W. Back

turning off thyristors

When thyristors are carrying A.C., they will turn off at every zero-crossing — which can be a nuisance. When carrying D.C., however, they won't turn off at all — which is worse.
This article takes a basic look at how to cope with the latter problem.

There is a growing tendency in electronics for electromechanical switches to be replaced by semiconductor devices. In light current applications transistors are now capable of switching currents which a few years ago would have required the use of relays, whilst in power engineering thyristors can switch loads that would normally require fairly hefty contact breakers, without the associated problems of contact wear due to arcing.

A.C. current control with thyristors is fairly simple, but this article takes a basic look at some methods of switching D.C. currents with thyristors.

Switching of A.C. currents with thyristors is relatively easy. As is well known, in its non-conducting state a thyristor will block a potential applied to it in a forward direction (i.e. positive to anode, negative to cathode). However, application of a positive trigger pulse to the gate will cause it to conduct, and it will remain conducting even after the gate input is removed. The only way of returning the thyristor to its blocking state (unless it is a gate turn-off device) is to reduce the current through it below a critical value (the holding current) for a period of time depending on the device in question (the turn-off time).

In A.C. circuits of course, the current through the thyristor attempts to reverse during the negative half-cycle of the waveform, but since a thyristor will not conduct in the reverse direction it turns off at the zero-crossing point of the waveform. No such convenient trick occurs in D.C. circuits.

In D.C. circuits the only two methods of turning off a thyristor are:

- break the circuit so that the current is interrupted.
- momentarily divert the current from the thyristor so that it will turn off.

The first proposition is obviously impractical as breaking the circuit would require a switch or relay capable of switching the current that the thyristor was carrying, which defeats the object of the exercise. The second proposition brings us to the principle of capacitor commutation. If a capacitor is charged and then connected so as to reverse bias the thyristor, then the load current will see the capacitor as a very low impedance into which it will momentarily flow, and the thyristor will turn off.

Figure 1 is the most basic example of such a circuit. When current is flowing in the load R_L then C1 will charge with the polarity shown via R1. When the switch S is closed the capacitor is connected with reverse polarity across the thyristor. The load current sees this as a low impedance and is momentarily diverted into it. The thyristor meanwhile is reverse biassed by the voltage across the capacitor and turns off.

This circuit is clearly not of much practical use, since it also requires a switch, but it does illustrate the principle. A more practical variant of the circuit is illustrated in figure 2. This uses an auxiliary thyristor to switch in the capacitor. R1 is chosen such that after Th1 has turned off and C1 has charged through Th2 with the opposite polarity to its original charge, then the current flowing through Th2 via R1 must be less than the holding current of Th2 so that this thyristor will turn off. This clearly places a lower limit on the value of R1.

The lowest value of C1 is also limited by the time it takes to discharge to zero volts on turning on Th2. This must be greater than the turn-off time of Th1 as otherwise C1 will have discharged and begun to recharge in the opposite direction before Th1 can turn off.

The maximum rate at which the circuit may be switched on and off is determined by the time taken to recharge C1 through R1 after Th1 has been turned on again.

Even with the minimum permissible values for C1 and R1 the switching rate is limited to a few hundred Hz in most instances.

A method of increasing the maximum switching rate is to use capacitor turn-off with a ringing choke, and the basic circuit is given in figure 3. If Th2 is initially turned on then C1 will charge through Th2 and R_L, until it has acquired full supply potential, when Th2 will turn off. If Th1 is now turned on then a parallel resonant circuit consisting of L and C1 is completed, which starts to ring due to the initial charge on C1.

During the first half-cycle current flows through Th1, D and L and reverse charges C1. The diode prevents C1 from attempting to discharge back through L and Th1. Of course, a D.C. current also flows through Th1 into the load. If Th2 is now turned on the reverse-charged C1 is connected across Th1, turning it off. With this method switching rates of up to 1 kHz can be achieved.

Figure 1. Capacitor commutation using a switch to connect the capacitor across the thyristor.

Figure 2. Using an auxiliary thyristor to switch in the commutation capacitor.

Figure 3. Using a ringing choke arrangement to increase the maximum switching rate.

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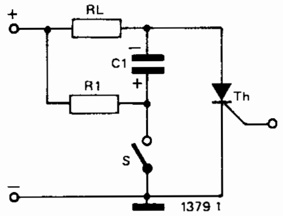

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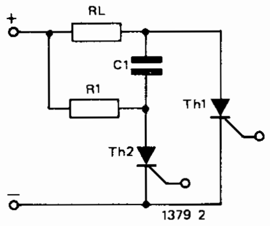

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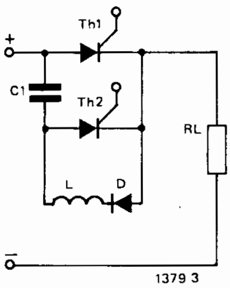


Calculation of commutation capacitor

When the auxiliary thyristor is turned on a negative voltage appears across the main thyristor. This reduces to zero as the load current flows into the capacitor and, provided the main thyristor actually turns off, the voltage on the capacitor will eventually assume full positive supply voltage, at which point the auxiliary thyristor will turn off.

It is evident that the main thyristor must turn off before the voltage on the commutation capacitor assumes a positive value, or it will never turn off. This means that the time taken for the voltage across the capacitor to reach 0 V must be greater than the turn-off time of the main thyristor. Now this time is determined by two factors, the charging current flowing into the capacitor through the load and the capacitance of the capacitor.

Initially current is being driven through the load by a voltage 2 V_b. (supply voltage plus the initial voltage across the capacitor). By the time the voltage across the capacitor has reached zero the current is being driven by the supply voltage V_b.

Initially therefore the current is $\frac{2\,V_b}{R_L}$, and finally it is $\frac{V_b}{R_L}$.

The average current is therefore approximately $\frac{1.5\,V_b}{R_L}$. This is of course a gross approximation as it assumes linear charging, but it is adequate for calculating the commutation capacitor.

Now since $Q = CV = I\Delta t$.

where Q is charge on capacitor.
C is capacitance
V is voltage on capacitor (= V_b).
I is average charging current (= $\frac{1.5\,V_b}{R_L}$).
Δt is charging time (= turn-off time of thyristor).

Then

$$\frac{1.5\,V_b \cdot \Delta t}{R_L} = CV_b.$$

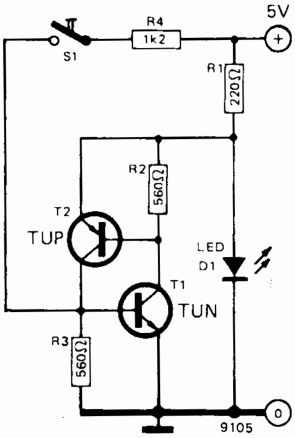
Therefore

$$C = \frac{1.5\,\Delta t}{R_L}$$

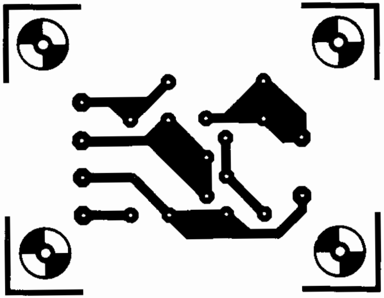
This is the minimum value of capacitor to turn off current flowing through a load R_L. In practice the value of C should be slightly larger than this to ensure reliable commutation. The commutated turn-off time of the thyristor (usually designated t_q) can be obtained from the manufacturer's data sheets, and the load R_L is of course known, so C can easily be calculated.

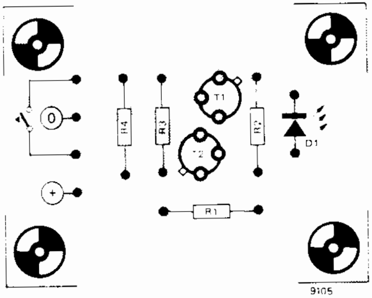
M. Keul

TUT



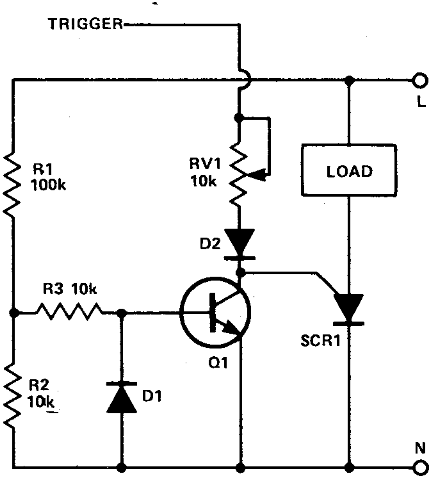
The circuit shows a transistorised universal thyristor, or TUT.
It operates as follows:
When S1 is open, the LED will light when the supply voltage is turned on, because T1 and T2 are both turned off.
If S1 is now closed, T1 receives a base current, so that this transistor turns on and T2 is driven into saturation.
The voltage drop across the emitter-collector junction of T2 and across the base-emitter junction of T1 will be lower than the voltage drop across the LED, so that the LED will extinguish.
The thyristor is now on, and re-opening of S1 makes no difference. Only a very brief interruption of the supply voltage can extinguish the thyristor causing the LED to light again.
This TUT circuit can be useful, for instance, as a mains failure indicator for a digital clock.





Zero Crossing Switch

J. R. W. Barnes.



Q1=GENERAL PURPOSE GERMANIUM
D1,2=GENERAL PURPOSE SILICON
SCR1=TO SUIT APPLICATION

When switching loads with the aid of a thyristor a large amount of RFI can be generated unless some form of zero crossing switch is used. The circuit shows a simple single transistor zero crossing switch which, using surplus components, can be built for as little as fifty pence.

R1 and R2 act as a potential divider, the potential at their junction being about one tenth of mains. This voltage level is fed, via R3, to the transistor's base. If the voltage at this point is above 0V2 the transistor will conduct, shunting any thyristor gate current to ground. Only when the mains potential is less than about 2 V it is possible to trigger the thyristor.

The diode D1 is to remove any negative potential that might cause reverse breakdown.

Opto-isolated detector protects thyristors

by Charles Roudeski
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Although gating a thyristor with short pulses greatly reduces the gate and driver dissipation, failure of the driving logic can turn on the thyristor full time, possibly destroying it, the driver, and their supply. Described here is an opto-isolated zero-crossing detector that generates a 100-microsecond pulse each time its 60-hertz power-line input traverses through zero. Besides isolating for the logic element, the circuit terminates the generation of pulses if almost any detector component fails.

Most of the line voltage (see figure) is dropped across the 10-kilohm input resistor before it is rectified. The 25-microfarad capacitor charges during most of the 60-Hz cycle, but the 2N2907 transistor is held off by any full-wave rectified voltage above 2.3 V.

As the line voltage drops to about 4.5 V, the transistor begins to turn on and the capacitor discharges through the 4N26's photodiode, sourcing about 14 milliamperes. This produces a pulse centered about the zero crossing. Wider pulse widths are obtained by reducing the value of the 15-kΩ resistor. If a longer rise time is tolerable, the 33-kΩ resistor in the base lead of the optocoupler's phototransistor can be eliminated.

The 3-V zener establishes the reference voltage for the circuit. ☐

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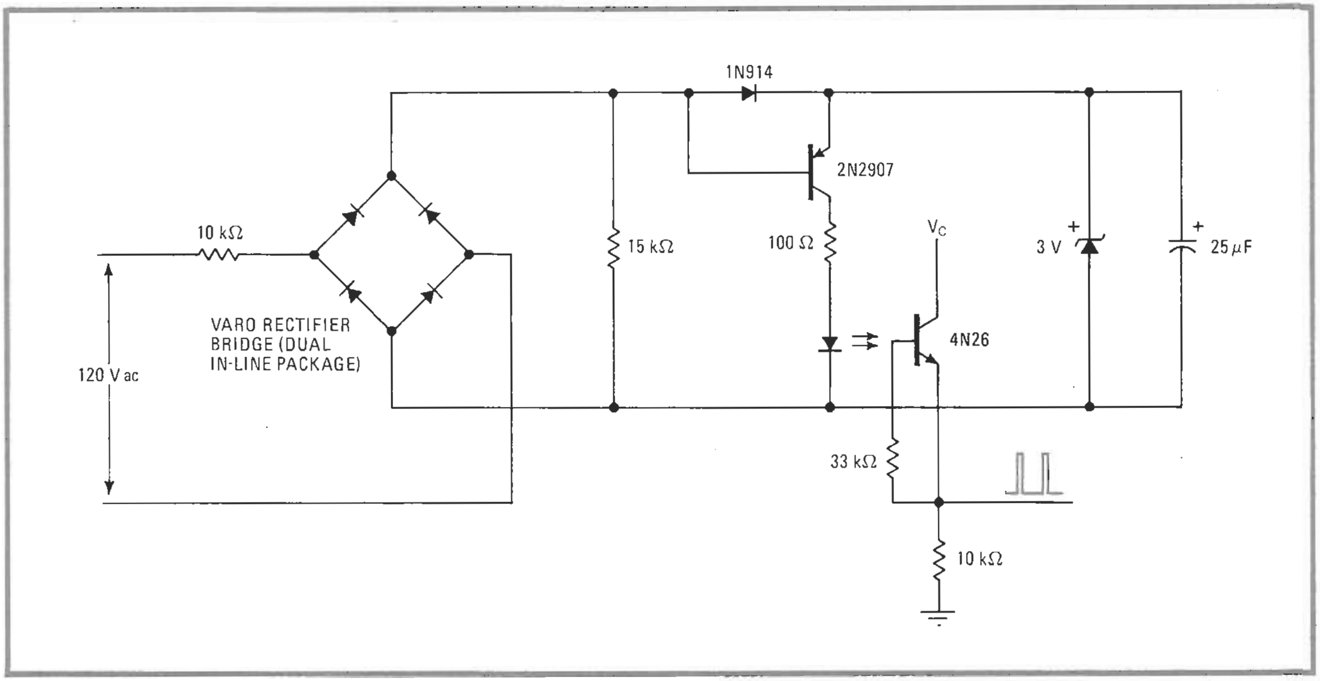
Protection. Zero-crossing detector uses optocoupler for gating of thyristors by power line. Output pulses, produced 120 times per second as input voltage traverses through zero, last 100 μs. Output of 4N26's phototransistor will be zero if most any element in detector fails, thereby protecting thyristor, driver, and supply from damage that would be caused by activating the thyristor continuously.



SCR zero-cross trigger limits maximum load power

by Richard Eckhardt
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A zero-cross trigger for a silicon controlled rectifier will limit the maximum power delivered to a load if it is made to fire the SCR only on alternate cycles of the ac line input. Such an SCR triggering circuit is useful for driving loads rated at less than 110 volts. There are two advantages to limiting SCR conduction in this way—large amounts of power do not have to be wasted through dissipation, and the load can be powered continuously without the need for a power transformer.

With a zero-cross trigger, the SCR is fired only when the voltage across it is at or near the zero point in the driving ac waveform or pulsating dc waveform. Zero-voltage firing minimizes the generation of noise spikes that may occur when the voltage and current to the load are changed too rapidly.

The zero-cross trigger shown here employs a general-purpose operational amplifier as a comparator. The control-voltage input varies the power applied to the load by governing the ratio of SCR on cycles to SCR off cycles. To increase the power supplied to the load, the control voltage is made larger.

Some of the pulsating dc voltage produced by the rectifier bridge is applied to the noninverting input of the op amp. The control voltage, which goes to the op amp's inverting input, charges capacitor C_1 through resistor R_1 until the capacitor's voltage exceeds the minimum point of the pulsating dc voltage.

When this happens, the output of the op amp goes negative, switching off the transistor and permitting the SCR to fire. Since the SCR is triggered at the minimum point of the pulsating dc voltage, the SCR turns on only when the ac voltage across it is at or near zero. The output of the op amp remains low until capacitor C_1 discharges through diode D_1 and resistor R_2.

This capacitor must be charged again by the control voltage before the SCR can be fired again. The charging time of capacitor C_1 determines how many successive cycles of the input voltage are included in the interval between SCR firings.

The circuit's dynamic range is established by the resistance ratio of charging resistor R_1 to discharging resistor R_2. ☐

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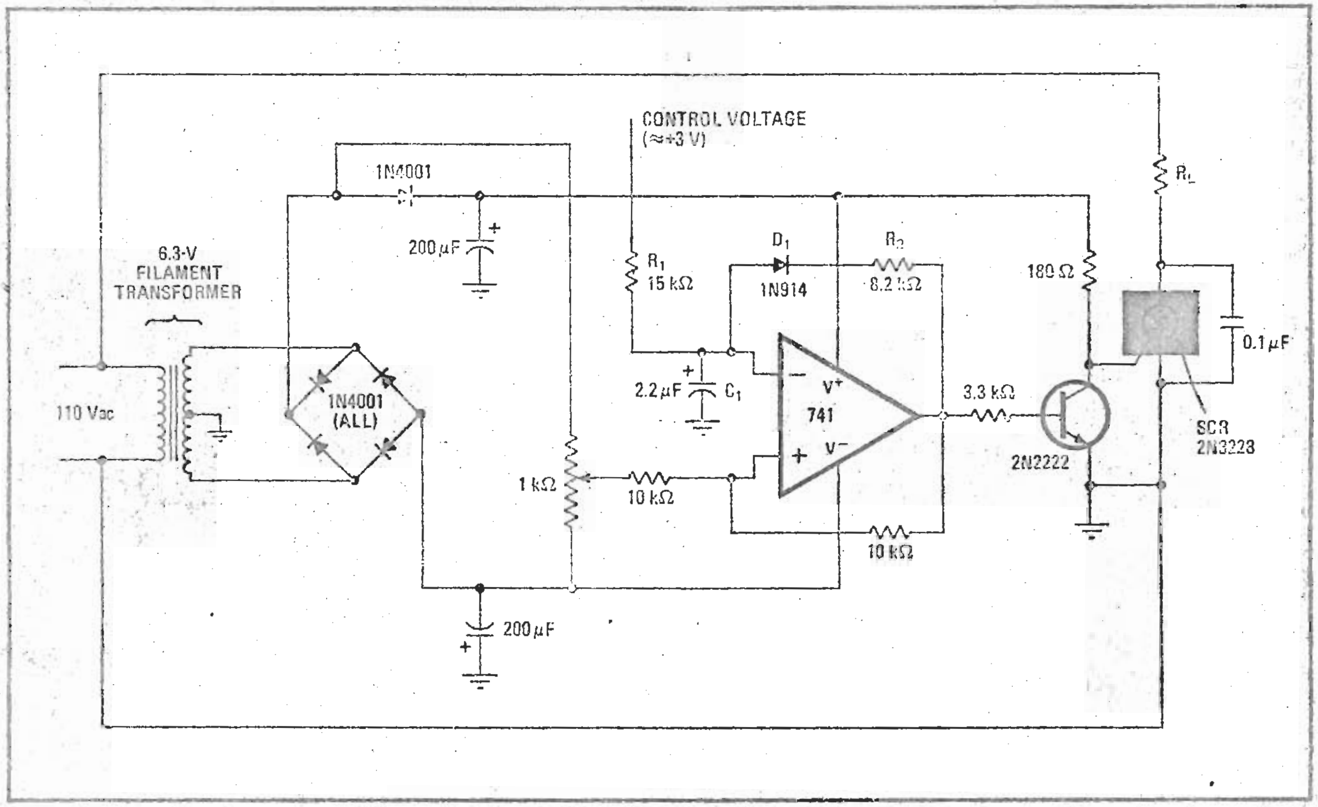


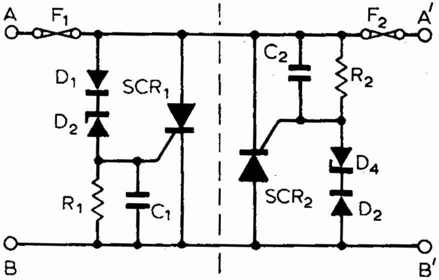
Power limiting without power waste. Because this zero-cross trigger fires its SCR only on every other cycle of the ac line, the maximum power delivered to the load can be limited without the need for a power transformer or wasteful power dissipation. The control-voltage input determines the ratio of SCR on cycles to SCR off cycles. The larger the control voltage is, the greater the power to the load.

Thyristor protection circuit

When different pieces of equipment are being interconnected by a signal interface, the danger exists of high voltages appearing on the interface lines as the result of a malfunction. These can be dangerous, e.g. mains, or nuisance voltages which will damage delicate components. A protection circuit which will provide very little signal degradation is shown. The components may be selected to meet a wide variety of conditions. Suppose there is a voltage $V_{AB}>0$. If $V_{AB}>V_{D3}+V_{D1}\approx V_{D3}$ then thyristor SCR_1 will latch and V_{AB} will reduce to ~1V within 1 to 2μs. If F_1 is a suitable value it will blow, and isolation will result between AA′.

When $V_{AB}<0$ and if $V_{BA}>V_{D4}+V_{D2}\approx V_{D4}$ then thyristor SCR_2 will latch and F_2 will blow. By suitable selection of Z_1 and Z_2 suitable voltages may be catered for.

Capacitors C_1 and C_2 guard against spurious triggering, or triggering on signal spikes transmitted through the diode capacitance, and D_1 and D_2 prevent forward voltage drops across D_3 and D_4.



With the following values:

Z_1, Z_2 CV7144 10V zener
D_1, D_2 CV9637 small-signal silicon diode
R_1, R_2 10kΩ
C_1, C_2 0.047μF
Tr_1, Tr_2 2N4147

the circuit will operate with pulses of 20ns with no noticeable degradation, and the circuit will latch if V_{AB} exceeds 11V.

Higher powered thyristors may be used where necessary with consequent slowing down of edges. Typical component cost is £1.10 for values as shown.

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Buffer keeps noise from triggering thyristor

by L. R. Rice
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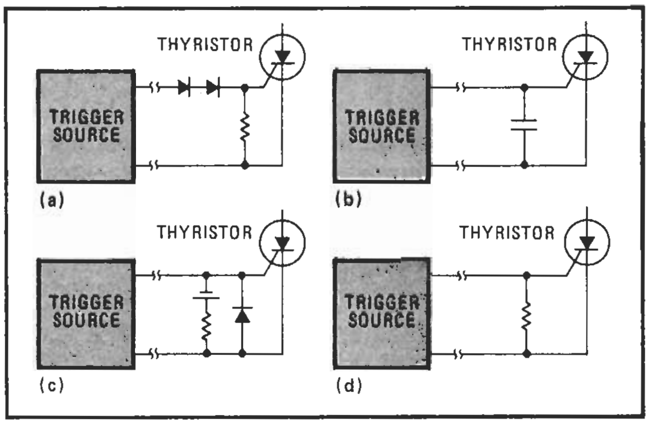
Certain shortcomings in passive noise-rejection networks have led to development of an active circuit designed to prevent false triggering of thyristors. Such undesired firing can occur when noise transients cross the thyristor gate conductors, and can produce fluctuations of load power, oscillations in control circuits, and equipment damage. The offending pulses usually arise from reactive-load energization or de-energization, such as the discharge of a capacitor or the switching of a relay.

In the field, passive networks that discriminate against both signal and noise, such as those shown in Fig. 1, are often used, but they are impractical at times and some application problems simply cannot be solved with these techniques. Therefore an active circuit, consisting of a buffer connected between the trigger source and the thyristor gate, is needed.

As shown in Fig. 2, this buffer consists of an RC integrating circuit, a comparator, and a pulse generator. An incoming voltage, either signal or noise, charges 0.02-microfarad capacitor C through resistor R. The 2N697 comparator amplifier turns on when the capacitor voltage reaches the threshold value equal to the sum of the voltage drops in diode D_2, the base-to-emitter junction, and zener diode D_3. This threshold voltage is given by

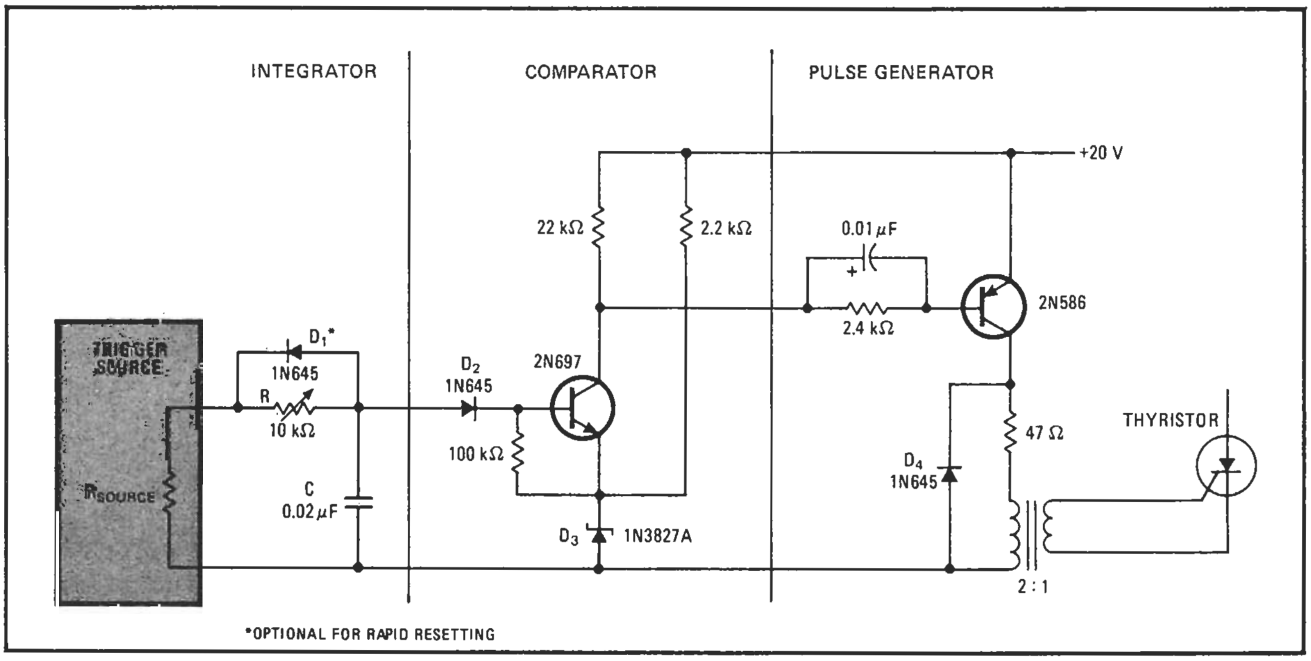


1. Quick fixes. Noise in thyristor gate lead is sometimes suppressed by one or another of these means: (a) diodes raise threshold voltage; (b) capacitor shunts high frequencies; (c) saturated diode reverse-biases gate; (d) resistor decreases gate sensitivity.

$$V_{TH} = V_{diode} + V_{BE} + V_{zener}$$
$$= (1.0 + 0.45 + 6.0) \text{ volts}$$
$$= 7.45 \text{ volts}$$

When the capacitor voltage reaches this value and turns on the comparator, the 2N586 pulse generator starts to conduct and fires the thyristor.

Variable resistor R is adjusted so that the time constant RC is large enough to prevent noise pulses from charging C to threshold. For example, if the noise ambience can be represented by a 50-volt pulse of 1-micro-



2. Buffer. Integrator prevents false triggering of thyristor by discriminating between genuine trigger signals and noise transients. Trigger signal must last long enough to charge capacitor C to the threshold voltage of the comparator, which then turns on the pulse generator. Variable resistor R permits adjustment of the charging-time constant so that noise pulses cannot charge C to the comparator's threshold.

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*Now with White-Westinghouse Corp., Mansfield, Ohio.

second duration, the value of R that would allow C to just reach threshold in 1 μs is found from the charging equation

$$
\begin{aligned}
V_C &= V_O - V_O \exp(-t/RC)\\
7.45 &= 50 - 50 \exp(-1/0.02R)\\
\exp(-1/0.02R) &= 0.85\\
R &= 300 \text{ ohms}
\end{aligned}
$$

Therefore, to prevent the 50-V/1-μs noise pulse from firing the thyristor, R is made a bit larger than 300 ohms.

After the noise pulse has ended, capacitor C discharges back through R, or through diode D_1 if quicker recovery is required.

A signal voltage from the trigger source charges up the capacitor just as a noise pulse does, but the signal duration is made long enough for the capacitor to reach threshold. If the trigger signal is 12 volts, for example, and R has been set for 300 ohms, then the signal must be applied for at least a time duration t (in microseconds) given by

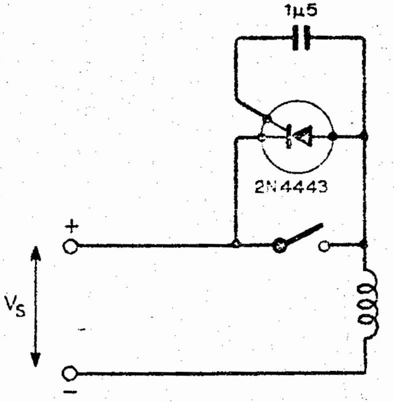
$$7.45 = 12 - 12 \exp[-t/(300 \times 0.02)]$$

or t = 6 μs. Thus the 12-V trigger signal must last for 6 μs to fire the transistor.

Because this circuit delays the normal firing point to achieve noise rejection, timing in the trigger source may require adjustment if not controlled by feedback from the load. □

Switch spark quench for inductive loads

The circuit may be used to suppress arcing of switch contacts, an especially troublesome problem when switching large inductive loads. The chosen controlled rectifier must pass the full circuit current during the switch-off period and must be capable of operating at voltages in excess of twice the supply voltage. The 2N4443 quoted in the example will work up to 500V and will switch short pulses of current of up to 80A although for this rating the current pulses must not be longer than 8ms; for longer pulse times suitable de-rating must be applied. The capacitor provides the gate drive to turn the s.c.r. on, ≈ 0.7V, and uses the initial part of the circuit switch-off transient as the thyristor turn-on pulse. It is essential that the thyristor is fully turned on.



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