University of Glasgow

Power Electronics

Lecture 3

Power Switches

For Switching Power Conversion

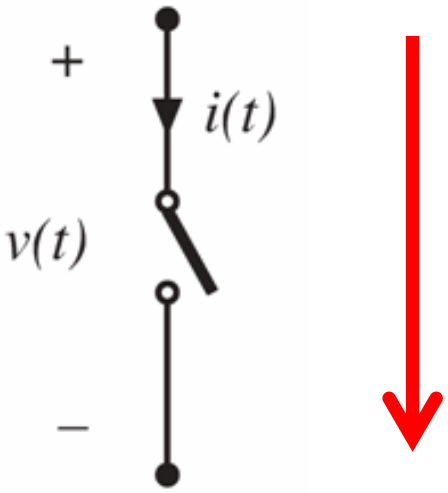
Please read

pages 16-31 in Chapter 2

Pages 546-661 Chapter 21-26

of the textbook

Ideal Semiconductor Power Switches



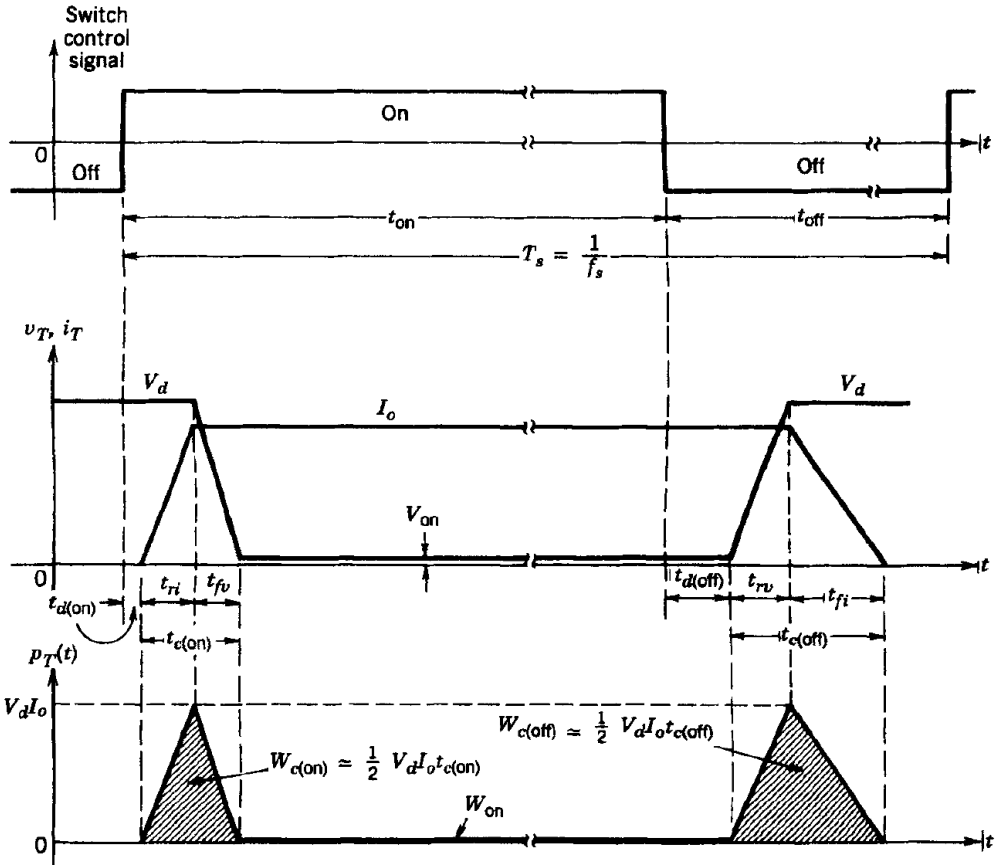
General Switch

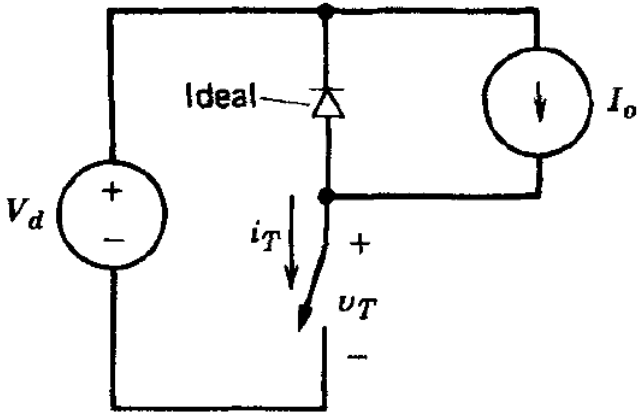
1. Unidirectional current flow
2. Zero on-state voltage drop
3. ∞ Voltage/Current rating
4. Instantaneous switching on/off

Constraints of Actual Power Switch

- Power Losses ⟶ **The smaller, the better**
  - Conduction loss due to voltage drop V_{on} >0
  - Switching loss due to switching on/off time $t_{c(on)}$, $t_{c(off)}$ >0
- Limited Power Rating （等级）⟶ **The larger, the better**
  - Limited voltage/current rating
  - Limited dv/dt and di/dt
- Driver Circuit ⟶ **The easier & more efficient, the better**
  - Specific driver circuit for device's switching on/off
- Thermal Management ⟶ **The tougher, the better**
  - Limited operation temperature range

Generic-Switch Power Loss





Turn-on On-State Turn-off

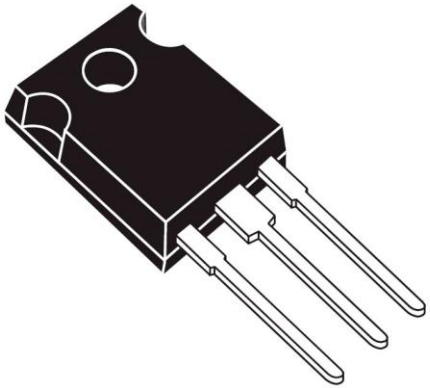
Total Power Loss:

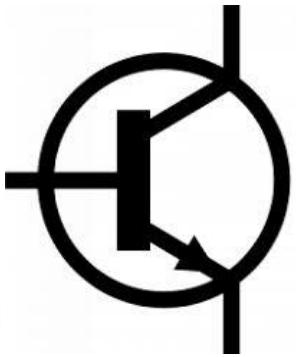
$$P_s = \frac{1}{2} V_d I_o f_s \left(t_{c(on)} + t_{c(off)} \right) + P_{on} = V_{on} I_o \frac{t_{on}}{T_s} = V_{on} I_o f_s t_{on}$$

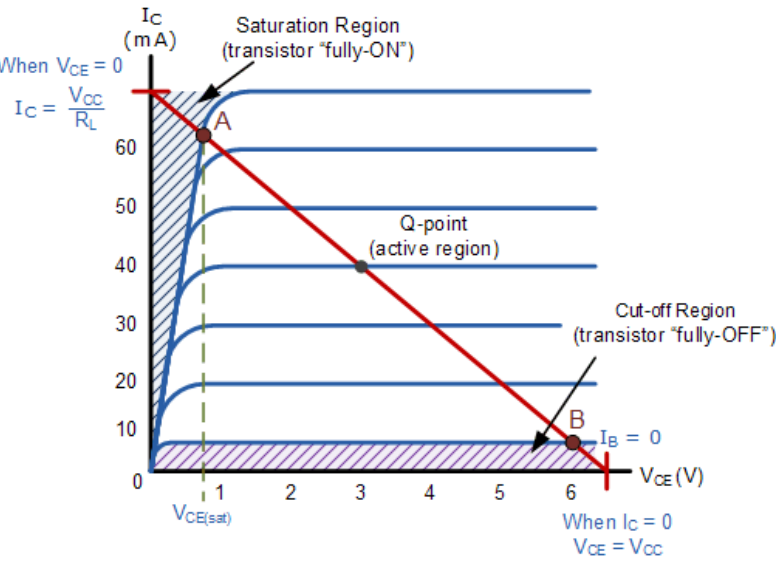
Switching Power Loss — Conduction Power Loss

$t_{c(on)}, t_{c(off)} \to 0 \Rightarrow$ faster switching capability; $V_{on} \to 0 \Rightarrow$ higher efficiency

(Semiconductor) Transistor Switch



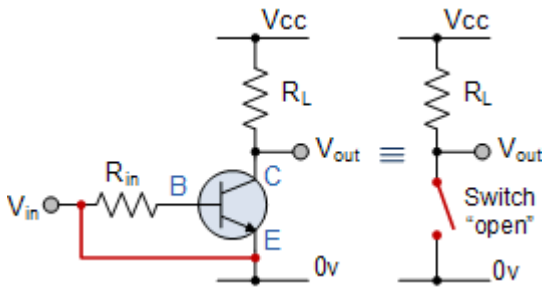


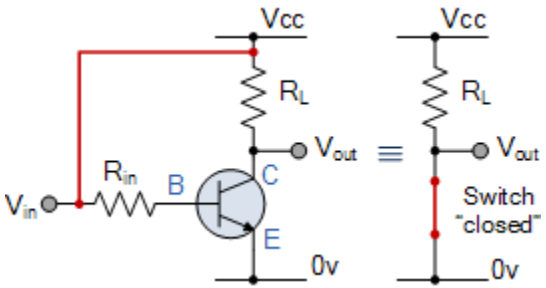


As an amplifier, the transistor operates in amplification region;

As a switch, the transistor operates in saturation region for the reduction of conduction voltage drop V_{on};

Of Course, unlike transistor amplifiers, the transistor switches are specifically designed and manufactured to behave like an ideal switch – fast, efficient, easy for drive…..

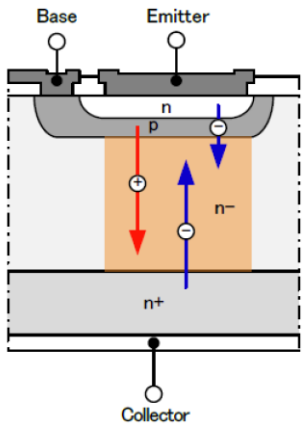
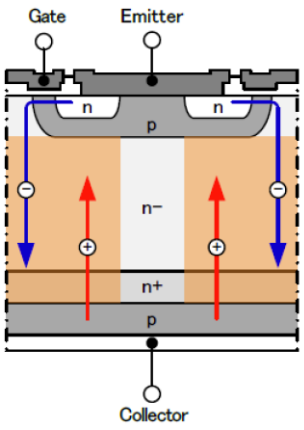
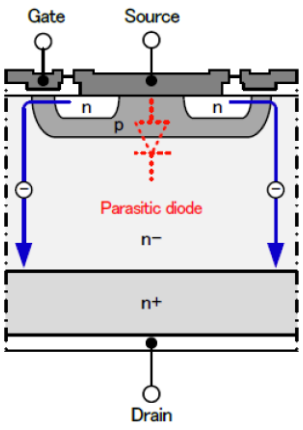




Switches Classification I

- Controllability (可控性）
  - Uncontrollable: Power Diode
  - Semi-controllable: Thyristor
  - Fully-controllable: GTR(Giant transistor), MOSFET, IGBT(Insulated Gate Bipolar Transistors), GTO(Gat turn-off transistor) …
- Driving Method （驱动方式）
  - Voltage drive: MOSFET, IGBT, MCT(MOS-controlled thyristor)
  - Current drive: GTR, GTO, Thysistor
- Carriers （载流子）
  - Unipolar: MOSFET, Schottky （肖特基） Diode
  - Bipolar: GTR, Thyristor, GTO
  - Hybrid: IGBT, MCT（MOS Controlled Thyristor)

Basic Transistor Structure Comparison

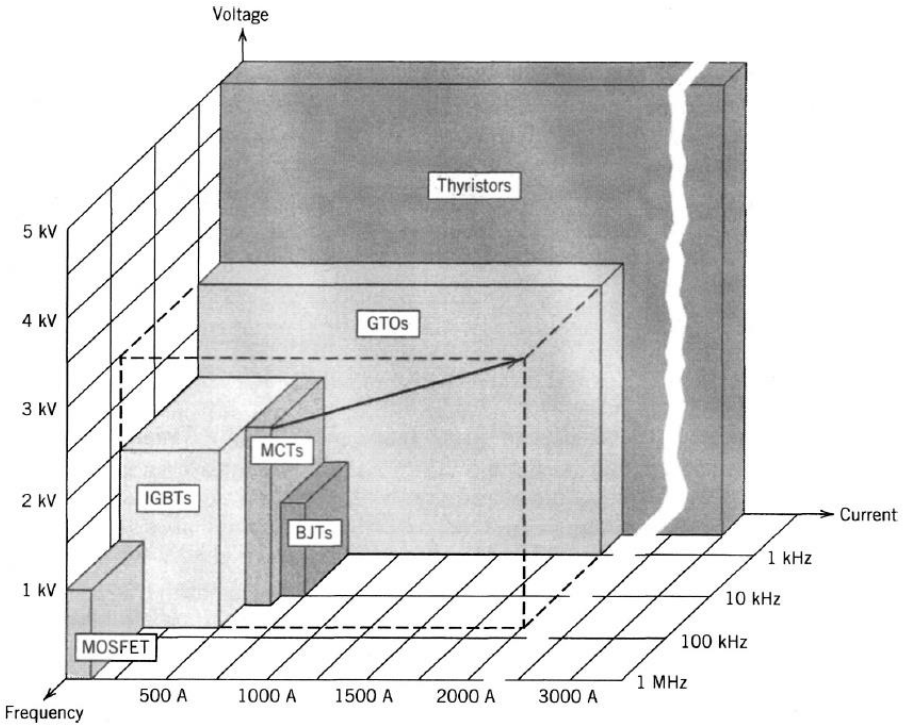
		Bipolar Transistor	IGBT	Power MOSFET
Structure				
Charact eristics	Carriers	Electrons and holes	Electrons and holes	Electrons only
	Drive capability	High	Low	Low
	High current	○	◎	×
	Operating frequency	Low	A few KHz～20KHz	Several 10KHz～300KHz

- **Voltage drive** : High input impedance, low required driving power, simple drive circuit, high operating frequency
- **Current drive** : conductance modulation effect, low on-state voltage , low conduction loss , low operating frequency, high required driving power, complicated driving circuit .

Switches Classification II

- Rating （等级）
  - Voltage/current, switching frequency
- Material
  - Silicon, SiC (Silicon Carbide), GaN
- Package/Integration
  - HVIC (high voltage IC), SPIC (smart power IC), IPM (intelligent power module)

封装



Power Semiconductor Switches

Uncontrolled

(SCR)

Partially Controlled

Invention of Thyristor

晶闸管

Application of fast-switching fully-controlled semiconductor devices

Smarter

High Power

High Frequency

Easy Control

Cost-effective

High Efficiency

Mercury arc rectifier
Vacuum-tube rectifier
Thyratron

Power diode
Thyristor

GTO
GTR
Power MOSFET
Thyristor
(microprocessor)

IGBT
Power MOSFET
Thyristor
(DSP)

SiC

GaN

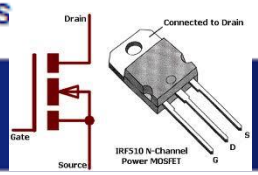
devices

1900

1957

mid 1970s

late 1980s



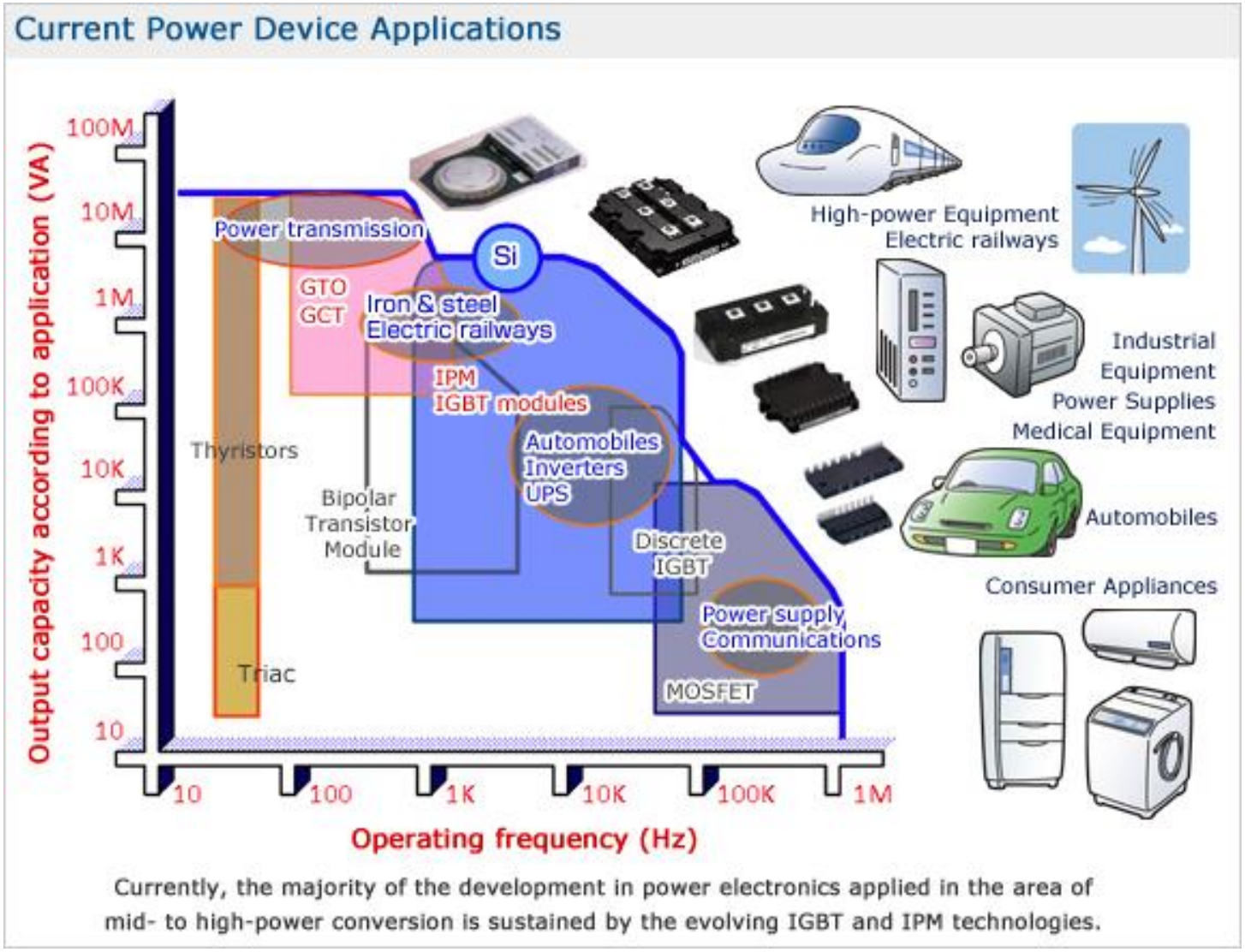
Pre-history

1st phase

2nd phase

3rd phase

The break-through and evolution of power switch devices benchmark the history of power electronics.



There is a trade-off among voltage, current and frequency for power switches.

Towards Faster, Higher Power, More Efficient and Smart Power Switches

The integrated gate-commutated thyristor (**IGCT**)

IGCT

Faster, More Efficient “GTO”

Intelligent Power Module

Silicon Carbide 碳化硅

GaN 氮化镓

Smaller, Faster, Tougher

SiC is used in semiconductor electronics devices that operate at high temperatures or high voltages, or both

Typical Power Switches.

There are several different electronic devices used for switching appreciable amounts of electrical power. Those to be examined in the next two lectures are:

1.Power Diodes 电力二极管 (uncontrolled)

2.Thyristors (Silicon Controlled Rectifiers; SCRs) 晶闸管 (half-controlled)

3. GTOs (Gate turn-off Thyristors) 可关断晶闸管 (fully controlled)

4. TRIACs (triode for alternating current) & Solid State Relays (SSRs) 双向晶闸管与固态继电器

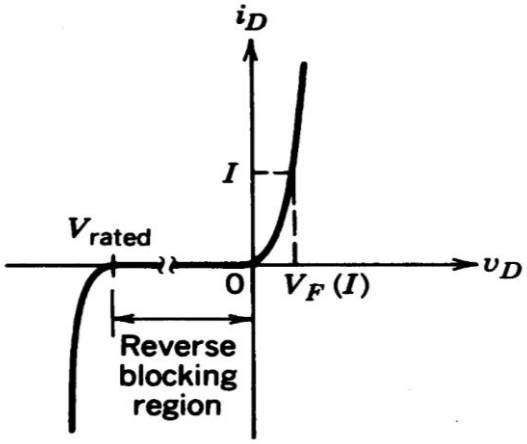
5. MOSFETs (Metal Oxide Semiconductor Field Effect Transistors) (fully controlled)

6. GTR (Giant Transistor)大功率晶体管 (fully controlled)

7. IGBT (Insulated Gate Bipolar Transistors) 绝缘栅极双极性晶体管 (fully controlled)

Pictures courtesy of International Rectifier

Practical Considerations for Switch Selection:



I.How much control do we have (or need)?

→ Controllability

I.How much voltage will it drop when on?

→ Conduction Resistance

I.How much voltage can it block 阻断 when off?

→ Voltage Rating

I.How much current can it carry承受?

→ Current Rating

I.How long does it take to turn on and off?

→ Switching Frequency