1. Power Transistors

2. DC–DC Converters

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1.0 Outline – Power Transistors

- Power Electronic Devices
- Power Transistors
  - Power BJT
  - Power MOSFET
  - IGBT
- Comparison

Power semiconductor devices

Important feature

Controllability

- Power Diode – uncontrollable
- Thyristor (THYRatron tube & transISTOR)
  - **SCR (Silicon Controlled Rectifier)** – ON controllable
  - TRIAC (Triode ac switch) – ON controllable
  - GTO (Gate turn-off thyristor) – **ON/OFF controllable**
- Power Transistors – **ON/OFF controllable**
  - Power BJT
  - Power MOSFET
  - IGBT

Static induction transistor (SIT)

Not required

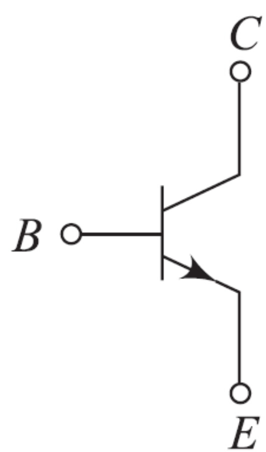
1.0 Power Transistors

- Feature:
  - Fully-controllable: The transistor remains in the ON-state as long as the control signal is present. When this control signal is removed, the power transistor is turned OFF.

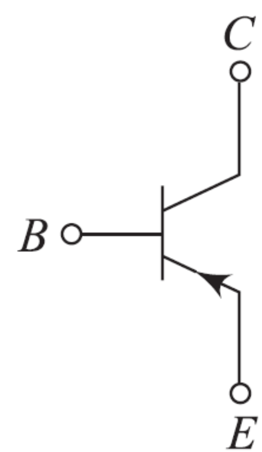
- Applications
  - In use from 1980s
  - GTR and GTO are seldom in use today
  - IGBT and power MOSFET are the two major power semiconductor devices nowadays

1.1 Power BJT (Bipolar Junction Transistor)

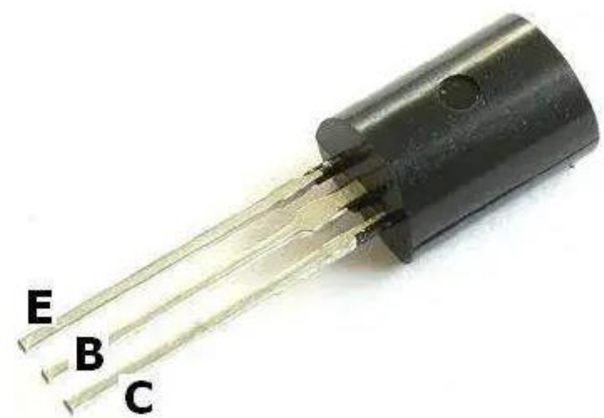
- Three terminals – collector (C), emitter (E), and base (B).
- Emitter with an *arrowhead* indicates the *direction* of emitter current.
- Three layer, two junction *NPN* or *PNP* semiconductor device.
- NPN type transistors are easy to manufacture, cheaper and very wide in high-voltage and high-current applications.
- *Bipolar* – the current flow in the device is due to the movement of both holes and electrons.



NPN type

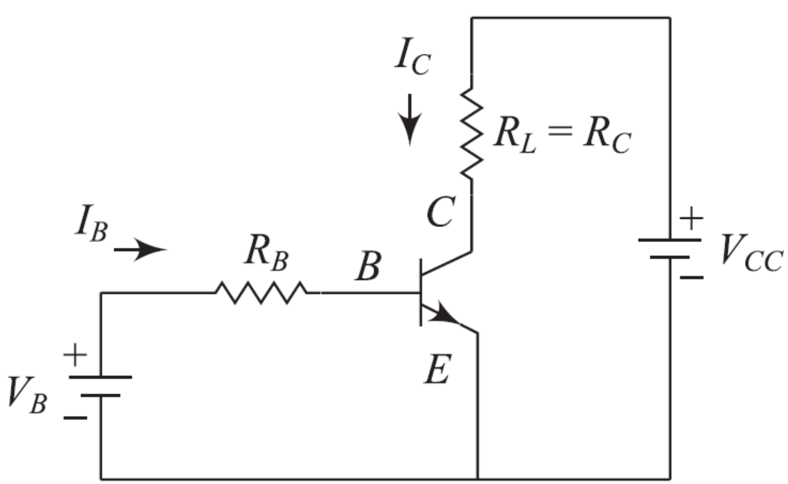


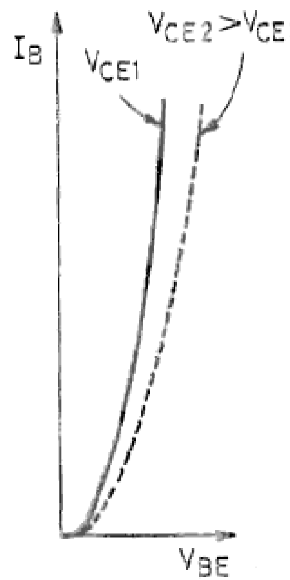
PNP type



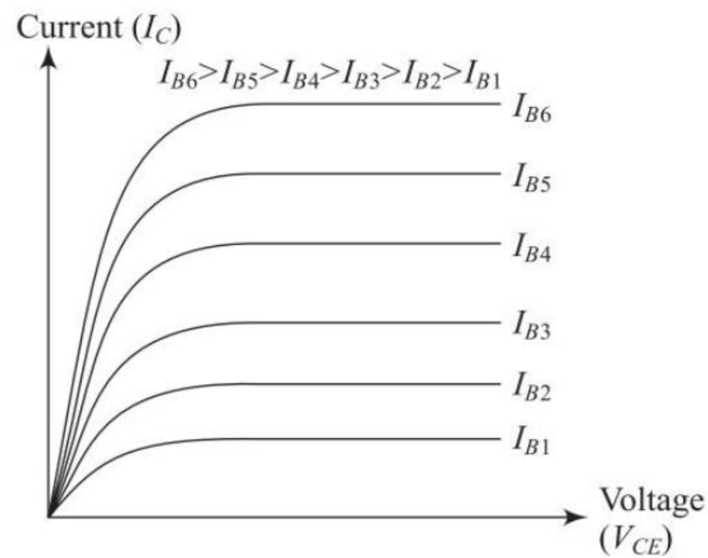
BJT I-V Characteristics

- Common-emitter (CE) is more common in switching applications.
- <u>Output characteristics</u>: Collector current (I_C) versus collector-emitter voltage (V_{CE}).
- For $I_B = 0$, as V_{CE} is increased, a small leakage current exists.
- As the base current is increased from $I_B = 0$ to I_{B1}, I_{B2} etc., collector current also rises as shown below:





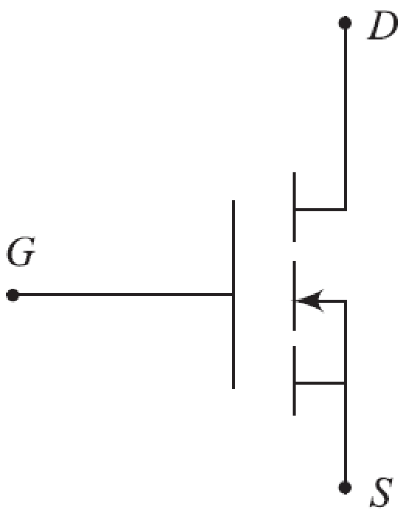
Input characteristics



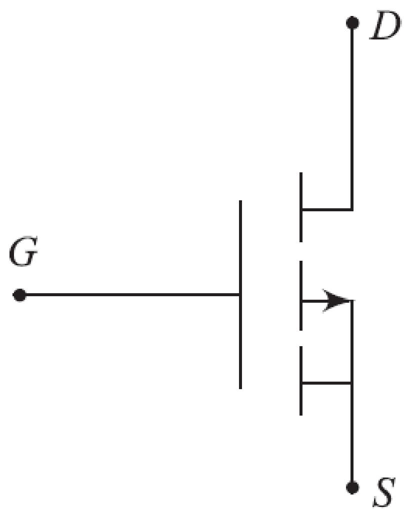
Output characteristics

1.2 Power MOSFET

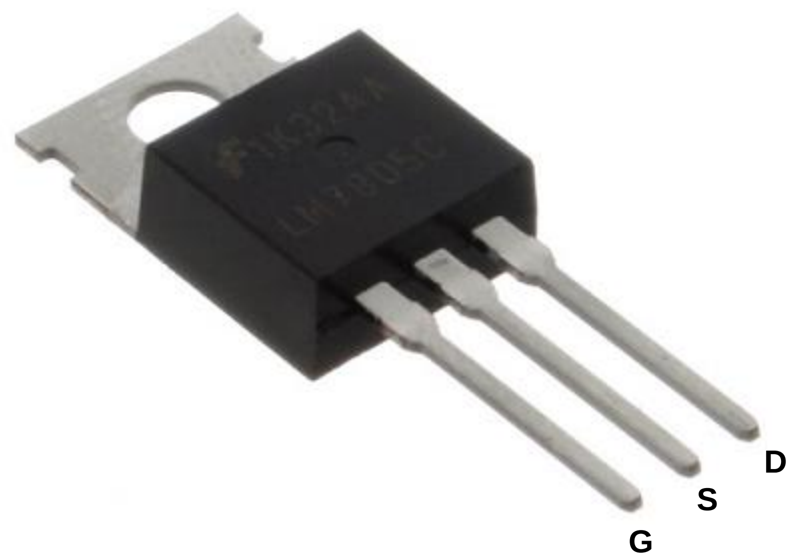
- Three-terminals – drain (D), source (S), and gate (G).
- Arrow indicates the direction of electron flow.
- BJT is current-controlled device whereas MOSFET is a voltage-controlled device.
- MOSFETs are used in low-power high-frequency converters.



n –channel MOSFET

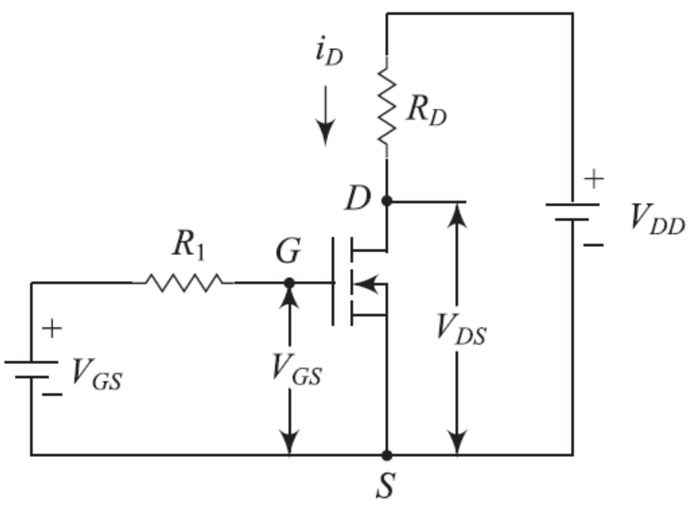


p –channel MOSFET

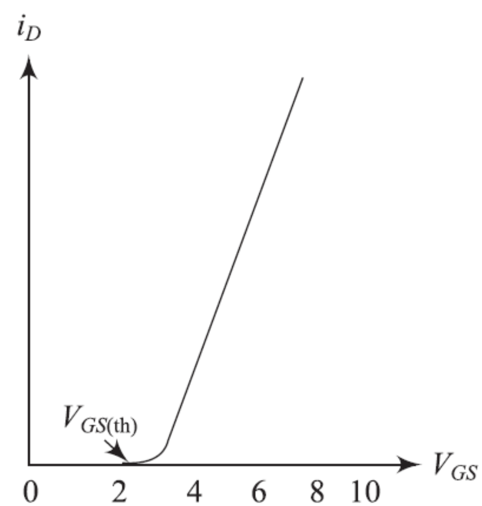


MOSFET I-V Characteristics

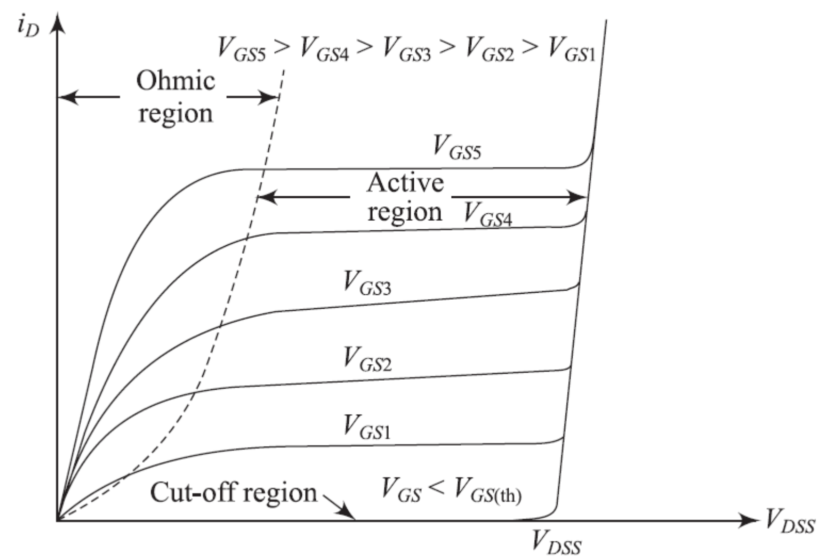
- Input signal V_{GS} is applied across gate to source & output signal V_{DS} is obtained from drain. Source terminal (S) is common between input & output of a MOSFET.
- *Transfer characteristics:* I_D is a function of V_{GS}. When $V_{GS} < V_{GS(th)}$, the current flow from D to S is zero. In general, the value of $V_{GS(th)}$ is about 2 to 3 V.
- *Output characteristics:* I_D is a function of V_{DS} with V_{GS} as a parameter. For given V_{GS}, if V_{DS} is increased, output characteristic is relatively flat indicating that drain current is nearly constant. It consists of cut-off, active and ohmic regions.



n −channel MOSFET



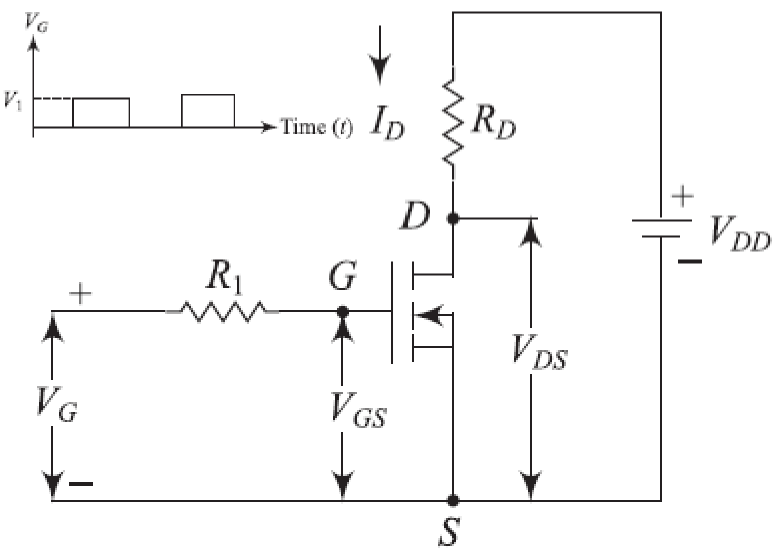
Transfer characteristics

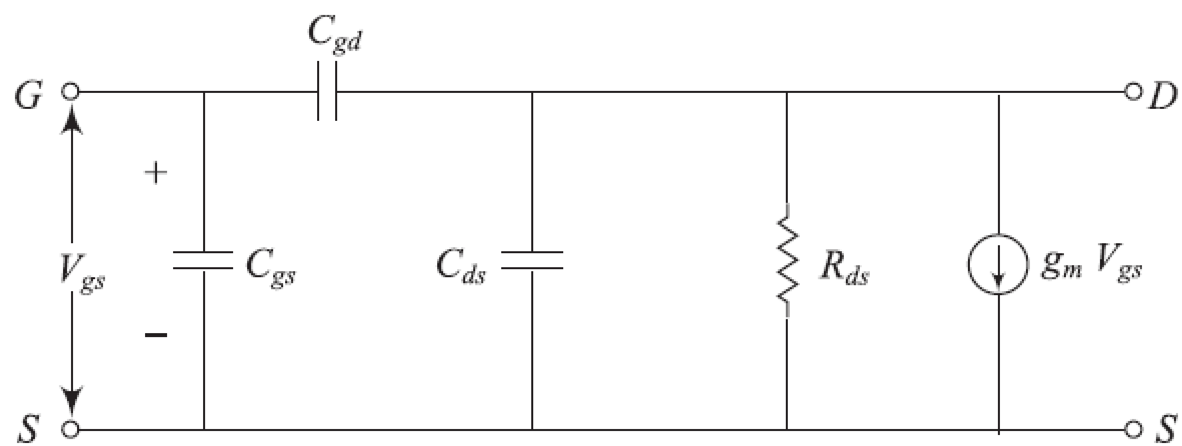


Output characteristics

Switching Characteristics

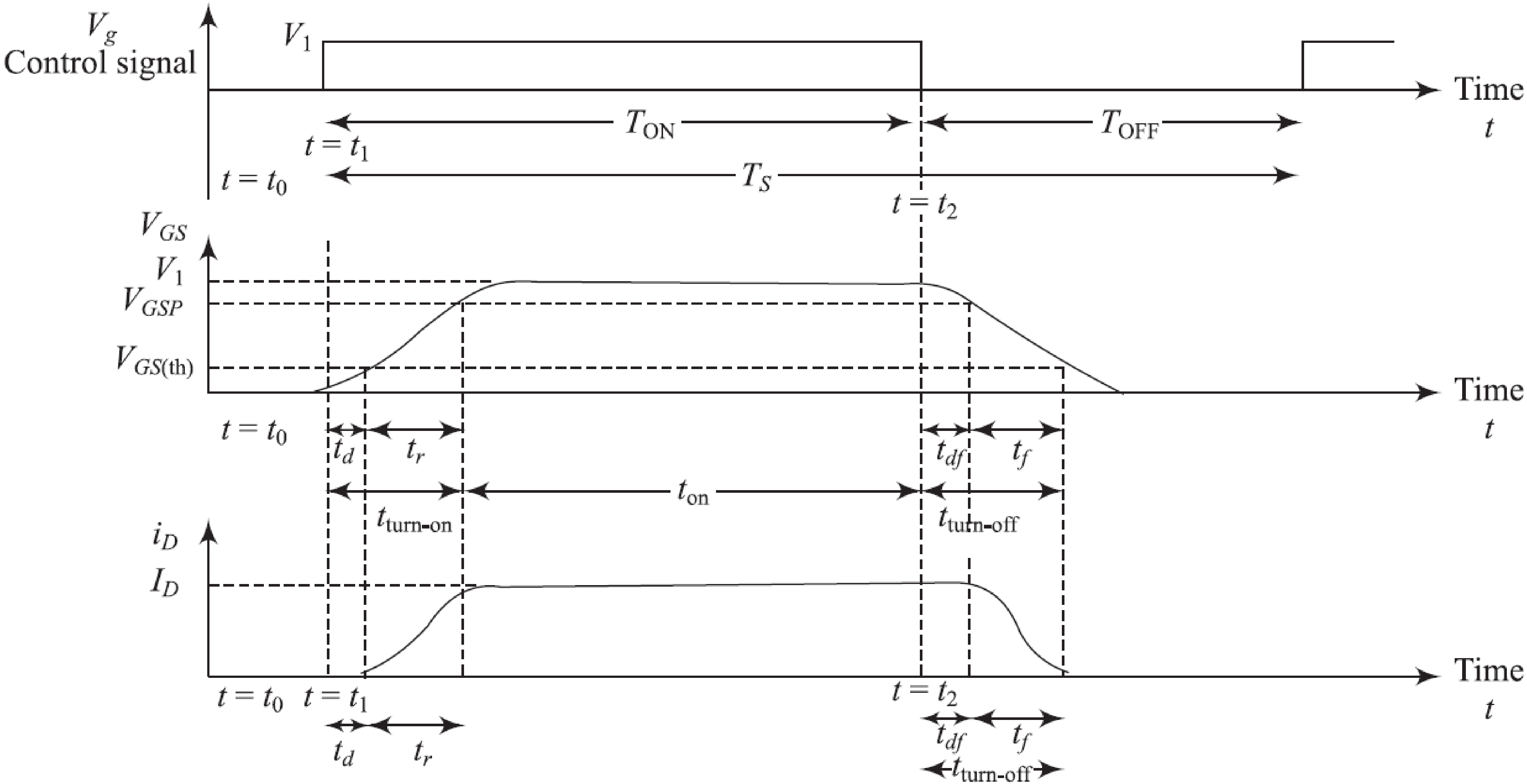
- When a pulse input voltage is applied to the gate of MOSFET, the device will turn-ON if $V_{GS} > V_{GS(th)}$.
- Switching characteristics' are influenced to large extent by internal capacitance.
- At $t = t_o$, input voltage $V_G = 0$ & $V_{GS} < V_{GS(th)} \rightarrow I_D = 0$, device in OFF state.
- At $t = t_1$, voltage starts to increase from 0 to $V_1 \rightarrow C_{gs}$ starts to charge. During t_d, C_{gs} is charged to $V_{GS(th)}$. During t_r, V_{GS} increases from $V_{GS(th)}$ to full gate voltage V_{GSP} to operate the transistor in linear region, also increases to I_D.





Switching model of MOSFET

Switching Characteristics

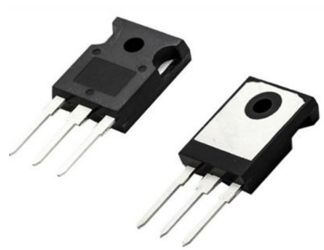


Applications and Features different from BJT

- High-frequency switching applications, varying from few W to kWs.
- Very popular in switch mode power supplies and inverters.
- Unipolar device whereas BJT is bipolar device.
- High input impedance whereas BJT has low impedance.
- Voltage controlled device whereas BJT is current controlled device.
- Conduction loss of MOSFET is larger than that of BJT due to a larger voltage drop for high-voltage applications.
- Lower switching losses whereas BJT has higher switching losses.

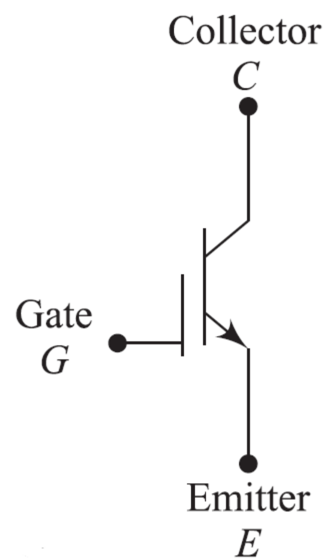
1.3 IGBT (Insulated Gate Bipolar Transistor)

- Combination of power transistors BJT and MOSFET.
- High input impedance like MOSFET and low on-state power loss as in BJT.
- Voltage controlled device.
- IGBT is very popular amongst power electronic engineers.
- MOSIGT ⟺ COMFET ⟺ GEMFET

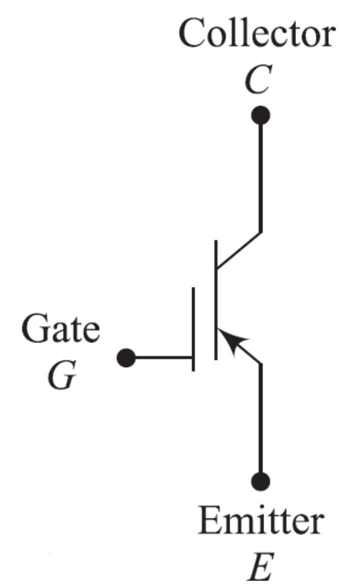


Features

- Low conduction loss (BJT)
  – High-speed turn-ON (MOSFET)
  – Low-power, easy drive (MOSFET)



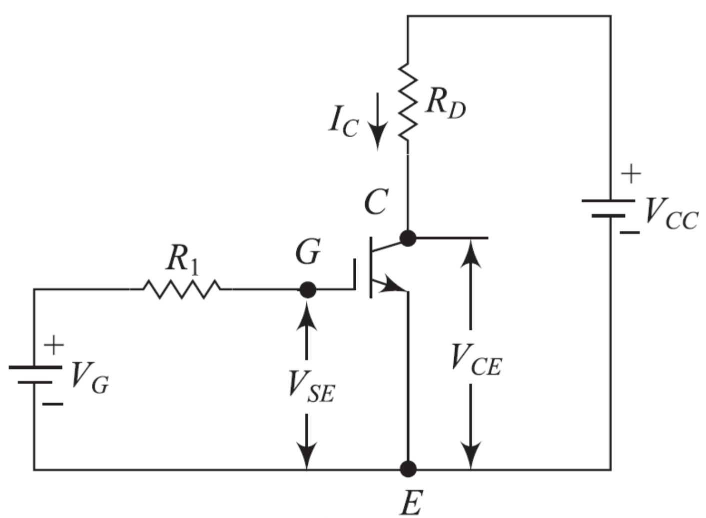
n –channel IGBT

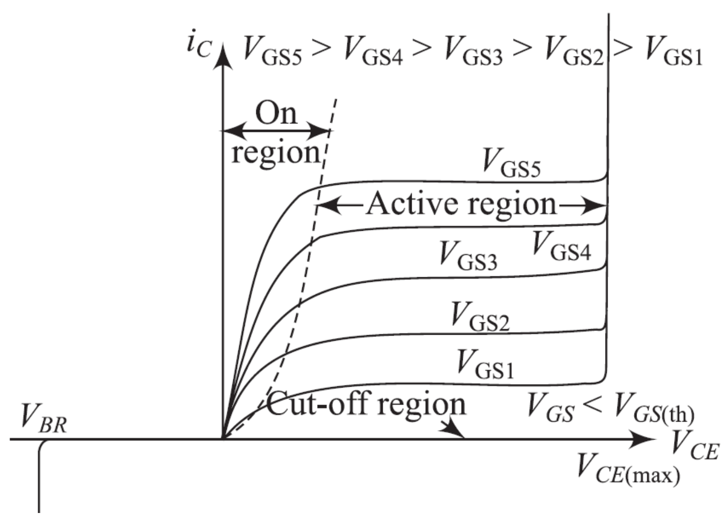


p –channel IGBT

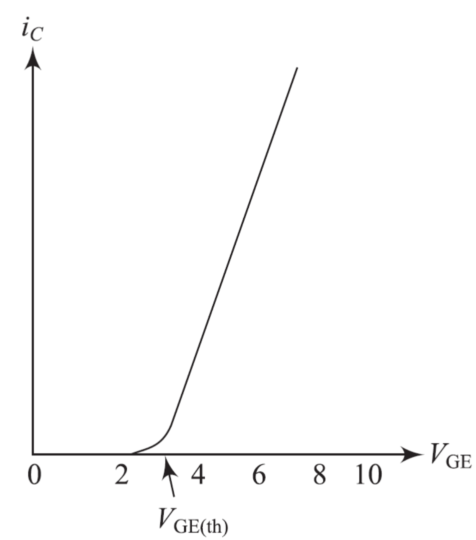
IGBT I-V Characteristics

- Emitter terminal is common between input and output of IGBT.
- *Transfer characteristics:* I_C versus the V_{GE} – similar to MOSFET.
- *Output characteristics:* I_C versus V_{CE} for various values of V_{GE1}, V_{GE2} etc., In the forward direction, the shape of the output characteristic is like that of BJT. But here the controlling parameter is V_{GE} because IGBT is voltage-controlled device.





Output characteristics



Transfer characteristics

Review of the classifications

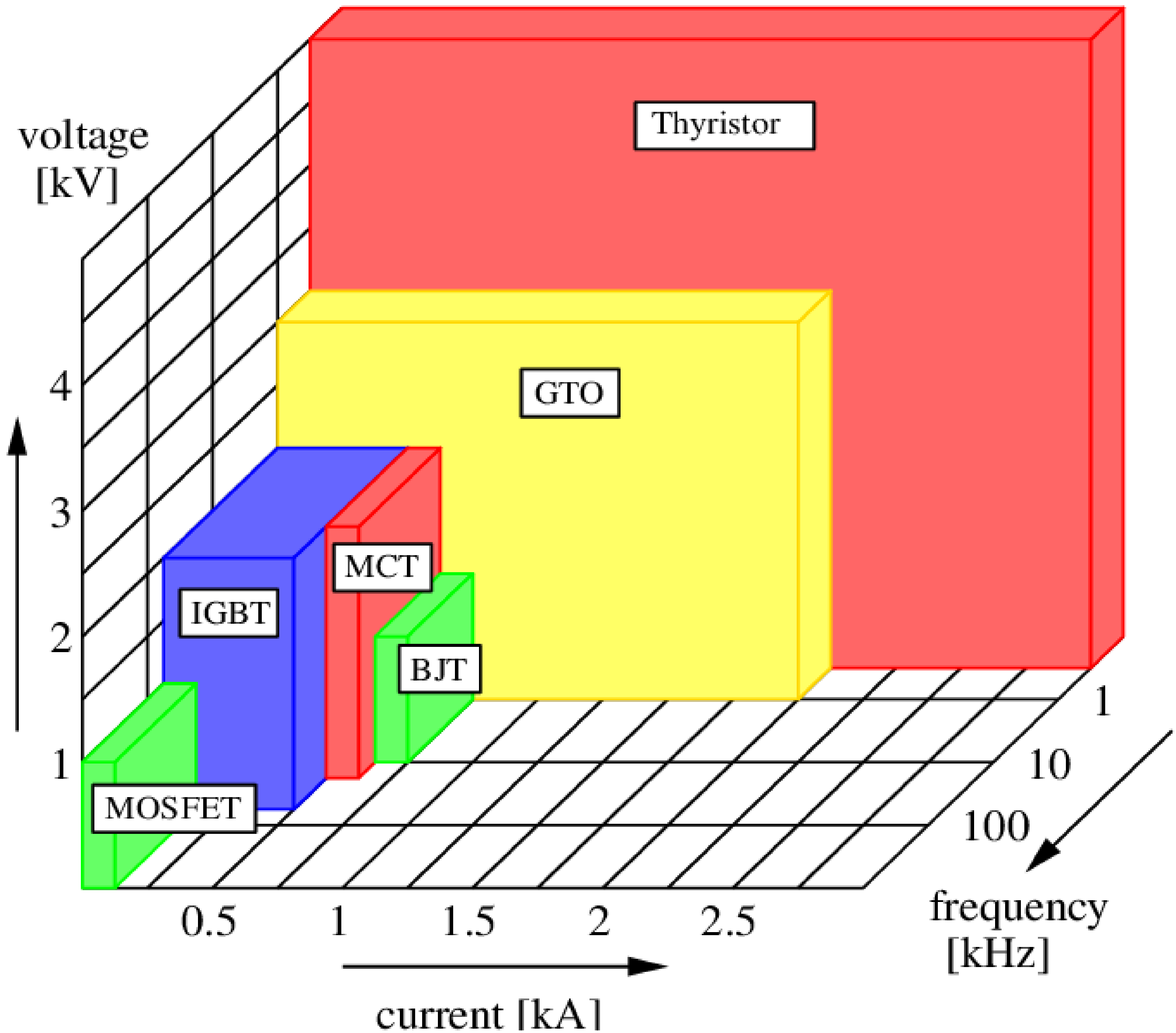
power electronic devices

- Current-driven (current-controlled) devices: thyristor, GTO, GTR
- Voltage-driven (voltage-controlled) devices (Field-controlled devices):power MOSFET, IGBT, SIT, SITH, MCT, IGCT

power electronic devices

- Pulse-triggered devices: thyristor, GTO
- Level-sensitive (Level-triggered) devices: GTR,power MOSFET, IGBT, SIT, SITH, MCT, IGCT

Comparison of power semiconductor devices

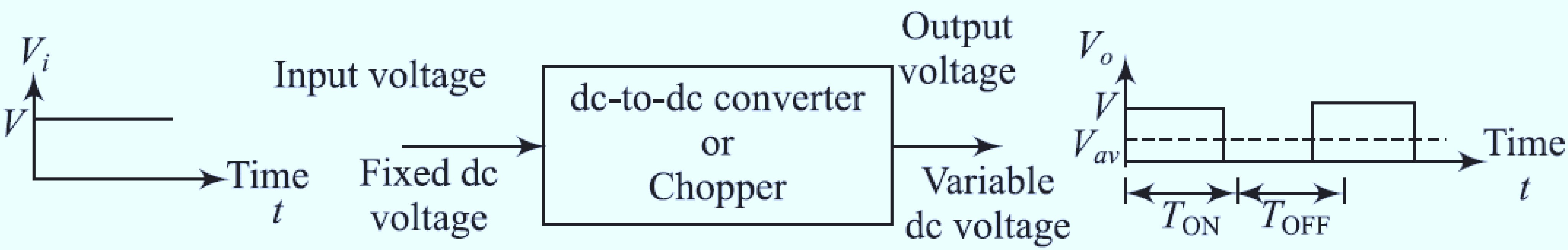


2.0 Outline – DC to DC Converters

- ✓ Step-down operation
  - Duty cycle generation
- ✓ Types of DC-DC converter
  - Buck converters
  - Boost converters
  - Buck-Boost converter
- ✓ Closed-loop control of DC-DC converters

2.1 Types of DC-DC Converters

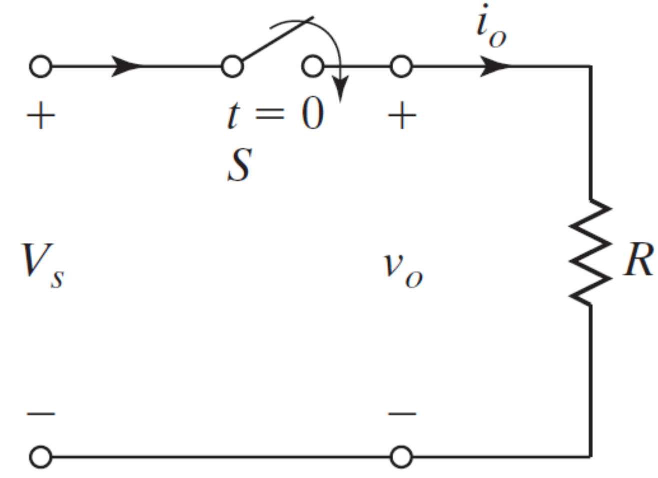
- DC-DC converters (also called *choppers*) can be used to obtain a *variable dc voltage from a fixed dc supply*.
- Step-down (*Buck converters*) – output voltage is less than input voltage.
- Step-up (*Boost converters*) – output voltage is higher than input voltage.
- Step-up/down: *Buck-boost converters*
  - the output voltage can be higher or less than the input voltage.



T_{ON} Is ON time of switch

T_{OFF} Is OFF time of switch

2.1.1 Step-down operation



- Operates in two modes:
  - Switch S is ON → $v_o = V_s$
  - Switch S is OFF → $v_o = 0$

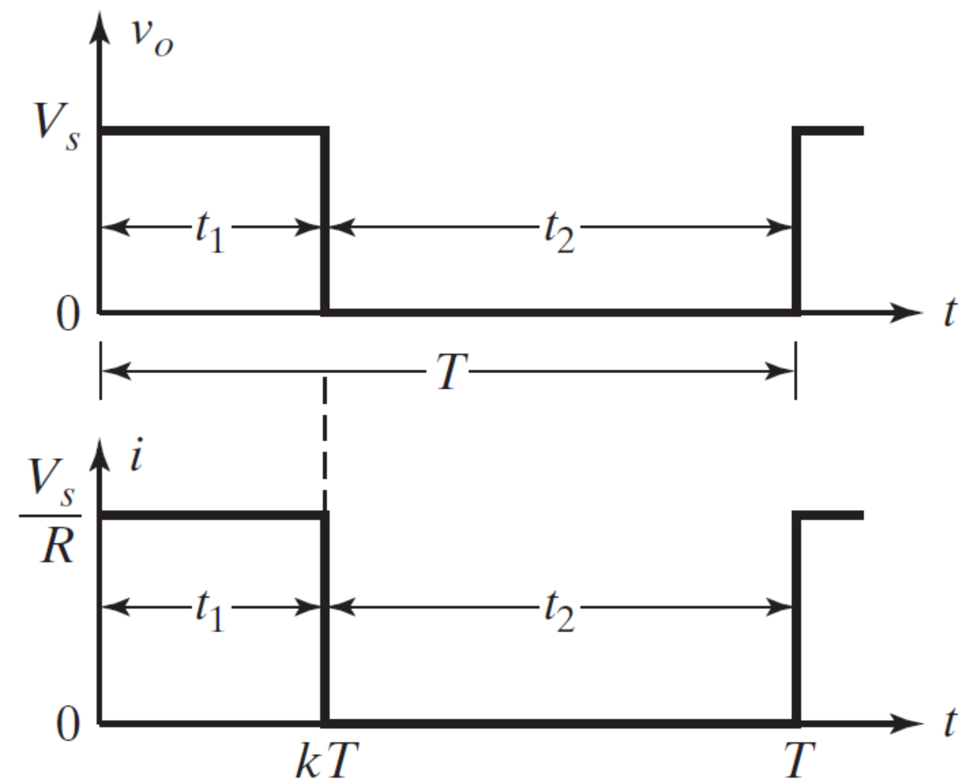
- Average output voltage:

$$V_o = \frac{1}{T}\int_0^T v_o(t)dt = \frac{1}{T}\int_0^{t_1} V_s\, dt = \frac{t_1}{T}V_s = kV_s$$

where k is the duty cycle;

t_1 – ON time period of switch.

t_2 – OFF time period of switch.



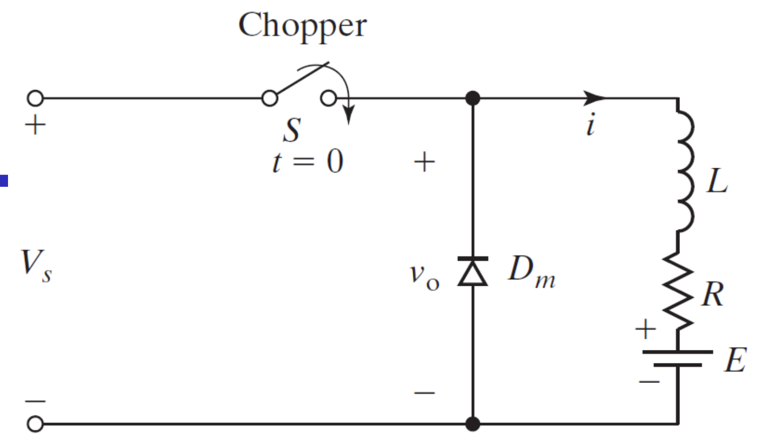
- RMS output voltage:

$$V_{RMS} = \left[\frac{1}{T}\int_0^T {v_o}^2(t)\, dt\right]^{1/2} = \sqrt{k}V_s$$

Switch ⟹ BJT, MOSFET, IGBT

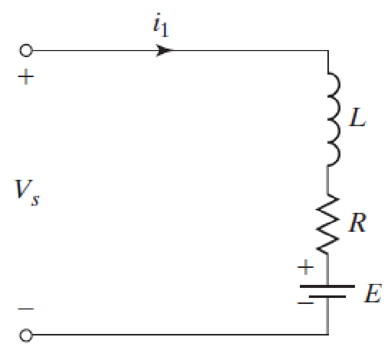
2.1.2 Step-down operation

- Operates in two modes (RL –load):
  - ➢ Switch *S* is ON → current flows from supply to load
  - ➢ Switch *S* is OFF → load current continues to flow thru freewheeling diode.

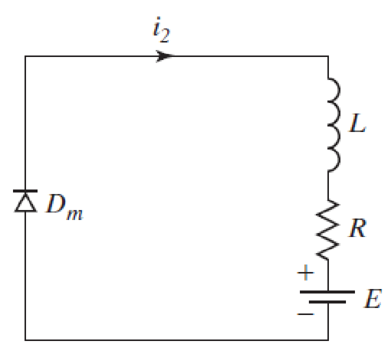


- Assume that the load current rises linearly.

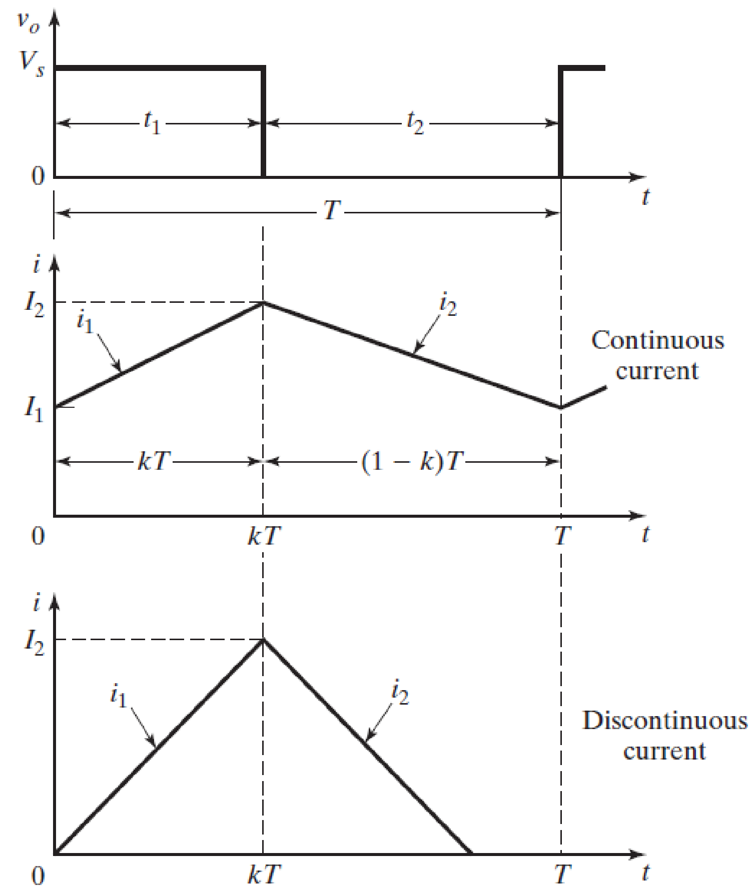
- However, the current flowing through an RL load rises or falls exponentially with a time constant ($\tau = L/R$), which is generally much higher than switching period T.



Mode 1

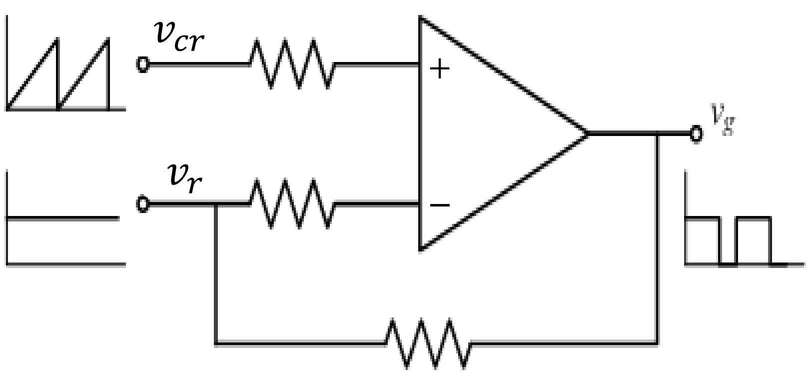


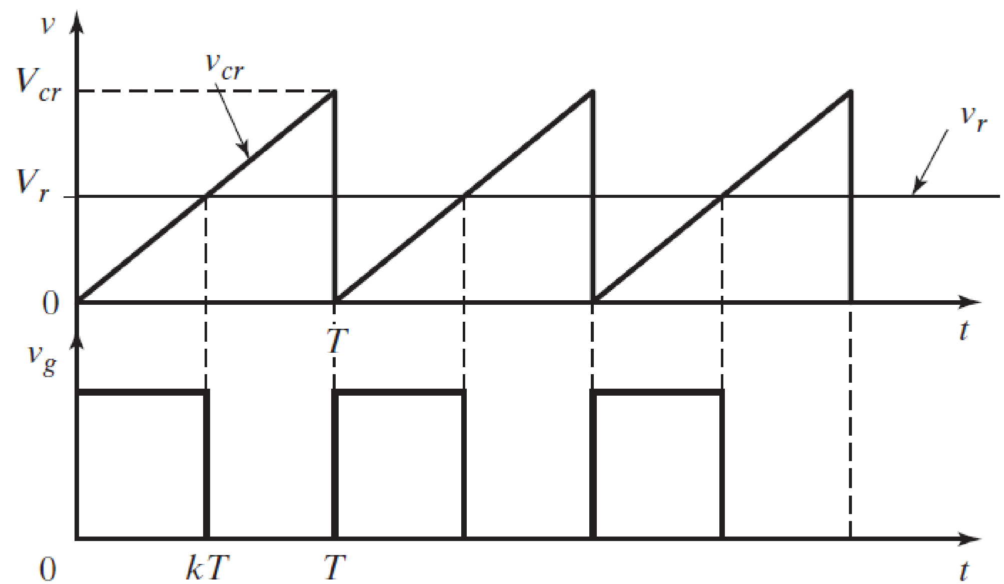
Mode 2



2.1.3 Generation of duty cycle

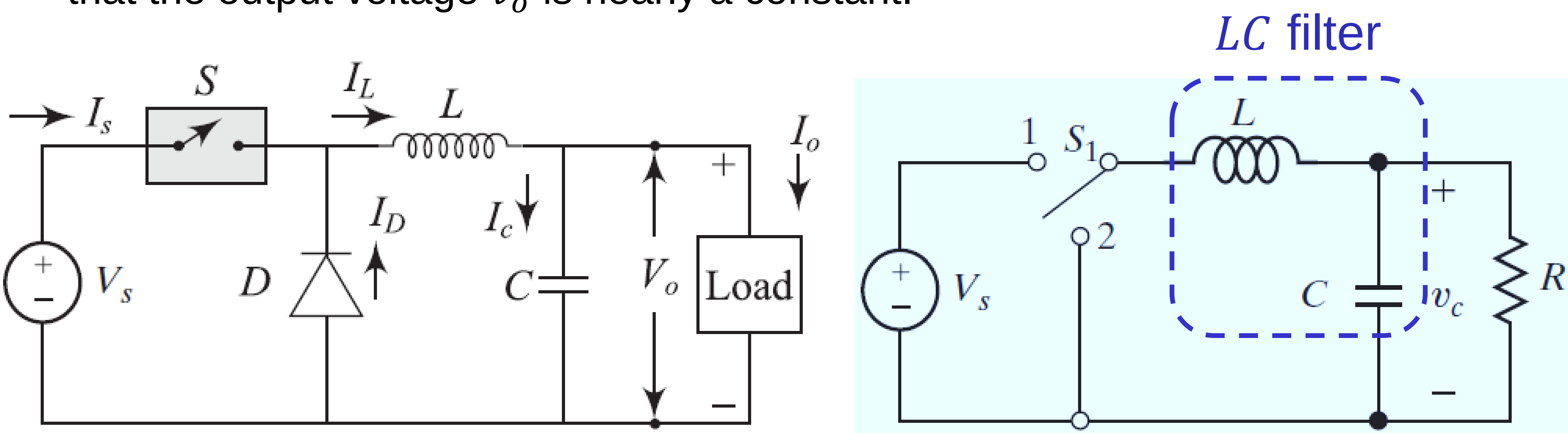
- If a saw-tooth signal v_{cr} and a DC reference signal v_r are supplied to a comparator, then the output of comparator is shown as v_g.
- The duty cycle of v_g is given as, $k = \frac{V_{cr}}{V_r}$
  - ✓ V_{cr} – is the peak value of v_{cr}; V_r – is the peak value of v_r.
  - ✓ By varying the carrier signal v_{cr} from 0 to V_{cr}, the k can be varied from 0 to 1.
- This is how we control the voltage of a DC-DC converter.





2.2 Buck Converter

- Average output voltage is *less than* input voltage – hence, called *buck* converter.
- One switch and one diode (to overcome the problem of stored inductive energy).
- Switch S can be a power BJT and acts as a controlled switch; diode D is uncontrolled switch – operate as *two* SPST bidirectional switches, shown below.
- LC filter to remove switching harmonics and to pass only the DC component so that the output voltage v_o is nearly a constant.



Buck converter → Two switches representation

See you in the next class (April 21st)

✓Continue in the next Lecture

The End