Inexpensive power switch includes submicrosecond circuit breaker

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The circuit in Figure 1 lets you switch high-voltage power to a grounded load with a low-voltage control signal. The circuit also functions as a submicrosecond circuit breaker that protects the power source against load faults. Power switches to the load when you apply a logic-level signal to the output control terminal. When the signal is lower than 0.7V, transistor Q₃ is off and the gate of P-channel MOSFET Q₄ pulls up to the positive supply through R₆, thus holding Q₄ off. During this off condition, the circuit’s quiescent-current drain is 0A.

![Figure 1](image)

**Figure 1** This inexpensive power switch incorporates a submicrosecond circuit breaker.

A 3 to 5V signal at the control terminal turns on Q₃, which pulls R₇ to 0V, providing gate drive for Q₄. The MOSFET now turns on and sources the load current, Iₘ, through sense resistor R₃ to the load. If R₃’s and Q₄’s on-resistances are smaller than the load resistance, the magnitude of the supply voltage, Vₛ, and the load resistance mainly determine the load current.

Under normal load conditions, the sense voltage developed across R₃ is too small to bias Q₁ on; thus, Q₁ and Q₂ are both off. If, however, the load current increases, the voltage across R₃ may become large enough to turn on Q₁. At that point, base current flows through R₅ to Q₁, and Q₁’s collector current in turn provides base current for Q₂. As Q₂ turns on, it provides extra base drive for Q₄, and
the two transistors rapidly latch in the on-state.

With \( Q_1 \) saturated, its collector pulls \( D_2 \)'s anode to the positive supply, which clamps \( Q_1 \)'s gate voltage to a diode drop below \( V_S \). Without gate drive, the MOSFET turns off, and \( I_L \) falls to 0A. With \( Q_1 \) and \( Q_2 \) both latched on, \( Q_4 \) remains off, which protects the power source from excessive load currents. You can reset the circuit breaker simply by taking the control signal low or by cycling the power. The resistance values in Figure 1 are suitable for operation at supply voltages of 20 to 30V. Assuming that the transistors are suitably rated, the circuit can operate at much higher voltages, but you must scale the resistor values accordingly. Operation at a voltage as low as approximately 5V is also possible, but you may need to reduce the values of \( R_1 \) and \( R_5 \) to ensure proper drive for \( Q_1 \) and \( Q_2 \). Resistors \( R_6 \) and \( R_7 \) form a potential divider, which sets \( Q_4 \)'s gate-to-source voltage, \( V_{GS} \), to a value large enough to enhance the MOSFET fully when \( Q_3 \) is turned on.

At low supply voltages, you may need to change the ratio of \( R_6 \) to \( R_7 \) to ensure that the gate-to-source voltage is large enough to provide adequate gate drive for \( Q_4 \). When the circuit is operating at high voltages, you may need small-signal diode \( D_1 \) to prevent reverse avalanche breakdown of \( Q_2 \)'s base-to-emitter junction when \( Q_3 \) is off. However, you can omit \( D_1 \) at low supply voltages, which are too small to cause avalanche breakdown.

When selecting components, choose high-gain devices for the bipolar transistors and ensure that \( D_2 \) has low reverse-leakage current; avoid using a Schottky diode. In the off-state, each transistor has the full supply voltage across its collector-to-emitter or drain-to-source terminals, so ensure the maximum voltage ratings across these terminals are greater than the maximum supply voltage.

The circuit breaker trips at a load-current threshold: \( I_{L(TRIP)} \sim 0.5V/R_3 \). For example, with a supply voltage of 24V and with \( R_3 \) having a value of 6.8O, a test circuit using the values in Figure 1 trips at a load current of 70 mA. The actual trip point varies slightly with temperature and depends on the device you use for \( Q_1 \), so be prepared to adjust the value of \( R_3 \) to achieve the desired trip current.

In addition to providing a latching function, the positive feedback loop around \( Q_1 \) and \( Q_2 \) ensures that the circuit breaker responds quickly to an overload current. The actual trip time depends somewhat on the magnitude of the fault current. With a supply voltage of 24V and with \( R_3 \) having a value of 6.8O, the test circuit takes 6 \( \mu \)sec to trip at a fault current of 80 mA. However, increasing the fault current to 200 mA results in a trip time of just 500 nsec.

Capacitive loads, filament bulbs, and motors exhibit a large inrush current and could cause the circuit breaker to trip when the control signal goes high even though the normal, steady-state load current is below the trip threshold. If this scenario is likely to be a problem, consider connecting \( R_7 \) to a separate transistor so that you can independently control the circuit breaker and the power switch. This approach lets inrush current subside before enabling the circuit breaker.