CHAPTER 4

Static Swiching

4.1 Solid State Static Relays

There is no exact, universal electronic replacement for the mechanical relay. Semiconductors can be used to duplicate the function of a relay but must be tailored to fit a particular application.

Either transistors or thyristors can be used as switches to isolate a load from, or connect it to, a power source. The control of either device can be completely electronic, in which case the circuit is called a static switch, or through the use of a switch with small current capability, which forms a static contactor. A transistor requires continuous drive power during the time it is conducting. A thyristor requires only a pulse of power to turn it on but it must be commutated off either forceably or by natural commutation of an alternating voltage source. Either type of device can be used on ac or dc, but the circuit used must be designed for the power source used.

AC Power Source

Semiconductor devices which are basically dc devices, such as transistors and SCRs, require special circuits when they are used on ac; these special circuits are not required for devices such as triacs, which will pass current in both directions. Figures 4-1 through 4-3 show circuits which use a transistor, a silicon controlled rectifier, and a triac as the switching element. The circuit of Figure 4-1 maintains ac to the load and at the same time provides dc to the transistor, which is the controlled element, through the use of a bridge rectifier. The transistor must be able to withstand the peak voltage of the power source when it is off and it must be capable of handling the peak load current when it is on. It also must have adequate safe operating area for the switching load line. Since the transistor requires continuous drive power to keep it on, it will begin to turn off immediately upon removal of the driving signal. This could create large voltage or current spikes in the circuit if reactive loads are used. If inductive loads are to be switched, then a circuit which will protect the transistor from over-voltage must be included. If high voltages or large currents

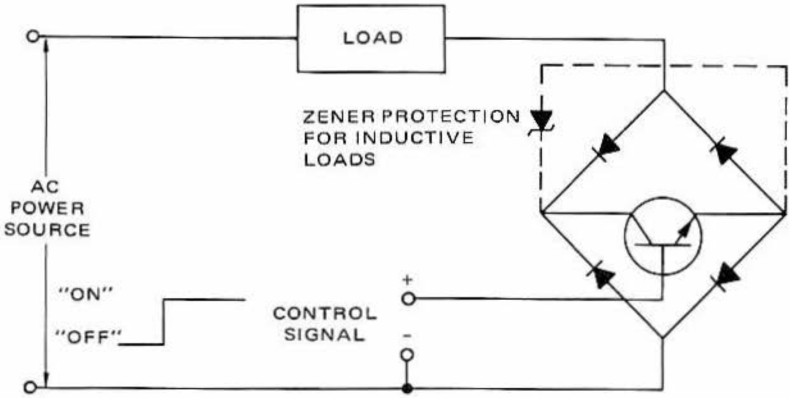


Figure 4-1 – AC Solid-State Static Relay Using Transistor Control Element

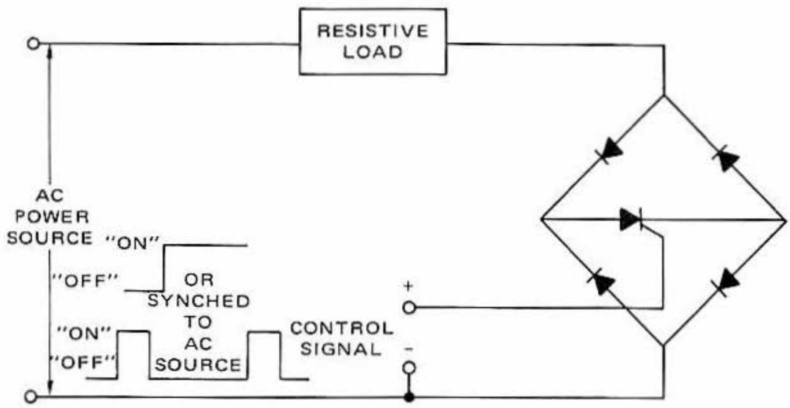


Figure 4-2 – AC Solid-State Static Relay Using SCR Control Element

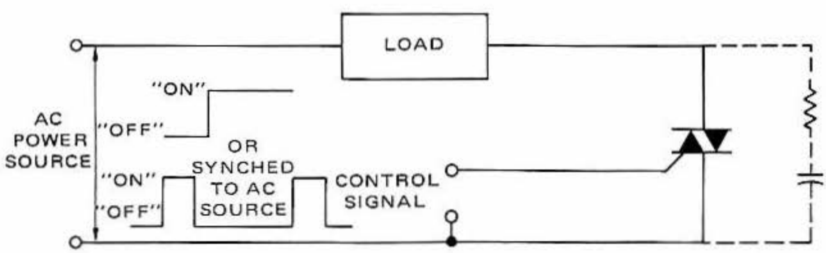


Figure 4-3 – AC Solid-State Static Relay Using Triac Control Element

are to be switched, the transistors that can be used are usually expensive and the driving power required can get quite high. For these reasons the circuit in Figure 4-1 is not recommended for switching high voltages and/or high currents.

For resistive loads, a circuit which performs much like that in Figure 4-1 is shown in Figure 4-2. In this case the transistor has been replaced by an SCR. The SCR does not require large drive power; it will turn on as soon as the gate drive is provided and will turn off each half cycle when the current goes to zero. Therefore, to keep the SCR on, either continuous gate drive must be provided or a gate driving power pulse must be delivered each half cycle. The turn-off time of the SCR limits the maximum frequency of present SCR switching circuits to approximately 30 kHz. If the supply frequency is around 60 Hz or less, a triac can be used as the control element as shown in Figure 4-3. It will conduct (or control) current in both directions. Unlike the SCR, the triac can be triggered by either positive or negative gate drive, but more power is required for negative drive than for positive drive. Since the triac also turns off every time the current goes to zero, the drive requirements for a triac used on ac are the same as described for the SCR. The series R-C network across the triac is required for inductive loads to prevent the rate of voltage rise (dv/dt) developed when the triac turns off from immediately returning it to the on state.

DC Power Source

Either thyristors or transistors can be used as the controlled switching element with a dc supply if the circuits are adapted to satisfy each device's particular characteristics. Transistors play an important role here since the continuous drive required to keep them on is readily available and easily obtained. Special circuit adaptation is required for thyristors since these devices remain on once turned on. Thus, another circuit which will force the current in the device to drop to zero is required to turn the thyristor off.

Figure 4-4 shows a typical connection for using a transistor as a switch. The transistor must be able to withstand the supply voltage when off and be able to handle the load current when on. Also, it must have a safe operating area adequate to handle the switching load line. The amount of drive power required is an inverse function of the gain of the device and a direct function of the load current. Therefore, the drive requirements are dependent on the circuit parameters. If the load is inductive then the transistor must be protected from voltage spikes created by the switching action. One method for achieving this is to place a diode across the load as shown in Figure 4-4. If high voltage supplies are to be used or large currents are to be switched this circuit is not recommended since an expensive transistor and large driving power are required.

The thyristor circuit shown in Figure 4-5 uses silicon controlled rectifiers as the controlled switching elements. A power pulse applied to the gate of SCR Q1 will turn the device on, connecting the "cold terminal" of the load and the commutating capacitor to the negative side of the supply. The capacitor then charges to the supply voltage minus the SCR drop. Q1 will stay on until a power pulse is applied to the gate of Q2. This turns Q2 on and applies a reverse voltage to Q1 via capacitor C1. The capacitor then discharges through Q1 forcing the current to drop below the holding current, turning Q1 off and disconnecting the load from the power source. Once Q2 comes on it will remain on until the control signal pulse is again applied to the gate of Q1. At this time the reverse of the

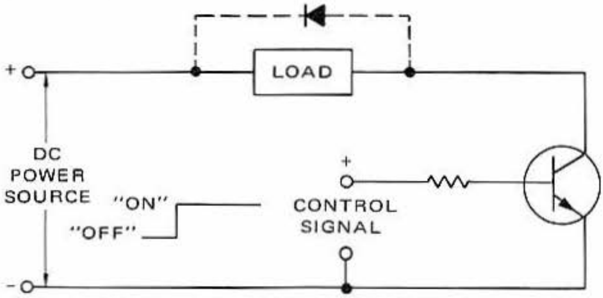


Figure 4-4 – DC Solid-State Static Switch Using Transistor Control Element

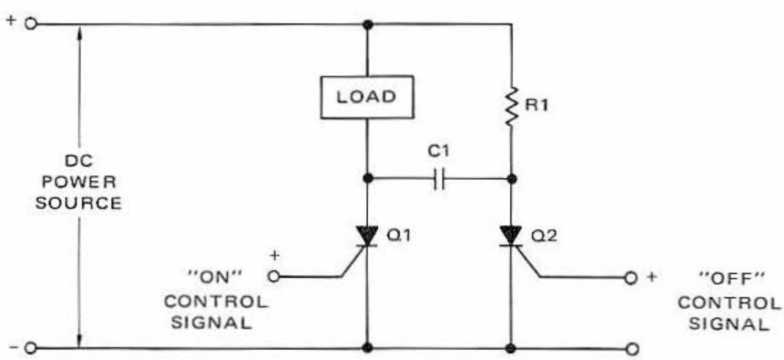


Figure 4-5 – DC Solid-State Static Switch Using SCRs as the Control Element

commutating action just described occurs and Q2 is turned off while Q1 is turned on. If the duty cycle of the control signal is low, Q2 can be smaller than Q1 since Q2 must be able to withstand a nonrepetitive current surge equal to the peak commutation current plus the current through R1, rather than the continuous load current. This circuit gives excellent results when switching with high voltage supplies and/or with large load currents.

4.2 Triac Static Motor-Starting Switch for 1/2 hp, 115 Vac Motor

Single-phase induction motors require a starting winding which is used only until the rotor obtains a speed of approximately 75% of full-load speed. The circuit shown in Figure 4-6 can be used to control the starting winding of such a motor; essentially a triac replaces the centrifugal switch normally used for this purpose.

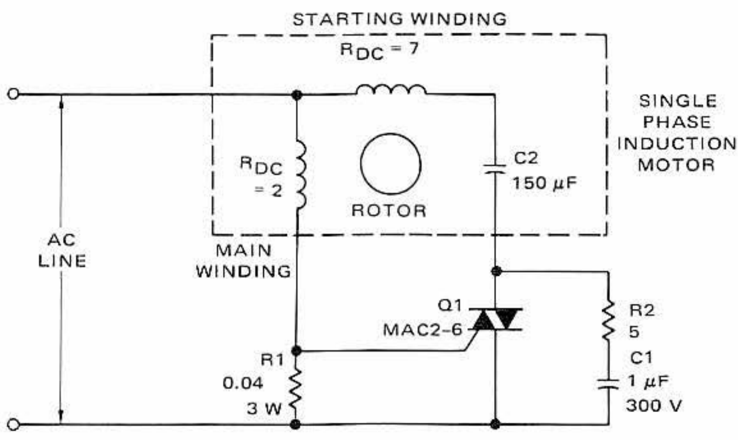


Figure 4-6 – Triac Static Motor-Starting Switch for ½ Hp 115 Vac Single-Phase Induction Motor

Since the inrush current during starting in the main winding of the motor is several times the running current, this inrush current can be used as the source of control for the starting winding. The voltage developed across resistor R1 is used to gate on triac Q1 when the voltage exceeds its threshold level. The resistance must be large enough to develop sufficient voltage to turn Q1 on, but small enough that the normal peak running current will not develop enough voltage to turn it on. Some selection of this value may be necessary to accommodate any triac that may be used; a slide-wire resistor may be used to select the proper trigger level.

When the current drops to zero in the triac, the device turns off and the voltage across it will increase rapidly to the value of the line voltage since there is phase shift due to the inductive load. If the rate of rise of this voltage (dv/dt) is too great, the triac will again turn on. Therefore, a circuit must be provided to assure the dv/dt is low enough. The network consisting of R2 and C1 is used to limit the dv/dt across the triac to within its capability. This rating is lowest at high temperatures, so the network values should be chosen for proper operation at the highest temperature the circuit will encounter.

The values shown on the schematic were used with a 1/2 hp, 115 volt motor. The peak starting current of this motor was 40 amperes while the peak running current was 8 A. The value of the resistor was chosen so that the triac would not turn on when current was less than 12 A. This occurred for this motor after 12 cycles. It should be possible to use the triac shown for integral-horsepower motors since the triac conducts for only a few cycles. Of course, maximum current ratings must be observed. This circuit as shown has been operated at temperatures as high as 80° C. The motor-starting capacitor limits the maximum ambient temperature to +65°C and the duty cycle of the motor of a maximum of 60 starts of one second duration per hour. The triac will perform satisfactorily under these conditions.

4.3 Triac Prevents Relay Control Arcing

A common problem in contacts switching high current is arcing which causes erosion of the contacts. A solution to this problem is illustrated in Figure 4-7. This circuit can be used to prevent relay contact arcing for loads up to 50 amperes. There is some delay between the time a relay coil is energized and the time the contacts close. There is also a delay between the time the coil is de-energized and the time the contacts open. For the relay used with this circuit both times were about 15 ms. The triac across the relay contacts will turn on as soon as sufficient gate current is present to fire it. This occurs after switch S1 is closed but before the relay contacts close. When the contacts close, the load current passes through them, rather than through the triac, even though the triac is receiving gate current. If S1 should be closed during the negative half cycle of the ac line, the triac will not turn on immediately but will wait until the voltage begins to go positive, at which time diode D1 conducts providing gate current through R1. The maximum time that could elapse before the triac turns on is 8-1/3 ms for a 60 Hz supply. This is adequate to assure that the triac will be on before the relay contact closes. During the positive half cycle, capacitor C1 is charged through D1 and R2. This stores energy in the

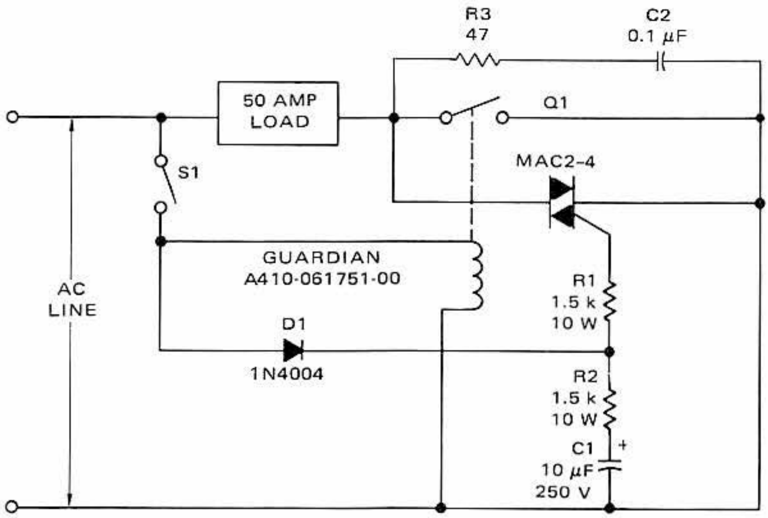


Figure 4-7 — Triac Prevents Relay Contact Arcing

capacitor so that it can be used to keep the triac on after switch S1 has been opened. The (R1 + R2)C1 time constant was set such that sufficient gate current would be present at the time of relay dropout after the opening of S1, to assure that the triac would still be on. For the relay used, this time was 15 ms. The triac therefore limits the maximum voltage across the relay contacts upon dropout to its voltage drop of about 1 volt. The triac will conduct until its gate current falls below the threshold level after which it will turn off when the anode current goes to zero. The triac will conduct for several cycles after the relay contacts open.

This circuit not only reduces contact bounce and arcing but also reduces the physical size of the relay. Since the relay is not required to interrupt the load current, its rating is only based on two factors: the first is the rms rating of the current-carrying metal, and the second is the contact area. This means that many well-designed 5 ampere relays can be used in a 50 ampere load circuit. Because the size of the relay has been reduced, so will the noise on closing. Another advantage of this circuit is that lifetime of the relay will be increased with no contact burning, welding, etc.

The R-C circuit shown across the contact and triac is to reduce dv/dt if any other switching element is used in the line. Typical values are 47 ohms and 0.1 μF.

4.4 AC Static Switches and Static Contactors

AC static switches and static contactors with essentially zero-point switching on all but the first cycle are illustrated by the circuits in Figures 4-8 through 4-11.

The circuit shown in Figure 4-8 can be used to switch resistive loads on an ac supply at frequencies below 30 kHz with electrical control signals. SCR Q1 is used to prevent gate current in Q2 when Q2 is reverse-biased by the supply voltage, which could occur the first time Q2 is turned

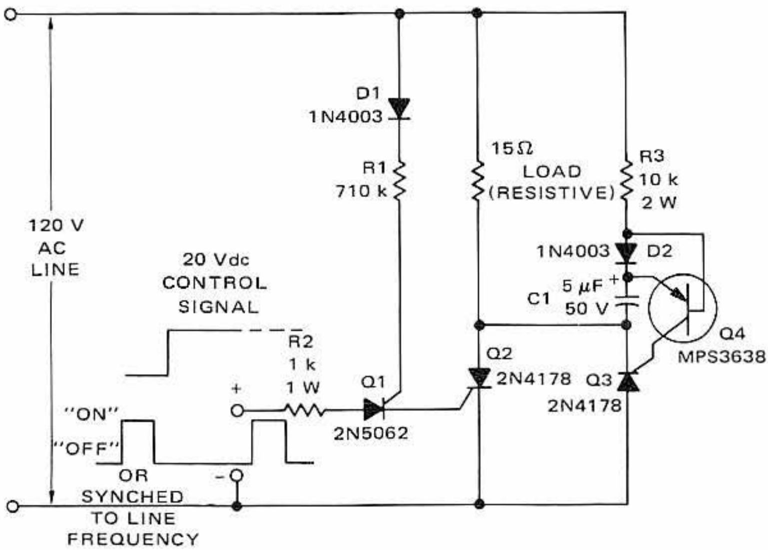


Figure 4-8 – SCR AC Static Switch

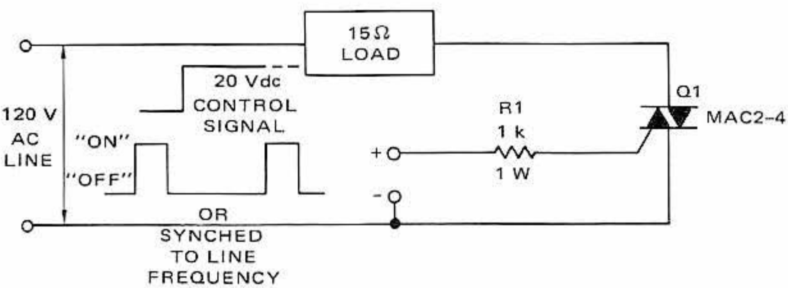


Figure 4-9 – Triac AC Static Switch

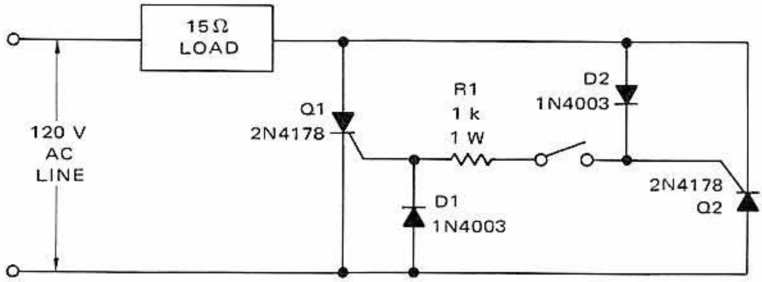


Figure 4-10 – SCR AC Static Contactor

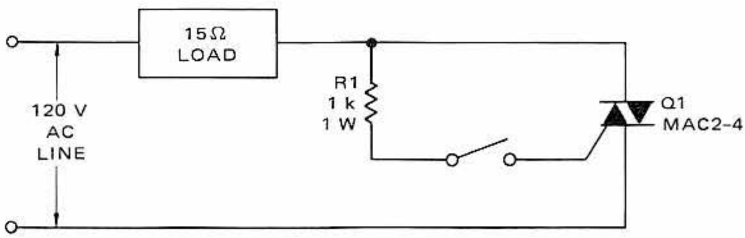


Figure 4-11 – Triac AC Static Contactor

on. Q1 will turn on during the first positive half cycle following the application of the control signal to R2. Q1 provides gate current to Q2, thereby turning Q2 on. The device used for Q1 is a sensitive gate SCR. This allows the value of R1 to be large, which limits the amount of current in the gate of Q2 to a value below turn on when no voltage is applied to R2. Diode D1 prevents reverse breakdown of the gates of Q1 and Q2. During the half cycle that Q2 is on, capacitor C1 charges through D2 and R3 to the peak line voltage. When D2 becomes reverse-biased by the decaying line voltage, C1 discharges through the base-emitter junction of Q4, R3 and the load, thus turning Q4 on and providing another discharge path through Q4 and the gate of Q3. The gate current of Q3 must be above its threshold level when the line voltage reverses for Q3 to turn on. The values shown were chosen to provide 50 mA of gate current when the anode-cathode voltage of Q3 reaches 10 volts. This circuit will work at other supply frequencies below approximately 30 kHz. This maximum frequency is due primarily to the recovery time of the SCRs.

This circuit will not switch large reactive loads since Q2 turns off when its current goes to zero, and by the time that occurs with a current which lags the voltage, the gate current of Q3 has decayed to a value less than its threshold level thereby preventing the device from turning on.

A circuit that can be electronically controlled to switch resistive or reactive ac loads statically is shown in Figure 4-9. The triac will turn on when the control signal is applied to R1. It will remain on until the control signal is removed, after which it will turn off when the current goes to zero. As mentioned in section 4.1, present triacs are limited to a maximum supply frequency of about 60 Hz by commutation dv/dt.

If it is not necessary to provide complete static switching, then a small switch can be used as in the static contactor shown in Figure 4-10, in which the SCRs remove the load from the line when the switch is open. When the switch is closed, diode D2 provides gate current to Q1 during the positive half cycle, turning Q1 on, and D1 supplies current to Q2 during the negative half cycle, turning Q2 on. Resistor R1 limits the gate current immediately after closing the switch until one of the SCRs comes on. The maximum load current capability is limited only by the ratings of the devices used.

In Figure 4-11, the main control element is the triac. Gate current is provided when the switch is closed, turning the device on. The supply voltage must be greater than the gate threshold voltage each half cycle for the triac to turn on. If the load is reactive, the current will either lead or lag the voltage. For this condition, the triac will turn off each half cycle when the voltage is greater than zero. If the phase shift is great enough that the magnitude of the voltage is larger than the trigger level of the triac at turn off, then the triac will turn on immediately. Should the load be resistive, so that there is no phase shift, there will be a dead band until the supply voltage exceeds the triggering level. When the control signal is obtained from a 120 volt rms supply, the dead band is negligible. After the switch is opened, the triac turns off when the current goes to zero.

4.5 DC Static Switches and Static Contactors

The circuits shown in Figure 4-12 through 4-15 are dc switches and static contactors. Static contactors use small switches with low current-carrying capacity to switch heavy loads; typical contactors are shown in Figures 4-12 and 4-13. The switches shown can be remote from the load. In Figure 4-12, a transistor is used as the controlled device. The circuit is off when the switch is open. When the switch is closed, resistor R1 provides base current to the transistor holding it on. Resistor R2 is used to hold the base at the potential of the emitter when the switch is open. If there is an inductance in the load, diode D1 is required to protect the transistor from voltage spikes which occur during the switching time. A circuit that does not require continuous drive is shown in Figure 4-13. The switch required is spring-loaded SPDT switch with a center off position. When S1 is thrown to the on position, resistor R1 provides gate current to SCR Q1, connecting the load to the supply. The switch is returned to the center off position since gate drive is not required once the SCR is on. While Q1 is on, capacitor C1 charges to the supply voltage through resistor R2. When it is desired to turn the circuit off, S1 is pushed to the off position which provides gate current to Q2 through R1 and R3. As before, S1 is returned to the center off position. Q2 is smaller than Q1 since it is used only to commutate Q1 off and its average power dissipation is small. Since Q2 is a smaller device than Q1, its gate current requirement is less

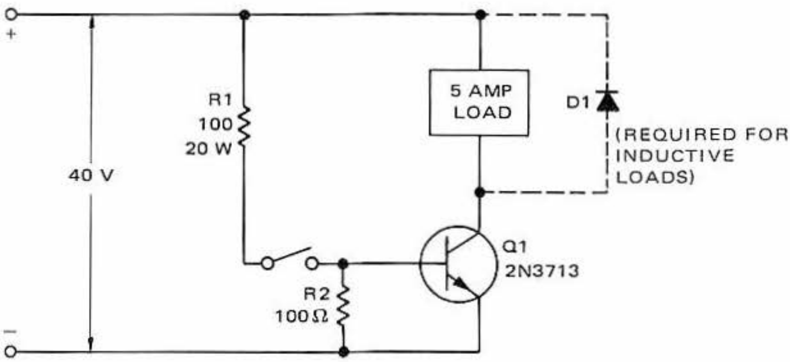


Figure 4-12 – Transistor DC Static Contactor

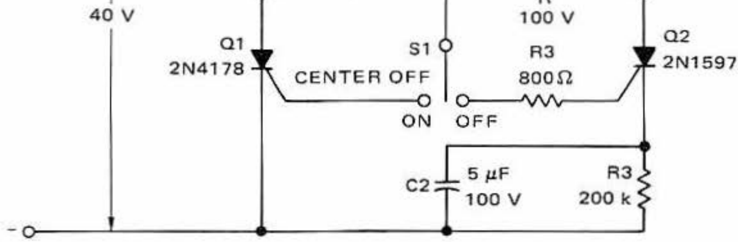


Figure 4-13 – Thyristor DC Static Contactor than that of Q2; therefore, resistor R3 is required to limit the gate current of Q2 below its maximum value. When Q2 first turns on, capacitor C2 has no voltage across it, permitting the energy stored in C1 to turn Q1 off. C2 then charges to the supply voltage, at which time Q2 turns off since its current falls below the holding level. Following this, R3 discharges C2, returning C2 to its initial uncharged state. R3 must be large enough that it

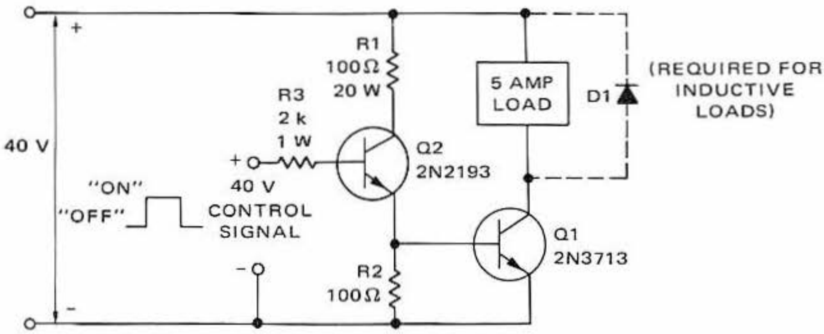


Figure 4-14 – Transistor DC Static Switch

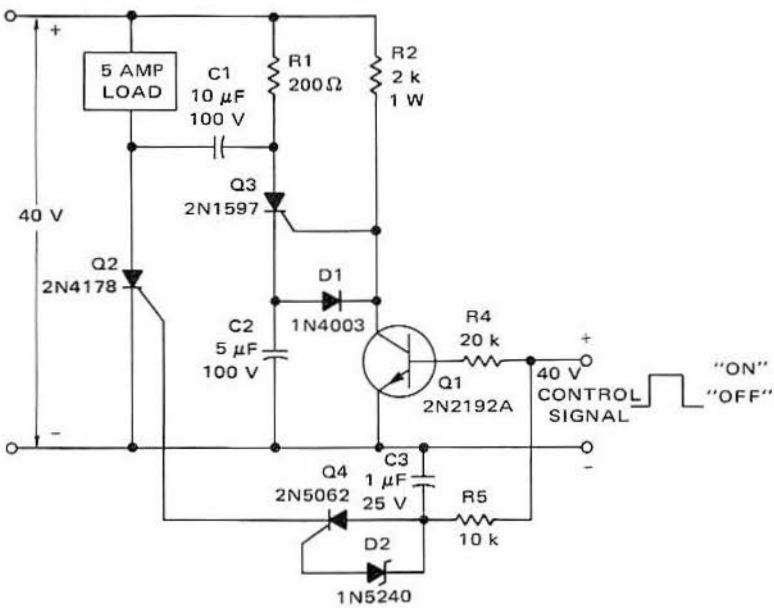


Figure 4-15 – Thyristor DC Static Switch

will not draw enough current to hold Q2 on after it has been turned on. The C2-R3 network assures that this circuit will draw no current when off.

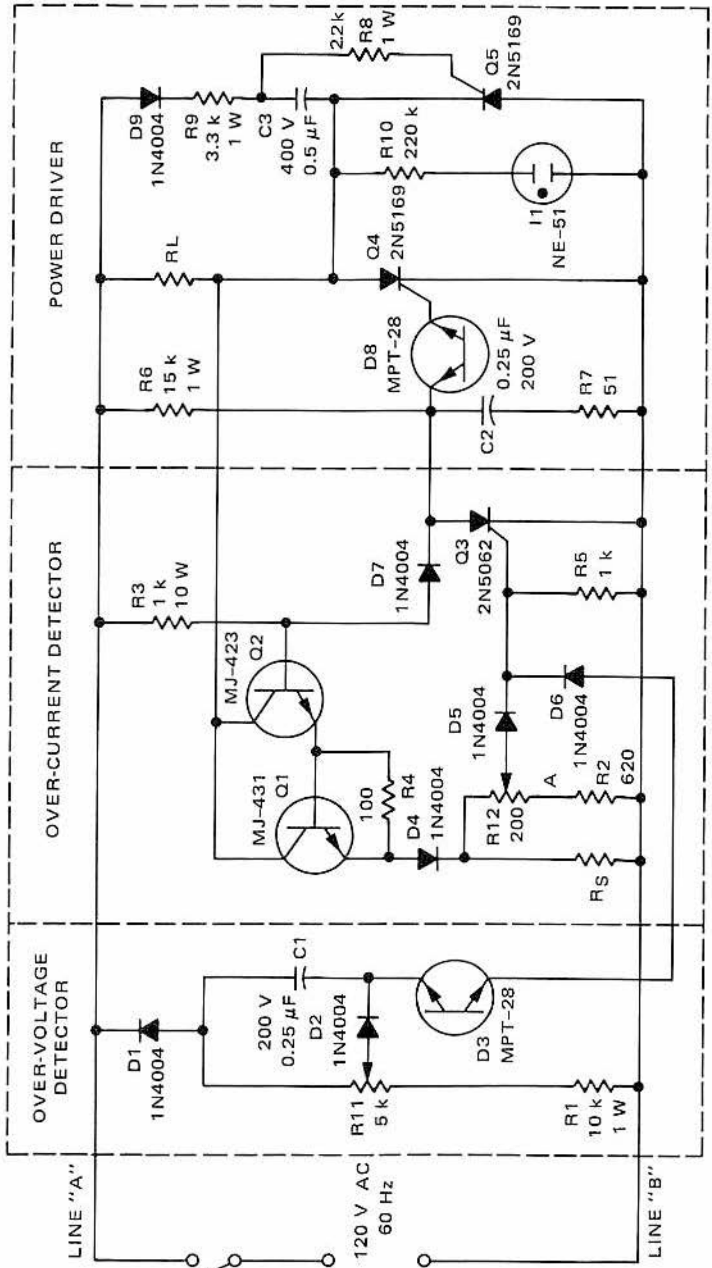
These basic circuits can be used to provide static switching if the switches are replaced by semiconductors as shown in Figures 4-14 and 4-15. In Figure 4-14, transistor Q2 is used to control power transistor Q1. When the control signal is applied to R3, transistors Q1 and Q2 turn on, connecting the load to the power supply. When the control signal is removed both devices turn off. If a voltage other than that shown is to be used as the control signal, then R3 should be changed to keep the base current of Q2 at 2 mA. Figure 4-15 shows the schematic of a thyristor static switch. The basic circuit is the same as that shown in Figure 4-13 except that the components associated with Q1 and Q3 replace the switch. When the control signal is applied, transistor Q1 turns on, clamping the gate of Q3 to ground, thus preventing it from turning on. Diode D1 is used to remove any charge on C2 through itself and Q1, thus protecting the gate of Q3. At the same time C3 begins charging. When the voltage across C3 reaches the breakdown voltage of zener diode D2, D2 conducts and turns on Q4, which in turn fires Q2. This circuit is required to prevent false triggering of Q2 and a possible "latch up" condition in which both Q2 and Q3 are on. When the control signal is removed, Q1 and Q4 turn off. This removes gate drive from Q2 and provides gate drive to Q3, which then commutates Q2 off. Q3 turns off when C2 becomes charged, thus removing the circuit from the supply.

4.6 Overvoltage and Overcurrent Protective Circuit with Automatic Reset

The circuit shown in Figure 4-16 can be used to protect a resistive load from both excessive voltage and excessive current. It can be used with 20 A, 115 Vac power supplies. There are three basic sections to the circuit, the power driver, the overcurrent detector and the overvoltage detector. Each one will be analyzed separately.

Power Driver

When line "A" goes positive with respect to line "B", C2 charges through R6 and R7 until the breakover voltage (about 28 volts) of three-layer diode D8 is reached. D8 then turns on, and a pulse of current is supplied to the gate of SCR Q4, causing Q4 to conduct. At this time all the line voltage, minus the forward voltage drop of Q4 (about 1 volt), is across R_L. This voltage also appears across D9, R8, R9 and C3. Capacitor C3 will charge until the line voltage falls below the voltage on C3. At this



$^*R_S \approx 0.1 \quad R_{LOAD}$

Figure 4-16 – AC Overvoltage and Overcurrent Protection with Automatic Reset for 20 A 115 Vac Power Supply

time, D9 becomes reverse-biased, and C3 discharges through R8 and the gate of Q5. The values of R8, R9, and C3 are adjusted so that as the line voltage goes through zero there is still ample charge on C3 to provide sufficient gate current to turn on Q5. Q5 is therefore slave-fired from Q4, since Q4 must be turned on before Q5 can be turned on.

Overcurrent Detector

This circuit offers a unique approach to overcurrent protection in that it does not require a current sensing element in series with the load. One way to keep the load from being connected across the line in the event of a short circuit or some other excessive current load is to prevent diode D8 from firing Q4. In order to do this, the overcurrent detector must work before the voltage across C2 and R7 reaches the breakover voltage of D8. When line "A" goes positive with respect to line "B", Q1 and Q2 are biased on by R3, thus allowing the load current to flow through the sense resistor R_S. Assuming that R_L is much greater than R_S, R_L will act as a current source and the voltage developed across R_S is sufficient to forward-bias D5 and the gate of Q3, then Q3 will turn on and clamp the voltage across C2 and R7 to approximately 1 volt. This prevents D8 from turning on, and also turns off Q1 and Q2 since base drive is removed from Q2 by D7. The only current now in the load is the leakage currents of Q1, Q2, Q4, Q5, and the "on" current of the fault indicator, neon lamp I1.

Component tolerance considerations force the overcurrent circuit to work before the line voltage reaches 20 volts. The available circuit gain limits the collector current of Q1 to 3.5 amperes which sets the maximum peak load current at

$$I_p = \frac{(V_p)(I_{C\,max})}{V_{sense\,(max)}} = \frac{165 \times 3.5}{20} = 28.8\text{ A}.$$

The maximum rms load current is therefore 20 A. Consideration of the voltage levels required for circuit operation allows the following equation to be used in determining the minimum value of R_S:

$$R_{S(min)} = (R_L)\left(\frac{V_{RS}}{V_{RL}}\right),$$

where V_{RS} = the voltage across R_S,

and V_{RL} = the voltage across R_L.

V_{RS} must be large enough to assure that D5 and the gate of Q3 can be forward-biased. Two volts will satisfy this requirement.
Therefore,

$$R_{S(min)} = R_L\left(\frac{2}{20}\right),$$

$$\text{or}\quad R_{S(min)} = \left(\frac{1}{10}\right)R_L\,.$$

In order to assure that R_L will appear as a current source to R_S, however, the *maximum* value of R_S should be less than or equal to 1/10 R_L; therefore, the proper value for R_S in this case is 1/10 R_L.

The voltage divider consisting of R12 and R2 permits a selection of the "trip" point of overcurrent protection. This divider must be set so that the voltage at point A is adequate to fire Q3 before the collector current of Q1 reaches 3.5 A. Diode D4 protects Q1 and Q2 from the reverse line voltage. Resistor R4 compensates for leakage current (I_{CBO}) in Q1. D5 and D6 form an OR gate permitting the overcurrent and the overvoltage circuits to both work into Q3. The maximum voltage across Q3 is the breakover voltage of D8, therefore it need only withstand this voltage. R7 is used to limit the discharge current of C2 through Q3.

The maximum forward surge current (I_{FM} surge) of Q4 and Q5 is 240 A. This is the maximum current this circuit will withstand. If a short in the load should occur at peak line voltage (168 volts), then this circuit will withstand the resulting current if the total source impedance R_G in the 115 V line is equal to or greater than 0.7 ohms:

$$R_{G(min)} = \frac{V_{LINE\,(max)}}{I_{FM\,(surge)}} = \frac{168}{240} = 0.7 \text{ ohm.}$$

Q4 and Q5 will never have to handle more than one-half cycle of overload current each before the overcurrent detector reacts. A 5 μH choke in series with the load will protect the SCRs from destruction due to excessive di/dt if a fault occurs at this worst-case condition. When the cause of the excessive current is corrected, the overcurrent circuit no longer fires Q3 and the load is automatically connected to the line through Q4 and Q5.

Overvoltage Detector

This circuit is a peak voltage detector. The detector circuit detects any excessive voltage on the negative half cycle (line "B" positive with respect to line "A") and prevents Q4 and Q5 from turning on as long as the overvoltage exists. This is accomplished as follows: capacitor C1 charges through D1 and D2 to a voltage level determined by R11 and R1. D2 prevents C1 from discharging back through R11. With normal line voltages, R11 is set so that C1 charges to a value less than the breakover voltage of three-layer diode D3 plus the sum of the forward voltage drops of D6 and the gate of Q3. If the line voltage goes above normal, then this level is exceeded and Q3 breaks over, discharging C1 through D6, R11, and R1, and into the gate of Q3.

The point in the cycle at which D3 will fire, depends on the setting of R11. During the negative half cycle (line B positive, line A negative), the voltage across D3 is equal to the voltage on C1, which is determined by the setting of R11, minus the line voltage from B to A (and the diode drops of D6 and the gate of Q3). Thus, if R11 is set so that C1 charges to 40 volts, and D3 fires at 30 volts, then D3 will fire when the line voltage equals approximately 10 volts. Once the line voltage goes positive (A with respect to B), the voltage on D3 equals the voltage on C1. Therefore, the overvoltage circuit will trigger Q3 only during the negative half cycle. The time constant of R11 plus R1 and C1 must be long enough to provide adequate gate current to fire Q3 when the line voltage goes positive.

The overvoltage circuit detects an overvoltage each cycle in which an overvoltage is present. When the condition is corrected, D3 no longer breaks over and the load is again connected to the line through Q4 and Q5.

4.7 DC Overvoltage Current Control

The circuit shown in Figure 4-17 is a dc electronic circuit breaker designed to protect a load against transient voltage or current overloads. It can protect circuits which cannot be protected by slower-acting mechanical circuit breakers, as it will remove power to the load in 4 to 10 μs as opposed to 8 to 10 ms for a mechanical circuit breaker. This overvoltage, overcurrent control can be used to safeguard the output stages of transistor transmitters, receivers, amplifiers, or any other circuit where transient overloads longer than 10 μs in duration may cause damage.

When power is applied to the circuit, the control circuitry is activated and, under normal conditions, connects the load to the power source. The supply voltage to base two of unijunction transistors Q1 and Q2 in the control circuit is regulated by zener diode D1. Q2, the overcurrent control transistor, senses the load current since the voltage at its emitter is a direct function of the load current. This is so since R8 is

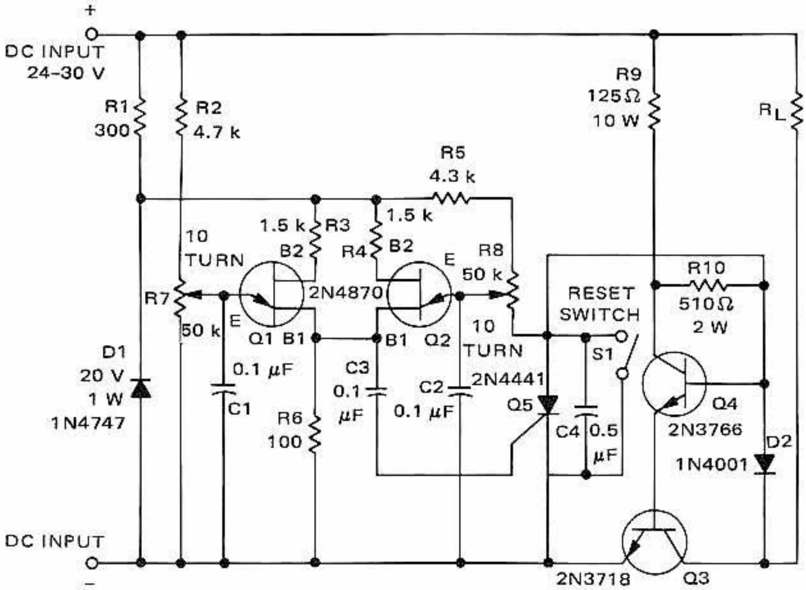


Figure 4-17 – Electronic Circuit Breaker

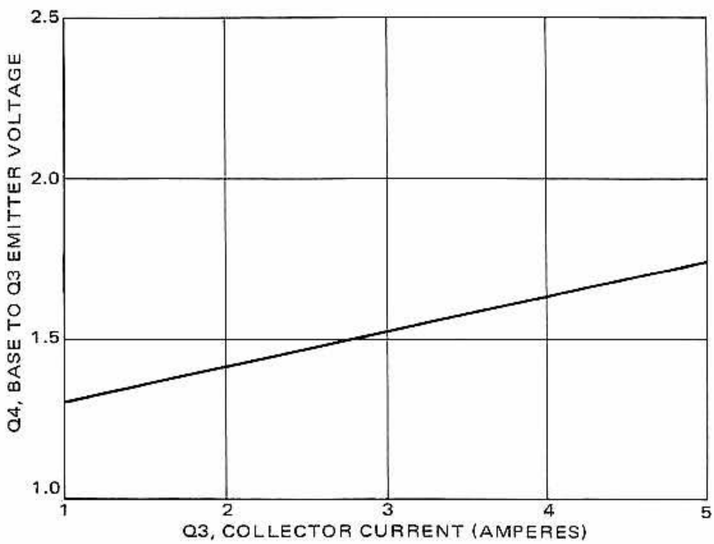


Figure 4-18 – Base-Ground Voltage of Q4 versus Collector Current of Q3 (30 V Supply)

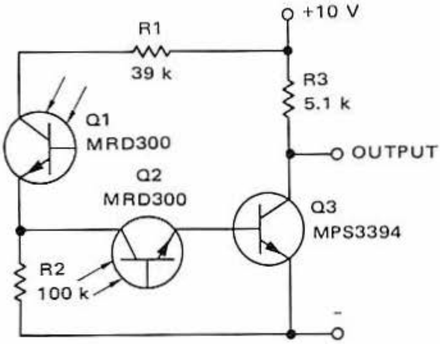
connected to negative common through the base-emitter junctions of Q4 and Q3, and in parallel with these, D2. Q4, which is initially biased on by R10, biases Q3 on. Q3 is driven hard enough that it is in saturation and is capable of handling the current through D2 and through the load. The $V_{CE(sat)}$ of Q3 is less than 1 V for load currents as high as the rated current of 5 amperes. D2, when forward biased, maintains an almost constant voltage between the base of Q4 and the collector of Q3. After Q3 is turned on, any current increase through it due to the load will raise its collector-emitter voltage. D2 will follow this increase and raise the voltage at the base of Q4. The increase in voltage between the base of Q4 and the negative supply terminal, versus current through Q3, is quite linear from 1 to 5 A (see Figure 4-18), and is used as a current-to-voltage converter and as the sense point for Q2. The voltage at the arm of R8 is set just below the firing level of Q2 at the maximum load current desired. If the current rises above this level, Q2 fires and discharges C2 through the emitter into base one and R6. The rapid discharge of C2 creates a pulse that is transmitted through C3 to the gate of SCR Q5 and turns it on. When Q5 is on, Q4 is switched off which shuts off Q3 because the sum of the forward diode voltage drops of the emitter-base junctions of Q4 and Q3 is more than the forward voltage drop of Q5. If the cause of the overload is removed, the circuit can be reset by closing the reset switch. This drops Q5 out of conduction and the circuit is reset for normal operation when the switch is released.

The overvoltage control works in a similar manner. Q1 receives its sense voltage through potentiometer R7 and resistor R2, which are in series and are connected across the input supply. The sense voltage is set slightly below the voltage which will fire Q1 so that any increase in the supply voltage will trigger Q1. This discharges C1 into R6 and the gate of Q5. Q3 is then turned off as previously described.

4.8 Optical Logic Drivers for Power Devices

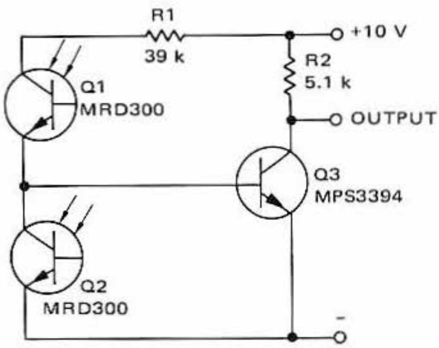
It is possible to provide logic control of power devices with optical signals if circuits such as those shown in Figures 4-19 through 4-22 are used to convert the light signals into electrical signals. The truth table for these circuits show outputs for positive logic.

For the circuit shown in Figure 4-19, a "one" output is obtained at all times except when both Q1 and Q2 are exposed to bright light. Approximately 220-foot candles to Q1 and Q2 will drive Q3 into saturation. Resistor R2 provides a path for leakage currents so that Q3 does not conduct until an adequate light level is presented to Q1 and Q2. The positive output will provide almost 2 mA to a load.



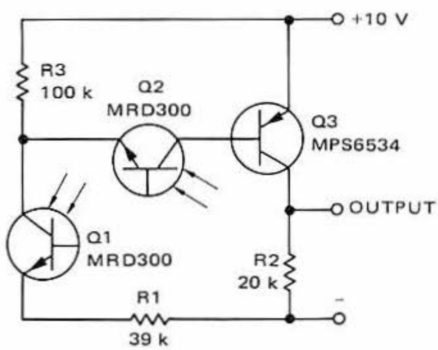
TRUTH TABLE	
Q1, Q2	OUTPUT = 0
Q1, $\overline{Q}2$	OUTPUT = 1
$\overline{Q}1$, Q2	OUTPUT = 1
$\overline{Q}1$, $\overline{Q}2$	OUTPUT = 1

Figure 4-19 – Optical Logic Driver



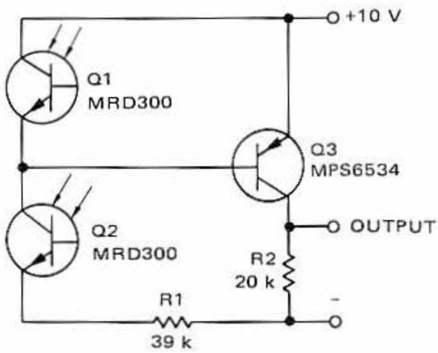
TRUTH TABLE	
Q1, Q2	OUTPUT = 0
Q1, $\overline{Q}2$	OUTPUT = 1
$\overline{Q}1$, $\overline{Q}2$	OUTPUT = 1
$\overline{Q}1$, Q2	OUTPUT = 1

Figure 4-20 – Optical Logic Driver



TRUTH TABLE	
Q1, Q2	OUTPUT = 1
Q1, $\overline{Q}2$	OUTPUT = 0
$\overline{Q}1$, $\overline{Q}2$	OUTPUT = 0
$\overline{Q}1$, Q2	OUTPUT = 0

Figure 4-21 – Optical Logic Driver



TRUTH TABLE	
$\overline{Q}1$, Q2	OUTPUT = 1
Q1, Q2	OUTPUT = 0
$\overline{Q}1$, $\overline{Q}2$	OUTPUT = 0
Q1, $\overline{Q}2$	OUTPUT = 0

Figure 4-22 – Optical Logic Driver

The circuit shown in Figure 4-20 provides a positive output voltage at all times except when Q1 is on and Q2 is off. For this case, the base drive to Q3 is provided through R1 and Q1. As in the previous circuit, normal room lighting does not turn Q3 on, but about 220 foot-candles from a flashlight shining on Q1 will allow Q3 to saturate.

The maximum current this circuit can provide a load is 2 mA. The inverse of the output of the two previous circuits can be obtained through the use of an additional inverting stage or by the circuits shown in Figure 4-21 and 4-22. If a current sink is required, an inverter should be used, but if a current source is required, the circuits in Figures 4-21 and 4-22 should be used. The output of the circuit shown in Figure 4-21 is zero at all times except when both Q1 and Q2 are on. As in the previous circuits, about 220 foot-candles of illumination on Q1 and Q2 is enough to saturate Q3 so that it can provide at least 10 mA to a load. The value of R2 is high so it does not require any current that can be supplied to the load. A current in R2 of 1/2 mA gives satisfactory results. Resistor R3 provides a path for leakage currents so that Q3 does not conduct until Q1 and Q2 are illuminated.

The circuit in Figure 4-22 provides a zero output for all conditions except when Q1 is off and Q2 is on. For this condition, base current is provided to Q3 through Q2 and R1. Here also, 220 foot-candles is enough to allow Q3 to saturate and drive a 10 mA load. For this circuit, also, the value of R2 is high so it does not rob current from the load. Q1 must be turned on hard enough to shunt the base-emitter junction of Q3 to keep Q3 from coming on when Q2 is on. This is achieved with the illumination intensity mentioned previously.

All four of these circuits can be used as the sensing part of a two-input static switch. These outputs then become the control signal for the power switching circuits shown earlier in this chapter.