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
The Silicon Controlled Rectifier (SCR) is simply a conventional rectifier controlled by a gate signal.
The main circuit is a rectifier. However, a gate signal is required for turning \textbf{ON}.

Once switched \textbf{ON} by a gate signal, but even after the gate signal is removed, the thyristor remains in the \textbf{ON} state until any turn \textbf{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**

- **Forward conduction**
  - $I_{G_3} > I_{G_2} > I_{G_1}$
- **Holding current**
- **Reverse leakage**
- **Avalanche breakdown**
- **Forward leakage**
- **Forward breakover voltage**

Diagram showing the different regions of operation for a thyristor.
Gate Turn–Off Thyristor (GTO)

- 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
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.
Insulated-Gate Bipolar Transistor

- 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...

Cyril Buttay, based on model in "Power semiconductor devices" by B. J. Baliga, ISBN 0-534-94098-6, CC BY-SA 3.0
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...

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...

- **Optocoupler (MOC3021)**: Used to isolate the control signal from the high voltage circuit.
- **Resistors (R1: 360 Ohms, R2: 470 Ohms)**: Used to limit current and control the voltage.
- **Capacitors (C1: 0.05uF)**: Used for filtering and decoupling.
- **Triac (BT136)**: Used to control the flow of current in one direction.
- **Snubber Circuit**: Requires only for inductive load (e.g., motor).

Additional components include:
- 5v/0v (on/off) switch
- Gnd
- Power Supply (e.g., 220v 50Hz)

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.
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.
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.
UJT Relaxation Oscillator...

\[
2n2647 \quad R_{BBO} = 4.7 - 9.1k \quad \eta = 0.68 - 0.82 \quad I_V = 8mA \quad I_P = 2\mu A
\]

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

# Field Effect Transistors (JFETS & MOSFETS)

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 Courtesy of Electronics Tutorials, Aspen Core, Inc.
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.
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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