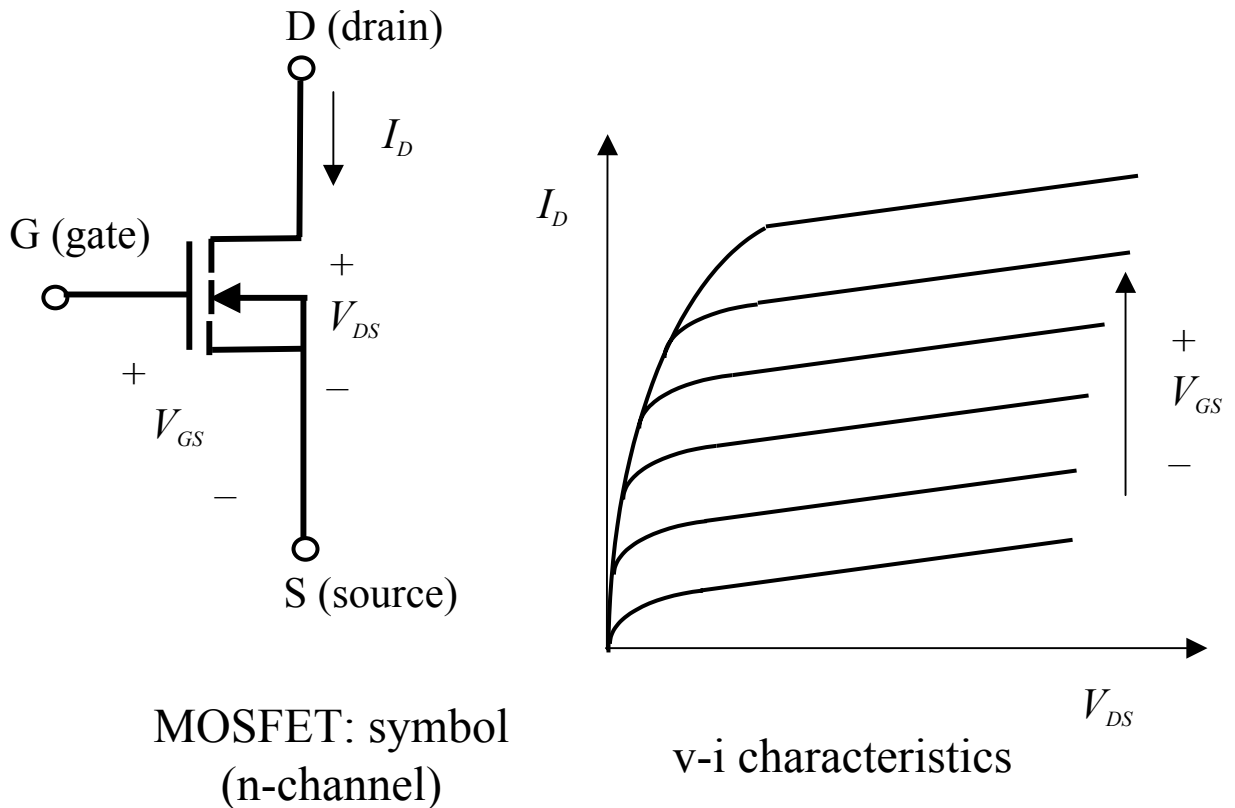


# Metal Oxide Silicon Field Effect Transistor (MOSFET)

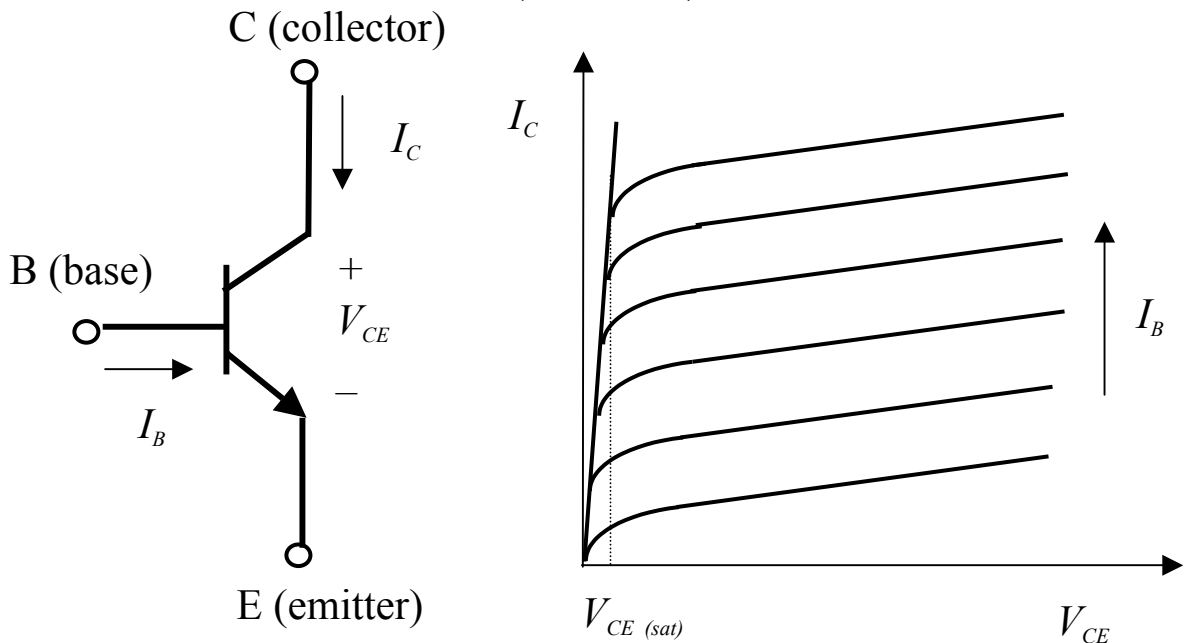


- Ratings: Voltage  $V_{DS} < 500V$ , current  $I_{DS} < 300A$ .
- Very fast device:  $> 100KHz$ . For some low power devices (few hundred watts) may go up to MHz range.

# MOSFET characteristics

- Turning on and off is very simple. Only need to provide  $V_{GS} = +15V$  to turn on and  $0V$  to turn off. Gate drive circuit is simple.
- Basically low voltage device. High voltage device are available up to  $600V$  but with limited current. Can be paralleled quite easily for higher current capability.
- Internal (dynamic) resistance between drain and source during on state,  $R_{DS(ON)}$ , limits the power handling capability of MOSFET. High losses especially for high voltage device due to  $R_{DS(ON)}$ .
- Dominant in high frequency application ( $>100kHz$ ). Biggest application is in switched-mode power supplies.

# Bipolar Junction Transistor (BJT)



BJT: symbol (npn)

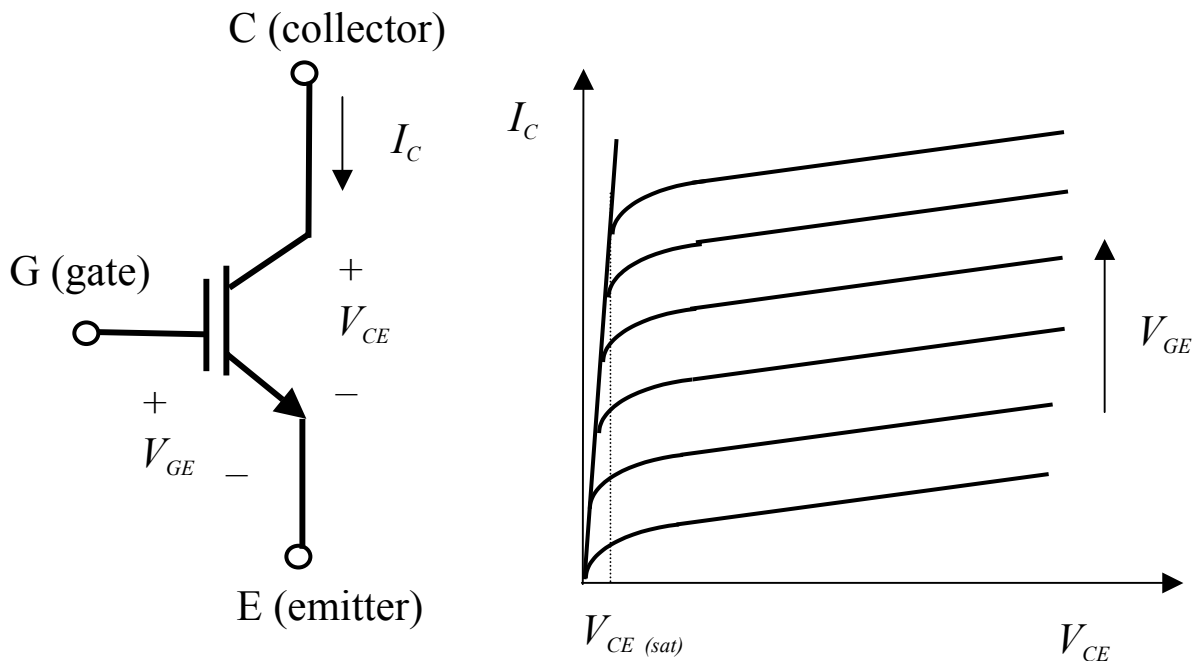
v-i characteristics

- Ratings: Voltage:  $V_{CE} < 1000$ , Current:  $I_C < 400$ A. Switching frequency up to 5kHz. Low on-state voltage:  $V_{CE(sat)} : 2-3$ V
- Low current gain ( $\beta$ ). Need high base current to obtain reasonable  $I_C$ . Expensive and complex base drive circuit.
- Not popular in new products.

# BJT characteristics

- To turn on/off the device, a base drive circuit is connected to the base and emitter terminal.
- To turn on, current is injected into the base terminal. When turned on, conventional current passes from collector to emitter.
- To turn-off, the base current is removed.
- The current gain of a BJT tends to be low when operated in the saturated ON condition.  $\beta < 10$  is common. It deteriorates as voltage ratings increase.
- It is normal to use Darlington connection for higher current gain.

# Insulated Gate Bipolar Transistor (IGBT)



IGBT: symbol

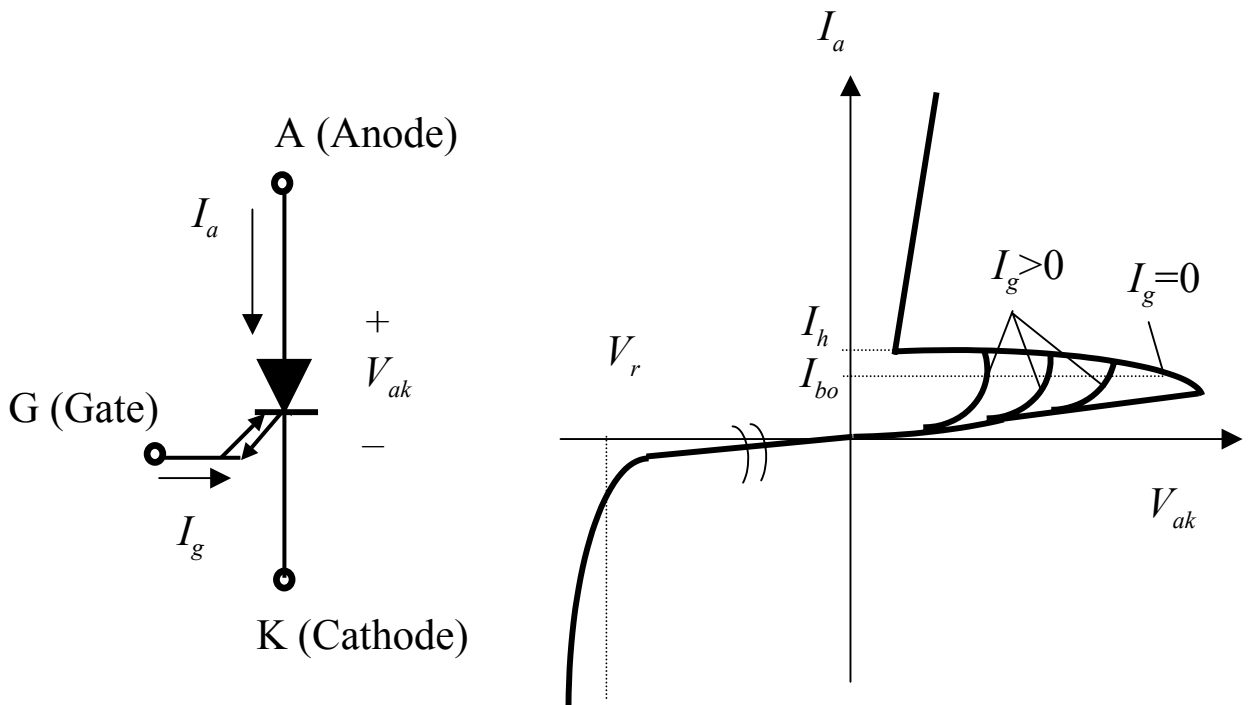
v-i characteristics

- Combination of BJT and MOSFET characteristics. Compromises include:
  - Gate behaviour similar to MOSFET - easy to turn on and off.
  - Low losses like BJT due to low on-state Collector-Emitter voltage (2-3V).

# IGBT

- Ratings: Voltage:  $V_{CE} < 3.3\text{kV}$ , Current, :  $I_C < 1.2\text{kA}$  currently available. Work in under progress for 4.5kV/1.2kA device. Constant improvement in voltage and current ratings
- Good switching capability (up to 100KHz) for newer devices. Typical application, IGBT is used at 20-50KHz.
- For very high power devices and applications, frequency is limited to several KHz.
- Very popular in new products; practically replacing BJT in most new applications.
- “Snubberless” operation is possible. Most new IGBTs do not require snubbers.

# Gate turn-off thyristor (GTO)



GTO: Symbol

v-i characteristics

- Behave like normal thyristor, but can be turned off using gate signal
- However turning off is difficult. Need very large reverse gate current (normally 1/5 of anode current)

# GTO

- Ratings: Voltage:  $V_{ak} < 5\text{kV}$ ; Current:  $I_a < 5\text{kA}$ . Highest power ratings switch. Frequency  $< 5\text{KHz}$ .
- Gate drive design is very difficult. Need very large reverse gate current to turn off. Often custom-tailored to specific application.
- Currently getting very stiff competition from high power IGBT. The latter has much simpler and cheaper drivers.
- GTO normally requires snubbers. High power snubbers are expensive.
- In very high power region ( $> 5\text{kV}$ ,  $> 5\text{kA}$ ), development in gate-controlled thyristor (GCT) may effectively end the future of GTO

# Application examples

- For each of the following application, choose the best power switches and reason out why.
  - An inverter for the light-rail train (LRT) locomotive operating from a DC supply of 750 V. The locomotive is rated at 150 kW. The induction motor is to run from standstill up to 200 Hz, with power switches frequencies up to 10KHz.
  - A switch-mode power supply (SMPS) for remote telecommunication equipment is to be developed. The input voltage is obtained from a photovoltaic array that produces a maximum output voltage of 100 V and a minimum current of 200 A. The switching frequency should be higher than 100kHz.
  - A HVDC transmission system transmitting power of 300 MW from one ac system to another ac system both operating at 50 Hz, 230 kV rms line to line and the DC link voltage operating at 200 kV.