SEE 3263: ELECTRONIC SYSTEMS

Chapter 5: Thyristors

1

THYRISTORS

- Thyristors are devices constructed of four semiconductor layers (*pnpn*).
- Four-layer devices act as either open or closed switches; for this reason, they are most frequently used in control applications.
- Thyristors include: Shockley diode, silicon-controlled rectifier (SCR), diac and triac.
- They stay on once they are triggered, and will go off only if current is too low or when triggered off.
- Usage: lamp dimmers, motor speed controls, ignition systems, charging circuits, etc.

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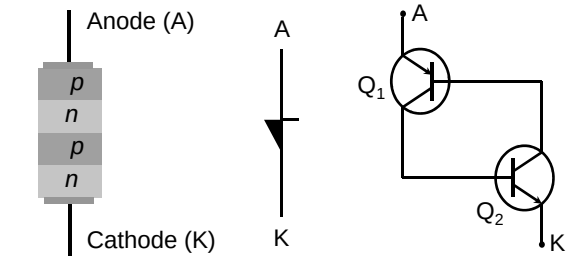
The Shockley Diode

- The **4-layer diode** (or Shockley diode) is a type of thyristor that acts something like an ordinary diode but conducts in the forward direction only after a certain anode to cathode voltage called the forward-breakover voltage is reached.

- The symbol reminds you that it acts like a diode.
- It does not conduct when it is reverse-biased.



Basic Construction | **Schematic Symbol** | **Equivalent Circuit**

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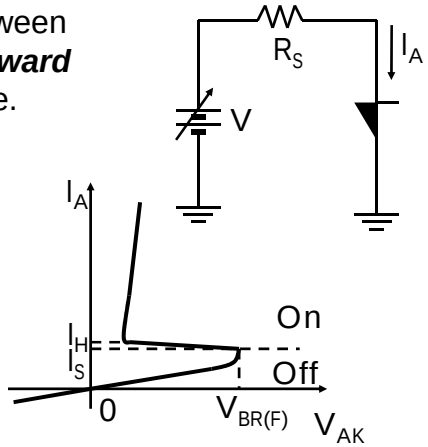
Shockley Diode Characteristic Curve

- The characteristic curve between 0 V and $V_{BR(F)}$ shows the ***forward blocking region*** i.e. off state.
- When the anode-to-cathode voltage, I_A exceeds $V_{BR(F)}$, conduction occurs.
- Once conduction begins, I_A increases rapidly and will continue until I_A is reduced to less than the ***holding current*** (I_H).
- This is the only way to stop conduction.



$V_{BR(F)}$ = forward-breakover voltage
I_S = switching current
I_H = holding current

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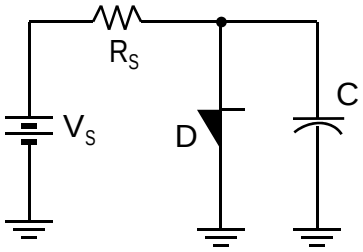
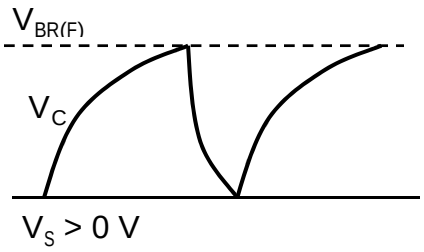
A Shockley Diode Application



Relaxation Oscillator



Voltage Waveform

Capacitor charges through R_S and discharges through D.

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Silicon-Controlled Rectifier (SCR)

- SCR is another four-layer *pnpn* device.
- Has 3 terminals: anode, cathode, and gate.
- In off state, it has a very high resistance.
- In on state, there is a small on (forward) resistance.
- Applications: motor controls, time-delay circuits, heater controls, phase controls, etc.

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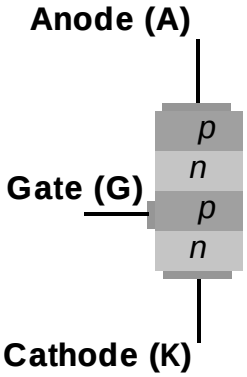
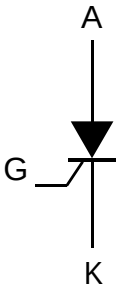
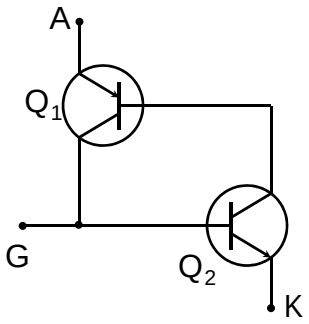
SCR continue….



Basic Construction



Schematic Symbol



Equivalent Circuit

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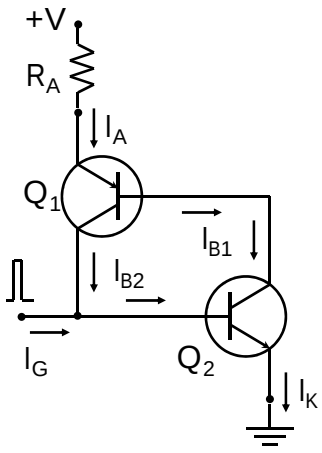
Turning The SCR On

- The positive pulse of current at the gate turns on Q_2 providing a path for I_{B1}.
- Q_1 then turns on providing more base current for Q_2 even after the trigger is removed.
- Thus, the device stays on (latches).



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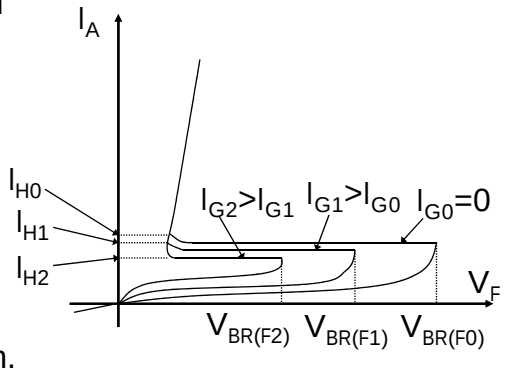
Turning The SCR On

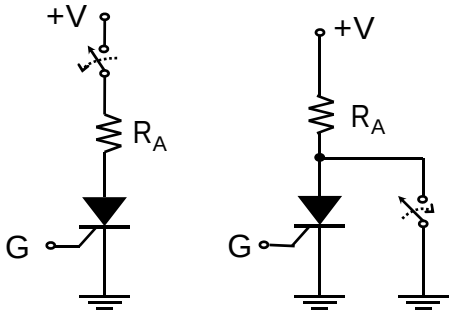
- The SCR can be turned on by exceeding the forward breakover voltage or by gate current.
- Notice that the gate current controls the amount of forward breakover voltage required for turning it on.
- $V_{BR(F)}$ decreases as I_G is increased.



SCR characteristic curves for different I_G Values

Turning The SCR Off

- The SCR will conduct as long as forward current exceeds I_H.
- There are two ways to drop the SCR out of conduction: 1) ***Anode Current Interruption*** and 2) ***Forced Commutation***.

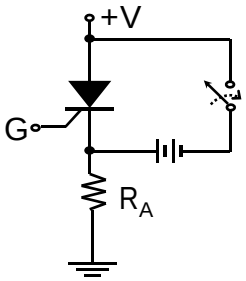


(1) Anode Current Interruption

Anode current can be interrupted by breaking the anode current path (shown here), providing a path around the SCR, or dropping the anode voltage to the point that $I_A < I_H$.

Turning The SCR Off

Force commutation uses an external circuit to momentarily force current in the opposite direction to forward conduction.



(2) Forced Commutation

SCRs are commonly used in ac circuits, which forces the SCR out of conduction when the ac reverses.

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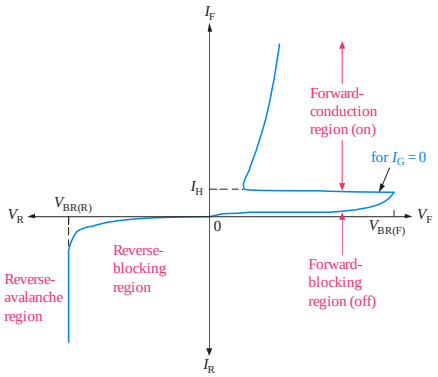
SCR Characteristics & Ratings

- **Forward-breakover voltage, $V_{BR(F)}$:** voltage at which SCR enters forward-conduction (on) region.
- **Holding current, I_H:** value of anode current for SCR to remain in on region.
- **Gate trigger current, I_{GT}:** value of gate current to switch SCR on.
- **Average forward current, $I_{F(avg)}$:** maximum continuous anode current (dc) that the SCR can withstand.
- **Reverse-breakdown voltage, $V_{BR(R)}$:** maximum reverse voltage before SCR breaks into avalanche.



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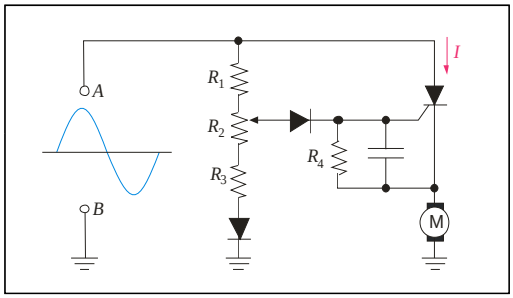
SCR Applications

- SCRs are used in a variety of power control applications.
- One of the most common applications is to use it in *ac* circuits to control a *dc motor* or appliance because the SCR can both rectify and control.

The SCR is triggered on the positive cycle and turns off on the negative cycle.

A circuit like this is useful for speed control for fans or power tools and other related applications.



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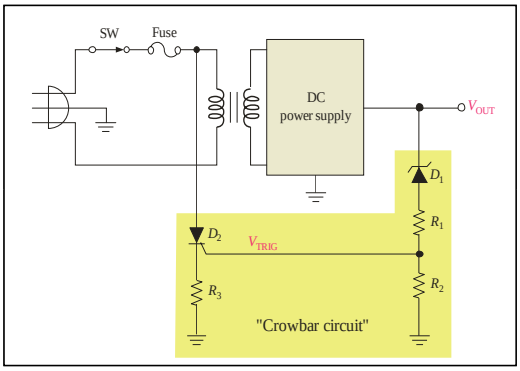
SCR Applications

- Another application for SCRs is in crowbar circuits (which get their name from the idea of putting a crowbar across a voltage source and shorting it out!)

The purpose of a crowbar circuit is to shut down a power supply in case of over-voltage.

Once triggered, the SCR latches on.

The SCR can handle a large current, which causes the fuse (or circuit breaker) to open.



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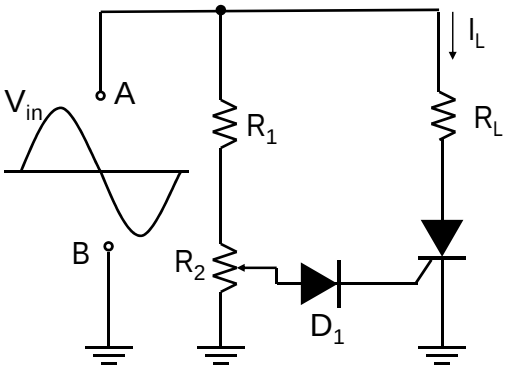
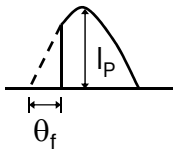
Half-Wave Power Control 0º-90º





$$I_{L(AVG)} = \frac{I_P}{2\pi}(1+\cos\theta_f)$$

where θ_f = firing angle
= 90^0 max.

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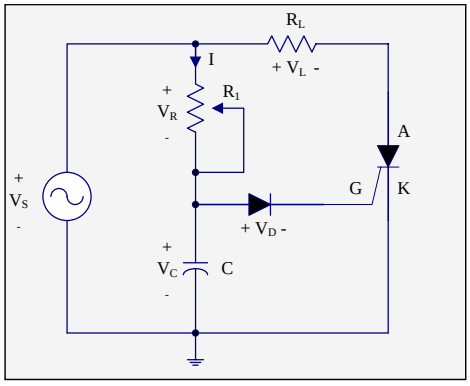
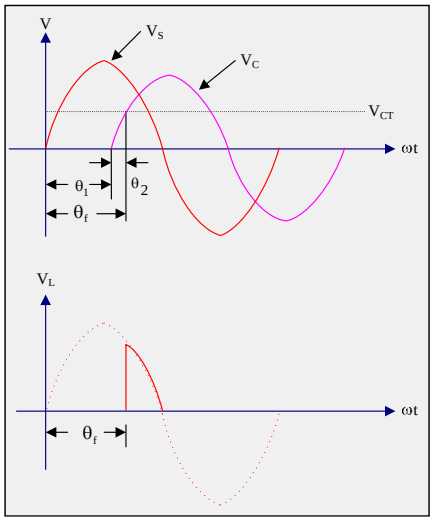
Half-Wave Power Control 0º-180º





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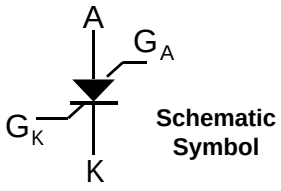
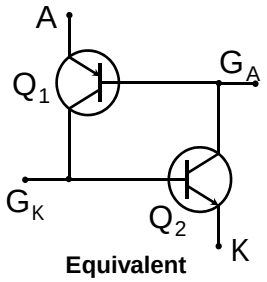
Silicon-Controlled Switch (SCS)

- SCS can be turned on either by a positive pulse at the cathode or a negative pulse at the anode.
- SCS can be turned off by using pulses of the reversed polarity or by anode current interruption methods.
- SCS and SCR are used in similar applications.
- SCS has faster turn-off with pulses on either gate terminal; but it has lower maximum current and voltage ratings than SCR.



Schematic Symbol



Equivalent Circuit

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The Diac and Triac

- Both the diac and the triac are types of thyristors that can conduct current in both directions (bilateral).
- They are four-layer devices.
- The diac has two terminals, while the triac has a third terminal (gate).
- The diac is similar to having two parallel Shockley diodes turned in opposite directions.
- The triac is similar to having two parallel SCRs turned in opposite directions with a common gate.

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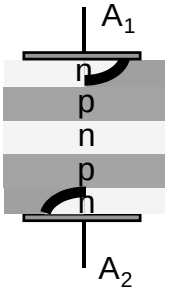
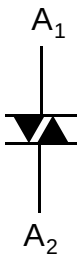
The Diac

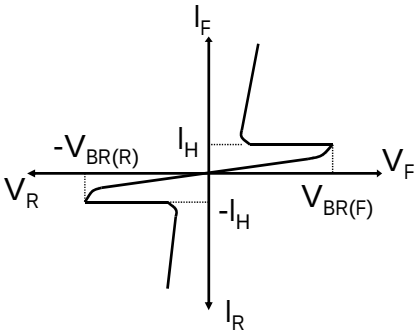
- The **diac** is a thyristor that acts like two back-to-back 4-layer diodes.
- It can conduct current in either direction. Because it is bidirectional, the terminals are equivalent and labeled A_1 and A_2.



Basic Construction



Symbol



Characteristic Curve

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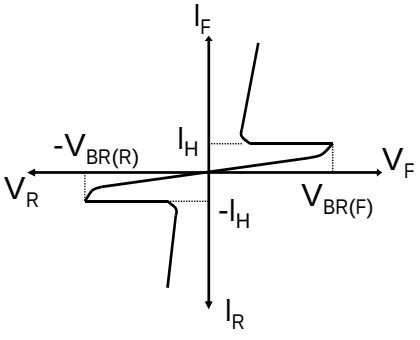
The Diac

- The diac conducts current after the breakdown voltage is reached.
- At that point, the diac goes into avalanche conduction, creating a current pulse sufficient to trigger another thyristor (an SCR or triac).
- The diac remains in conduction as long as the current is above the holding current, I_H.



Characteristic Curve

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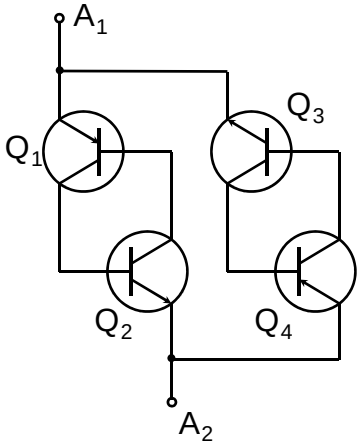
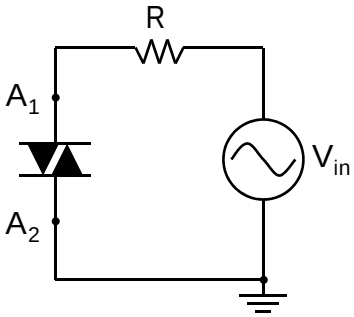
Diac Equivalent Circuit

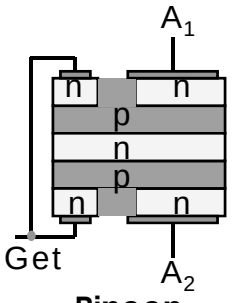




Current can flow in both directions

The Triac

- The **triac** is essentially a bidirectional SCR but the anodes are *not* interchangeable.
- Triggering is done by applying a current pulse to the gate; breakover triggering is not normally used.



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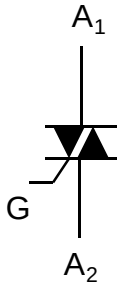
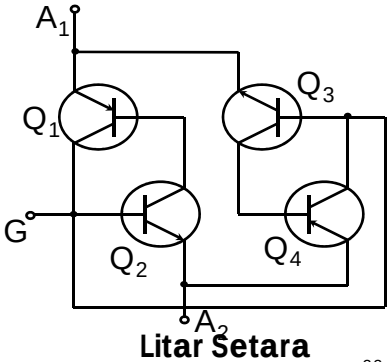


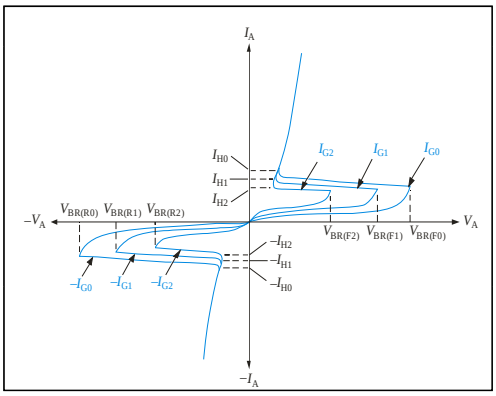
Simbol



Litar Setara

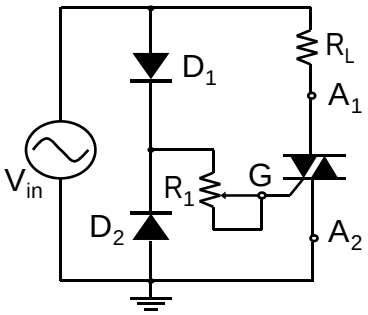
The Triac

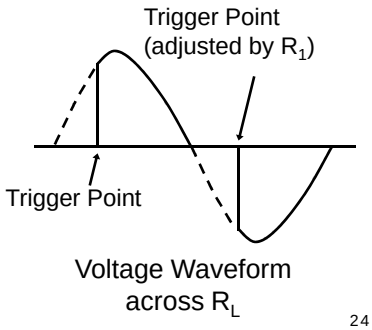
- When the voltage on the A_1 terminal is positive with respect to A_2, a gate current pulse will cause the left SCR to conduct.
- When the anode voltages are reversed, the gate current pulse will cause the right SCR to conduct.



Triac Applications (Phase-Control Circuit)

- Triacs are used for control of ac in applications like electric range heating controls, light dimmers, and small motors.
- Like the SCR, the triac latches after triggering and turns off when the current is below the I_H, which happens at the end of each altenation.

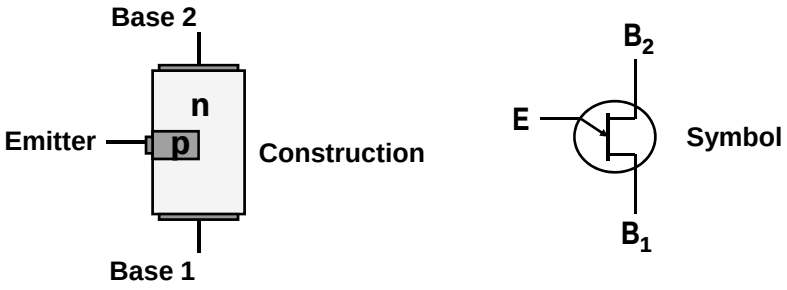




Voltage Waveform across R_L

The Unijunction Transistor (UJT)

- The **UJT** consists of a block of lightly-doped (high resistance) *n*-material with a *p*-material grown into its side.
- It has only one pn junction.
- It has an emitter and two bases, B_1 and B_2.
- It is often used as a trigger device for SCRs and triacs.



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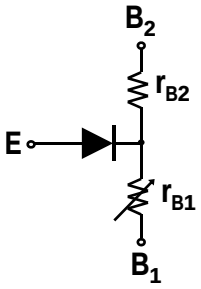
THE UJT

- UJT has only one pn junction.
- It has an emitter and two bases, B_1 and B_2.
- r_{B1} and r_{B2} are internal dynamic resistances.
- The inter-base resistance, $r_{BB} = r_{B1} + r_{B2}$.
- r_{B1} varies inversely with emitter current, I_E
- r_{B1} can range from several thousand ohms to tens of ohms depending on I_E.



Equivalent Circuit

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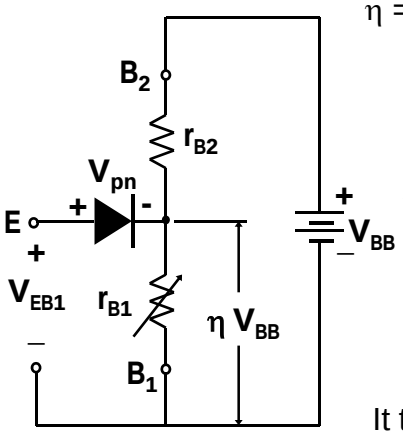
Basic UJT Biasing And Equivalent Circuit

$V_{rB1} = \eta V_{BB}$

$\eta = r_{B1}/r_{BB}$ is the intrinsic standoff ratio.



If $V_{EB1} < V_{rB1} + V_{pn}$, $I_E = 0$ since pn junction is not forward biased(V_{pn} = barrier potential of pn junction)

At $V_P = \eta V_{BB} + V_{pn}$, the UJT turns on and operates in a negative resistance region up to a certain value of I_E.

It then becomes saturated and I_E increases rapidly with V_E.

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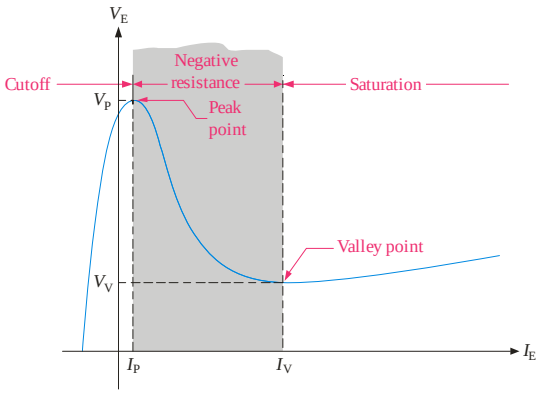
UJT Characteristic Curve

The UJT is a switching device; it is not an amplifier. When the emitter voltage reaches V_P (the peak point), the UJT "fires", going through the unstable negative resistance region to produce a fast current pulse.



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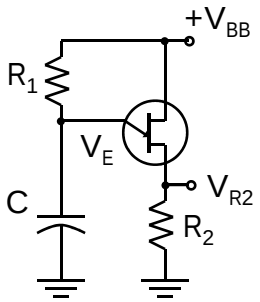
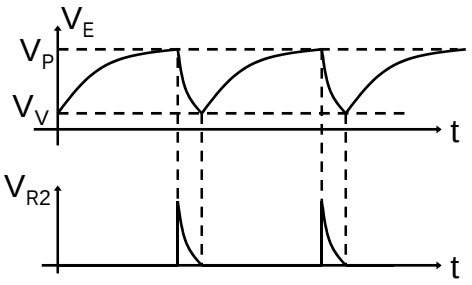
Applications of UJT

UJT can be used as trigger device for SCRs and triacs.

Other applications include non-sinusoidal oscillators, sawtooth generators, phase control, and timing circuits.



Relaxation oscillator



Waveforms for UJT relaxation oscillator

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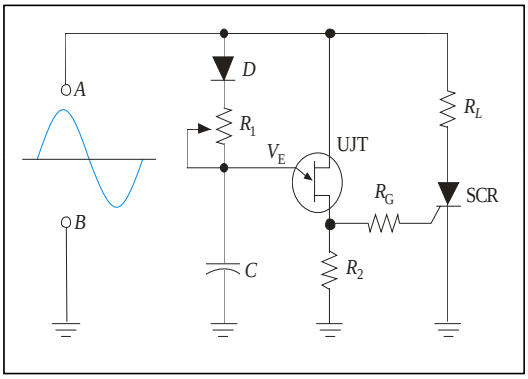
Applications of UJT

A circuit using a UJT to fire an SCR is shown. When the UJT fires, a pulse of current is delivered to the gate of the SCR. The setting of R_1 determines when the UJT fires. The diode isolates the UJT from the negative part of the ac.



The UJT produces a fast, reliable current pulse to the SCR, so that it tends to fire in the same place every cycle.

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Conditions For UJT Oscillator Operation

- In the relaxation oscillator, R_1 must not limit I_E at the peak point to less than I_P at turn-on, i.e., $V_{BB} - V_P > I_P R_1$.
- To ensure turn-off of the UJT at the valley point, R_1 must be large enough that I_E can decrease below I_V, i.e., $V_{BB} - V_V < I_V R_1$.
- So, for proper operation:

$$\frac{V_{BB} - V_P}{I_P} > R_1 > \frac{V_{BB} - V_V}{I_V}$$

R_2 is usually << R_1, and the frequency of oscillations is

$$f_o = \left[R_1 C \ln\left(\frac{V_{BB} - V_V}{V_{BB} - V_P} \right) \right]^{-1}$$

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The Programmable UJT

- The PUT is a 4-layer thyristors with a gate.
- It is primarily used as a sensitive switching device.
- It is more similar to an SCR (four-layer device) except that its anode-to-gate voltage can be used to both turn on and turn off the device.
- The gate pulse can trigger a sharp increase in current at the output.
- It can replace the UJT in some oscillator applications.

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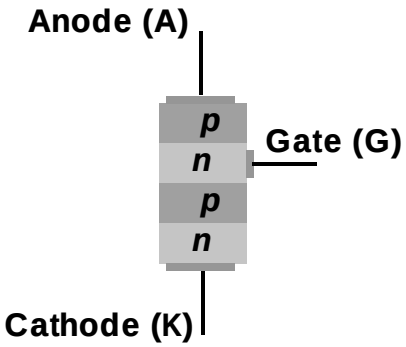
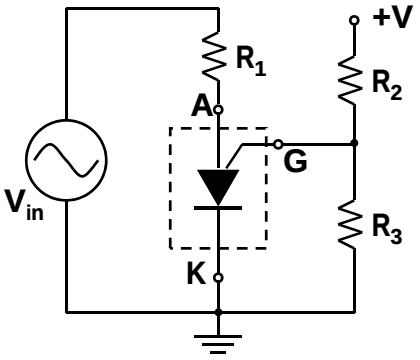
PUT Construction & Symbol



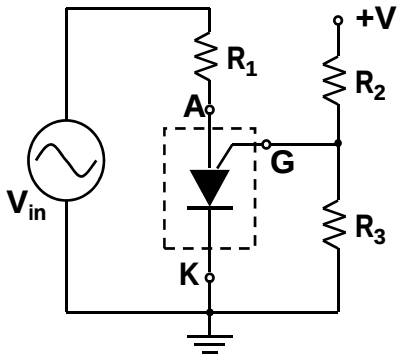
Basic Construction



PUT Symbol and Biasing

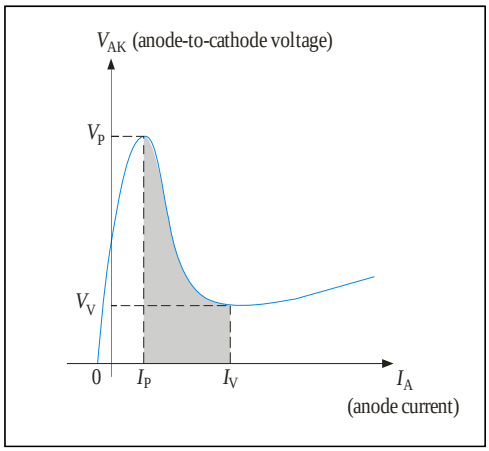
THE PUT

- Notice that the gate is connected to the *n* region adjacent to the anode.
- The gate is always biased positive with respect to the cathode.
- When $V_A - V_G > 0.7$ V, the PUT turns on.
- The characteristic plot of V_{AK} versus I_A is similar to the V_E versus I_E plot of the UJT.



THE PUT Characteristic Curve

The characteristic of a PUT is similar to a UJT, but the PUT intrinsic standoff ratio can be "programmed" with external resistors and the UJT has a fixed ratio.



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Application of PUT

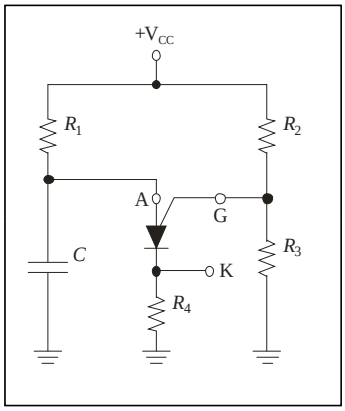
The principle application for a PUT is for driving SCRs and triacs, but, like the UJT, can be used in relaxation oscillators.

For the circuit to oscillate, R_1 must be large enough to limit current to less than the valley current (I_V). The period of the oscillations is given by:

$$T = R_1 C \ln \frac{1}{1-\eta}$$

where

$$\eta = \frac{R_3}{R_2 + R_3}$$



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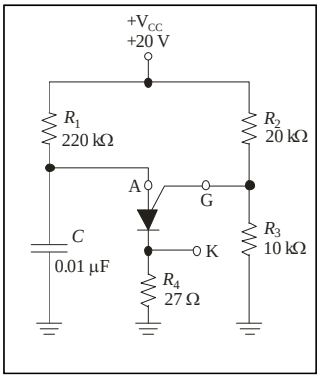
Example: What is intrinsic standoff ratio, and the period of the circuit?



Solution:

$$\eta = \frac{R_3}{R_2 + R_3} = \frac{10\ \text{k}\Omega}{20\ \text{k}\Omega + 10\ \text{k}\Omega} = 0.33$$

$$T = R_1 C \ln \frac{1}{1-\eta}$$

$$= (220\ \text{k}\Omega)(0.01\ \mu\text{F}) \ln \frac{1}{1-0.33} = 0.89\ \text{ms}$$

Follow-up:

What is the frequency? 1.12 kHz

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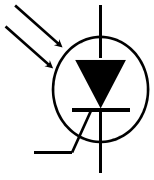
The Light-Activated SCR

- The light-activated SCR (LASCR) operates essentially as does the conventional SCR except it can also be light-triggered.
- Most LASCRs have an available gate terminal for conventional triggering.
- The LASCR is most sensitive to light when the gate terminal is open.

Symbol



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Selected Key Terms

4-layer diode	The type of 2-terminal thyristor that conducts current when the anode-to-cathode voltage reaches a specified "breakover" value.
Thyristor	A class of four-layer (*pnpn*) semiconductor devices.
SCR	Silicon-controlled rectifier; a type of three terminal thyristor that conducts current when triggered by a voltage at the single gate terminal and remains on until anode current falls below a specified value.

SEE 3263 THYRISTORS

Selected Key Terms

LASCR	Light-activated silicon-controlled rectifier; a four layer semiconductor device (thyristor) that conducts current in one direction when activated by a sufficient amount of light and continues to conduct until the current falls below a specified value.
Diac	A two-terminal four-layer semiconductor device (thyristor) that can conduct current in either direction when properly activated.
Triac	A three-terminal thyristor that can conduct current in either direction when properly activated.

Selected Key Terms

SCS Silicon-controlled switch; a type of four-terminal thyristor that has two gate terminals that are used to trigger the device on and off.

UJT Unijunction transistor; a three terminal single *pn* junction device that exhibits a negative resistance characteristic.

PUT Programmable unijunction transistor; a type of three terminal thyristor (physically more like an SCR than a unijunction) that is triggered into conduction when the voltage at the anode exceeds the voltage at the gate.

Quiz

1. The 4-layer (Shockley) diode can conduct current if
   a. the anode-to-cathode voltage exceeds V_{BR}
   b. a current pulse is applied to the gate
   c. both a and b are correct
   d. none of the above

Quiz

2. The SCR can conduct current if

a. the anode-to-cathode voltage exceeds V_{BR}

b. a current pulse is applied to the gate

c. both a and b are correct

d. none of the above

Quiz

3. A bidirectional thyristor is the

a. 4-layer diode

b. SCR

c. triac

d. silicon-controlled switch

Quiz

4. A thyristor that looks like two back-to-back 4-layer diodes is the

a. SCR

b. triac

c. SCS

d. diac

SEE 3263 THYRISTORS

Quiz

5. An SCR turns off when the

a. gate trigger current drops below a specified level

b. anode current drops below the holding current

c. both a and b are true

d. none of the above

Quiz

6. The purpose of a crowbar circuit is to protect a load from

a. excessive ripple

b. low-voltage

c. over-voltage

d. all of the above

Quiz

7. A diac and triac are similar in that both devices

a. can use breakover triggering

b. can be used in ac circuits

c. are bidirectional

d. all of the above

Quiz

8. A device that has an unstable negative resistance region is the

a. UJT

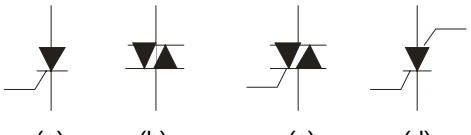
b. diac

c. triac

d. SCS

Quiz

9. The symbol for a silicon-controlled switch (SCS) is



Quiz

10. A programmable unijunction transistor (PUT) is "programmed" by choosing the

a. *RC* time constant

b. gate resistors

c. power supply voltage

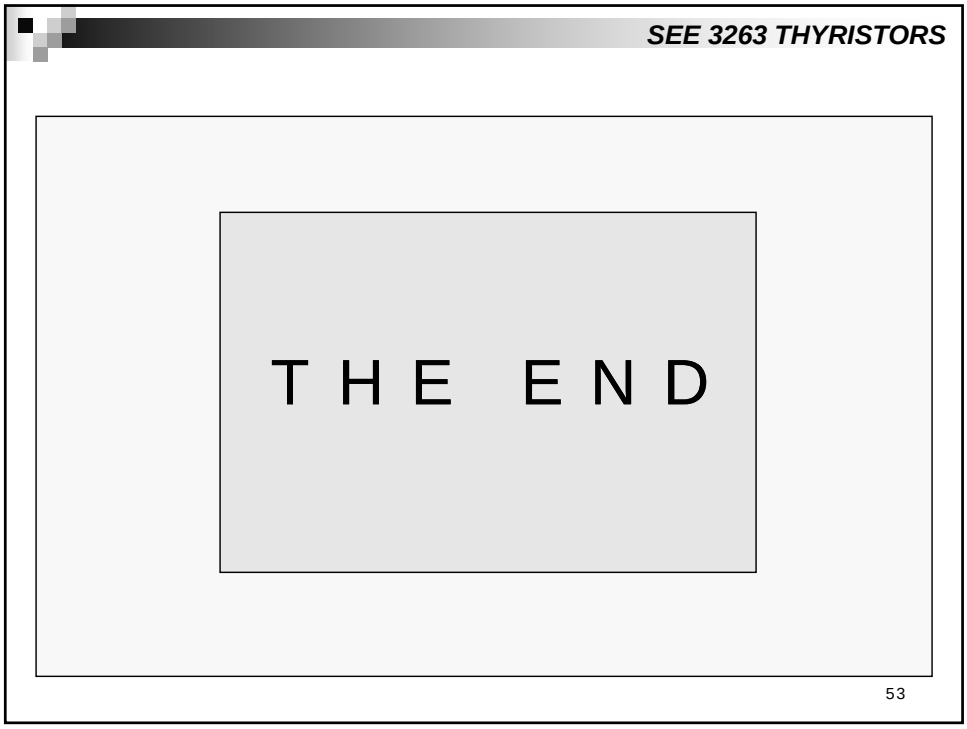
d. cathode resistor

SEE 3263 THYRISTORS

Quiz

Answers:

1. a	6. c
2. c	7. d
3. c	8. a
4. d	9. d
5. b	10. b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THE END
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