TB3099

Extending Relay Life by Switching at Zero Cross

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INTRODUCTION

This short technical brief describes how to implement a Zero-Cross Detect feature on the PIC16F1708 microcontroller. This will also be used to switch a 220V relay to a 220 volt AC motor. Switching the relay at the zero-crossing point reduces spark across the contacts, extending relay life, and also reduces EMI. Switching at the zero-crossing point reduces EMI in both relays and high-voltage solid-state switches.

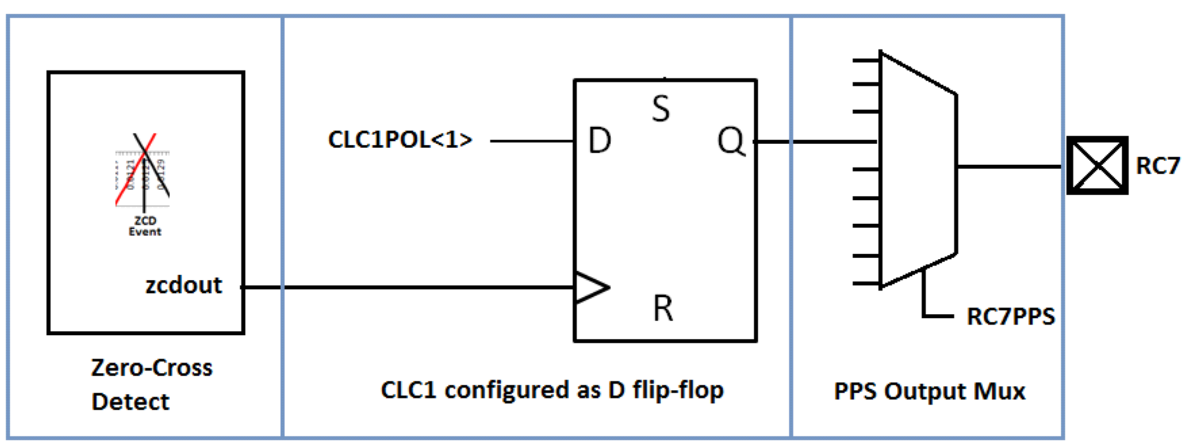
This application also demonstrates the “Core Independent Peripherals” concept, wherein interconnected peripherals are set up in advance of events, allowing fast switching with no processor interruption.

The zero-crossing detect event is routed through the CLC module to cause the switch to happen within microseconds of the zero-cross detect event occurring. Making use of the CLC for this function has numerous benefits:

- Fast response to the zero-crossing event:
  - No CPU intervention required
  - Switching speed is independent of processor speed
  - Switch occurs on microsecond scale
- It frees CPU to handle other processes while events occur.
- It can operate while device is in Sleep to lower current consumption.

The zero cross has been structured such that the main program requests the switch, and the switch will occur at the next zero-cross rising edge event. The flip-flop receives its clock from the zero-cross detect output signal. The data into the flip-flop is controlled through the CLC1POL<1> bit. The data is routed to the RC7 output pin through the RC7PPS MUX.

FIGURE 1: STRUCTURE OF ZERO-CROSS DETECT SWITCH



This technical brief will provide the implementation for a motor switch. The user can switch the motor off and on with a momentary button press. The relay will be opened and closed at the zero-crossing point in order to extend the life of the relay contacts and reduce EMI. Switching at zero cross also has applications in power-factor correction.

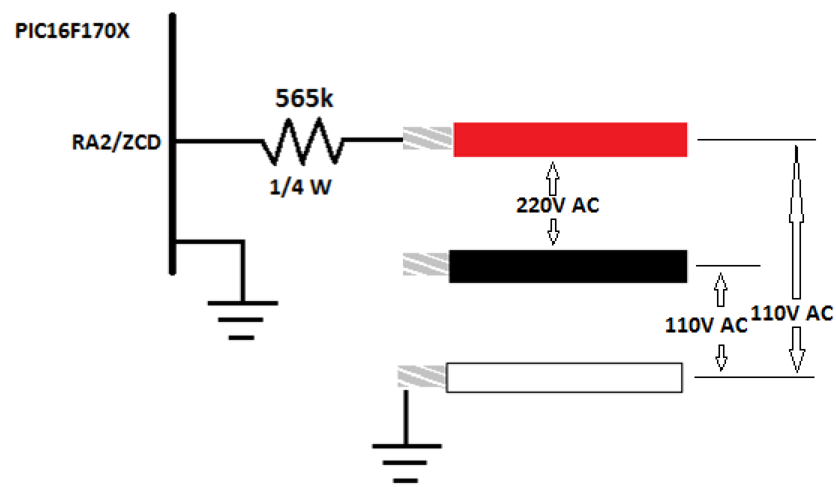
RESOURCE REQUIREMENTS

TABLE 1: RESOURCE REQUIREMENTS FOR ZERO-CROSS SWITCHING

CLC modules	1
RAM	1 byte
Program memory	119 of 4096 locations

PIC16F170X products are equipped with a zero-cross detect circuit. The zero-cross detect feature requires the use of one high-value resistor. It is important to use a large resistor to prevent overcurrent/overvoltage from damaging the PIC® device. The circuit diagram for zero-cross detect is shown below (Figure 2):

FIGURE 2: CONNECTION DIAGRAM FOR ZERO-CROSS PIN (RA2/ZCD) TO HIGH-VOLTAGE MAINS



Note that the zero-cross detect pin has been hooked to the red (hot) wire through the 565 kΩ resistor. It could optionally be hooked to the black (hot) wire. It is necessary that the ground be hooked to the white (common) wire.

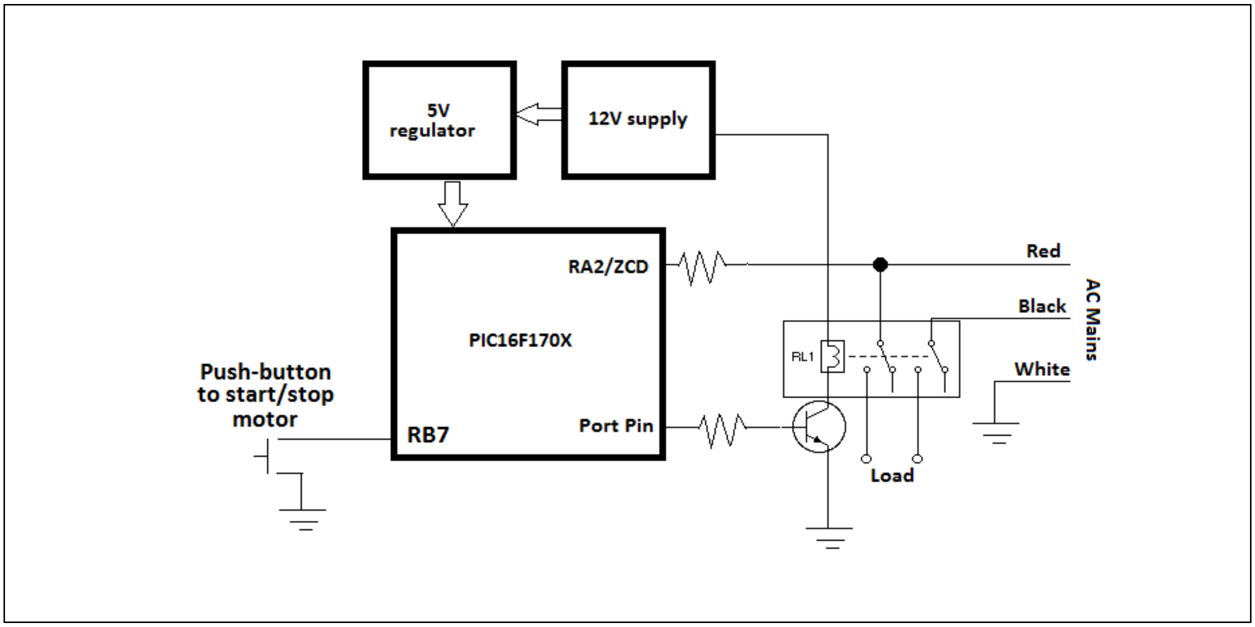
The RA2/ZCD pin should nominally sink/source 300 µA maximum. For a 120V (RMS) sine wave, it will have a peak of (120 *2^(1/2)) = 169.7V, using Ohm's law:

V/I = R = 169.7/300 µA = 565 kΩ

The zero-cross detect peripheral has the option of generating interrupts on positive and negative-slope zero crossings. Two different power modes (High and Low) give flexibility in managing power consumption.

For this example, we are going to switch a 220V relay with a 12V DC coil. A push button switch (connected to pin RB7) is configured with an internal weak pull-up. The block diagram below (Figure 3) shows the primary connections:

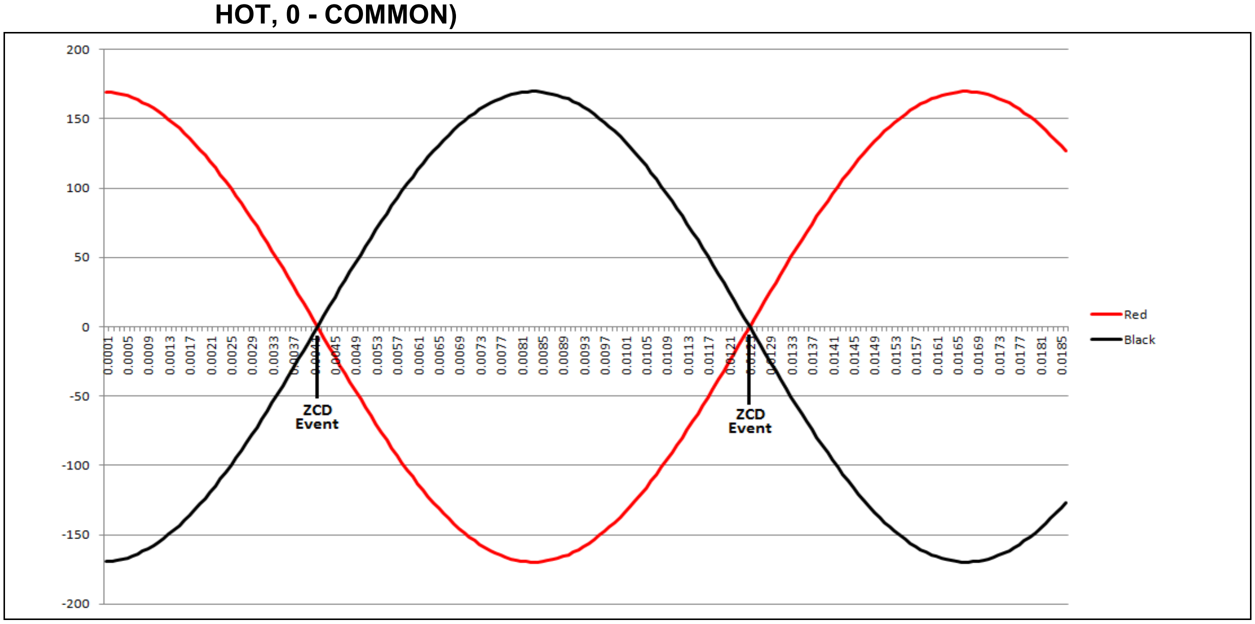
FIGURE 3: SCHEMATIC DIAGRAM FOR ZERO-CROSS DETECT MOTOR SWITCHING



AC VOLTAGE WAVEFORMS (60 Hz)

The voltages on the red and black power connections are sine waves which are 180° out of phase with each other. The graph below (Figure 4) shows AC waveforms and the zero-crossing point. Note that if we switch at the zero-crossing point for one of the "hot" wires, it will be the same as the zero-crossing for the other "hot" wire. 110V (RMS) is the voltage of red or black with respect to the center line. It is easy to see that by taking the potential between both wires (red and black) you have doubled the amplitude of voltage difference (220V RMS).

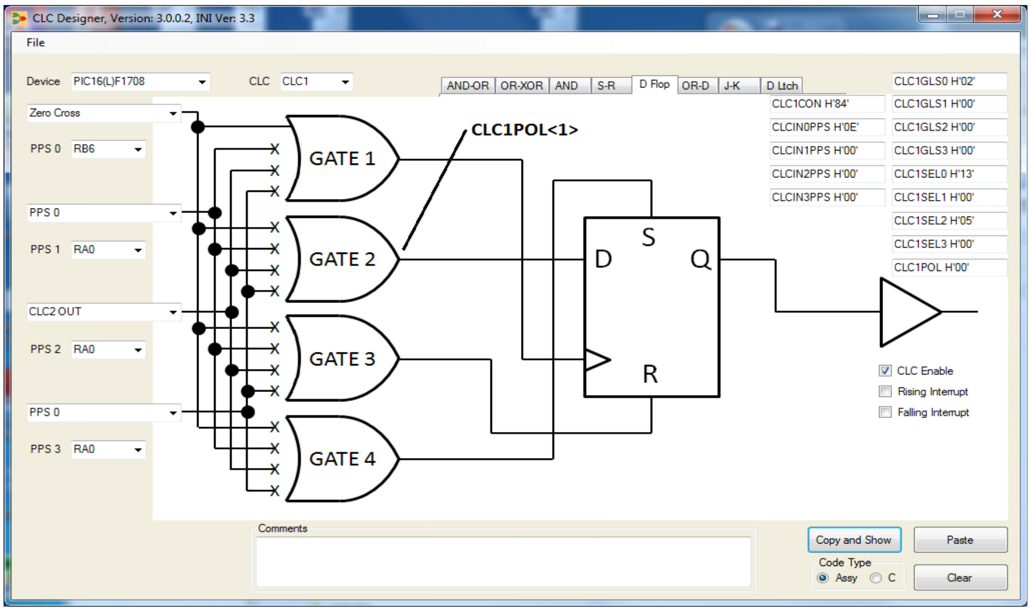
FIGURE 4: 60 Hz AC MAIN WAVEFORMS AS A FUNCTION OF TIME (RED - HOT, BLACK - HOT, 0 - COMMON)



CLC CONFIGURATION

To switch near the zero-crossing point, we are feeding the clock of a D flip-flop with the zero-cross signal. The screen shot below (Figure 5) shows CLC1 configured as a D flip-flop with the clock fed from the zero-cross signal, and the data is provided via the CLC1POL<1> bit.

FIGURE 5: CLC DESIGNER TOOL WITH CLC1 CONFIGURED AS D FLIP-FLOP

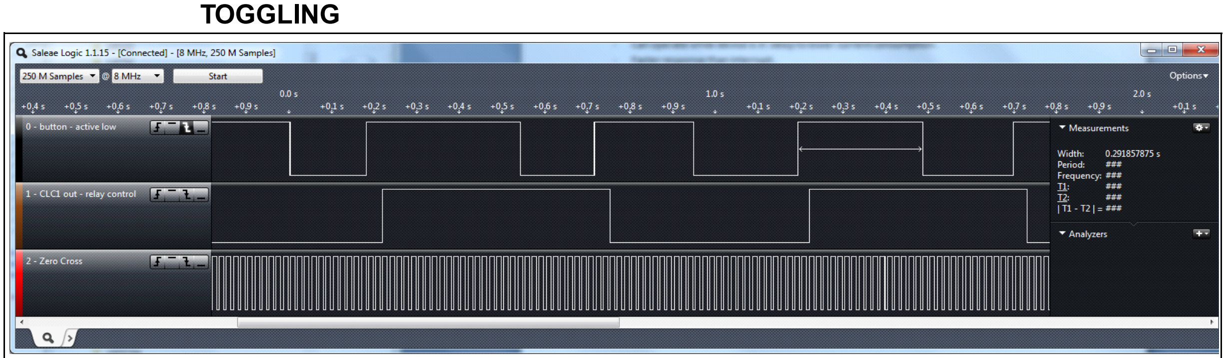


The logic waveform below (Figure 6) shows the following signals:

- Push button (active-low with internal pull-up from PIC device)
- Relay switching signal
- Zero-cross detect signal (brought out on port pin through the CLC module).

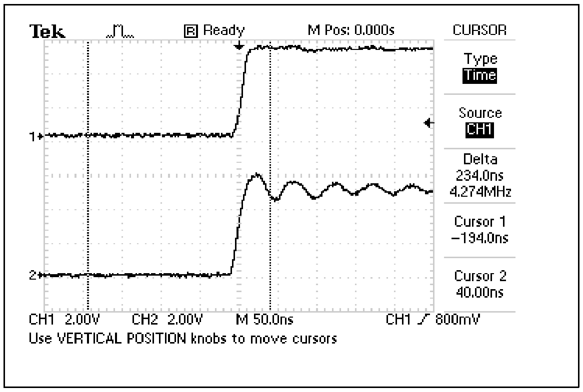
Notice that after each button press, there is a short delay to debounce the button, and then the state of the relay toggles. This allows a momentary push button to turn a motor on/off with successive presses. The change in CLC1OUT occurs on the rising edge of the zero-cross signal.

FIGURE 6: WAVEFORM SHOWING MULTIPLE BUTTON PRESSES AND RELAY OUTPUT TOGGLING



The next scope plot shows a zoomed-in view of the switch taking place at the zero-crossing point (Figure 7). The delay between the zero-cross signal and “CLC1OUT” is solely gate propagation delay and is independent of the processor clock. The signals are almost simultaneous because the zero-cross signal is internal to the PIC device. Propagation delay in the CLC is negligible, but each signal sees the same delay at the respective output pad.

FIGURE 7: RELATIVE TIMINGS BETWEEN ZERO-CROSS RISING EDGE AND OUTPUT SIGNAL CHANGE



CONCLUSION

It is our hope that this technical brief provides a starting point for developing applications using the zero-cross detect peripheral. Switching at zero cross reduces EMI. This may provide cost reductions for some applications by reducing PCB noise and filtering components.

APPENDIX A

Code to switch the relay at the zero-crossing point is listed below.

```
#include "p16f1708.inc"
#define      RELAY_CONTROL     CLC1POL,1
#define          debounce_count     0x71          ; RAM location for debounce counter

start

     org 0x0000

          nop
          banksel     ZCD1CON
          bsf          ZCD1CON,ZCD1EN     ; Let's get started by turning on the Zero-cross detect module.

          banksel     ANSELB
          clrf     ANSELB               ; make port B digital
          movlw     0x04
          movwf     ANSELA               ; make port A digital
          movlw     0x04
          movwf     ANSELC               ; make port C digital, except RC2.

          banksel     TRISC
          movlw     0x04
          movwf     TRISC               ; port C all outputs, except RC2.
          movlw     0xC0
          movwf     TRISB               ; port B all outputs, except RB7 and RB6
          movlw     0x04
          movwf     TRISA               ; port A all outputs, except RA2.

          #include "zcd-clc1.inc"     ; this sets up the CLC1 module as a d-type flip-flop
                                      ; with "zero-cross" as clock and data provided through CLC1POL<1>
          banksel     RC7PPS
          movlw     0x04
          movwf     RC7PPS               ; map CLC1 output (relay control) to RC7.

          banksel     RC6PPS
          movlw     0x13
          movwf     RC6PPS               ; map "Zero-Cross" to RC6 (for visualization)

          banksel WPUA
          clrf     WPUA               ; make sure weak pull-up is not turned on for RA2/ZCD

          banksel     OPTION_REG
          bcf          OPTION_REG,7     ; enable weak pull-ups.

main_loop
          banksel     PORTB
          btfsc     PORTB,7               ; Is button depressed?
          goto     main_loop          ; No.

debounce
          movlw     0xff               ; Yes - button was pressed.
          movwf     debounce_count     ; load a counter to debounce my switch.
```

```
debounce_loop
         btfss     PORTB,7               ; Is button released?
         goto     debounce          ; No.
         call      delay               ; Yes. short delay,
         decfsz     debounce_count     ; and decrement counter. Has counter expired?
         goto     debounce_loop     ; No.
         banksel     CLC1POL
         btfss     RELAY_CONTROL     ; Is relay currently on?
         goto     relayon               ; No. request turn on.
         goto     relayoff          ; Yes. request turn off.

relayon
     bsf          RELAY_CONTROL          ; raise signal to request relay turn-on.
     goto     main_loop

relayoff
     bcf          RELAY_CONTROL          ; lower signal to request relay turn-off.
     goto     main_loop


delay
     nop
     nop
     return


     end
```

APPENDIX B

Appendix B contains the CLC configuration file that was generated with the CLC Designer Tool.

```
BANKSEL CLCIN0PPS
movlw   H'0E'
movwf   CLCIN0PPS
movlw   H'00'
movwf   CLCIN1PPS
movlw   H'00'
movwf   CLCIN2PPS
movlw   H'00'
movwf   CLCIN3PPS

BANKSEL CLC1GLS0
movlw   H'02'
movwf   CLC1GLS0
movlw   H'00'
movwf   CLC1GLS1
movlw   H'00'
movwf   CLC1GLS2
movlw   H'00'
movwf   CLC1GLS3
movlw   H'13'
movwf   CLC1SEL0
movlw   H'0E'
movwf   CLC1SEL1
movlw   H'05'
movwf   CLC1SEL2
movlw   H'00'
movwf   CLC1SEL3
movlw   H'00'
movwf   CLC1POL
movlw   H'84'
movwf   CLC1CON

BANKSEL CLC2GLS0
movlw  H'02'
movwf  CLC2GLS0
movlw  H'00'
movwf  CLC2GLS1
movlw  H'20'
movwf  CLC2GLS2
movlw  H'00'
movwf  CLC2GLS3
movlw  H'0E'
movwf  CLC2SEL0
movlw  H'00'
movwf  CLC2SEL1
movlw  H'06'
movwf  CLC2SEL2
movlw  H'00'
movwf  CLC2SEL3
movlw  H'00'
movwf  CLC2POL
movlw  H'81'
movwf  CLC2CON

BANKSEL CLC3GLS0
movlw  H'02'
movwf  CLC3GLS0
movlw  H'00'
movwf  CLC3GLS1
movlw  H'00'
movwf  CLC3GLS2
movlw  H'00'
movwf  CLC3GLS3
movlw  H'0E'
movwf  CLC3SEL0
movlw  H'04'
movwf  CLC3SEL1
movlw  H'06'
movwf  CLC3SEL2
movlw  H'00'
movwf  CLC3SEL3
movlw  H'02'
movwf  CLC3POL
movlw  H'84'
movwf  CLC3CON
```

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