Chapter 9: Thyristors

Thyristors

Thyristors are a class of semiconductor devices characterized by 4-layers of alternating p- and n-material. Four-layer devices act as either open or closed switches; for this reason, they are most frequently used in control applications such as lamp dimmers, motor speed controls, ignition systems, charging circuits, etc. 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. Some thyristors and their symbols are in figure 1.

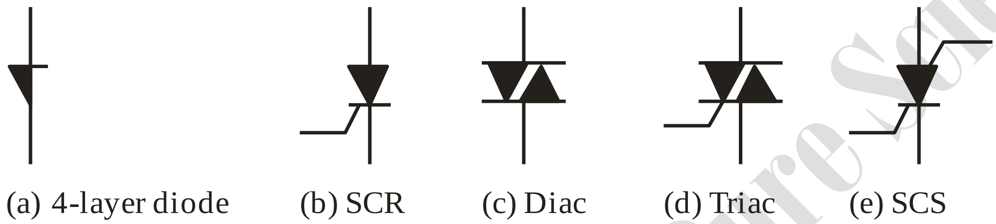

Figure 1

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 basic construction of a 4-layer diode and its schematic symbol are shown in Figure 2.

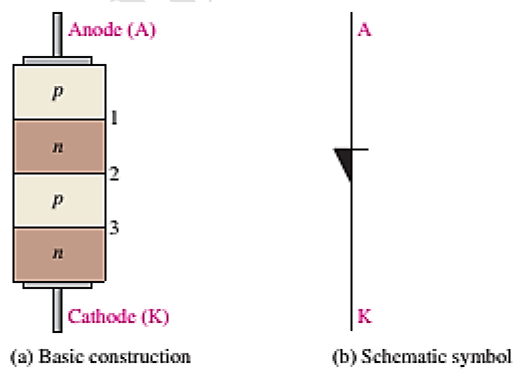

Figure 2: The 4-layer diode.

The 4-layer diode has two leads, labeled the anode (A) and the cathode (K). The symbol reminds you that it acts like a diode. It does not conduct when it is reverse-biased.

The concept of 4-layer devices is usually shown as an equivalent circuit of a pnp and an npn transistor. Ideally, these devices would not conduct, but when forward biased, if there is sufficient leakage current in the upper pnp device, it can act as base current to the lower npn device causing it to conduct and bringing both transistors into saturation

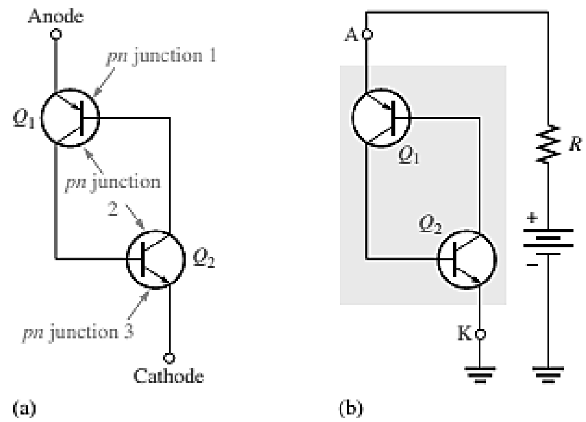

Figure 3: A 4-layer diode equivalent circuit.

Shockley Diode Characteristic Curve

The characteristic curve for a 4-layer diode shows the forward blocking region. When the anode-to-cathode voltage exceeds V_{BR}, conduction occurs. The **switching current** at this point is I_S. Once conduction begins, anode current (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.

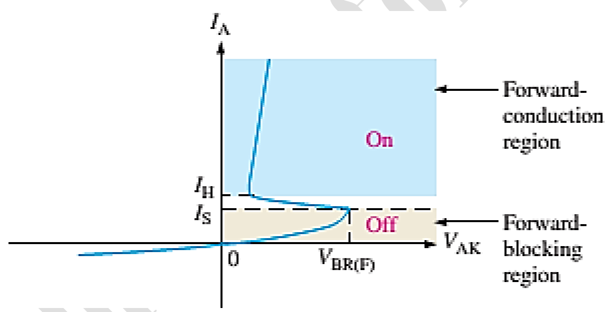

Figure 4: A 4-layer diode characteristic curve.

The Silicon-Controlled Rectifier

An SCR (silicon-controlled rectifier) is a 4-layer pnpn device similar to the 4-layer diode except with three terminals: anode, cathode, and gate. The basic structure and schematic symbol of SCR are shown in Figure 5.

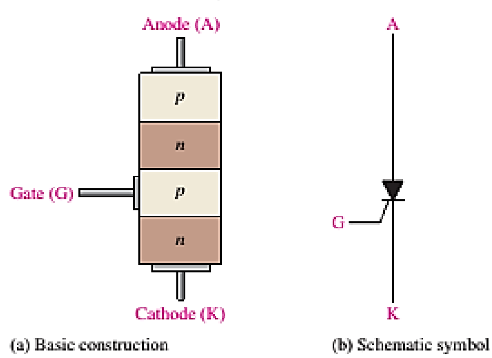

Figure 5: The silicon-controlled rectifier (SCR).

The SCR has two possible states of operation. In the off state, it has a very high resistance. In the on state, the SCR acts ideally as a short from the anode to the cathode; actually, there is a small on (forward) resistance.

The SCR operation can best be understood by thinking of its internal pnpn structure as a two-transistor arrangement, as shown in Figure 6. This structure is like that of the 4-layer diode except for the gate connection. The upper pnp layers act as a transistor, Q_1, and the lower npn layers act as a transistor, Q_2. Again, notice that the two middle layers are shared.

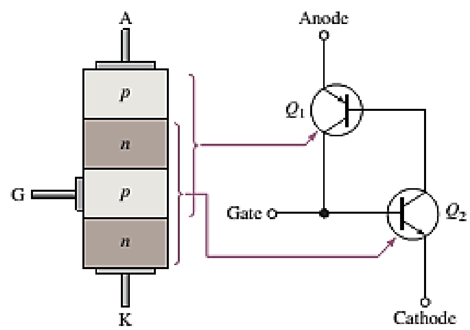

Figure 6: SCR equivalent circuit.

Turning the SCR On

The **SCR** had its roots in the 4-layer diode. By adding a gate connection, the SCR could be triggered into conduction. This improvement made a much more useful device than the 4-layer diode. The SCR can be turned on by exceeding the forward breakover voltage ($V_{BR(F)}$) or by gate current, as shown in Figure 7.. 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 above 0 V.

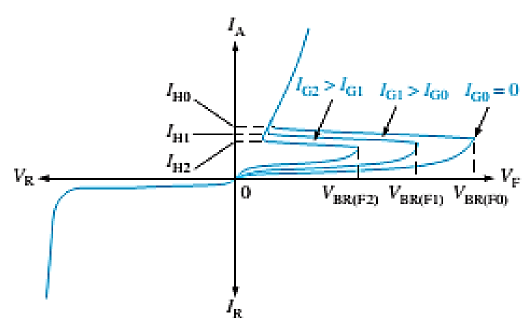

Figure 7: SCR characteristic curves.

Turning the SCR Off

Like the 4-layer diode, 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**. 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 $I_A < I_H$.

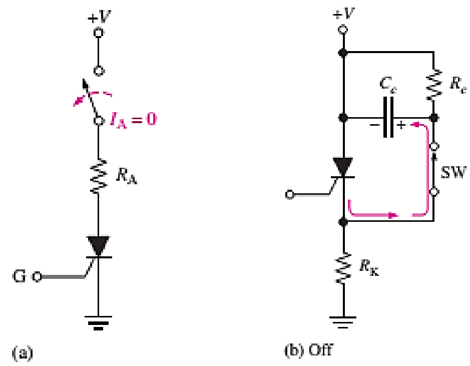

Figure 8: SCR turn-off by: (a) anode current interruption, and (b) forced commutation.

Force commutation uses an external circuit to momentarily force current in the opposite direction to forward conduction. SCRs are commonly used in ac circuits, which forces the SCR out of conduction when the ac reverses.

SCR Characteristics and Ratings

Several of the most important SCR characteristics and ratings are defined as follows.

- **Forward-breakover voltage**, $V_{BR(F)}$: voltage at which the SCR enters the forward conduction region.
- **Holding current, I_H:** This is the value of anode current below which the SCR switches from the forward-conduction region to the forward-blocking region.
- **Gate trigger current, I_{GT}:** This is the value of gate current necessary to switch the SCR from the forward-blocking region to the forward-conduction region under specified conditions.
- **Average forward current**, $I_{F(avg)}$: This is the maximum continuous anode current (dc) that the device can withstand in the conduction state under specified conditions.
- **Reverse-breakdown voltage**, $V_{BR(R)}$: maximum reverse voltage before SCR breaks into avalanche.

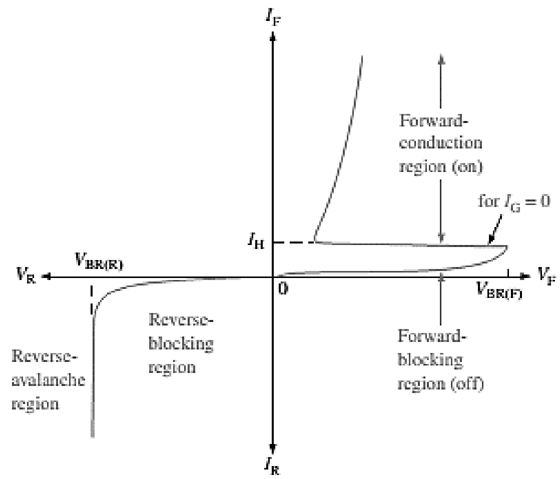

Figure 9: SCR characteristic curves For $I_G = 0$.

SCR Applications

A few of the more common areas of application for SCRs include relay controls, time-delay circuits, regulated power suppliers, static switches, motor controls, choppers, inverters, cycloconverters, battery chargers, protective circuits, heater controls, and phase controls.

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

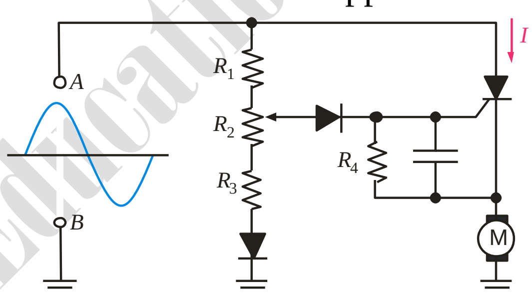

Figure 10: SCR motor control.

Another application for SCRs is an **over-voltage protection circuit**, which is called a "**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.

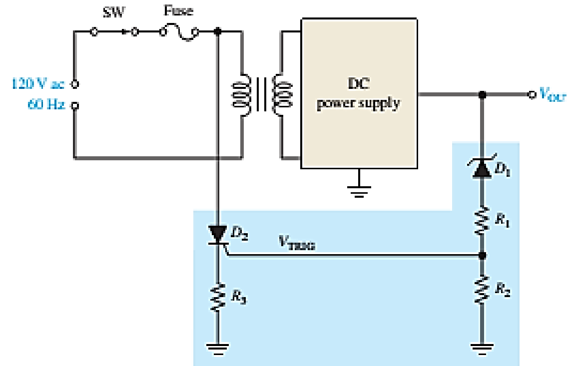

Figure 11: A basic SCR over-voltage protection circuit (shown in blue).

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.

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. 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.

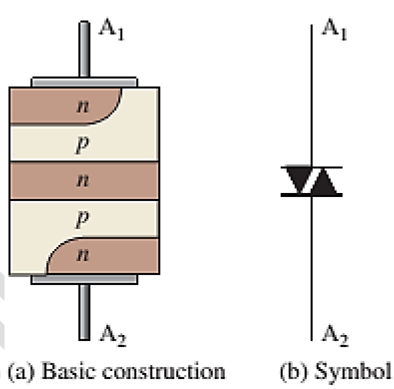

Figure 12: The diac.

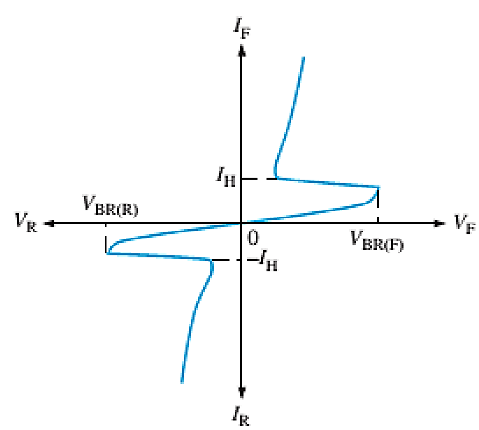

Figure 13: Diac characteristic curve.

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. 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.

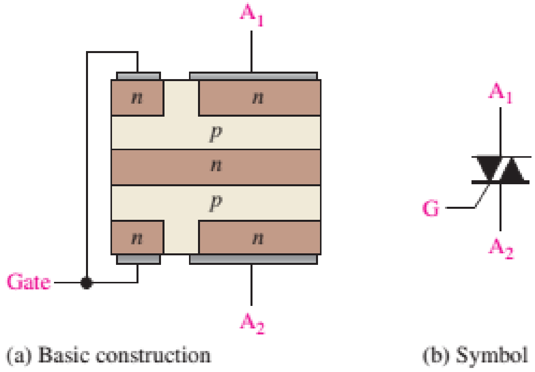

Figure 14: The triac.

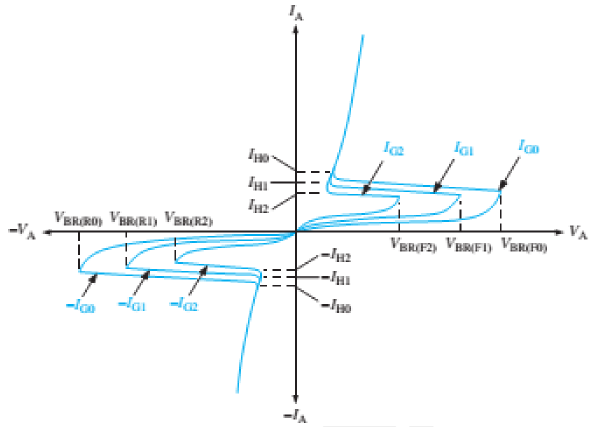

Figure 15: Triac characteristic curve.

Triac Applications

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 alteration.

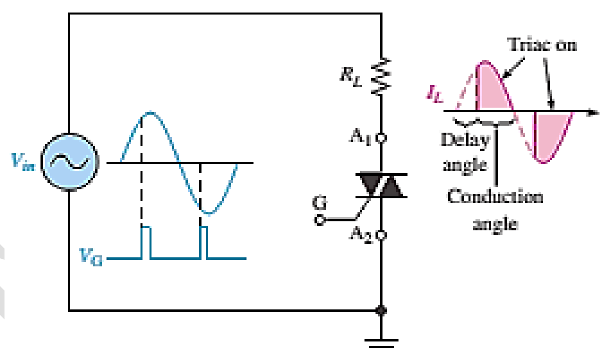

Figure 16: Basic triac phase control.

The Silicon-Controlled Switch (SCS)

The **SCS** is similar to an SCR but with two gates. It can be triggered on with a positive pulse on the cathode gate, and can be triggered off with a positive pulse on the anode gate. In the Figure 18, the SCS is controlling a dc source. The load is in the cathode circuit, which has the advantage of one side of the load being on circuit ground.

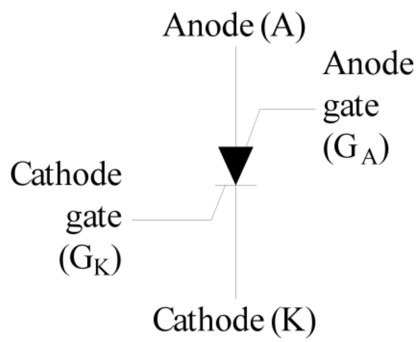

Figure 17: The SCS.

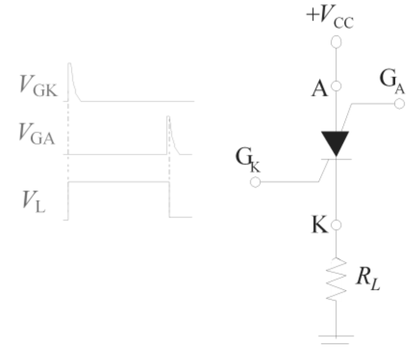

Figure 18: SCS characteristic curve.

The Unijunction Transistor (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.

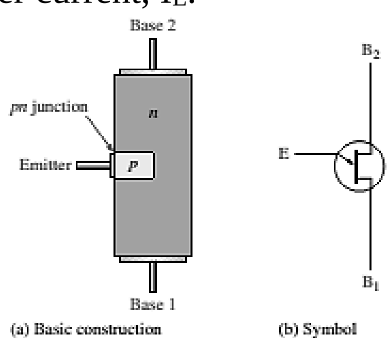

Figure 19: The unijunction transistor.

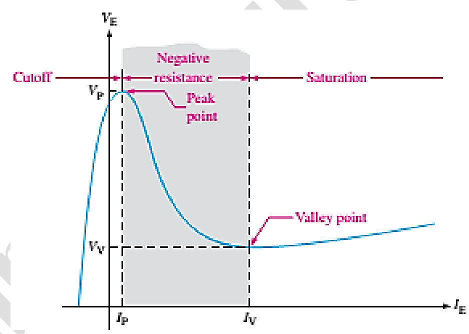

Figure 20: UJT characteristic curve.

The **UJT** consists of a block of lightly-doped (high resistance) *n*-material with a *p*-material grown into its side. It is often used as a trigger device for SCRs and triacs. 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.

The equivalent circuit for a UJT shows that looks like a diode connected to a voltage divider. The resistance of the lower divider ($\acute{r}_{B1}$) is inversely proportional to the emitter current. When the pn junction is first forward-biased, the junction resistance of $\acute{r}_{B1}$ suddenly appears to drop, and a rush of current occurs. An important parameter is h, which is the **intrinsic standoff ratio**. It represents the ratio of $\acute{r}_{B1}$ to the interbase resistance $\acute{r}_{BB}$ with no current.

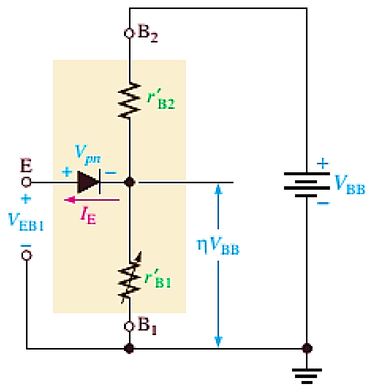

Figure 20: UJT equivalent circuit.

The Unijunction Transistor (UJT) Application

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.

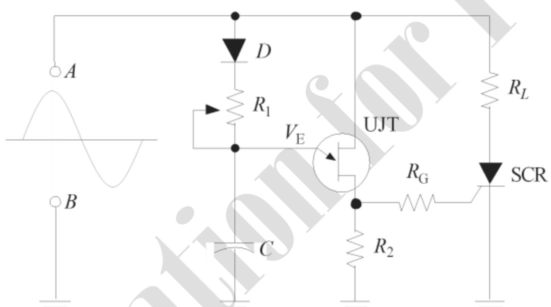

Figure 21

The Programmable Unijunction Transistor (PUT)

The PUT is a 4-layer thyristor with a gate. It is primarily used as a sensitive switching device. The gate pulse can trigger a sharp increase in current at the output.

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.

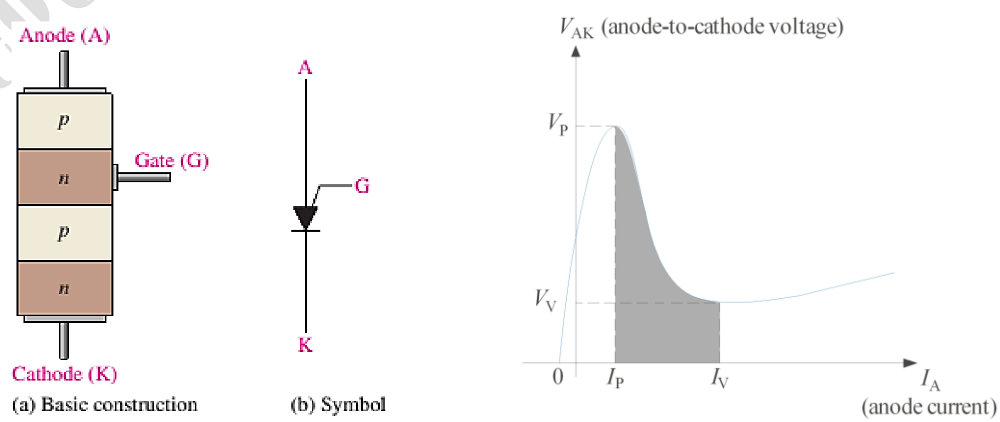

Figure 22: The programmable unijunction transistor (PUT).

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

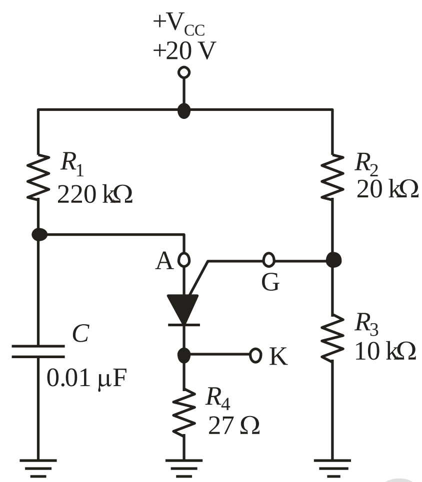

Figure 23: PUT relaxation oscillator.

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

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

H.W.: What is intrinsic standoff ratio, and the period of the circuit in the figure 23?

Answer: η =0.33, T=0.89 ms