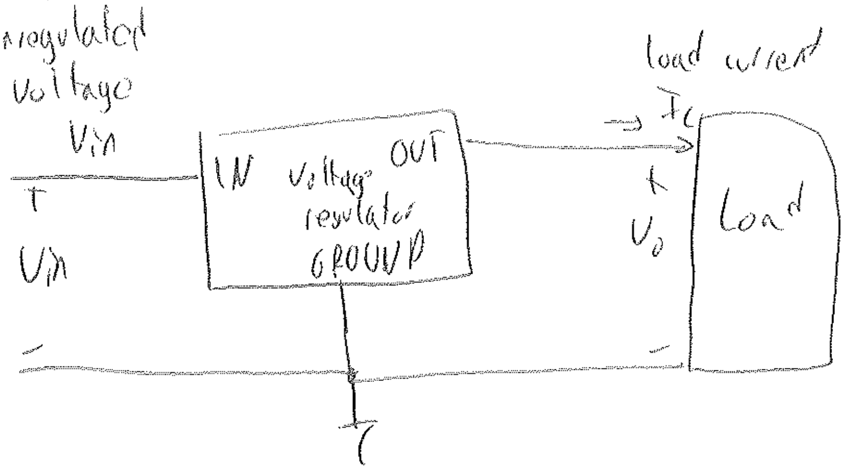
1

(1)

Switching Regulation

~~Provides efficient transfer of power to load.~~

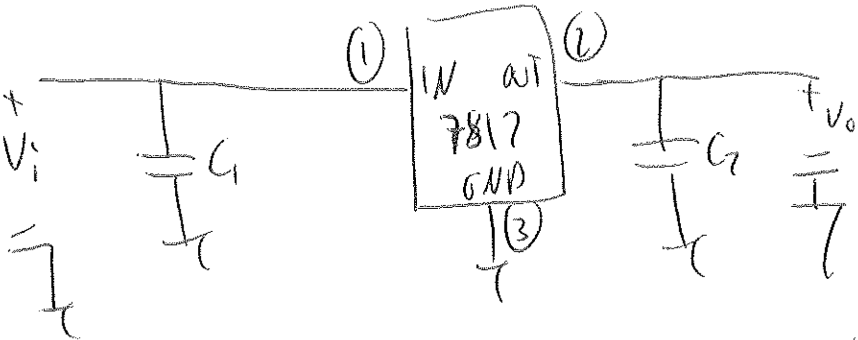
- It passes voltage to the load in pulses which are then filtered to produce a smooth DC voltage.
- Concepts related with power electronics should be studied for this purpose



IC Voltage regulator

- They contain circuitry for reference source, comparator amplifier, control device and overload protection all in a single IC (integrated circuit.
- Their fabrication are different from discrete analog regulators however their functionality is same
- They ~~regulate~~ provide regulation of either a fixed positive voltage, a fixed negative voltage or an adjustable set voltage

Three Terminal Voltage Regulators



↑ basic connection of of three terminal voltage regulator to load

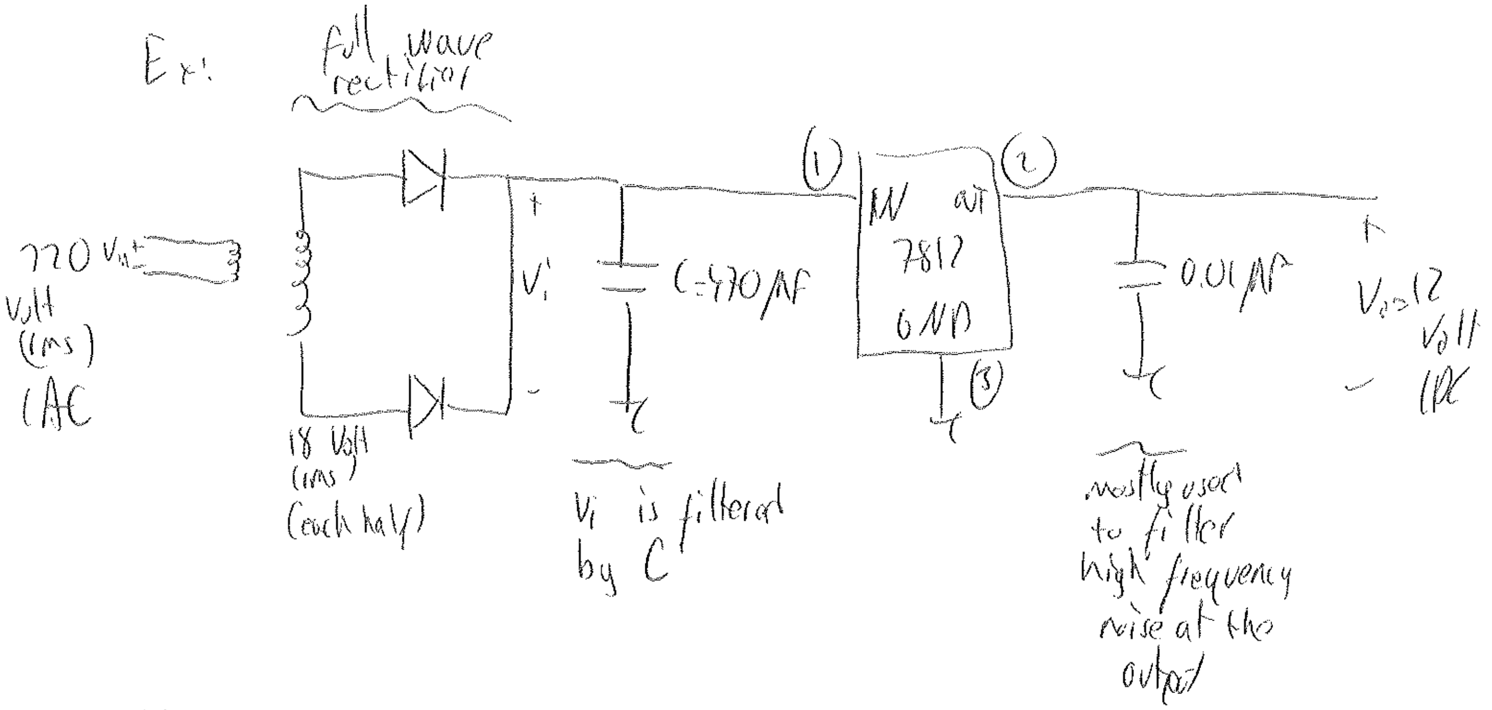
→ C_1, C_2 are used to hold the DC elements of V_i an V_o

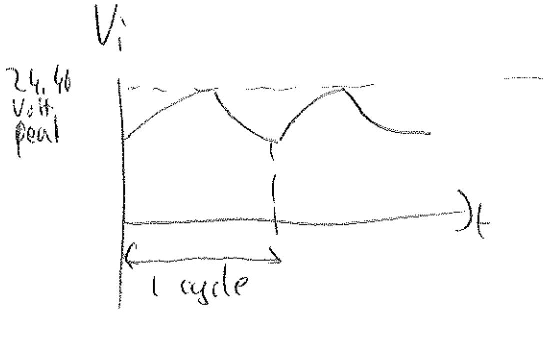
- optionally RC filter can also be used at the input or output section to filter out AC elements of V_i (2) ~~and/or V_o (if required)~~

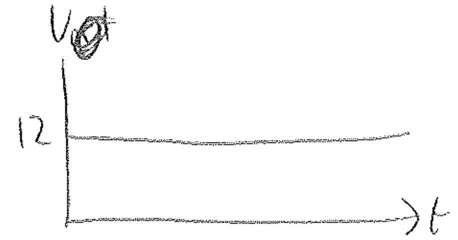
Fixed positive voltage regulator

The series 78 regulators provide fixed regulated voltages from 5V to 24V

Ex:







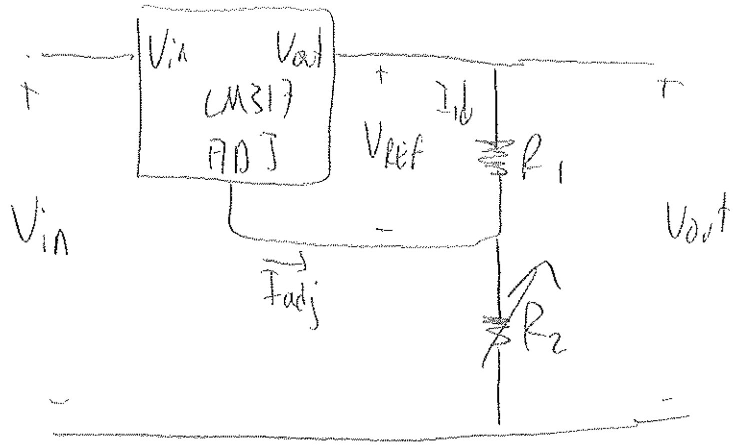
Dropout voltage: The minimum amount of voltage across the input-output terminals that must be maintained if the IC is to operate as a regulator

Fixed-Negative Voltage Regulators

- provide negative DC voltage
- fabrication and operation are simillar to fixed-positive voltage regulators
- 7900 IC series are used for this purpose

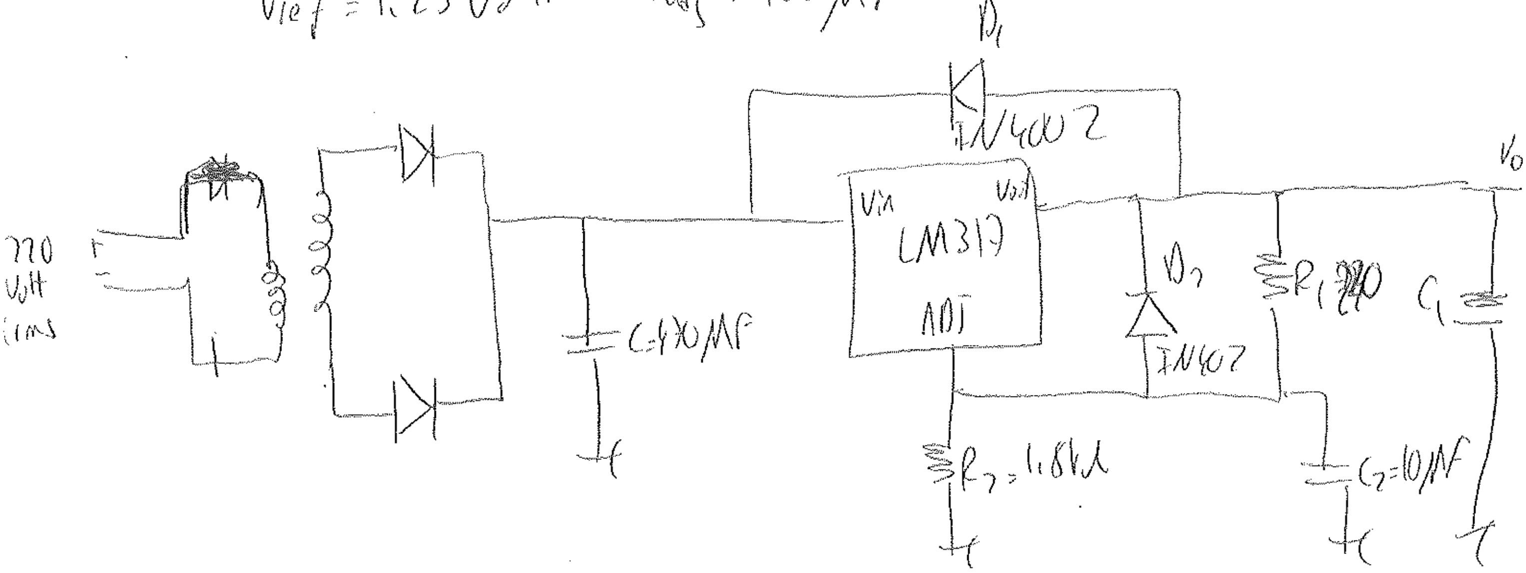
Adjustable Voltage Regulator

Ex. LM317 can be used to set output voltage b/w 1.2 to 37 Volt.



$$V_{out} = V_{ref}\left(1 + \frac{R_2}{R_1}\right) + I_{adj} R_2$$

$V_{ref} = 1.25$ Volt $I_{adj} = 100\,\mu A$



C_1, C_2, C used to hold DC voltage
Diodes proved current to flow in the

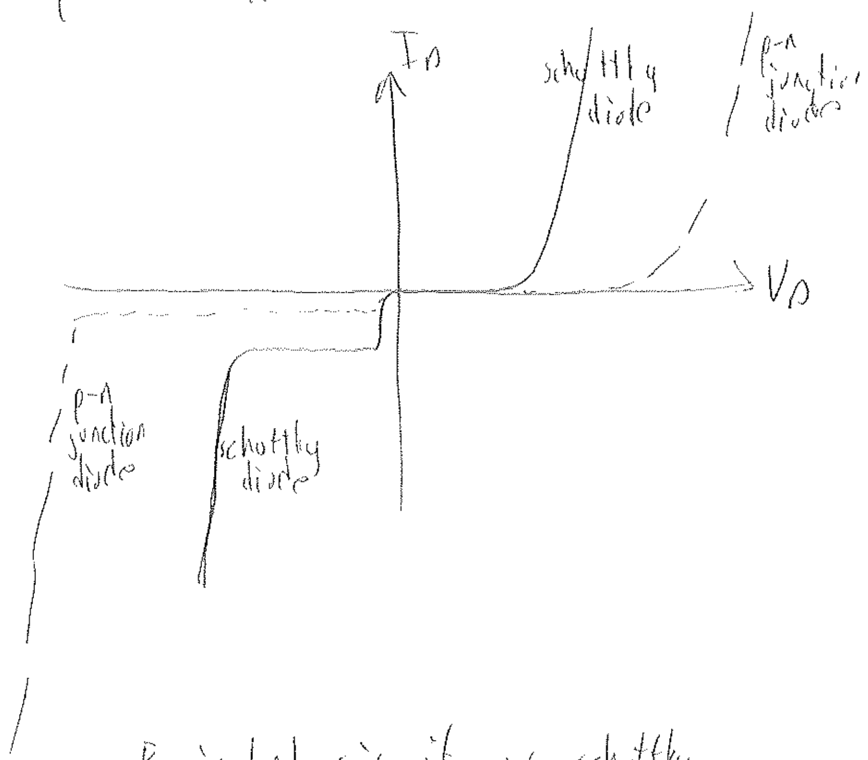
$$V_o = 1.25\left(1 + \frac{1.8}{240}\right) + 100\,\mu A\,(1.8k\Omega) = 10.8 \text{ Volt}$$

↑ regulated voltage value

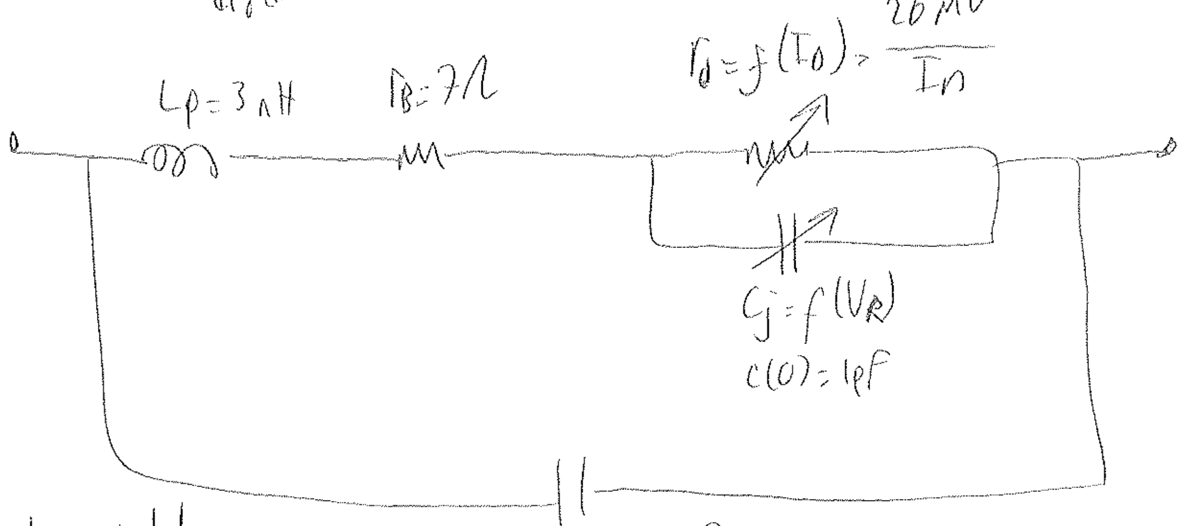
Two-Terminal devices

Schottky barrier (hot-carrier) diodes

- Has quick response time
- Can be used in high frequency applications
- Has lower noise figure (rejection of noise)
- New application area : ~~low/volt~~ low-voltage/high-current power supplied and ac-to-dc converters.



Equivalent circuit of schottky diode

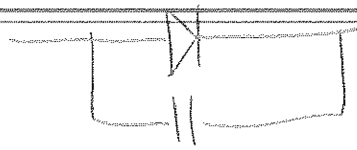


$L_p \rightarrow$ package inductance
$C_p \rightarrow$ " capacitance
$r_B \rightarrow$ series resistance

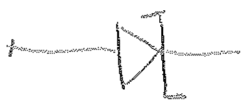
$r_d \rightarrow$ AC resistance
$C_j \rightarrow$ " capacitance

$V_R \rightarrow$ reverse bias voltage

Approximate equivalent circuit



circuit symbol



Varactor (VVC) (Voltage-variable capacitor)

— semiconductor, voltage-dependent, variable capacitors

— modes of operation depends on the capacitance that exists at p-n junction when element is reverse biased

$$C_T = \epsilon \frac{A}{W_d}$$

C_T → transition capacitance

A → p-n junction area

W_d → depletion region width of p-n junction

ϵ → permittivity of semiconductor material

— As (V_R → reverse bias potential) increases, W_d increase and reduces the transition capacitance

$$C_T = \frac{K}{(V_T + V_R)^n}$$

K → constant due to semiconductor material

V_T → knee potential

V_R → reverse bias voltage

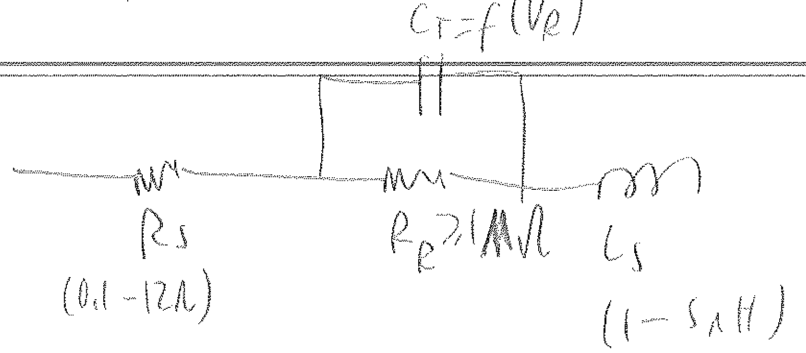
n → $\frac{1}{2}$ for alloy junctions

$\frac{1}{3}$ for diffused junctions

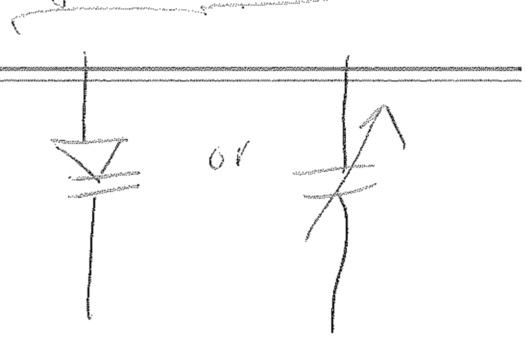
$$C_T(V_R) = \frac{C(0)}{\left(1 + \left|\frac{V_R}{V_T}\right|\right)^n}$$

C(0) → capacitor at zero-bias condition

Equivalent circuit



symbol

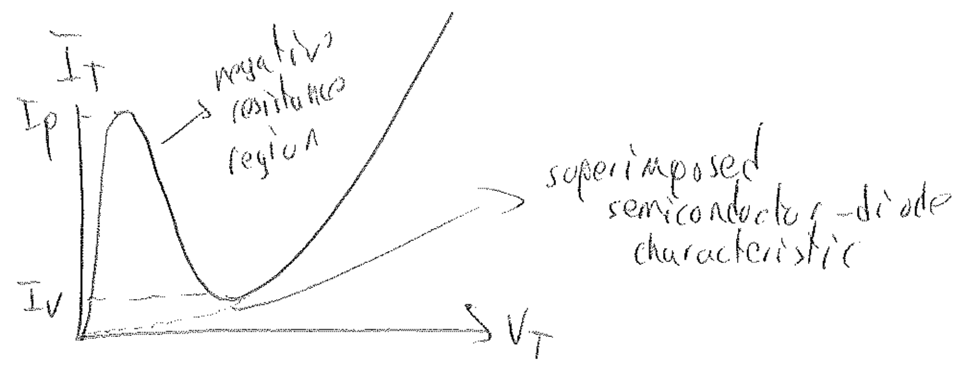


Power diodes

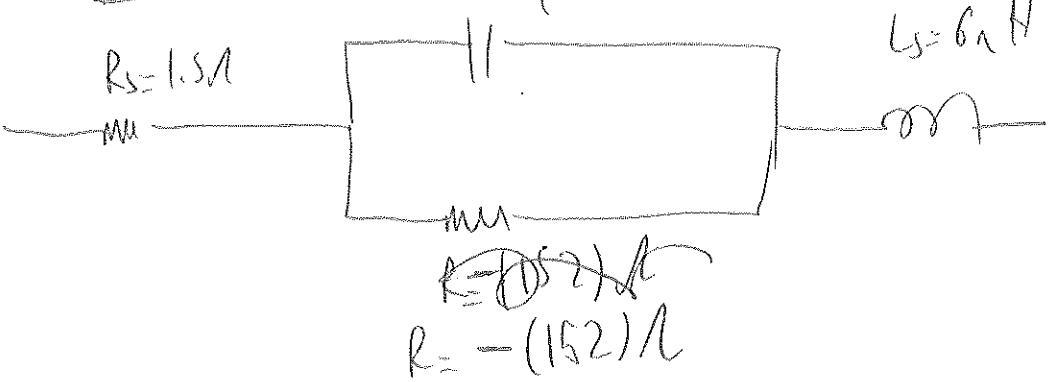
used in rectifiers with high power rating

Tunnel diodes

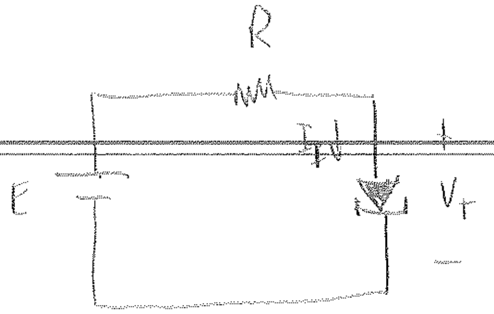
- has some negative resistance region
- in this region an increase in voltage results in a reduction in diode current

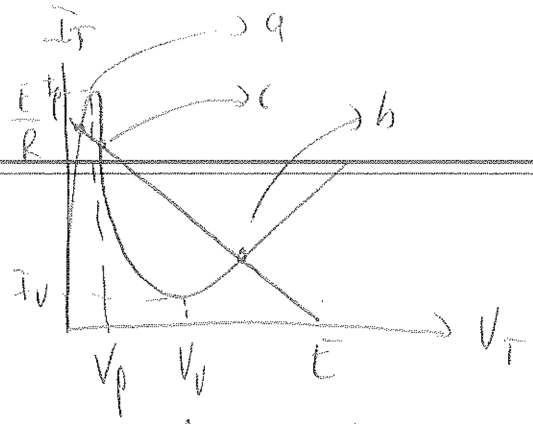


circuit model



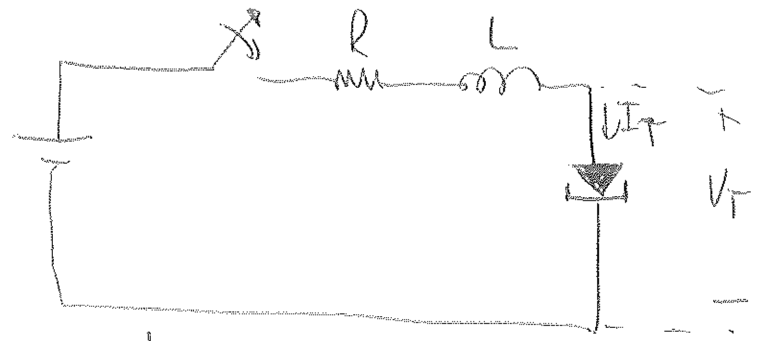
symbols

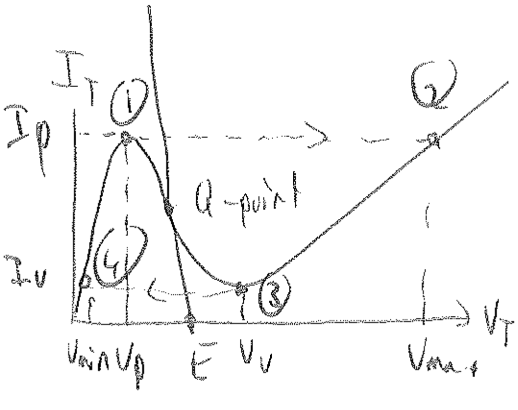


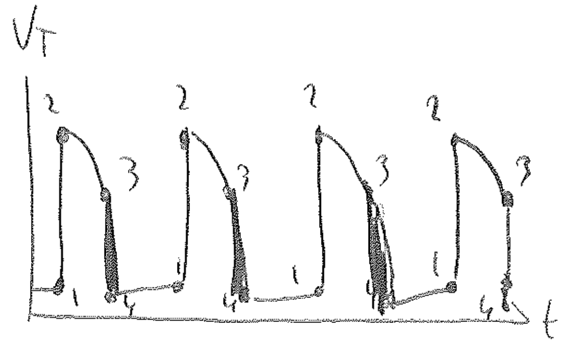


Tunnel diode and resulting load line

application: (negative resistance oscillator)







How this characteristics is obtained

- When power is turned on, the supply voltage will be E.
- Initially I_T will increase from 0 to I_p (this will result with storage of energy in inductor (in terms of magnetic field.

(8)

– Once $I_T = I_P$ is reached, the diode characteristics suggests that the current I_T must now ~~decrease with increase in the voltage~~ across the diode

This contradicts the fact that

$$E = I_T R + I_T(-R_T) \qquad E = \underbrace{I_T}_{\text{less}}\underbrace{(R - R_T)}_{\text{less}}$$

if both elements of the equation above were to decrease, it would be impossible for the supply voltage to reach its set value therefore the current I_T continue to rise and operating point shifts from (1) to (2)

– However at point (2) the voltage is greater than supply voltage ($V_{max} > E$, and point (2) is to the right of any point at the load line). To satisfy Kirchoff's voltage law, the polarity of the transient voltage across the coil must reverse and the current decreases from (2) to (3) gradually.

– When V_T drops to V_V (point (3)), the $I_T - V_T$ characteristics suggests that the I_T current will begin to increase again. This is unacceptable since V_T is still more than the applied voltage ~~again~~ ($E < V_V \geq V_T$) and the coil the coil is discharging through the series circuit

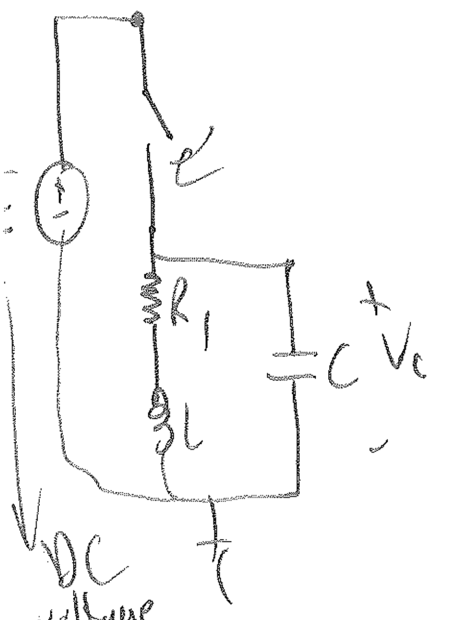
(10) — Thus, the point of operation jumps from (3) to (4) to permit a continuation of decrease in I_T.

— However at point (4) $E > V_{min}$, thus to satisfy ~~the equation~~ try to satisfy the load line equation once again the I_T should increase from I_v (point 4) to I_p again (point 1)

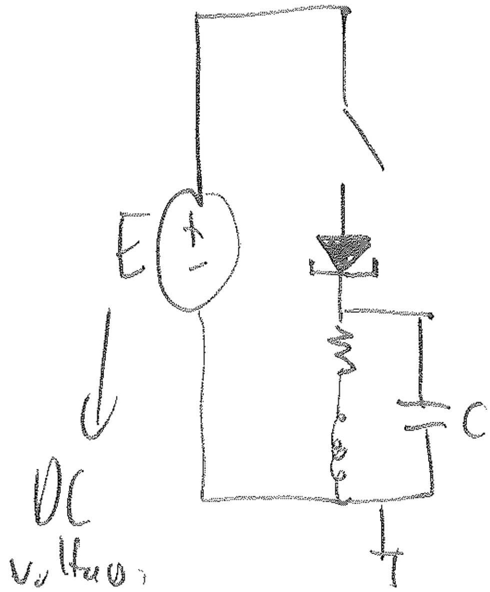
— After this cycle the process will repeat itself

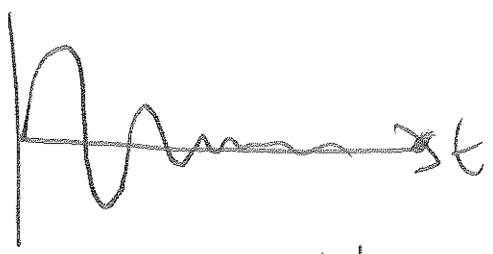
Tunael diode for oscillator

Tank circuit

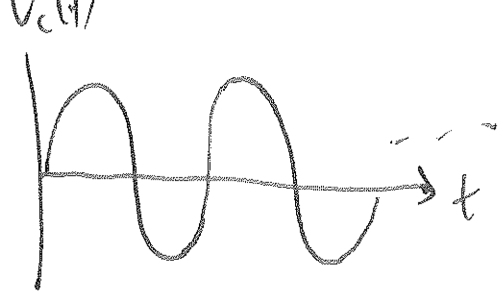


put a tunel diode





damping oscillations are observed due to dissipation element R_1



— The negative resistance of tank diode offsets (compensates) the resistive characteristics of tank circuit, resulting in undumped response.

The design must continue to result in a load line that (1) will intersect the characteristics only in the negative resistance region.

Photodiode

The energy of light wave

$$W = \hbar f \text{ joules}$$

$\hbar$ → plack constan = 6.624×10^{-3} $\frac{\text{joule}}{\text{second}}$ f → frequency

$$\lambda = \frac{v}{f}$$

v → velocity of light 3×10^{8} $\frac{m}{sec}$

λ → wavelength (the distance between two peaks)

f → frequency of travelling wave (Hertz)

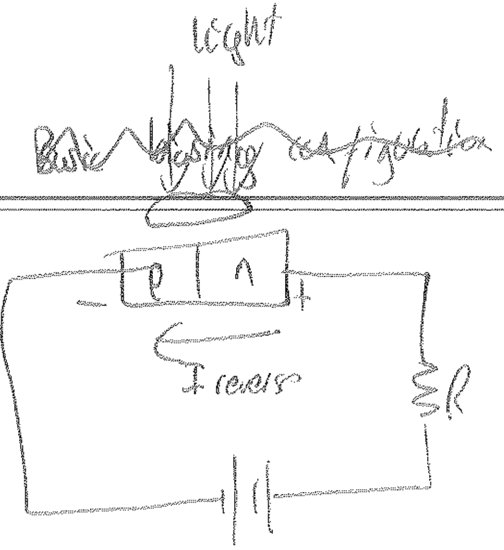
- wavelength determines the material to be used in the optoelectronic device (germanium, silicon, selenium)
- The free electrons generated in each material is proportional to intensity of the incident light. Light intensity is a measure of amount of luminous flux falling in a particular surface. Luminous flux is normally measured in lumens (lm) or Watts.

$$1\ lm = 1.496 \times 10^{-10}\ Watt$$

↓

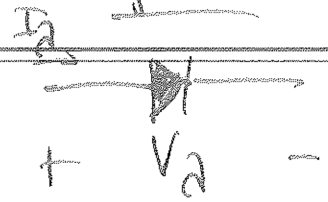
lumen

- Photodiode is a semiconductor p-n junction device whose region of operation is limited to the reverse bias region

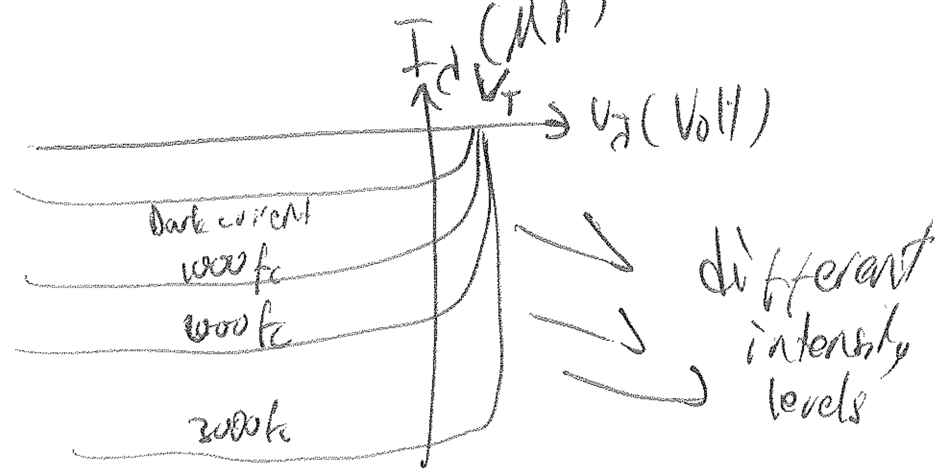


Basic biasing arrangement and construction

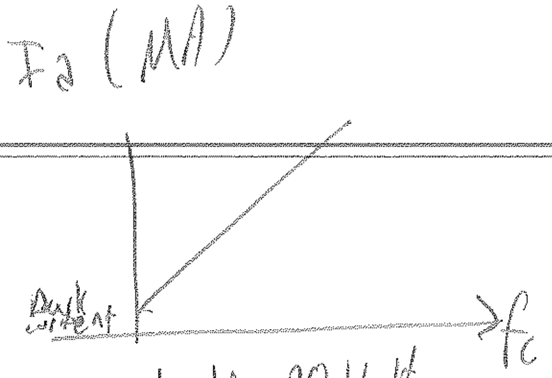
symbol



- reverse saturation current is nearly a few microamperes and it is due solely to the thermally generated minority carriers in the n-type and p-type materials.
- application of light to junction will result in a transfer of energy from the incident light waves to the atomic structure, resulting in an increased number of minority carriers and increased level of reverse current.



- Dark current = current value that will not exist with no applied illumination.
- Current only returns to 0 with a positive applied bias equal to V_T



at $V_d = 10$ Volt
for a photodiode (linear)

Photoconductive cells:

Two-terminal semiconductor device whose terminal resistance varies (linearly) with the intensity of the incident light.

— For obvious reasons, it is frequently called as photoresistive device.

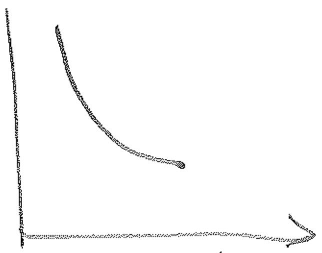
. symbol

Photoconductive cell-terminal characteristics

(14)

Thermistor

- Temperature-sensitive resistor
- Not a junction device
- Resistance depend on body temperature



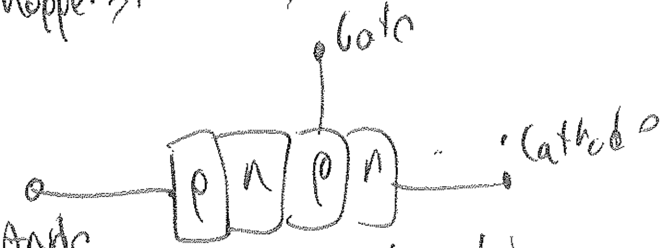
Characteristics

Symbol

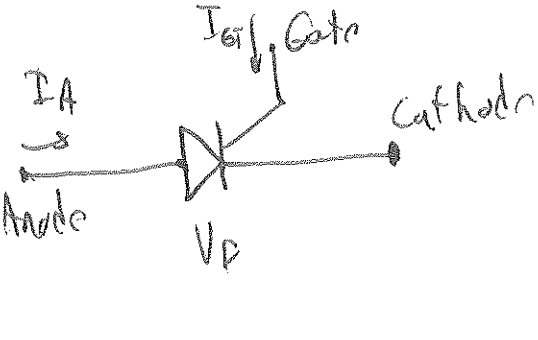
pnpn and other devices

Silicon-controlled rectifier

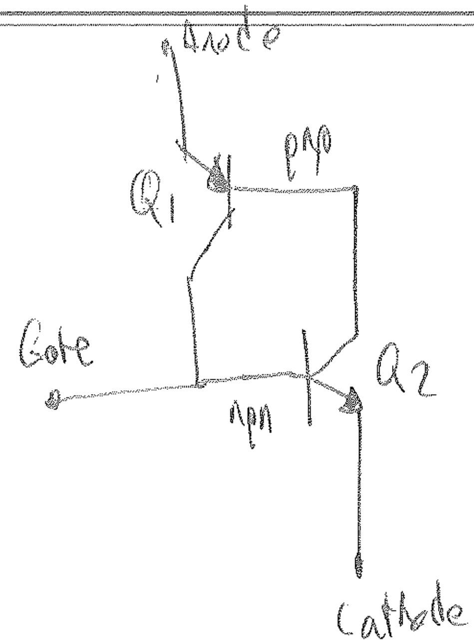
- introduced in 1956 by Bell Telephone Libraries
- used in relay controls, time delay circuits, regulated power supplies, static switches, motor control, choppers, inverters, heater control, phase control



basic contruction



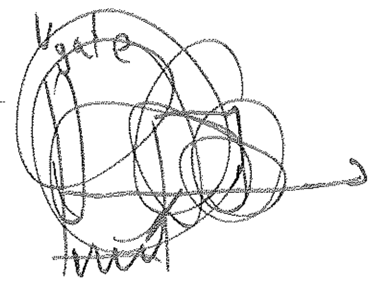
SCR two-transistor equivalent circuit

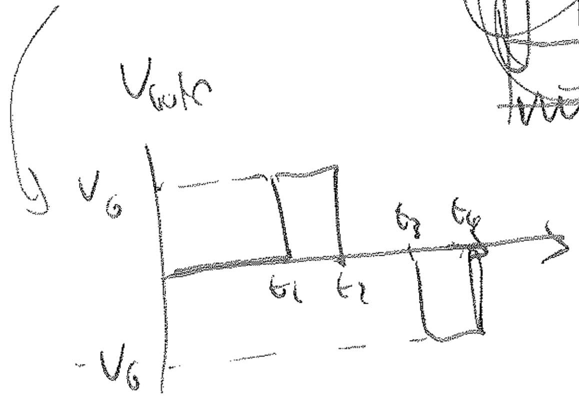


- In conduction region dynamical resistance of SRC is typically 0.001 Ω to 0.1 Ω
- In non-conduction region the reverse resistance is typically 100 kΩ.

- forward conduction; Anode should be positive w.r.t cathode. But this is not a sufficient for turning the device on. A pulse of sufficient magnitude must also be applied to the gate to establish a turn-on current, represented symbolically by I_{GT}.

~~Let's apply~~





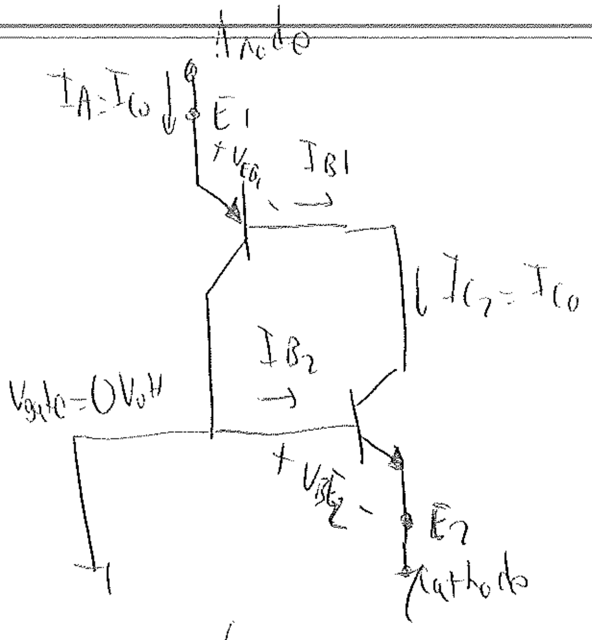
to the

Let's apply V_{gate} to the gate terminal.

~~- During $0 \to t_1$, $V_{gate} = 0$~~

During $t = 0 \rightarrow t_1$ $V_{Gate} = 0$ Volt

In this case the circuit equivalent diagram will be



During

$V_{BE_2} = V_{Gate} = 0 \Rightarrow I_{B_2} = 0$

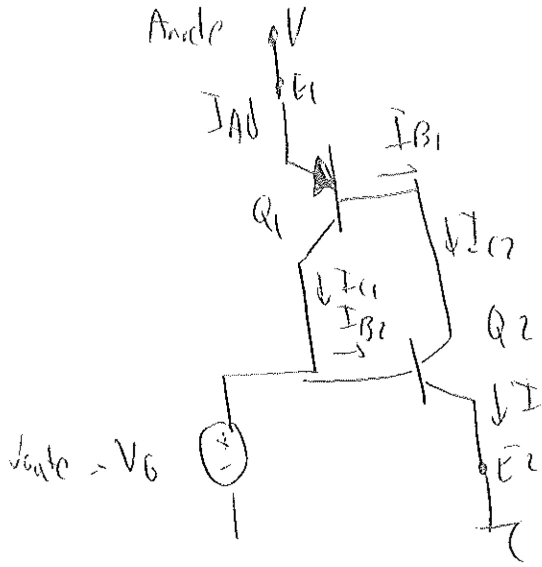
$I_{C_2} = I_{CO}$ $I_{B_1} = I_{C_2} = I_{CO}$ too small to turn Q_1 on.

Both transistors are therefore off resulting in high impedance btw collector and emitter of each transistor hence the SCR will be open circuit

resulting circuit $t: 0 \rightarrow t_1$ $V_{Gate} = 0$ Volt

At $t = t_1$ a pulse V_G Volt will appear at SCR gate

the circuit configuration will be

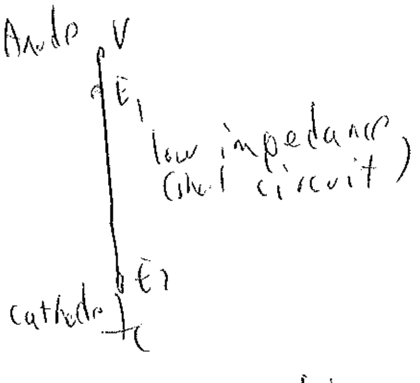


V_G chosen sufficiently large to turn Q_2 on. The collector current of Q_2 (I_{C2}) will then rise to a value sufficiently large to turn Q_1 on ($I_{B1} = I_{C2}$) as Q_1 turns on I_{C1} will increase hence it will also increase I_{B2}. The increase in I_{B2} will further increase I_{C2}. Resulting in a regenerative increase in the collector current of each transistor.

Resulting anode-to-cathode resistance $R_{SCR} = \frac{V}{I_A} \approx 0$ (small value)

such that R_{SCR} is nearly 0.

Hence corresponding circuit will be short circuit



The regenerative action results in SCRs having typical turn-on times of 0.1 μs to 1 μs. However high-power devices in range 100A to 400A may have 10 to 25 μs turn-on times.

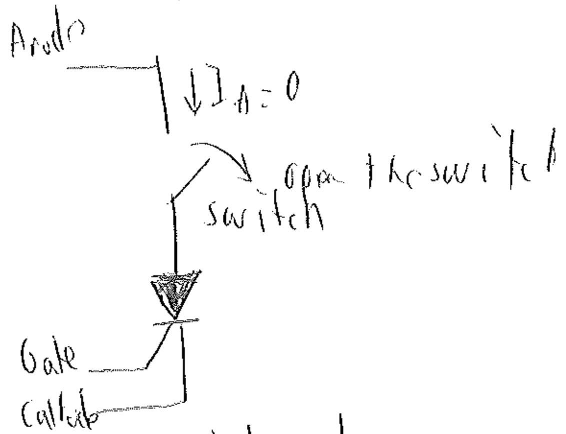
- SCR can be turned also ON by raising anode-to-cathode voltage to the breakover value.

- A SCR cannot be turned off by simply removing the gate signal, and only a special few can be turned off by applying a negative pulse to the gate terminal at $t = t_3$

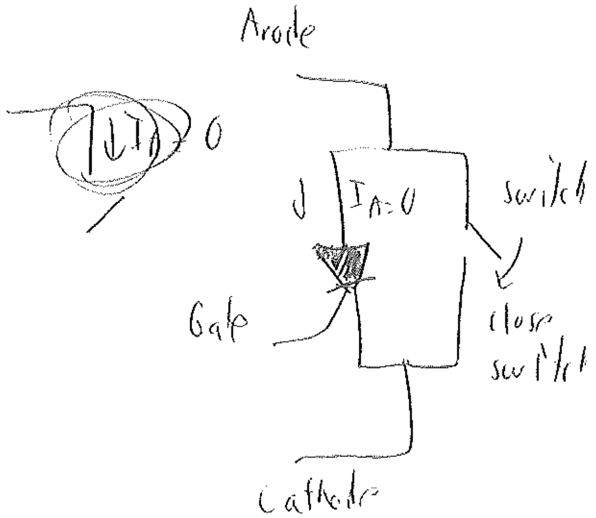
- Two methods for turning off an SCR are anode current interruption and forced commutation

Anode current interruption

- Generally done by a switch

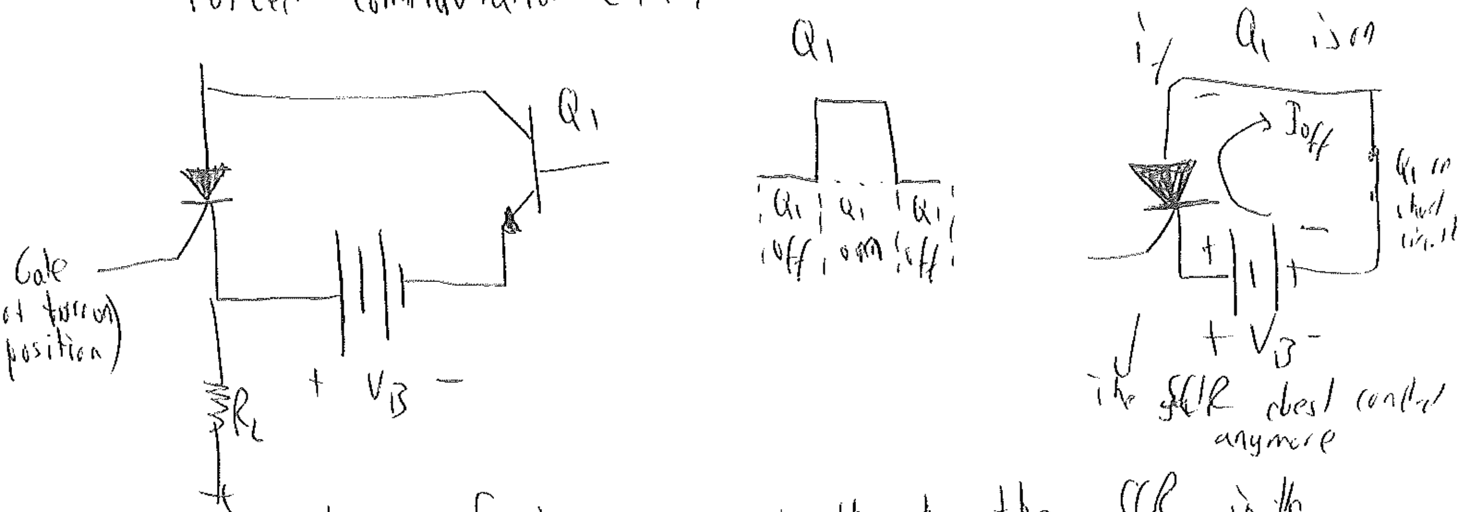


series interruption



Shunt interruption

Forced Commutation example



- Forced commutation: Forcing of current through the SCR in the direction opposite to conduction.
- Turn-off times of SCRs are typically 5 μsec to 30 μsec

(14)

SCR characteristics and ratings

— Forward breakover voltage: $V_{(BR)F^*}$ is the voltage above which SCR enters to the conduction region.

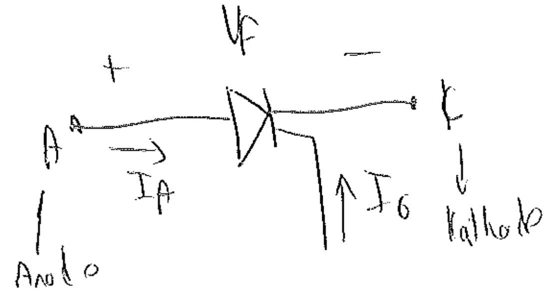
$*$ denotes the letter to be added, which is dependent on the condition of the gate terminal as follows

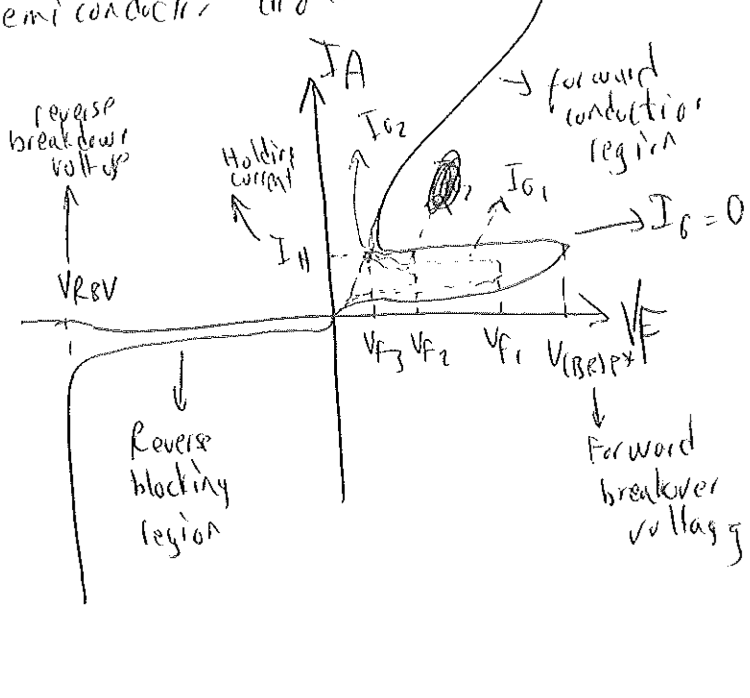
O = open circuit from G to K
S = short circuit from G to K
R = resistor from G to K
V = fixed bias (voltage) from G to K

— Holding current: I_H = the current value below which the SCR switches from conduction state to forward blocking region under stated conditions

— Forward and reverse blocking regions: The regions corresponding to open-circuit condition for controlled rectifier that block flow of charge (current) from anode to cathode.

— Reverse breakdown region: Zener or avalanche region of the fundamental two-layer semiconductor diode

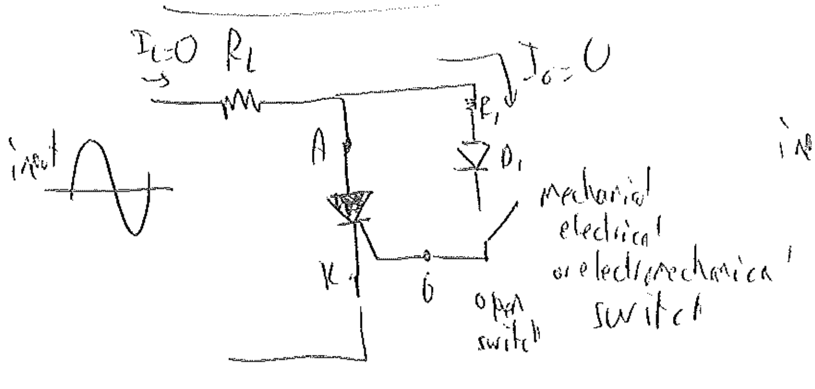


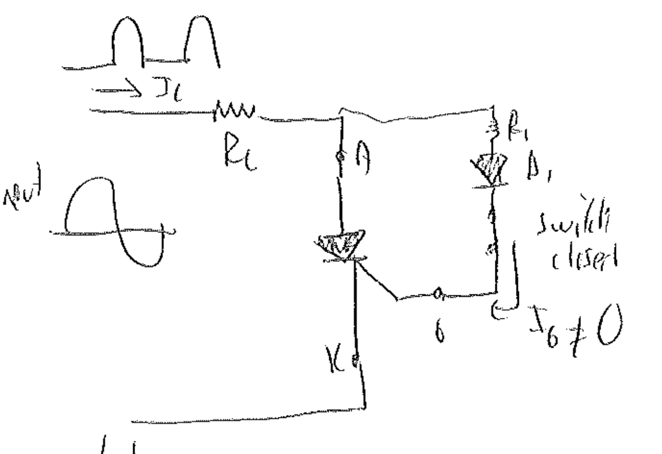


- When $I_G = 0$ V_F should reach to largest required breakover voltage ($V_{(BR)F}$) before the "collapsing" effect results and the SCR can enter the conduction region. (on state)
- If I_G is increased to I_{G1} ($I_{G1} > I_G$) the value required for conduction is less ($V_F > V_{F1}$)
- I_H drops as I_G increases.
- If gate current increases to I_{G2} ($I_{G2} > I_{G1} > I_G = 0$) the SCR will fire at very low values (V_{F3}) and characteristic will be similar to basic p-n junction
- For a particular V_F (say V_{F2}), if gate current is increased for $I_G = 0$ to I_{G1} or more, SCR will fire

Applications

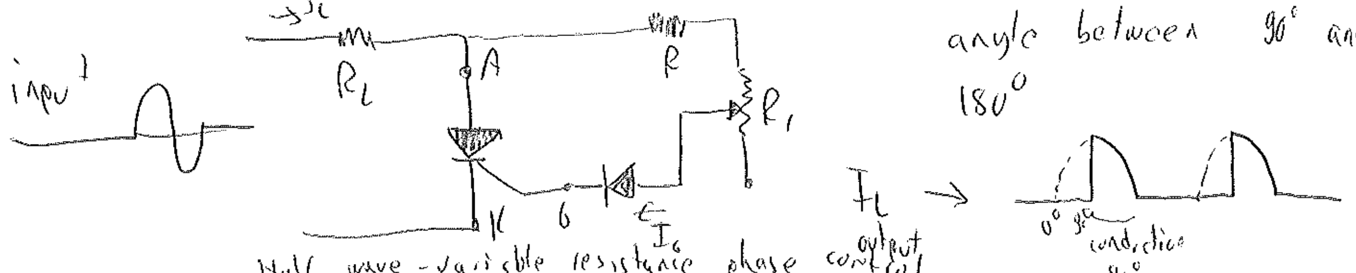
Series static switch





Half-wave series static switch

Variable-resistance phase control



Half wave-variable resistance phase control

- Establishes a conduction angle between 90° and 180°

(21)

- Combination of R and R_1 limits the gate current in the positive cycle of input

---

- If R_1 is set to max value, gate current may never reach to turn-on magnitude..
- As R_1 decreased from its max value, the gate current will increase from the same input voltage. In this way the required turn-on gate ~~voltage~~ current can be established in any point b/w $0°$ and $90°$

— output I_L