Introduction to Power Electronics

What is Power Electronics?

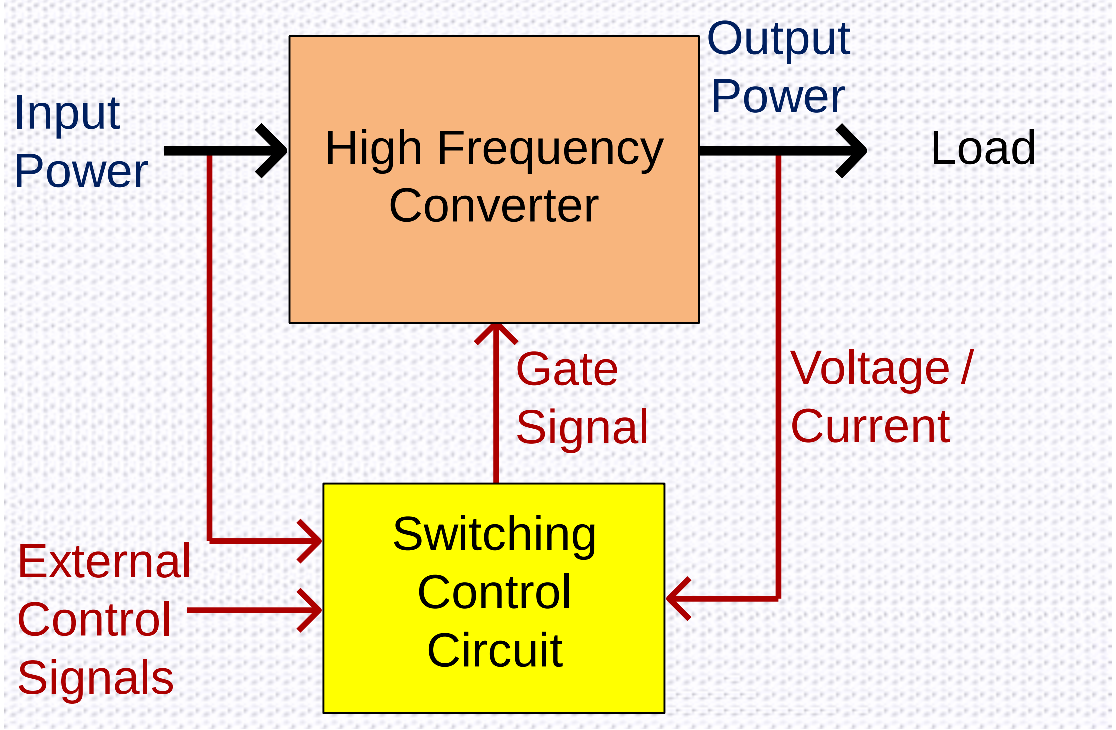
- Power + Electronics
  - Power conversion by processing electric power to expected voltage, current and / or frequency with semiconductor devices
  - High frequency >20kHz
  - Rapidly developed since 80s
  - Applications
    - Industrial, commercial and residential purposes
    - Electrical vehicles, aerospace and space technologies

Applications of Power Electronics

- Switched Mode Power Supplies (SMPS)
  - Steady and regulated output voltage / current
- Applications of SMPS
  - Low voltage high current DC power supplies
  - Battery chargers
  - Welding machines with over 100A
  - Aerospace power systems
  - Several KV power supplies for radar systems, cathode ray

Applications of Power Electronics

- Switched Mode Power Supplies (SMPS)
  - Closed loop control for regulating output
  - Pulse-width-modulation (PWM), frequency modulation or phase modulation control
  - Control ICs (Unitrode, Maxim)
  - Microprocessors
  - DSPs
  - Range of operation concerned



Applications of Power Electronics

- Inverters
  - AC current or mainly voltage output
  - DC/AC converters or inverters
  - DC input

- Applications of Inverters
  - AC power supplies
  - AC drives
  - Induction heating
  - Electronic ballasts

Applications of Power Electronics

- Waveform Shaping & EMI Control Systems
  - Shaping input / output and voltage / current
- Applications of Waveform Shaping
  - Switched-mode amplifiers
  - Harmonic waveform generation system
- Applications of EMI Control
  - Power factor correction rectifiers
  - Active filters

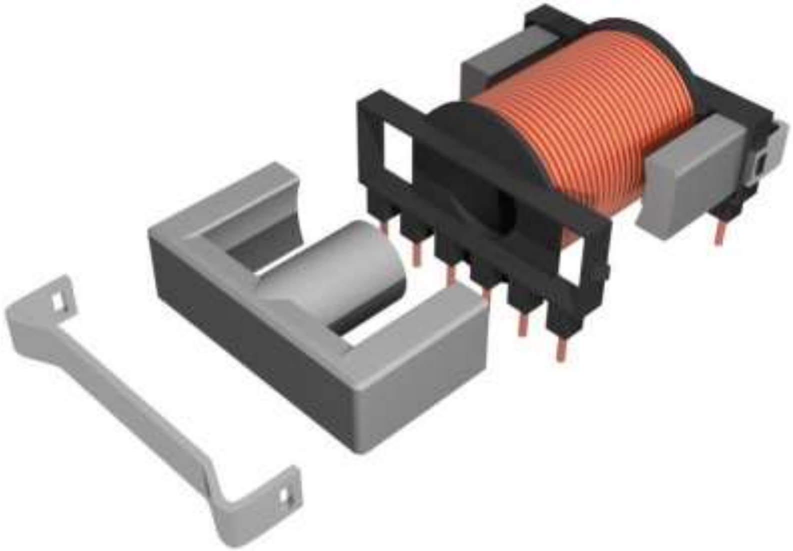
Applications of Power Electronics

- Uninterruptible Power Supplies
  - With DC/DC converter of charging and discharging battery
  - With Inverter for AC output

- Motor Drives
  - Choppers for brush-type DC motors
  - Variable speed drives (VSD) for induction motors
  - Converters for brushless DC motors
  - Converters for switched reluctance motors

Power Components

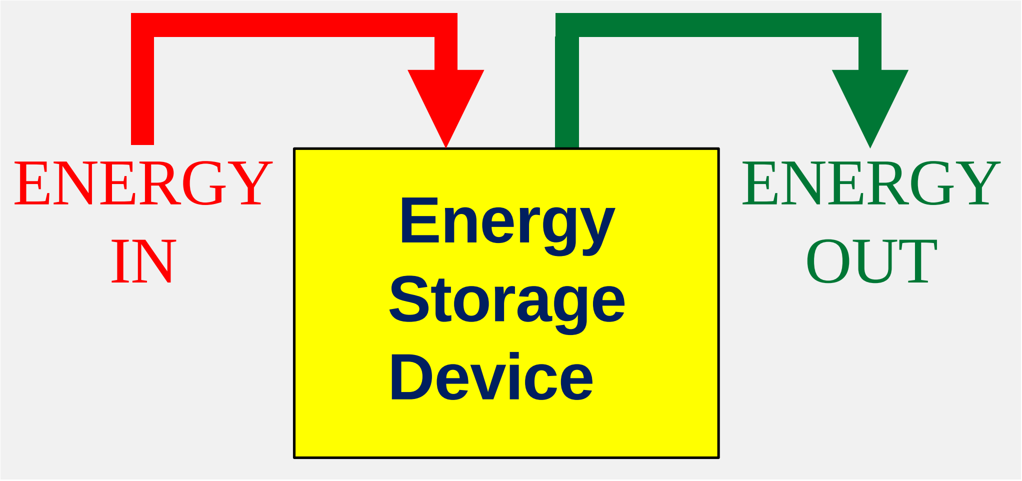
- Energy Storage Components
  - Inductors, capacitors, transformers
- Active Switching Devices
  - MOSFET, IGBT
  - Thyristors (SCR),
  - Gate turn-off thyristors (GTO)
  - Bipolar Junction Transistors (BJT)
- Passive Switching Devices (Power Diodes)
  - General purpose diodes
  - Ultra-fast recovery diodes
  - Schottky barrier diodes



Why high frequency?

- Small size and light weight
- Inductors

$$P_L = E_L f_S = \frac{1}{2} L I_L^{2} f_S$$

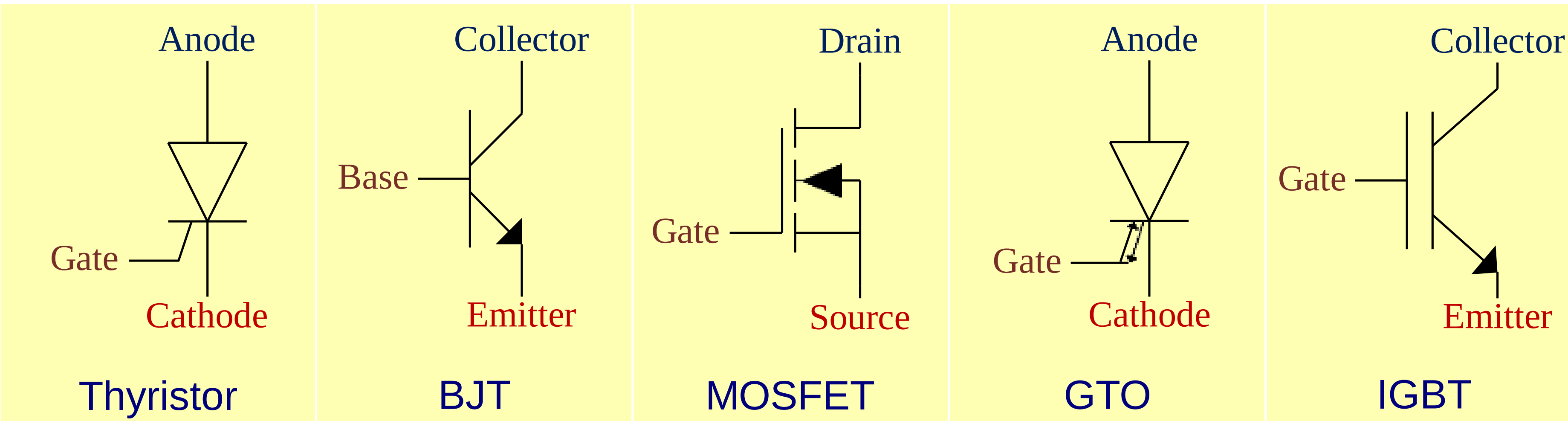


- Capacitors

$$P_C = E_C f_S = \frac{1}{2} C V_C^{2} f_S$$

Characteristics of Active Switching Devices

- Symbol of Active Switching Devices

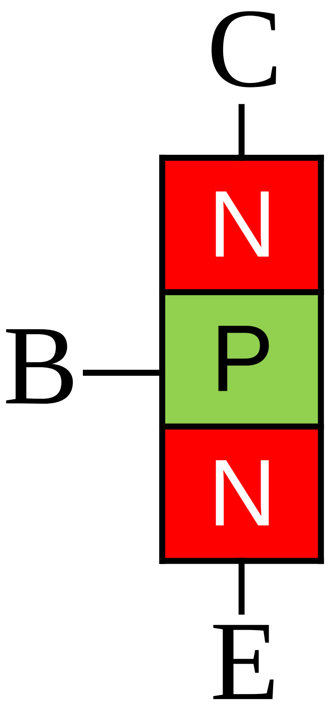


Characteristics of Active Switching Devices

- Thyristor / Silicon Controlled Rectifier(SCR)
  - Developed in 1960s
  - Switched on by a short injecting gate current pulse
    - Firing or Triggering
  - Switched off when reverse biased
  - Ratings up to 5kV and 4000A
    - Very high power applications
  - Around 2V on-state voltage
  - Slow response
    - $f_S < 1\text{kHz}$
  - Force commutation necessary

Characteristics of Active Switching Devices

- Bipolar Junction Transistor (BJT)
  - Controlled by base current
  - On and off only
    - Linear region avoid
  - Ratings up to 1kV and 4000A
  - Very high power applications
  - On-state voltage >1V
  - $f_S < 5$kHz
    - Faster than thyristors
    - Slower than MOSFET and IGBT
  - Rarely used



Characteristics of Active Switching Devices

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

Characteristics of Active Switching Devices

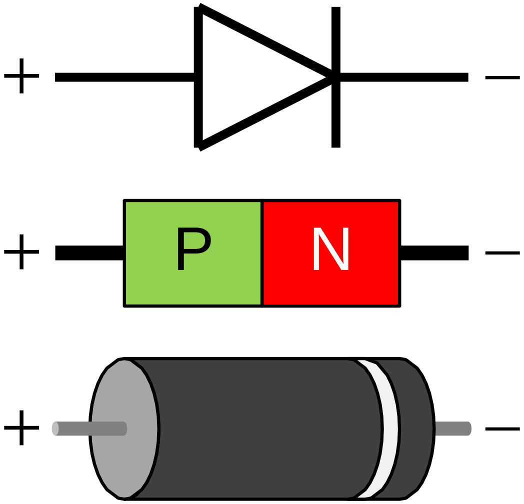
- Gate Turn-off Thyristor (GTO)
  - Developed in mid 1980s
  - Similar to thyristor
    - Switched on by a injecting short gate current pulse
    - Switched off by reverse biased
    - Switched off by a high and short reverse current pulse
  - Ratings up to 4.5kV and 3000A
    - High power applications
  - On-state voltage 2V to 3V
  - Response faster than thyristors
    - $f_S < 2\text{kHz}$

Characteristics of Active Switching Devices

- IGBT
  - Insulated Gate Bipolar Transistor
  - Developed in late 1980s
  - Combination of MOSFET and BJT
  - Controlled by gate-to-emitter voltage (V_{ge})
    - 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 f_S < 40kHz, faster for some models

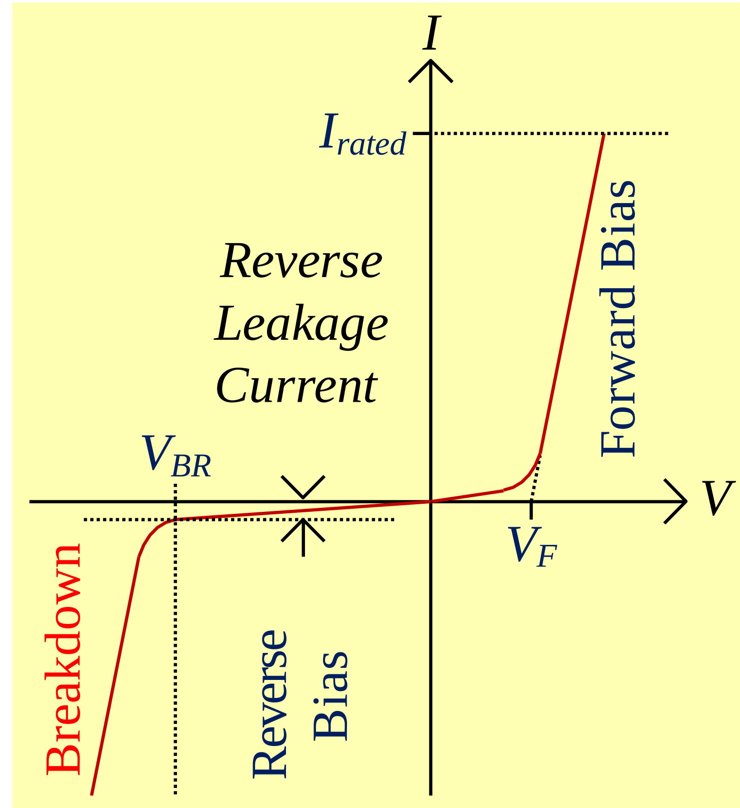
Characteristics of Power Diodes

- 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, V_F)



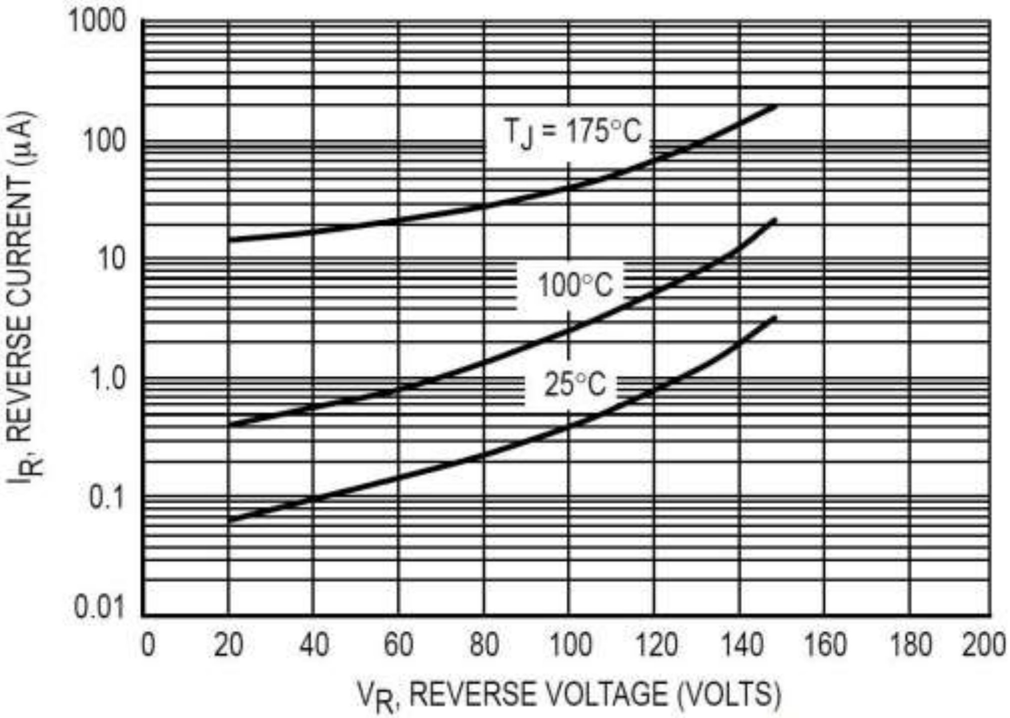
Characteristics of Power Diodes

- Forward Bias
  - Low forward voltage drop (forward voltage, V_F)
    - Temp related
    - 0.2V to 3V
    - Decreasing with temp increase
  - Typical V_F provided in datasheet



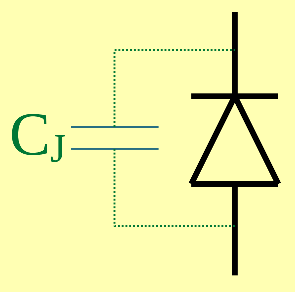
Characteristics of Power Diodes

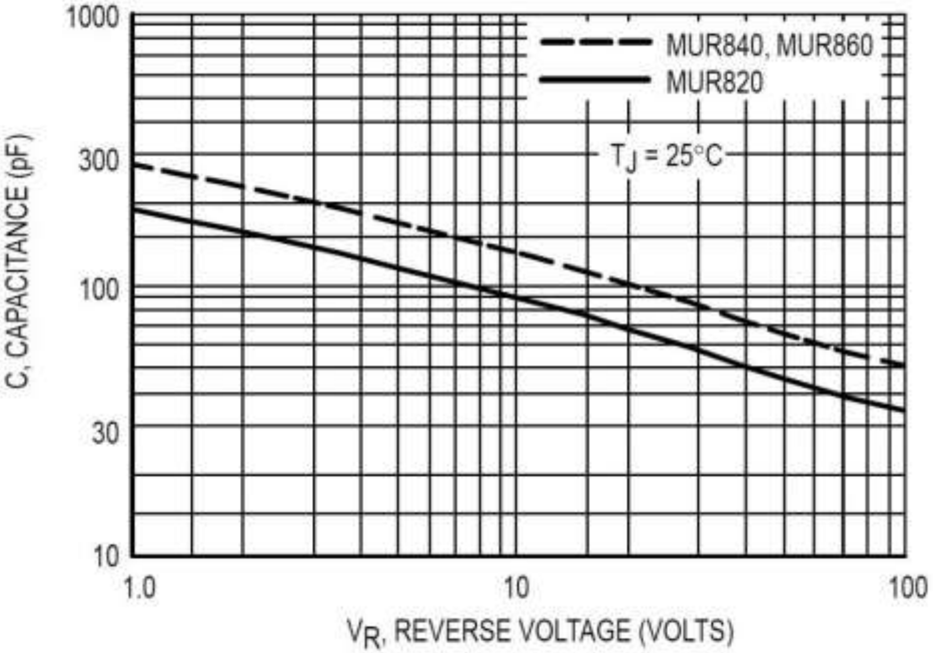
- Reverse Bias
  - Reverse leakage current
    - *μA* to *mA*
    - Increasing with increase of junction temp, T_j
    - Increasing with increase of reverse voltage, V_R



Characteristics of Power Diodes

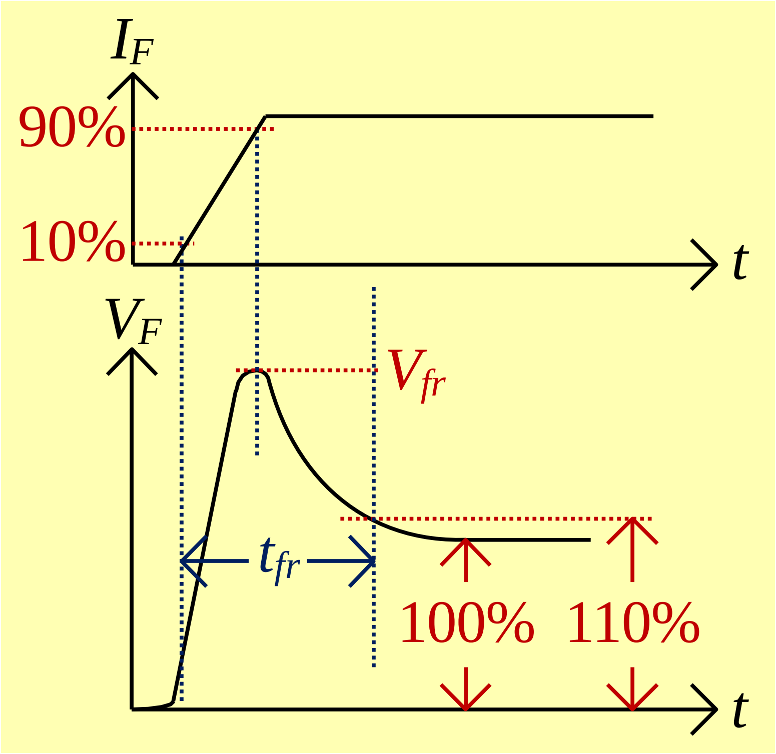
- Junction Capacitance
  - Diode as a capacitor in reverse bias
    - Junction capacitance between anode and cathode
  - Parasitic oscillations caused
    - Solved by resonant converter techniques
    - Acting as resonant component
  - Decreasing with the increase of reverse voltage





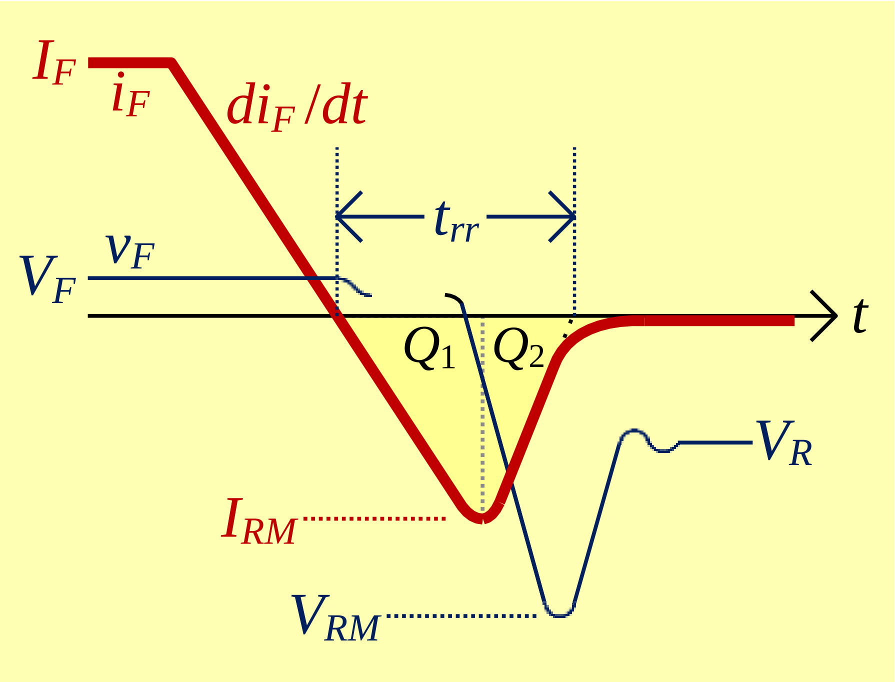
Forward Recovery of Power Diodes

- During the change from reverse bias to forward bias
- Forward voltage, V_F, increasing and back to normal
- Affecting high current and high voltage systems
- Not affecting low power systems



Reverse Recovery of Power Diodes

- During the change from forward bias to reverse bias
- Conducting for a period
  - Minority carriers remaining in p-n junction
- Ignoring in <400Hz sine wave
- Effect significant in high frequency and square wave
- Increasing with increases of I_F and di_F/dt



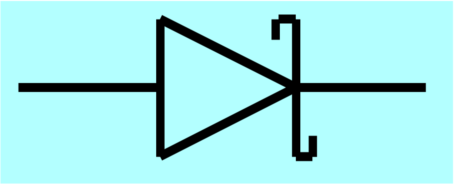
- Increasing Switching losses and peak reverse voltage of diode

Types of Power Diodes

- General Purpose Diode
  - Highest reverse recovery
  - For low frequency applications
- Ultra-fast Recovery Diode
  - Very short reverse recovery period
  - Soft-recovery diodes with lower peak recovery voltage
  - High frequency and high voltage applications

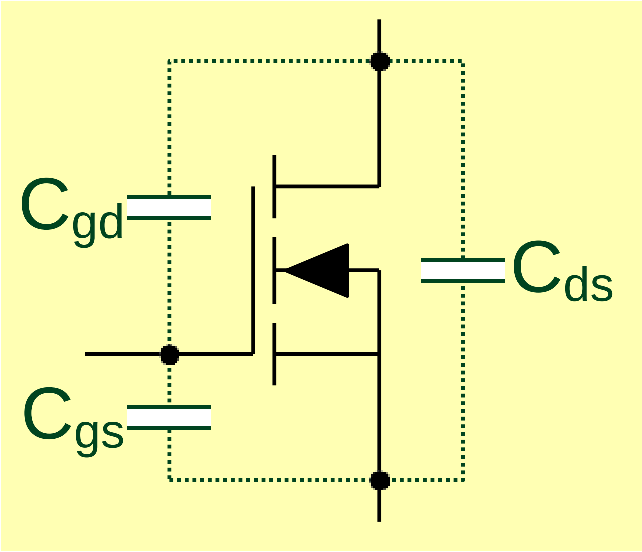
Types of Power Diodes

- Schottky Barrier Diodes
  - No reverse recovery
  - Higher junction capacitance
  - Lower voltage rating
  - More expensive
  - For high frequency, high performance and low voltage applications



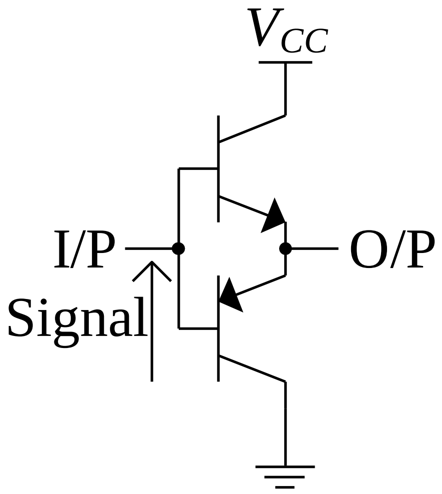
Junction Capacitance of MOSFET / IGBT

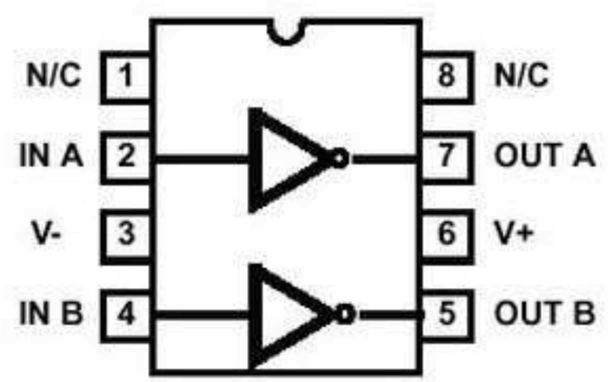
- All devices have junction capacitance between junctions
- MOSFET / IGBT Junction Capacitors
  - Input capacitance $C_{iss} = C_{gs} + C_{gd}$
    - Gate to source
    - Charging / discharging when devices switched on / off
  - Output capacitance $C_{oss} = C_{ds} + C_{gd}$
    - Drain to source
    - Switching loss and resonance when off
  - Reverse Transfer Capacitance $C_{rss} = C_{gd}$
    - Gate to drain
    - Miller effect



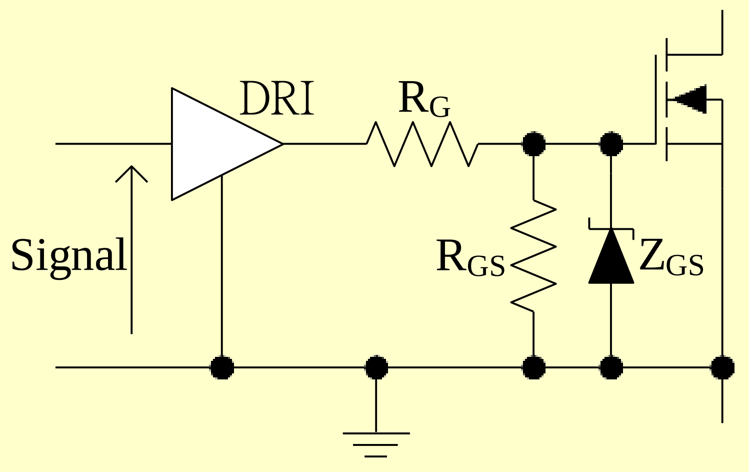
Gate Drivers for MOSFET / IGBT

- The shorter t_{on} and t_{off}, the lower conduction loss
- MOSFET / IGBT gate drivers
  - Totem-pole
  - High O/P current for charging up C_{iss} quickly
  - ICL7667, MC34151, MC34152
    - Logic-to-logic
    - High X_{in} and low X_o
    - Output >0.4A
    - Up to 500kHz



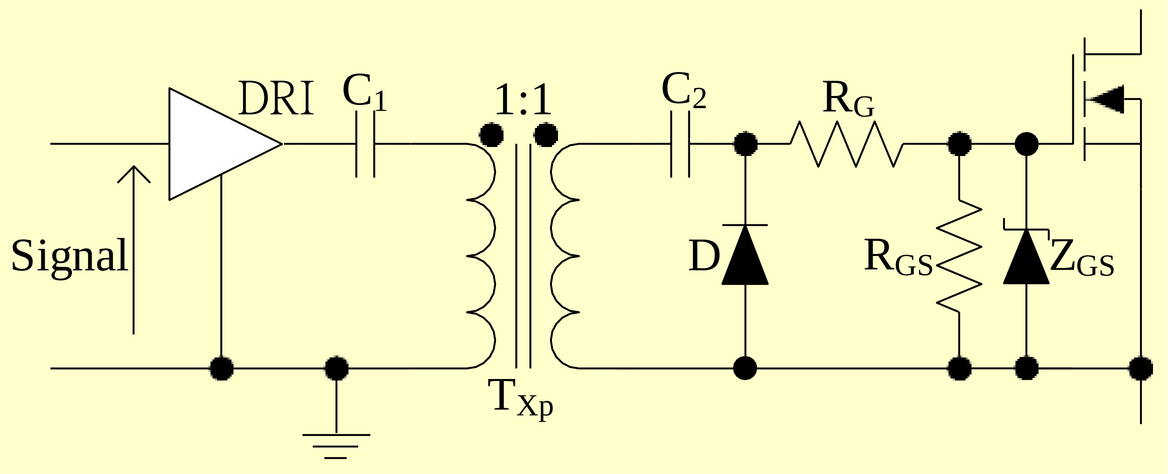


Non-floating Gate Drive Circuit



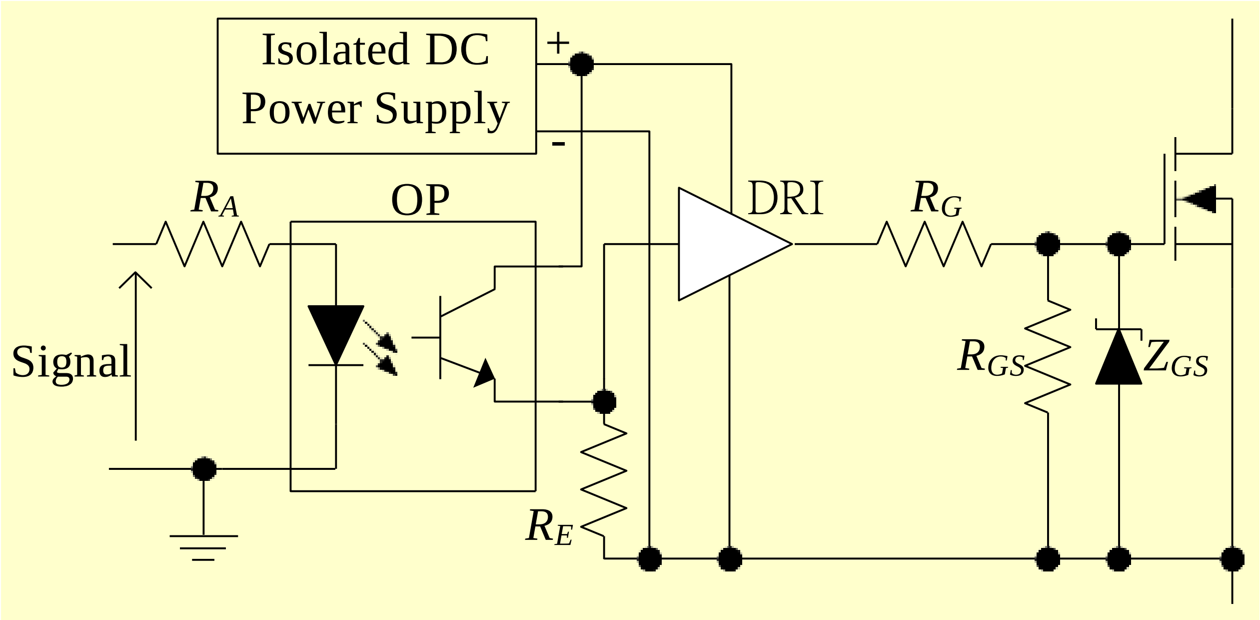
- Gate / emitter connected to ground
- R_G
  - Limiting charging current of junction capacitor
  - Damping swing of v_{gs}
  - 8 to 33Ω suggested
- R_{GS}
  - Speeding up discharging of junction capacitor
  - 1kΩ to 10kΩ
- Z_{GS}
  - Suppressing v_{gs} transient voltage
  - Voltage rating = peak output voltage of DRI

Floating Gate Drive Circuits



- Gate / emitter connected to ground
- Small pulse 1:1 transformer
  - Electrical isolation
- C_1 filtering DC component of O/P of DRI
  - $V_{dri}/2$ to $-V_{dri}/2$
- C_2 recovering the voltage from DC to AC square wave
  - V_{dri} to 0

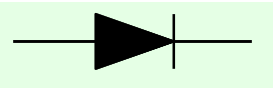
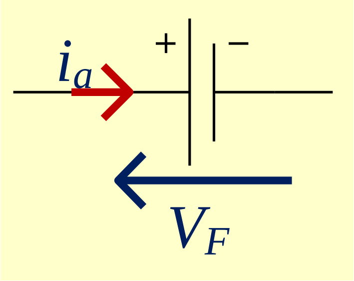
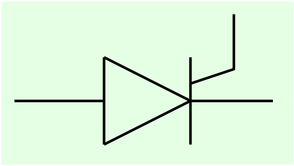
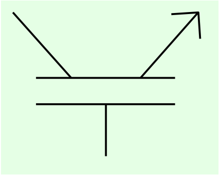
Floating Gate Drive Circuits



- Optocoupler
  - Electrical Isolation
- Very low power isolated DC power supply
  - Powering OP and DRI

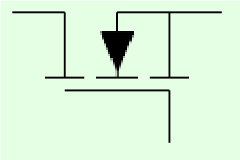
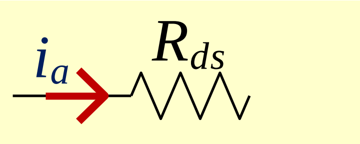
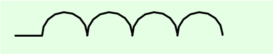
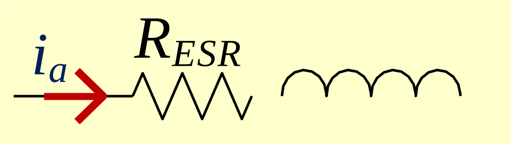
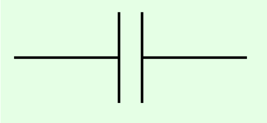
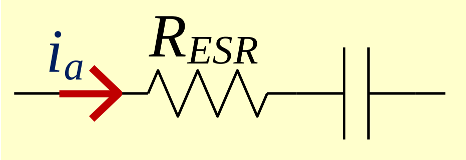
Conduction Characteristic and Conduction Losses

- Forward Voltage
  - Diodes
  - IGBTs
  - BJTs
  - Thyristors

Devices	Conduction Equivalent Circuit	Conduction Loss
 Diode		$V_F I_a$
 Thyristor		
 IGBT		

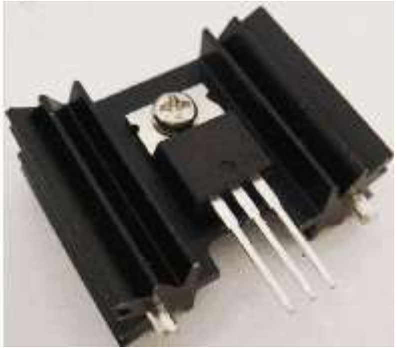
Conduction Characteristic and Conduction Losses

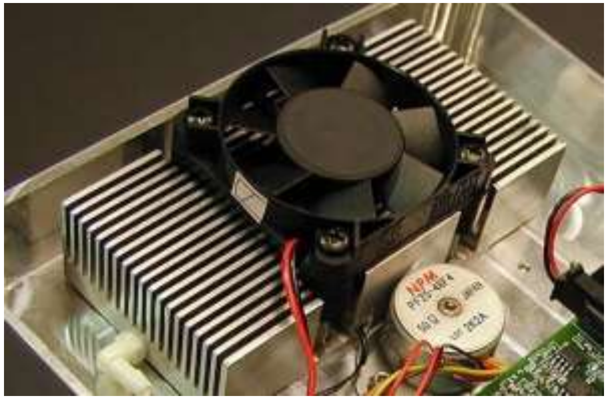
- Resistive
  - Inductors
  - Capacitors
  - MOSFETs

Devices	Conduction Equivalent Circuit	Conduction Loss
 MOSFET		$I_{a(rms)}^2 R_{ds}$
 Inductor		$I_{a(rms)}^2 R_{ESR}$
 Capacitor		

Cooling Devices

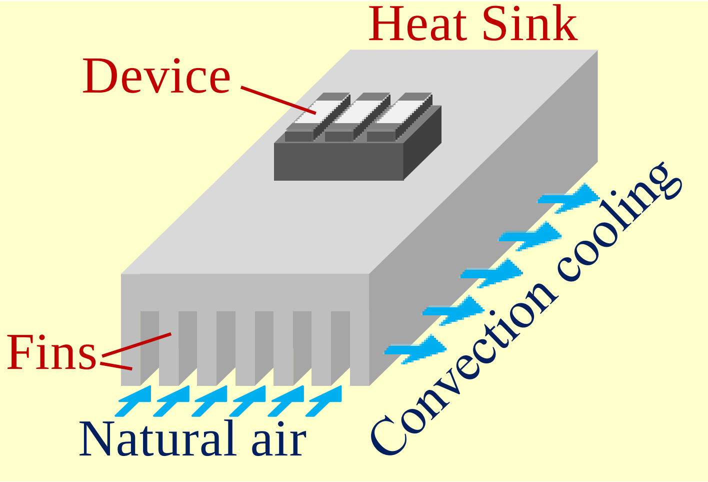
- Most power losses of devices converted into heat
  - Heat dissipation for long lifetime of devices
  - Too small surface area to flow heat to surrounding medium





Cooling Devices

- Air convection cooling
  - Low to medium power
  - Heat sink
    - Finned aluminium
    - Increasing surface area
    - Decreasing thermal resistance
  - Fan
    - Increasing air flow
  - The change of temp of device



$$\Delta T = T_j - T_a = P_{loss}\left(R_{j-c} + R_{c-h} + R_{h-a}\right)$$

Reference

https://www.google.com/search?q=ppt+of+power+electronics&rlz=1C1KMZB_enIN806IN806&oq=ppt+&aqs=chrome.0.69i59l2j69i57j0l5.3825j0j8&sourceid=chrome&ie=UTF-8