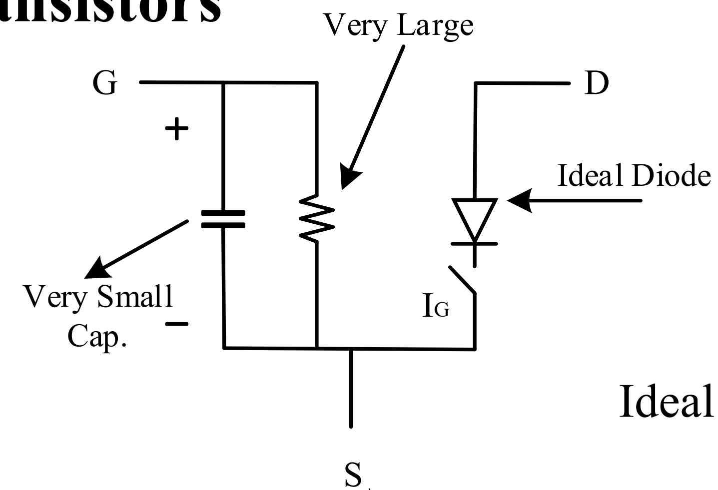
$$\begin{cases} \text{if } V_{GS}>V_T & \Rightarrow \text{ Switch is ON } \Rightarrow V_{DS}=0 \\ \text{if } V_{GS}<V_T & \Rightarrow \text{ Switch is off } \Rightarrow I_D=0 \end{cases}$$

V_T: Threshold Voltage

V_T depends on what kind of MOSTFET is used, and its value normally appeared in datasheets. The maximum value of VT is 5V.

Power Transistors

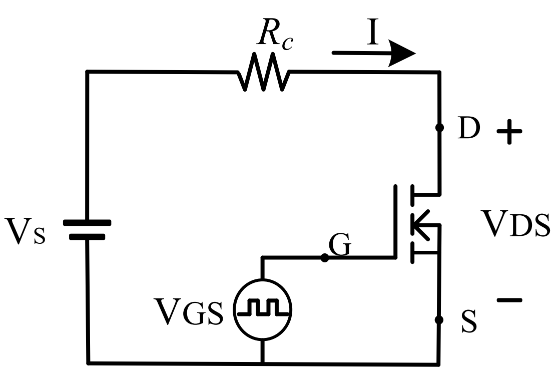
Circuit Model of MOSTFETs:



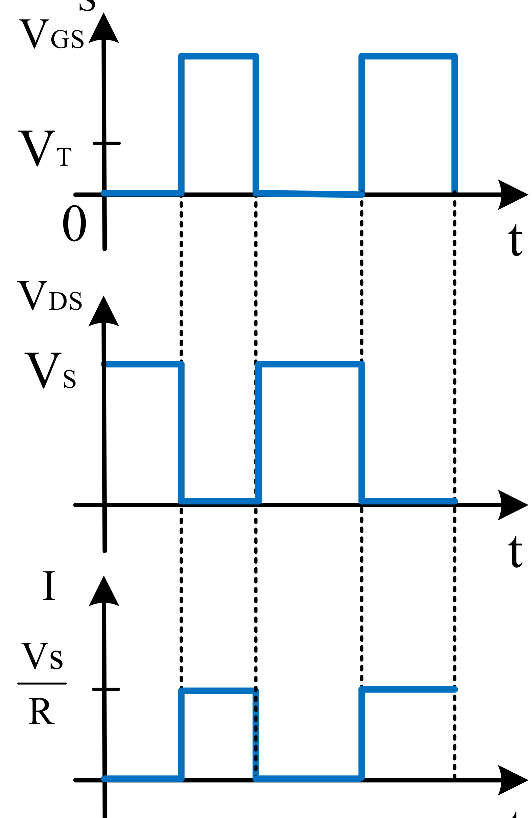
Ideal model

- The value of capacitor and resistor is mentioned in datasheet of MOSTFET.
- Switch is ON/OFF based on the logic mentioned in pervious page.

Example: Find the V_{DS} and the current of MOSTFET.



Solution: At t= 0 sec $V_{GS} < V_T$, therefore, switch is off and there is no current passing through the switch.
As soon as a voltage applied to the GS reach bigger than V_T, the device will be turned on. Therefore, it behaves like short circuit.



Power Transistors

4. IGBT:

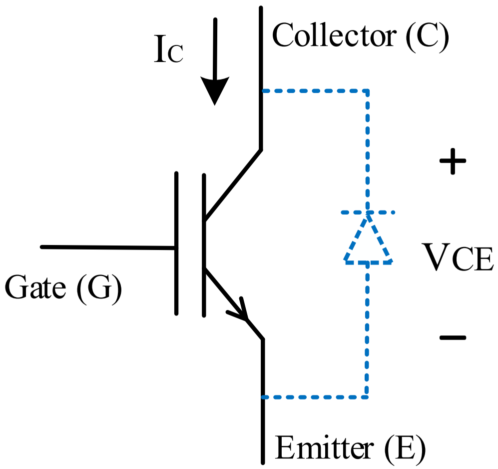
- Insulated Gate Bipolar Transistor
- Developed in late 1980s
- Controlled by gate-to-emitter voltage (VGE)

  - Same as MOSFET
- Ratings up to 3500V and 2000A

  - Medium to high power applications up to 200kW

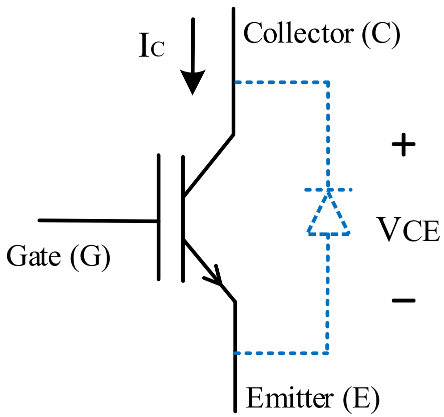
  - Popular in Motor drives
- On-state voltage 1.7V to 3V
- Fast response

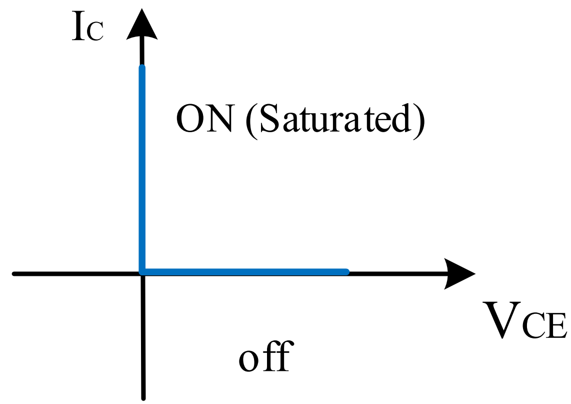
  - Typically fs< 40kHz, faster for some models



Schematic diagram of IGBT

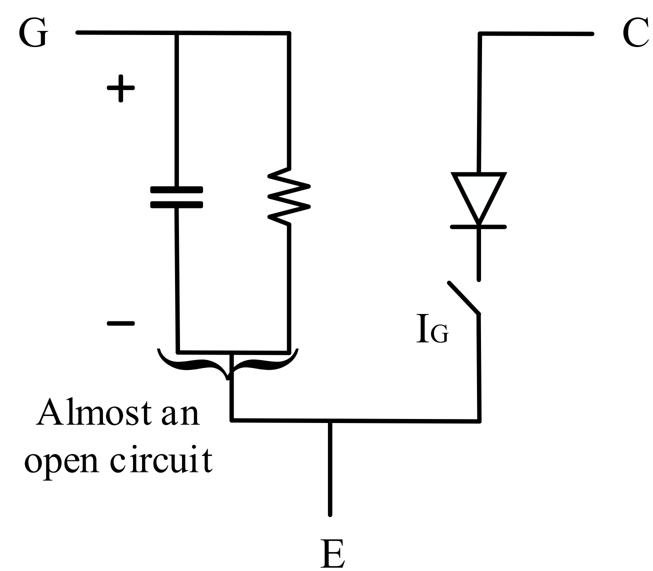
Power Transistors





Ideal IGBT

$$\begin{cases} \text{if} \quad V_{GE} > V_T \quad \Rightarrow \quad \text{Switch is ON} \quad \Rightarrow \quad V_{CE} = 0 \\ \text{if} \quad V_{GE} < V_T \quad \Rightarrow \quad \text{Switch is off} \quad \Rightarrow \quad I_C = 0 \end{cases}$$



Ideal Model

Power Transistors

- From our point of view power MOSTFETs and IGBTs are equal, however here are the differences.

	Switching Frequency	Maximum Voltage Rating (Vs)	Maximum Current rating
MOSTFET	Very High	1 kv	150 A
IGBT	High	5 kv (or more)	2 kA

- Power Switches all together

	Diode	SCR	MOSTFET	IGBT
Controlled turn on	X	✓	✓	✓
Controlled turn off	X	X	✓	✓
Continuous gate signal requirement	—	X	✓	✓
Bidirectional current capability	X	X	?	X

Questions and comments are most welcome!