Solid State Power Switching

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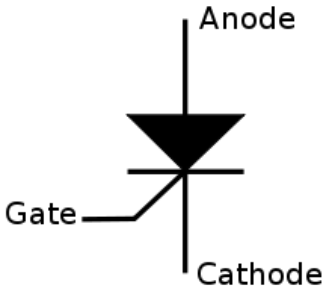
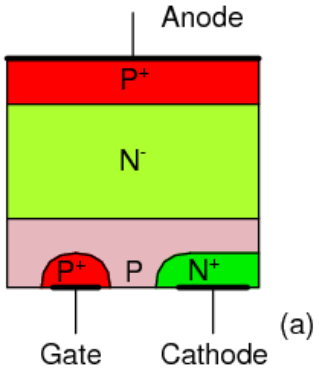
Topics

- Solid state power switching:
  - Silicon controlled rectifiers (SCR or Thyristor).
  - Gate Turn-Off Thyristor (GTO).
  - Integrated Gate-Commutated Thyristor.
  - Insulated-Gate Bipolar Transistor.
  - Triacs
- Additional Power Control
  - Unijunction transistor
  - Field effect transistors

Silicon Controlled Rectifiers (Thyristor)





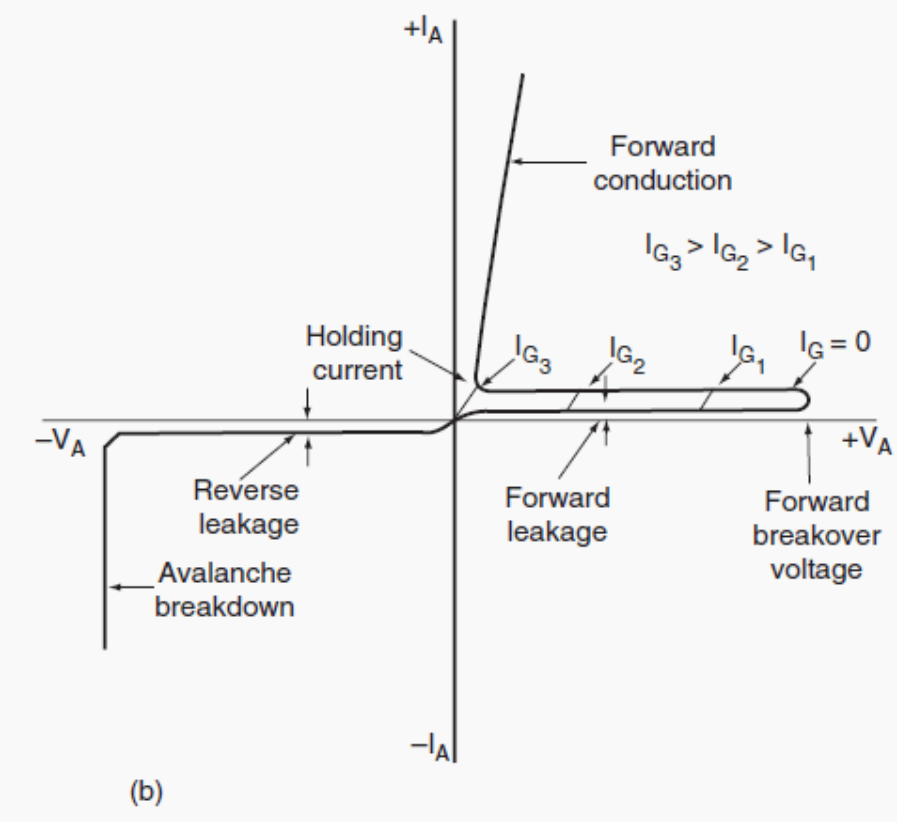
- The Silicon Controlled Rectifier (SCR) is simply a conventional rectifier controlled by a gate signal.

Middle: Image courtesy of All About Circuits, EETech Media, LLC. Thyristors.

SCR/Thyristor…

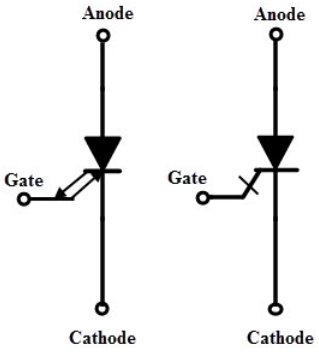
- The main circuit is a rectifier. However, a gate signal is required for turning ON.
- Once switched ON by a gate signal, but even after the gate signal is removed, the thyristor remains in the ON state until any turn OFF condition occurs.
  - Application of a reverse voltage to the terminals,
  - When the forward current falls below a certain threshold value known as the "holding current".
  - Thus, a thyristor behaves like a normal semiconductor diode after it is turned on or "fired".

Thyristor V-I Curve...

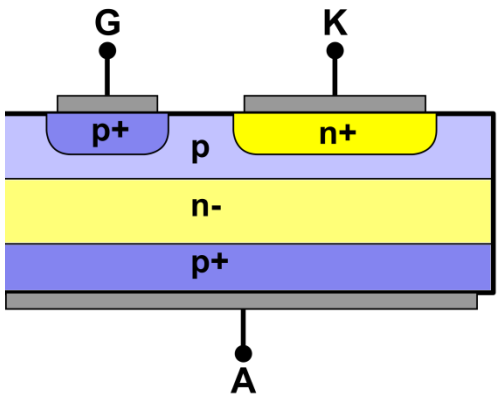


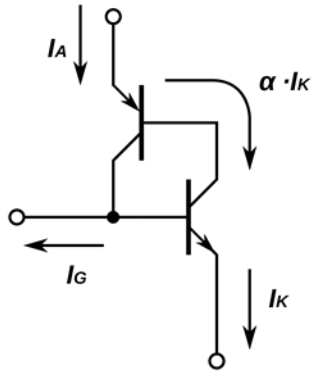
Wikipedia

Gate Turn-Off Thyristor (GTO)



Gate Turn-Off Thyristor Symbols

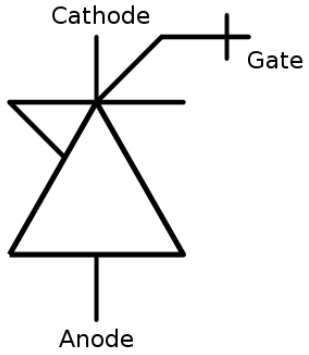


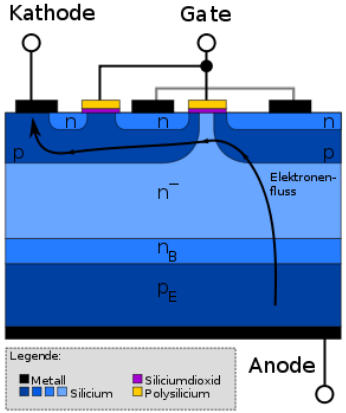


- Fully controllable switches that can be turned off by their gate.
  - The GTO can be turned on by a gate signal, and can also be turned off by a gate signal of negative polarity.
- Requires external devices ("snubber circuits") to shape the turn on and turn off currents to prevent device destruction.

Left & Center: Images courtesy of Wikipedia
Center: Image courtesy of Electronics Hub
Right: Image courtesy of Hello Trade

Integrated Gate-Commutated Thyristor …

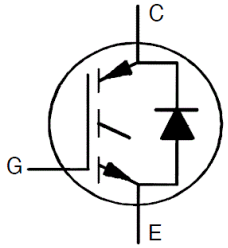




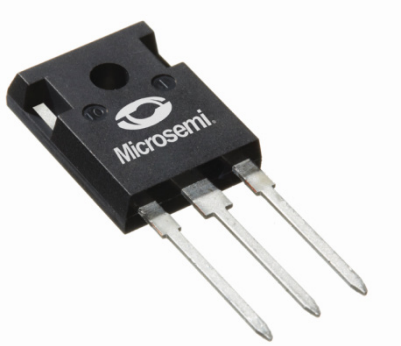
- An IGCT is a special type of thyristor similar to a gate turn-off thyristor (GTO).
- They can be turned on and off by a gate signal,
- Lower conduction loss as compared to GTOs, and withstand higher rates of voltage rise (dv/dt), such that no snubber is required for most applications.

Left, Center: Wikipedia
Right: Image courtesy of A&S Thyristor Co.

Insulated-Gate Bipolar Transistor



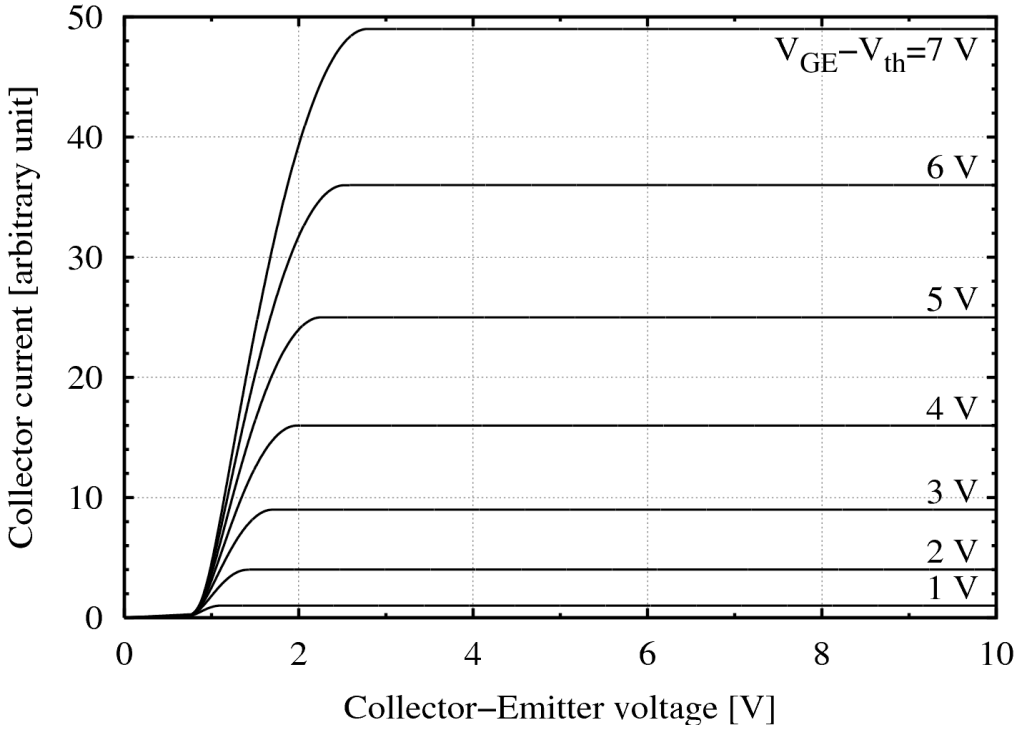
n-channel



- Three-terminal power semiconductor device primarily used as an electronic switch
- High efficiency and fast switching.
- Used in variable-frequency drives (VFDs), electric cars, trains, variable speed refrigerators, lamp ballasts, air-conditioners and stereo systems with switching amplifiers.

Wikipedia
Right: Image courtesy of RF Global Net

IGBT Collector Current to CE Voltage…



Triac

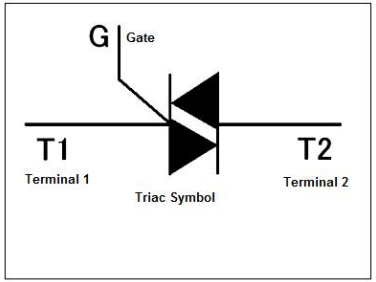


Image courtesy of Electronic Repair Guide.

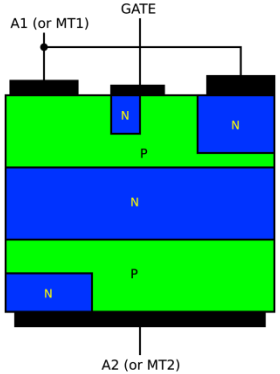
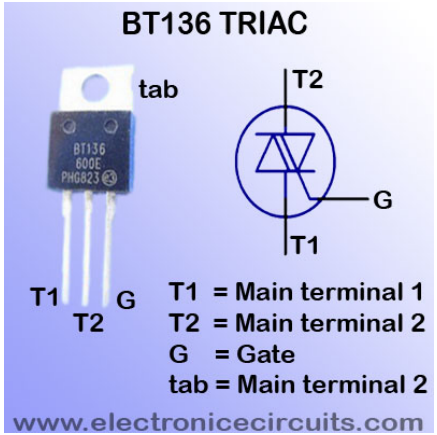
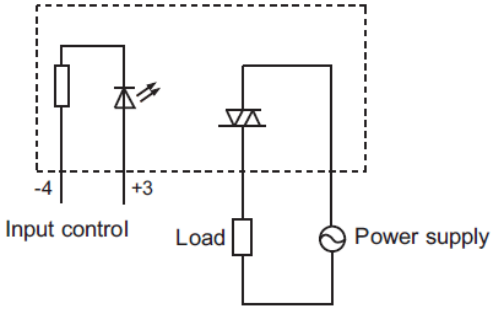


Image courtesy of Wikipedia



- Two anti-parallel SCRs. Generally used for motor speed control and in light dimmer.
- It can be triggered by either a positive or a negative voltage being applied to its gate electrode (with respect to T1, otherwise known as MT1 or A1).
  - Once triggered, the device continues to conduct until the current through it drops below a certain threshold value, the holding current, such as at the end of a half-cycle of alternating current (AC) mains power.

Examples of Solid State Relays…



SPST 3-15VDC 5A Solid State Relay.
SCR Chip, Photo Isolation.
Output Switching Voltage: 48 – 280 VAC.
Maximum Load Current: 0.1 – 5 A.
Maximum Surge Current: 250 A.

Dual SPST DIP Solid State Relay.
Input Control Current: 5-50 mA.
Output Switching Voltage: 0 – 60 V AC/DC
Load Current up to 400mA.

Images courtesy of Futurlec.

Controlling a High Voltage Device...

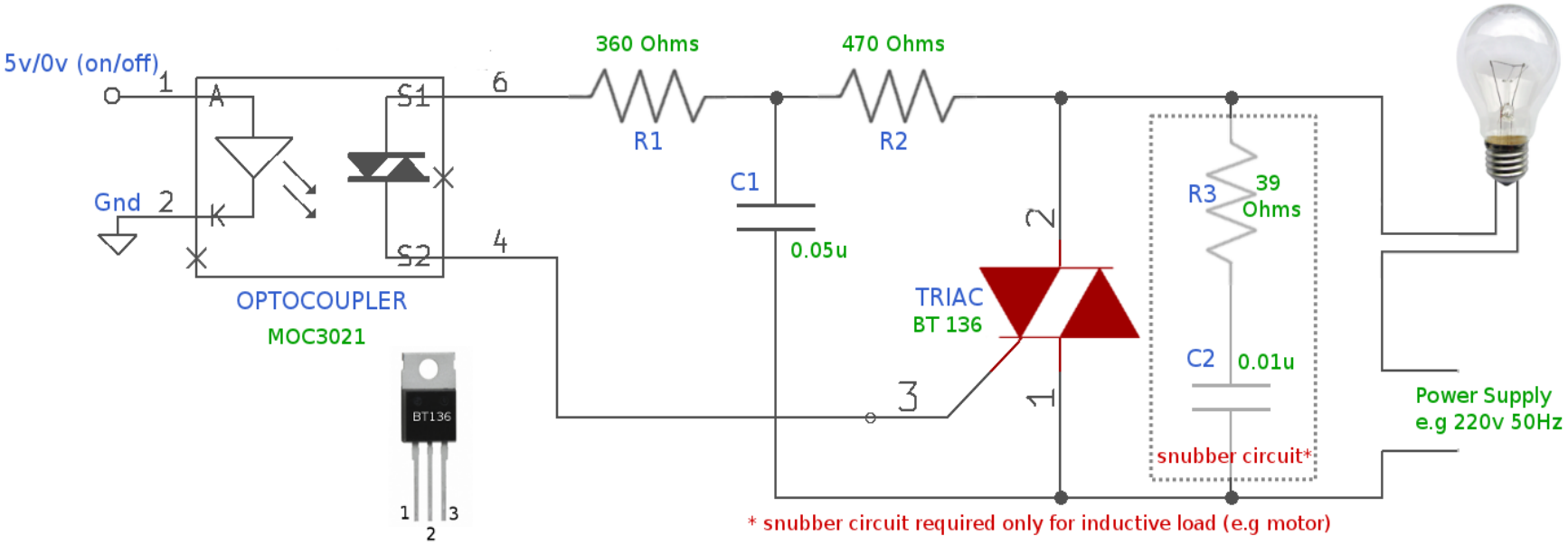
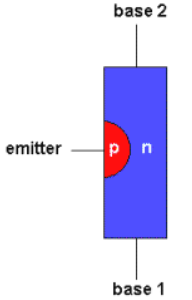
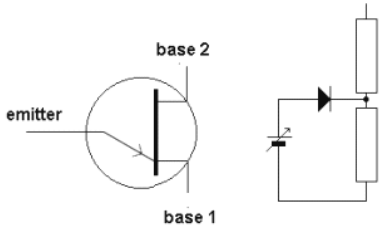
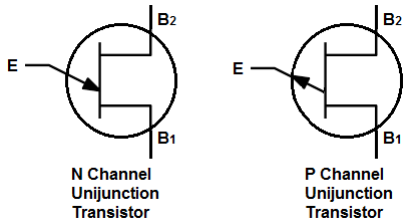


Image courtesy of Sigmatone.

Unijunction Transistor (UJT)



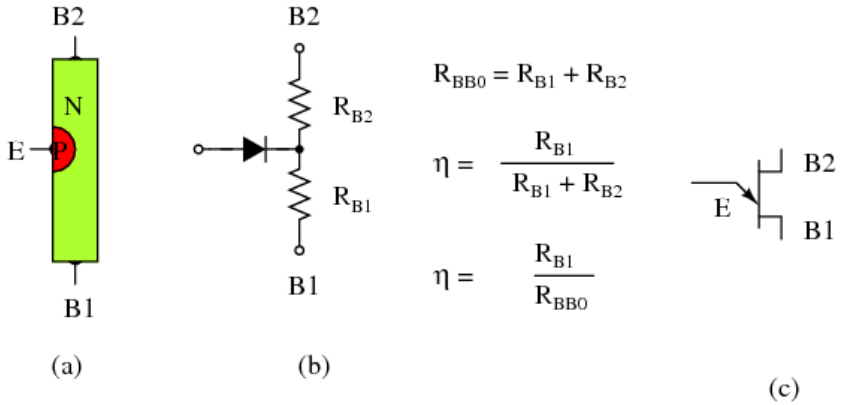




- Three-lead electronic semiconductor device with only one junction that acts exclusively as an electrically controlled switch. The UJT is not used as a linear amplifier.
- With the emitter unconnected, the bar acts as a potential divider, and about 0.5 volts appears at the emitter. If a voltage is connected to the emitter, as long as it is less than 0.5 volts, nothing happens, as the P-N junction is reversed biased. (see the right hand diagram).
- When the emitter voltage exceeds 0.5 volts, the junction is forward biased and emitter current will flow. This increase in current is equal to a reduction of resistance between base 1 and the emitter.
- Useful for triggering thyristors.

Left: Hobby Projects.com
Middle: Learning about electronics.com
Right: Image courtesy of Allied Electronics

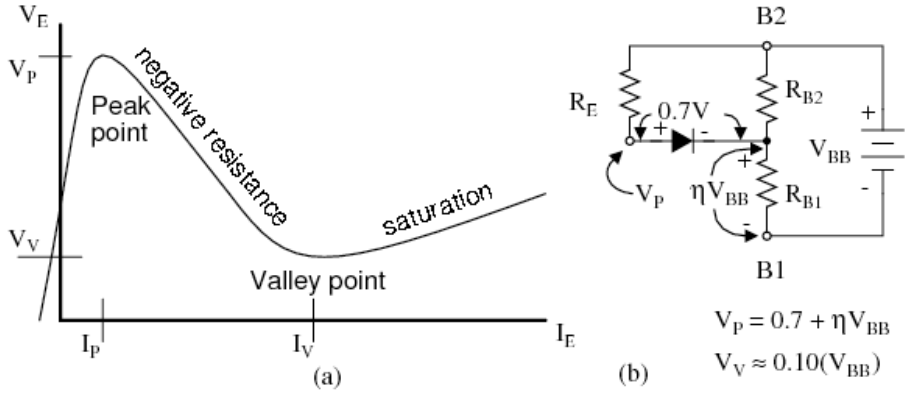
UJT...



- The connections at the ends of the bar are known as bases B1 and B2; the P-type mid-point is the emitter.
- With the emitter disconnected, the total resistance RBBO, a datasheet item, is the sum of RB1 and RB2.
- RBBO ranges from 4-12kΩ for different device types.
- The intrinsic standoff ratio η is the ratio of RB1 to RBBO. It varies from 0.4 to 0.8 for different devices.

All About Electronics, EETech Media, LLC, Chapter 7, Thyristors.

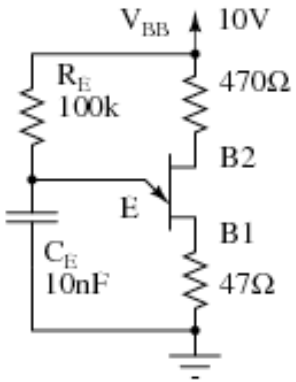
UJT Current vs Voltage…

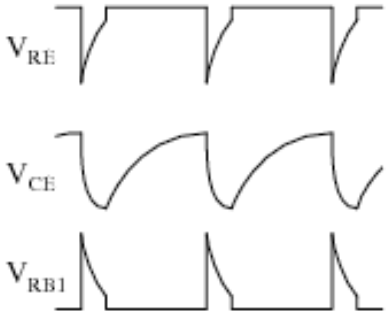


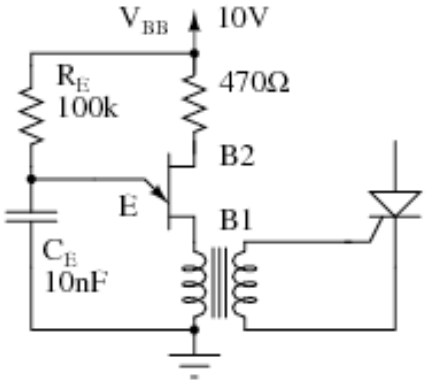
- As V_E increases, current I_E increases up I_P at the peak point.
- Beyond the peak point, current increases as voltage decreases in the negative resistance region.
- The voltage reaches a minimum at the valley point.
- The resistance of R_{B1}, the saturation resistance is lowest at the valley point.

All About Electronics, EETech Media, LLC, Chapter 7, Thyristors.

UJT Relaxation Oscillator...





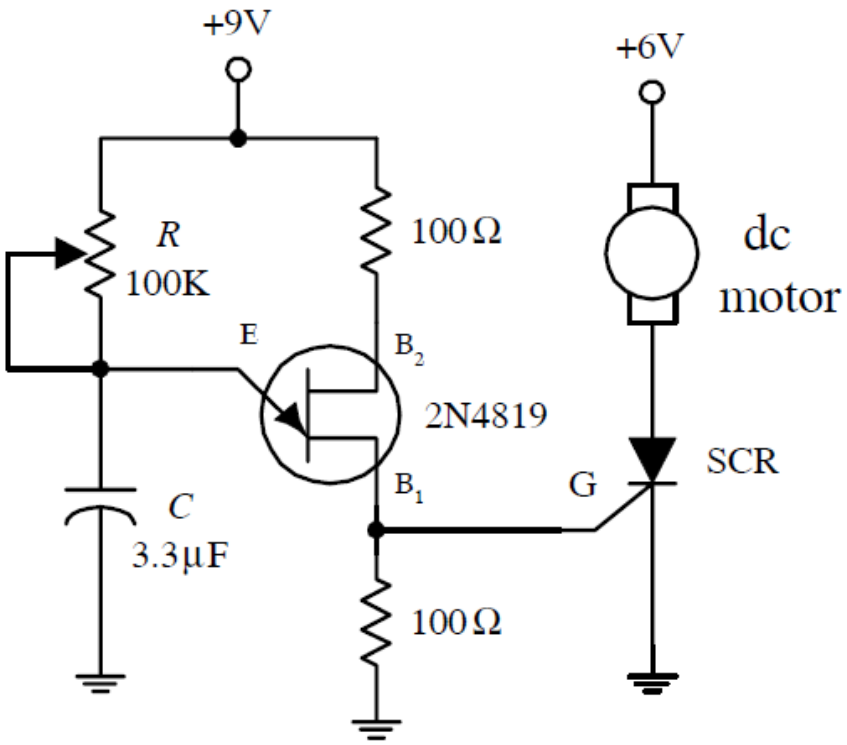


2n2647 $R_{BBO} = 4.7\text{—}9.1\text{k}$ $\eta = 0.68\text{—}0.82$ $I_V = 8\text{mA}$ $I_p = 2\mu\text{A}$

$$f = \frac{1}{RC \ln(1/(1-\eta))} = \frac{1}{(100\text{k})(10\text{nF}) \ln(1/(1-0.75))} = 1.39\text{kHz}$$

All About Electronics, EETech Media, LLC, Chapter 7, Thyristors.

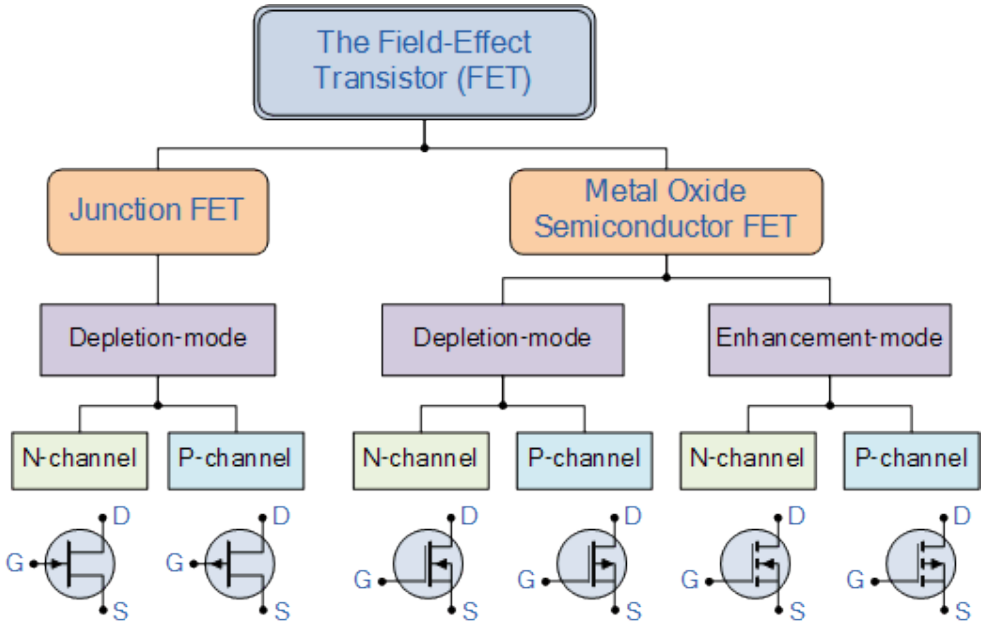
UJT/SCR Motor Control…



- Here we see control of motor speed by sending short pulses of current to the SCR.
- A UJT *relaxation oscillator* generates a series of pulses that drives an SCR on and off.
- To vary the speed of the motor, the UJT's oscillatory frequency is adjusted by changing the RC time constant.

Scherz, P.& S. Monk. *Practical Electronics for Inventors*, McGraw Hill, New York, NY (2016).

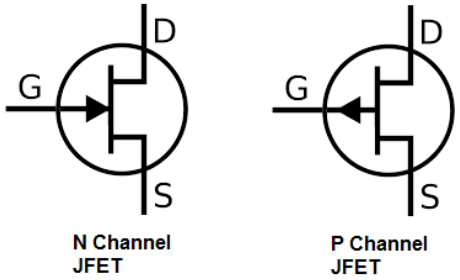
Field Effect Transistors (JFETS & MOSFETS)

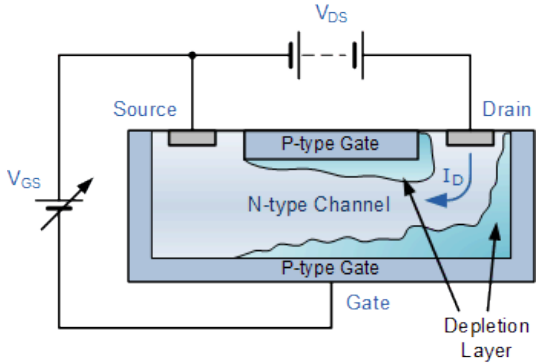


FET vs BJT	
Low voltage gain.	High voltage gain.
High current gain.	Low current gain.
High input and out impedance.	Low input and output impedance.
Easily damaged by static	Robust
Voltage Controlled	Current Controlled
High current needs like motors & servos	Low current relays, LEDs, lamps, amps, & oscillators

Courtesy of Electronics Tutorials, Aspen Core, Inc.

Junction Field Effect Transistor (JFET)…

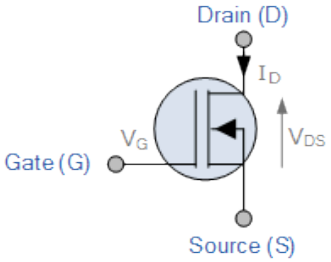




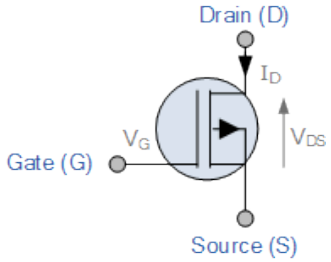
- The junction gate field-effect transistor (JFET) is the simplest type of field-effect transistor. They are three-terminal semiconductor devices that can be used as electronically-controlled switches, amplifiers, or voltage-controlled resistors.
- The control element for the JFET comes from depletion of charge carriers from the n-channel. When the Gate is made more negative, it depletes the majority carriers from a larger depletion zone around the gate. This reduces the current flow for a given value of Source-to-Drain voltage. Modulating the Gate voltage modulates the current flow through the device.

Left: Courtesy of Learning About Electronics.com
Right: Courtesy of Electronics Tutorials, Aspen Core, Inc.

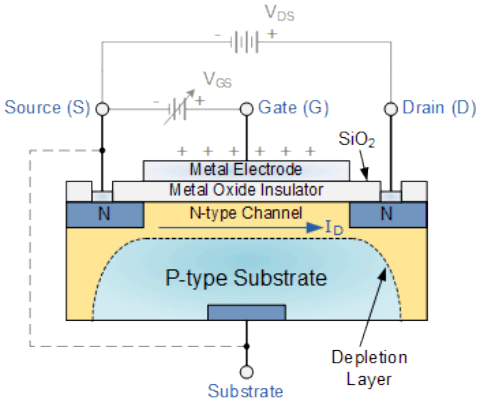
Metal Oxide Field Effect Transistor …

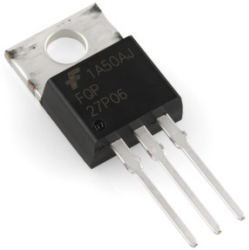


N-channel



P-channel

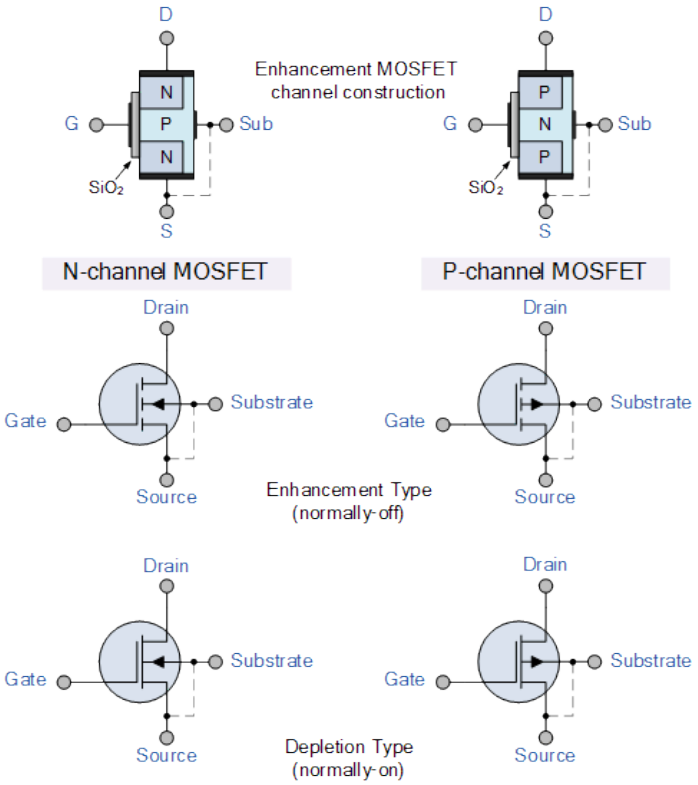




- The MOSFET differs from a JFET in that it has a “Metal Oxide” Gate electrode which is electrically insulated from the main semiconductor n-channel or p-channel by a very thin layer of insulating material usually silicon dioxide.
- This ultra thin insulated metal gate electrode can be thought of as one plate of a capacitor. The isolation of the controlling Gate makes the input resistance of the MOSFET extremely high.
- The MOSFET also acts like a voltage controlled resistor were the current flowing through the main channel between the Drain and Source is proportional to the input voltage

Courtesy of Electronics Tutorials, Aspen Core, Inc.

MOSFET…



- **Depletion Type**
  - The transistor requires the Gate-Source voltage, (V_{GS}) to switch the device "OFF".
  - The depletion mode MOSFET is equivalent to a "Normally Closed" switch.
- **Enhancement Type**
  - The transistor requires a Gate-Source voltage, (V_{GS}) to switch the device "ON".
  - The enhancement mode MOSFET is equivalent to a "Normally Open" switch.

Courtesy of Electronics Tutorials, Aspen Core, Inc.

Summary

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