MICROCHIP

AN597

Implementing Ultrasonic Ranging

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INTRODUCTION

Object ranging is essential in many types of systems. One of the most popular ranging techniques is ultrasonic ranging. Ultrasonic ranging is used in a wide variety of applications including:

- Auto focus cameras
- Motion detection
- Robotics guidance
- Proximity sensing
- Object ranging

This application note describes a method of interfacing PIC16CXX microcontrollers to the Polaroid 6500 Ranging Module. This implementation uses a minimum of microcontroller resources, a CCP module and two I/O pins. The two major components of the system are:

- Microcontroller
- Polaroid 6500 Ranging Module

The microcontroller performs the intelligence and arithmetic functions for ultrasonic ranging, while the Polaroid 6500 Ranging Module performs the ultrasonic signal transmissions and echo detection.

THEORY OF OPERATION

Ultrasonic ranging entails transmitting a sound wave and measuring the time that it takes for the sound wave to reflect off of an object and back to the origin. The reflection time is proportional to the distance that the object is from the source. In this implementation, the sound wave is transmitted and received from the same transducer. Therefore, a blanking interval is required between signal transmission and reception to eliminate false echoes (i.e., a transmitted signal being detected as its own echo).

CIRCUIT CONFIGURATION

In this implementation, a PIC16C74 is connected to the ranging module as shown in Figure 1. The RE0 and RE1 I/O pins are configured as digital outputs and are tied to INIT and BINH, respectively. The CCP1 pin is configured as a digital input and is tied to ECHO through a pull-up resistor. The pull-up resistor is needed since the ECHO signal is an open-collector output. The CCP1 pin is configured for capture mode (CCP1CON). Figure 2 shows the timing relationship for V_{DD} and the three signal lines (INIT, BINH, and ECHO).

Note:	The ranging module requires 5.0 milliseconds to stabilize during power-up.

FIGURE 1: RANGING MODULE INTERFACE

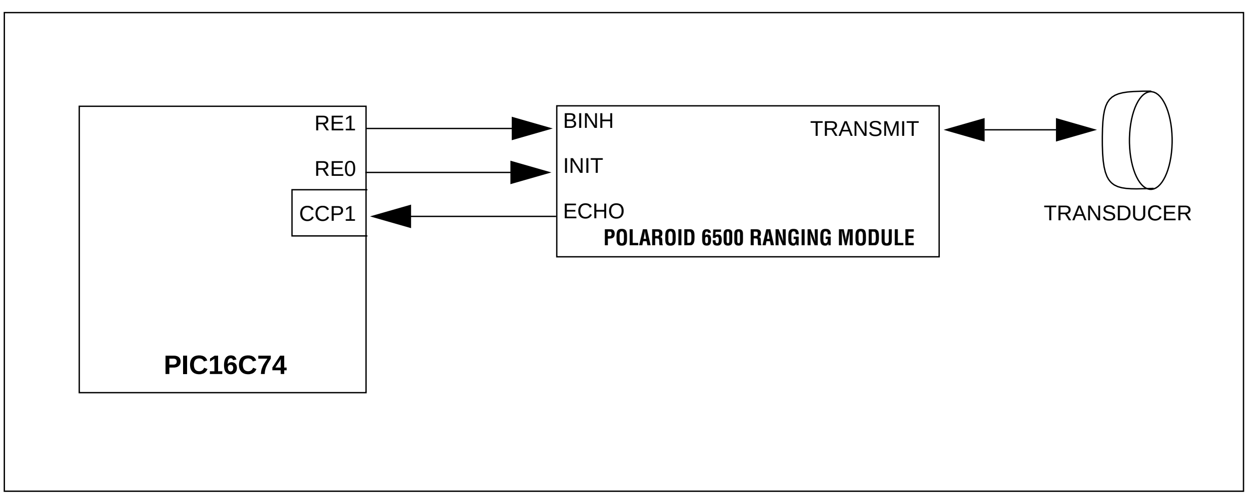
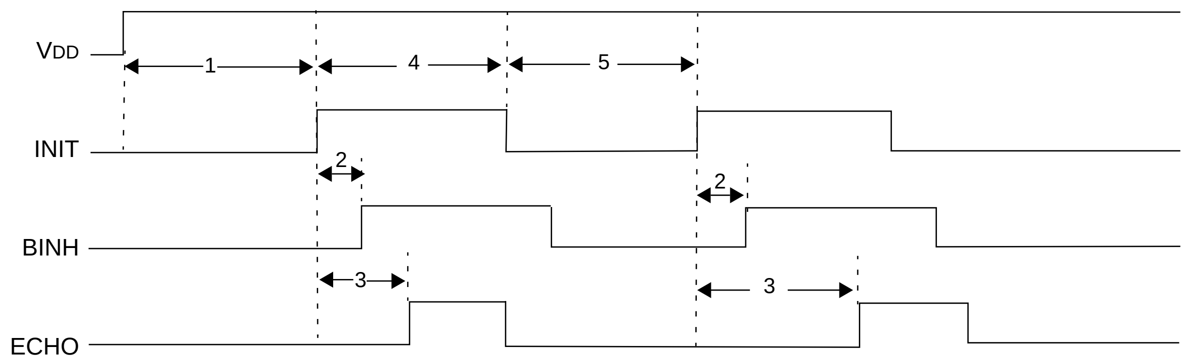


FIGURE 2: TIMING DIAGRAM OF RANGING MODULE CONTROL LINES



Parameter Number	Symbol	Characteristic	Min	Typ	Max	Units
1	Tpu	Ranging Module Stabilization Time	5.0	–	–	ms
2	TBINH	Blank Inhibit Time	0.9	2.38	–	ms
3	TECHO	Echo Time	–	–	–	–
4	TINIT_H	High Time for INIT	100	–	–	ms
5	TINIT_L	Low Time for INIT	100	–	–	ms

The PIC16C74 is configured to use one of its internal timers, Timer1, in capture mode to measure the time between signal transmission and echo detection. The resolution of the timer is determined by the microcontroller clock frequency. For this application, a 4 MHz external oscillator was used, giving a resolution of 1 ms per bit. The PIC16C74 initiates a ranging cycle by first clearing Timer1. Timer1 is then enabled and INIT is immediately asserted on the ranging module. When INIT is asserted, the ranging module transmits a series of 16 pulses on the transducer at 49.4 kHz. The transmitted pulses reflect off the object and are received back at the transducer.

The transducer is used for both transmitting and receiving sound waves. A blanking interval is needed to ensure that the transmitted signal has decayed on the transducer, in order not to receive false echoes. In normal operation, the ranging module has a blanking interval of 2.38 milliseconds, which corresponds to a minimum detection distance of approximately 17 inches. However, the BINH (blank inhibit) signal can be manipulated to reduce the blanking time on the transducer to allow for object ranging as close as 6 inches.

In this implementation, the PIC16C74 asserts the BINH signal approximately 0.9 milliseconds after signal transmission. This enables the transducer to receive reflections off objects at a distance of 6 inches. The ranging module asserts the ECHO signal when a valid reflection has been detected. The PIC16C74 uses the ECHO signal to trigger a capture of the Timer1 value. The capture register contains the 16-bit value representing the elapsed time between signal transmission and echo detection. The PIC16C74 then calculates object distance based on the Timer1 value, microcontroller clock speed, and the velocity of sound in the atmosphere. The basic equation for calculating distance is given below:

Distance (inches) = TECHO time / 147.9 microseconds

Note:	The minimum high and low time for INIT is 100 milliseconds, as seen in Figure 2.

DESIGN CONSIDERATIONS

There are several design considerations which must be taken into account and are listed below.

The absolute measuring distance supported by the ranging module is 6 inches to 35 feet with an accuracy of +/- 1%.

The distance output from the ranging module can be averaged over time to filter distance calculations.

In some applications, the gain of the receiver amplifier may be too low or too high and may need to be adjusted. For example, if the transducer is mounted in a cylinder, the gain may need to be lowered to reduce false echoes within the cylinder. In this case, R1 (refer to the Polariod Ultrasonic Ranging System manual) may be replaced with a 20 kΩ potentiometer to tweak the gain of the receiver amplifier to reduce false echoes.

In order for the Polaroid 6500 ranging module to operate properly, the power supply must be capable of handling high current transients (2.5 A) during the transmit pulse. The instantaneous drain on the power supply can be mitigated by installing a storage capacitor across the power lines at the ranging module. A value of 500 microfarads is recommended.

A 200 millisecond interval is recommended between ranging cycles (Figure 2) to allow the transducer to clear.

The ECHO line requires a pull-up resistor (4.7 kΩ was used in this application).

There must be a common ground between the PIC16C74 circuitry and the ranging module.

Some applications may not need the resources of the higher end PIC16CXX devices. It is still possible to do this application using a device that does not contain a CCP module (for ECHO timing). The capture function can be implemented in firmware. The effect of a firmware implementation is that the resolution of the ECHO time would be 3 Tcy cycles versus 1 Tcy cycle for the CCP module. Also, the firmware implementation would not allow other tasks to be performed while the capture function was occurring.

Refer to Appendix A for general ranging module specifications.

APPENDIX A: POLAROID MODULE SPECIFICATIONS

Note: This appendix contains general specifications from the Polaroid Ultrasonic Ranging System Manual. Please refer to the current Polaroid Ultrasonic Ranging System Manual for current information regarding ranging module design considerations.

DESIGN CONSIDERATIONS IN ULTRASONICS

Range: (with user custom designed processing electronics)

Farther

a) Use an acoustic horn to “focus” the sound (narrowing the beamwidth).
b) Use two transducers – 1 receiver and 1 transmitter – facing each other.
c) Lower the transmitting frequency (which will decrease the attenuation in air).

Closer

a) Use a shorter transmit signal (such as four cycles).
a) Use two transducers – one to transmit, one to receive (eliminates waiting for damping time).

Resolution

a) Above all, know the target and range well, and design a system with them in mind.
b) Use a higher transmit frequency.
c) Look at phase differences of a given cycle of the transmitted signal and received echo (as opposed to using and integration technique).
d) Increase the clock frequency of the timer.

Accuracy: (again, you must have a well defined target)

Temperature Compensate

a) Use a second small target, as a reference, at a known distance in the ranging path (such as a 1/4” rod several feet away), process both echoes, then normalize the second distance with respect to the first, since t1/d1 = t2/d2.
b) Incorporate a temperature sensing integrated circuit to drive a VCO to do the distance interval clocking.
c) To increase sensitivity of detection circuit change the value of C4 from 3300 pF to 1000 pF on the 6500 Series Ranging Module.

Beam Width:

Increase

a) Use an acoustic lens (to disperse the signal).
b) Decrease the transmitting frequency.
c) Use several transducers to span an area.

Decrease

a) Use an acoustic horn (to focus the sound).
b) Increase the transmitting frequency.

TABLE 1: RECOMMENDED OPERATING CONDITIONS

		Min.	Max.	Unit
Supply Voltage, V_{CC}		4.5	6.8	V
High-level input voltage, V_{IH}	BINH, INIT	2.1		V
Low-level input voltage, V_{IL}	BINH, INIT		0.6	V
ECHO and OSC output voltage			6.8	V
Delay time, power up to INIT high		5		ms
Recycle period		80		ms
Operating free-air temperature, T_A		0	40	°C

TABLE 2: ELECTRICAL CHARACTERISTICS OVER RECOMMENDED RANGES OF SUPPLY VOLTAGE AND OPERATING FREE-AIR TEMPERATURE (UNLESS OTHERWISE NOTED)

Parameter		Test Conditions	Min.	Typ.	Max.	Unit
Input current	BINH, INIT	V1 = 2.1V			1	mA
High-level output current, I_{OH}	ECHO, OSC	V_{OH} = 5.5V			100	µA
Low-level output voltage, V_{OL}	ECHO, OSC	I_{OL} = 1.6 mA			0.4	V
Transducer bias voltage		T_A = 25°C		200		V
Transducer output voltage (peak-to-peak)		T_A = 25°C		400		V
Number of cycles for XDCR output to reach 400V		C= 500 pF			7	
Internal blanking interval				2.38*		ms
Frequency during 16-pulse transmit period	OSC output			49.4*		kHz
	XMIT output			49.4*		
Frequency after 16 pulse transmit period	OSC output			93.3*		kHz
	XMIT output			0		
Supply current, I_{CC}	During transmit period				2000	mA
	After transmit period				100	

* These typical values apply for a 420 kHz ceramic resonator.

Please check the Microchip BBS for the latest version of the source code. For BBS access information, see Section 6, Microchip Bulletin Board Service information, page 6-3.

APPENDIX B: FIRMWARE LISTING

```
MPASM 01.02 Released      XDCR.ASM   11-14-1994  9:29:15                 PAGE  1
LOC  OBJECT CODE     LINE SOURCE TEXT
  VALUE

           0001 ;  XDCR.ASM
           0002 ;
           0003 ;  This routine continually executes ranging cycles in the
           0004 ;  following order:
           0005 ;
           0006 ;     1) Timers and Flags are cleared
           0007 ;     2) Ranging Cycle Executes
           0008 ;     3) Distance is Calculated (to 0.5 inch)
           0009 ;     4) HW is re-initialized for next cycle
           0010 ;
           0011 ;  The processor uses a 4MHz oscillator, so all timing
           0012 ;  calculations are referenced to that.  The calculated
           0013 ;  distance is a 16-bit result in the ACCbHI:ACCbLO registers.
           0014 ;
           0015
           0016         LIST P=16C74, F=INHX8M
           0017 ;
           0029
           0030 ;******************
           0031 ; Bank 0 Registers
           0032 ;******************
           0033 ;
           0034 ;  TMR1 is off, Prescaler is 1 for a capture timeout of 65 msec
0000 0190  0035   clrf    T1CON
           0036 ;  Set to capture on every rising edge
0001 3005  0037   movlw   0x05
0002 0097  0038   movwf   CCP1CON
           0039 ;  Clear the Ports
0003 0185  0040   clrf    PORT_A
0004 0186  0041   clrf    PORT_B
0005 0187  0042   clrf    PORT_C
0006 0188  0043   clrf    PORT_D
0007 0189  0044   clrf    PORT_E
           0045 ;
           0046 ;******************
           0047 ; Bank 1 Registers
           0048 ;******************
           0049 ;
0008 1683  0050   bsf     STATUS,RP0      ; Set RP0
           0051 ;  Port A is Digital, Port E is Digital
0009 3007  0052   movlw   0x07
000A 009F  0053   movwf   ADCON1
           0054 ;  Configure CCP1 (RC2) as an input, and all other ports
           0055 ;  as Outputs, (RE0 = INIT, RE1 = BINH)
000B 0185  0056   clrf    TRIS_A
000C 0186  0057   clrf    TRIS_B
000D 3004  0058   movlw   0x04
000E 0087  0059   movwf   TRIS_C
000F 0188  0060   clrf    TRIS_D
0010 0189  0061   clrf    TRIS_E
0011 1283  0062   bcf     STATUS,RP0      ; Clear RP0
0012       0063 Xdcr
           0064 ;
           0065 ;  Initialize Timers and Flags
           0066 ;
0012 1010  0067   bcf     T1CON,0         ; Disable TMR1
0013 018C  0068   clrf    PIR1            ; Clear Timer1 Overflow Flag & Timer1 Capture Flag
```

```
0014 018E  0069   clrf   TMR1L              ; Clear TMR1L
0015 018F  0070   clrf   TMR1H              ; Clear TMR1H
0016 0195  0071   clrf   CCPR1L             ; Clear CCPR1L
0017 0196  0072   clrf   CCPR1H             ; Clear CCPR1H
0018 1409  0073   bsf    PORT_E,0           ; Set INIT High on Ranging Module
0019 1410  0074   bsf    T1CON,0            ; Enable TMR1
001A 21F3  0075   call   DEL_9              ; Delay 0.9 msec for transducer to stabilize
001B 1489  0076   bsf    PORT_E,1           ; Enable Transducer to Receive (BINH)
001C       0077   chk_t1
001C 190C  0078   btfsc  PIR1,2             ; Check for Capture
001D 2822  0079   goto   chk_done           ; Jump if Capture
001E 1C0C  0080   btfss  PIR1,0             ; Check for TMR1 Overflow
001F 281C  0081   goto   chk_t1             ; Loop if nothing happened
0020 1010  0082   bcf    T1CON,0            ; Turn off TMR1
0021 2833  0083   goto   ovr_flo            ; Capture event did not occur
0022       0084   chk_done
           0085 ;
           0086 ; Calculate distance to 0.5 inch resolution
           0087 ;
0022 1010  0088   bcf    T1CON,0            ; Turn off TMR1
0023 0815  0089   movf   CCPR1L,W           ; Move LSB into W
0024 00A2  0090   movwf  ACCbLO             ; Move LSB into ACCbLO
0025 0816  0091   movf   CCPR1H,W           ; Move MSB into W
0026 00A3  0092   movwf  ACCbHI             ; Move MSB into ACCbHI
0027 304A  0093   movlw  0x4A               ; Move 75usec/0.50in into W
0028 00A0  0094   movwf  ACCaLO             ; Move LSB into ACCaLO
0029 01A1  0095   clrf   ACCaHI             ; Clear MSB (ACCaHI)
002A 208F  0096   call   D_divF             ; Call 16-bit/8-bit routine
           0097                             ; which is described in
           0098                             ; Application Note 544
002B 3025  0099   movlw  0x25               ; Check remainder to see if
002C 0224  0100   subwf  ACCcLO,W           ; we should round up...
002D 1803  0101   btfsc  STATUS,CARRY       ; If Remainder < (0.5 * Divisor), skip
002E 0AA2  0102   incf   ACCbLO,F           ; Round up
002F 1903  0103   btfsc  STATUS,Z           ; Check low byte for wrap around
0030 0AA3  0104   incf   ACCbHI,F           ; If LSB wrapped, increment high byte
0031 1D03  0105   btfss  STATUS,Z           ; Check high byte for wrap around
0032 2835  0106   goto   done               ; High byte didn't wrap
0033       0107   ovr_flo
0033 01A2  0108   clrf   ACCbLO
0034 01A3  0109   clrf   ACCbHI
0035       0110   done
0035 21FD  0111   call   DEL_100            ; Wait 100 msec before clearing HW.
0036 1009  0112   bcf    PORT_E,0           ; Disable INIT
0037 1089  0113   bcf    PORT_E,1           ; Disable BINH
0038 21FD  0114   call   DEL_100            ; Wait 100 msec before enabling HW.
0039 2812  0115   goto   Xdcr
           0116
           0120
           0149
           0150   end
           0151
MEMORY USAGE MAP ('X' = Used,  '-' = Unused)
0000 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXX------
0040 : ---------------- ---------------- ---------------- ----------------
All other memory blocks unused.
Errors   :    0
Warnings :    0
Messages :    0
```

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