Introduction

Until very recently, few alternatives to electromechanical and magnetic circuit breakers existed. Designers were forced to live with such undesirable characteristics as arcing and switch bounce (with corresponding noise and wear), while accommodating large unwieldy packages in their high power systems.

Solid state technology applied to this traditional device has resulted in circuit breakers free from arcing and switch bounce, that offer correspondingly higher reliability and longer lifetimes as well as faster switching times. A typical solid state circuit breaker will switch in a matter of microseconds, as opposed to milliseconds or even seconds for a mechanical version.

New solid state products currently on the market utilize the many benefits associated with power MOSFETs to deliver a product far superior to earlier silicon versions. Power MOSFETs offer low on resistances (as compared to bipolar transistors), low voltage drops, low EMI, faster switching times and good thermal stability of key parameters.

However, two key advantages that the electromechanical devices have over the solid state versions are simplicity and low cost. For example, a simple commercial circuit breaker relay combination will sell for $4.00 to $6.00 in low volume. The existing solid state circuit breakers will run from several times that amount, and typically include many bells and whistles that the average designer can do without. This cost difference is somewhat less in military versions, as the mechanical devices must also undergo extensive testing.

One reason for the corresponding complexity of the silicon based systems is the power MOSFET drive circuitry required. If N-channel FETs are to be used (N-channel FETs are preferable to P-channel as they have roughly 2.5 times lower $R_{DS(On)}$ and correspondingly lower cost), a charge pump or voltage tripler must be supplied to provide sufficient gate enhancement to turn on the FET. This involves supplying an oscillator as well as the necessary diodes and capacitors, which definitely take board/hybrid package space.

A simple, inexpensive solid state circuit breaker can be made using the MIC5013 power MOSFET predriver with overcurrent sense. This predriver was designed for driving N-channel FETs, and has an on-board charge pump to provide sufficient gate enhancement. This eliminates the issue of providing this enhancement externally; providing a one component solution to what once consumed extensive "real estate".

As any size FET can be driven by the MIC5013, almost any load can be accommodated. High inrush or inductive loads are driven with equal ease, greatly expanding the realm of possibilities for these circuit breaker topologies.

An internal comparator is used to sense an over-current condition; this feature allows the use of this product as a circuit breaker that can be programmed to trip at a specified current via choice of an external sense resistor. An overcurrent flag provides this information externally, allowing easy digital interface/control of the device. This feature allows its use in more complex, remotely controlled designs such as those currently used in high reliability applications.

Using this highly versatile device, four circuit breaker configurations have been devised; a low parts count, low cost externally resettable version, a minimal parts count remotely resettable version with indicator, a minimal parts count automatically resettable version, and a full blown power controller design with Z8™ microcontroller interface. Typical applications for the first three versions include a variety of commercial, industrial and military applications, such as battery pack circuit breakers/current limiting, electric vehicles, and heavy machinery. The latter design is useful in high end applications such as military avionics or industrial automation. It offers a substantial cost savings over the currently available remotely controllable electromechanical units, as well as most currently available hybrid designs of this complexity.

Minimum Parts Count Configuration

Figure 1 illustrates the most basic configuration. The overcurrent trip point is set via the design equations in this figure. The current sense operates via a comparator which compares the voltage on the sense pin to an offset version of the voltage on the source pin. The current on the threshold pin, set by choice of $R_{TH}$, is mirrored and returned to the source by a $1 \, \text{k}\Omega$ resistor.

This sets the trip voltage of the comparator. When a fault condition occurs, an internal current sense latch is set, which turns off the power FET. The control input pin must be toggled low then high by the reset switch before the FET will be switched on again (after the short has been removed). A $330\,\text{k}\Omega$ resistor is provided to hold the input low and keep the FET off until the circuit is reset. Advantages of this topology are its simplicity and correspondingly low cost.
Figure 1: Basic Circuit Breaker/Switch Configuration

Figure 2: Shutdown Time vs. % Current Overdrive

R1 = V+ / 1mA
R2 = 100Ω
R_s = (100mV + V_Trip) / I_L
R_TH = (2200/V_Trip) – 1000
For this example:
I_L = 10A (trip current)
V_Trip = 105mV
Response Time

Figure 2 illustrates an advantage that is common to all MIC5013 based topologies: fast response times. A graph of shutdown time versus current overdrive is shown. The data was taken using this simple topology without the 330kΩ pulldown resistor, however, all configurations (with similar loads) will have a similar response as it is mostly a function of device parameters. (Note: This data was averaged from a small sample size; about 5-10% variation from this line may occur).

Response times in the order of µs means that a short circuit can be detected in time to prevent extensive damage, and is an improvement of an order of magnitude over electromechanical circuit breakers.

Remotely Resettable Configuration

The circuit breaker configuration of Figure 3 is designed to be used for applications requiring remote indication and reset capability. When the breaker is tripped, the fault output pin switches high (to a diode drop below the positive rail). This output is used to drive a remotely located LED. (If an incandescent lamp is desired, the fault output should be used to drive a power FET switch that could withstand the inrush generated). Resetting of the breaker is accomplished by toggling the control input with a remotely located switch. If the distance between the control point and the breaker is large, an optocoupler is recommended to open any ground loops that may occur. Many switch manufacturers offer a package that combines both the switch and the indicator while providing internal isolation, making this circuit even more compact. Shown here is the NKK-SS12SDP2-LE, a small slide switch suitable for instrument or control panels where space is at a premium.

Potential applications for this circuit include use as remotely controlled circuit breakers in aircraft with the indicator/switch located in the cockpit, industrial control panels, heavy machinery, and robotics.

Automatically Resettable Configuration

The third circuit, shown in Figure 4, is useful when automatic resetting is desired. This is accomplished by adding feedback from the fault pin back to the control input. A simple Miller integrator circuit is used to test the load every 18 ms until the short is removed. When the short condition no longer exists, the circuit latches on and operates as before. Although no reset button is necessary, an indicator could be added to the fault line if remote notification of a short circuit condition is desired.

The beauty of this configuration is that no human intervention is necessary once a short has occurred. A possible drawback is that the gate does briefly turn on every 18ms to test the load. However, if the short still exists, it shuts down again in 10µs. This time duration is short enough to be acceptable in most applications.

Potential applications for this circuit include industrial automation, automotive circuitry, motor drive (stall sensing), and protection for power supplies/battery packs.
The NOR gate is pulled high, causing a low output on the NOR gate, indicating a short circuit has occurred, one input of the circuit breaker subsystem operates similarly to the other systems of most systems. See the Hewlett-Packard Optoelectronics Designer’s Manual for more details). Again, the optoisolator also provides isolation between the digital and analog portions of the circuit.

Low power detection is accomplished via the use of an opamp, the HCPL-3700, that also contains a Schmidt trigger. This provides hysteresis, allowing us to shut the system down when power reaches roughly 50% of rated value, and not turn back on again until we are at roughly 75% of rated value (These levels are chosen via selection of input resistor values and can be changed to meet the requirements of most systems. See the Hewlett-Packard Optoelectronics Designer’s Manual for more details).

Shutdown and resetting of the system in the case of a low power condition is accomplished as before, by triggering the cond_int subroutine, which in turn scans port 2 to find the appropriate cause for the trigger and lights the corresponding LED.
If subroutine cond_int detects an impossible combination of conditions, i.e. short and open, a hardware fault has probably occurred. The microcontroller then lights an indicator LED attached to P34, and hangs up until the problem is removed.

The emergency override feature allows a pilot (or vehicle commander) to keep the system alive even though a short circuit has been detected. In a combat or other emergency situation, the equipment could be kept operating until the short circuit causes the FET to blow.

A switch located in the cockpit is used to provide this function. When it is depressed, IRQ2 (P31) is pulled low, causing the internal timer/counter to begin an 11 ms switch debounce count. If IRQ2 is still low (switch is still depressed) after 11 ms, then internal interrupt IRQ5 is activated on time out. Interrupt service routine T1_int then keeps power flowing to the control input of the MIC5013, and toggles P23 high. This turns on the base of Q1, which pulls the signal on the sense input of the MIC5013 to ground, disabling the current sense function of the part. (If a 14-pin MIC5010 is used instead of the MIC5013, an external inhibit pin is available).

A key advantage of this circuit is that 2/4 interrupt lines and one complete I/O port is left unused. This would allow the microcontroller to be used for other functions in addition to power management.

If this is to be a dedicated power management system and the unused I/O has no other potential purpose, then some ideas for modifications include using an alphanumeric display instead of indicator LEDs, and including a self test mode with indicators on power-up.

If a PWM'ed load is to be used, the Z8 can be used to provide a variable frequency, variable pulse width signal by using the internal counter/timer registers (See the Z8 Design Manual for details). In this case, P36 should be connected to the control input of the MIC5013 instead of P35, and switch debounce will have to be performed in hardware instead of firmware. The MIC5013 can be switched up to a maximum frequency of 20kHz. Digital closed loop motion control can also be performed using the controller.

Figure 5: Z8 Based Power Controller
Summary

The MIC5013 MOSFET predriver with over current protection brings a whole new dimension to the world of power management with its versatility, ease of use, and quick response times. Four different lab tested circuit breaker configurations were presented and discussed; a minimum parts count version, a remotely resettable version, an automatically resettable version, and a complete microcontroller based power management system. Many more unique configurations are possible; a configuration to fit most needs can potentially be designed using the MIC5013.

References

1. The Z8 Design Manual, Zilog, 1985
3. Micrel Databook, 1995
6. HP Application Note 1004, "Threshold Sensing For Industrial Control Systems With the HCPL-3700 Interface Optocoupler"
5) Initialize flag.
clr dbnce_actv ; start with a clean debounce timer flag

6) All set up. Enable interrupts and go!

status_check:
tm P3,#00000100b ; check for bad condition
jr z,chk_pwr_cond ; active low

good_status:
ld P3,#00011000b ; sends power to 'OK' LED
jr ovrd_chk ; jump over subroutine call

chk_pwr_cond:
call cond_int ; check power circuits

ovrd_chk:
tm dbnce_actv,#1 ; if the emergency override has already been pressed, skip the
jr nz,status_check ; go back and start status check

tm P3,#00000100b ; Has the emergency override (P31) been pressed?
jr z,emer_ovrd ; if yes, trigger debounce timer
jr status_check ; no - start over again looking for status

emer_ovrd:
or dbnce_actv,#1 ; set debounce timer active flag
or dbnce_actv,#0 ; reset 'debounce active' flag
jr nz, status_check ; If not, then it was just noise

tm P3,#00001000b ; start debounce timer rolling
or status_check ; for status
jr nz, status_check ; go back and start status check

cond_int:
low_test:
tm P2,#00000100b ; see if P2 is high (low power condition).
jr z, end_cond_int ; jump if no low-voltage fault

and P3,#11011111b ; reset P35 to shutdown the MICS013
ld P2,#01110111b ; reset P27 to turn on "low power" LED
jr end_cond_int ; done with power condition tests

hw_fault:
and P3,#11001111b ; reset P34 to turn on "h/w fault" LED - we have a circuit breaker malfunction - and turn off the MICS013!
or P2,#00010000b ; turn off the "OK" LED, we have a HW fault and things are NOT OK!!
end_cond_int:
ret

end_T1_int:
ei

T1_int:
di ; disable interrupts
and irq,#00100000b ; Reset the interrupt source

and dbnce_actv,#0 ; reset 'debounce active' flag
and irq,#11011111b ; Reset the interrupt source

tm P2,#00000000b ; Don't take action if there is no short
jr nz, end_T1_int ; Bail out.

tm P3,#00000010b ; Check to see if override switch is depressed, Internal timer T1 begins counting for 11 ms (see main). At the end of this debounce routine, interrupt IRQ5 is asserted. This takes priority over the cond_int subroutine, and keeps the control input to the MICS013 on while disabling the current sense by pulling the sense pin to ground through transistor Q1.

jr nz, end_T1_int ; If not, then it was just noise
or irq,#11011111b ; Reset the interrupt source
and dbnce_actv,#0 ; reset 'debounce active' flag

or P2,#00010000b ; Sends power to Q1 to disable current sense
or P3,#00010000b ; Makes sure the control input is still on

end_T1_int:

Null iret:
and irq,#00010000b ; Reset any spurious pending interrupt.
iret