Department of Electrical and Computer Systems Engineering

Monash University

TRC3500 Sensors and Artificial Perception

The Ultrasonic Distance Meter

Introduction

The ultrasonic distance meter that you will build is similar in operation to one you might buy at a hardware store. It will enable you to determine a distance using the time of flight (TOF) of reflected sound waves. The distance will be displayed on a digital display.

Objectives

After completing this practical, you will:

- Have created a "Distance meter" that will show an ultrasonically measured distance on a display.

- Know what 7 segment displays are and how to use them.
- Know what display multiplexing is and how to apply it.
- Have a better understanding of how an ultrasonic transducer works
- Know how to design and create some electronics to interface to an ultrasonic transducer
- Have improved your skills in prototyping circuits

Customer's Requirements

You are required to construct a circuit that we will call a distance meter, which will be able to measure how far away objects are located.

The customer has been consulted and has given us some initial specifications, which are as follows:

- A microprocessor board will drive the whole circuit.
- The PSOC (Processor board) will be able to power the whole circuit, as it will derive its power from the USB cable. There will be no need to connect any other power supplies to the circuit.
- You will use an ultrasonic transmitter and receiver
- The unit will be able to work up to 30cm's.
- The unit should be as accurate as possible.
- You will receive a four digit, 7 segment LED display to use in your design. This will enable you to display the distance in milli-meters or centi-meters such as 24.4cm. There will also be a LED to indicate cm's or inches.
- As the unit may be sold into the United States, there needs to be some form of mechanism to switch between the imperial system (Inches) and the metric system.
- When the unit toggles from metric to imperial or vice versa, the unit will need to remember this by storing the information in EEPROM located with-in the PSOC.
- Each unit will need to be able to store a unique identification number which will be your group number. This will also need to be stored in EEPROM.
- The display updating will need to be accomplished using software
- Every time a switch is pushed, a 200mS beep should be heard.

Other requirements

While the PSOC microcontroller may have many digital blocks to aid in your design, most microcontrollers do not have these features. It is therefore important to be able to design a system using a standard microcontroller.		
Description	Use Hardware block	Software
Switch de-bounce.	Yes	Yes
7 segment display update.	Yes	Yes
Ultrasonic 40kHz Frequency	Yes	Yes
Beeper	No	Yes
Other	unspecified	unspecified

Operation talk through:

Under normal circumstances, the unit is not operational except for a flashing decimal point located on one of the multiplexed displays (Any one of them). This will flash at one hertz. When a measurement is to be taken, the operator points the unit at the object they are wishing to take a measurement from and a switch is then pressed momentarily. When activated (button pushed) the circuitry operates and sends out sound waves to the distant object and waits for an echo. The microcontroller calculates the time from transmission to the time of reception and converts this to cm's or inches depending on the mode of operation. The result is then displayed on the seven (7) segment displays for two (2) seconds and then the circuit goes back in to sleep mode.

Note: When the unit is being operated, it may happen in one of the two following modes:

- Type 1: If the switch is pushed down and held, it will do a measurement every 2 seconds and display the results. The last reading will stay on the display until the next reading is acquired and displayed. When the switch is released, the unit will keep displaying the last measurement for two (2) seconds and then go back into sleep mode.

- Type 2: If the switch is pushed down and released (e.g. 1 second), the unit will do a measurement and display this for two (2) seconds and then go back into sleep mode.

Sleep mode is defined as:

a) The display is blank
b) One of the decimal points on the display is blinking at a rate of one (1) hertz. (Any one of the four decimal points)

Calibration mode to get the best accuracy

In a perfect world, the distance measured would be accurate at both short and long distances. However, this is unlikely to be the case. If you find that your unit provides a linear and accurate reading at close distances but then becomes unstable and nonlinear at longer distances, you may need to implement the following calibration procedure.

Once the circuit has been created and the transducers are fixed in place, you will need to be able to put the unit in a factory calibrate mode where objects are placed at known distances from the unit and measurements are taken. This should only have to be completed once as the customer will only want to use the product and not calibrate it. These known distance measurements can then be stored in long-term memory inside the Microcontroller using EEPROM. In the table below, we can see six separate range tests numbered one to six. You may need to do more than this in the final version and possibly complete a test every 5mm or so. The "actual distance using ruler" is the distance you have placed the object from the sensor, the "reading from unit" is what your unit actually read and the "result to be displayed" is the figure you would use on the display. These figures could be read directly from EEPROM during the units use or at power up, the micro controller could read these figures out of EEPROM and save them in to some form of two or three-dimensional array for easy access.

Calibrate Distances			
Range test Number	Actual Distance using ruler	Reading from unit	Result to be displayed
1	5 cm	5	5
2	10 cm	10	10
3	15 cm	14.5	15
4	20 cm	20.5	20
5	30 cm	30	30
6	40 cm	40	40

Obtaining repeatable results

To obtain the best results from your unit, you may need to take multiple readings when the operate button is pushed. This will produce a more accurate result.

As an example:

1. The unit is pointed at an object
2. The button is pushed
3. Six (6) separate transmissions and receptions are done and the results are stored with-in about 1.2 seconds
4. Any readings that are not within a reasonable range are discarded. The remaining readings are averaged and the result is displayed.

Calculated Distance readings		
Reading 1	40 cm	Discard
Reading 2	11.8 cm	Keep
Reading 3	11 cm	Keep
Reading 4	12 cm	Keep
Reading 5	11.5cm	Keep
Reading 6	11 cm	Keep
Total	58	
Average	11.46	

The display should show (11.6).

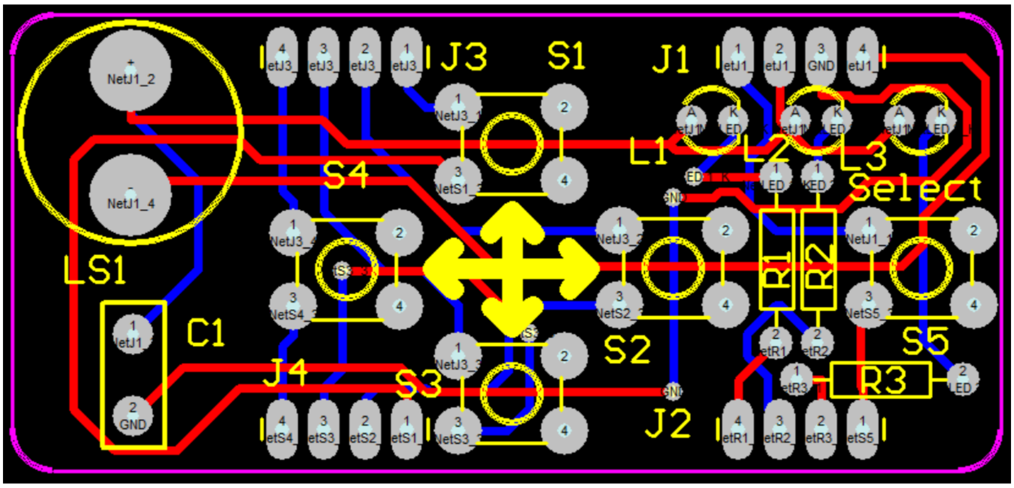
The Method

Step 1: Make sure you understand all of the requirements.

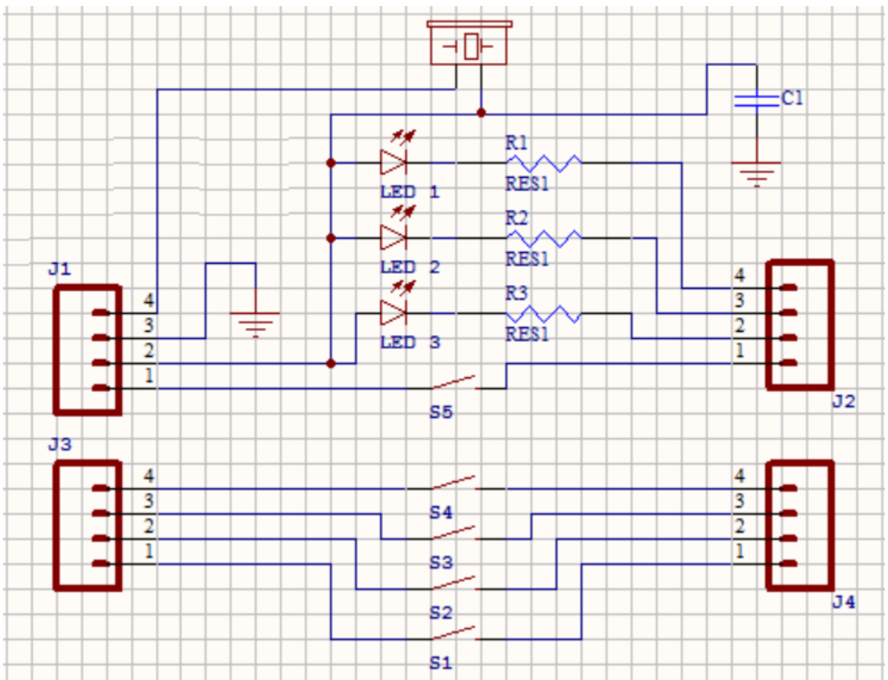
See above, and marking guide.

Step 2: Keyboard

You may be provided with one of these pre-assembled modules, which can plug directly into the breadboard. It has five switches, 3 LED’s and a buzzer for you to use in your project. Alternatively, you may just receive separate parts.



Above: Keyboard PCB



Above: The circuit for the keyboard PCB

Step 3: Display

Shown below is the suggested wiring for the display. The displays are common anode and their associated transistor can turn on or off each one of the four displays as required. Note that the PSOC port pins P2.0 to P2.7 are used for turning on the segments and this is done by taking the port pin low. The PSOC's pins can sink more current than they can supply and so we can make the display brighter. There are four port pins required to turn on the transistors and you may choose which ones are best for your design. Once again, you need to make the port pin low to turn on the transistor.

There are two types of common anode displays and each has a different pinout. The small display measures 16mm x 40mm and its PDF data sheet is titled **"7 Segment Display (Small)".** The large display's PDF data sheet is titled **"7 Segment Display (Large).**

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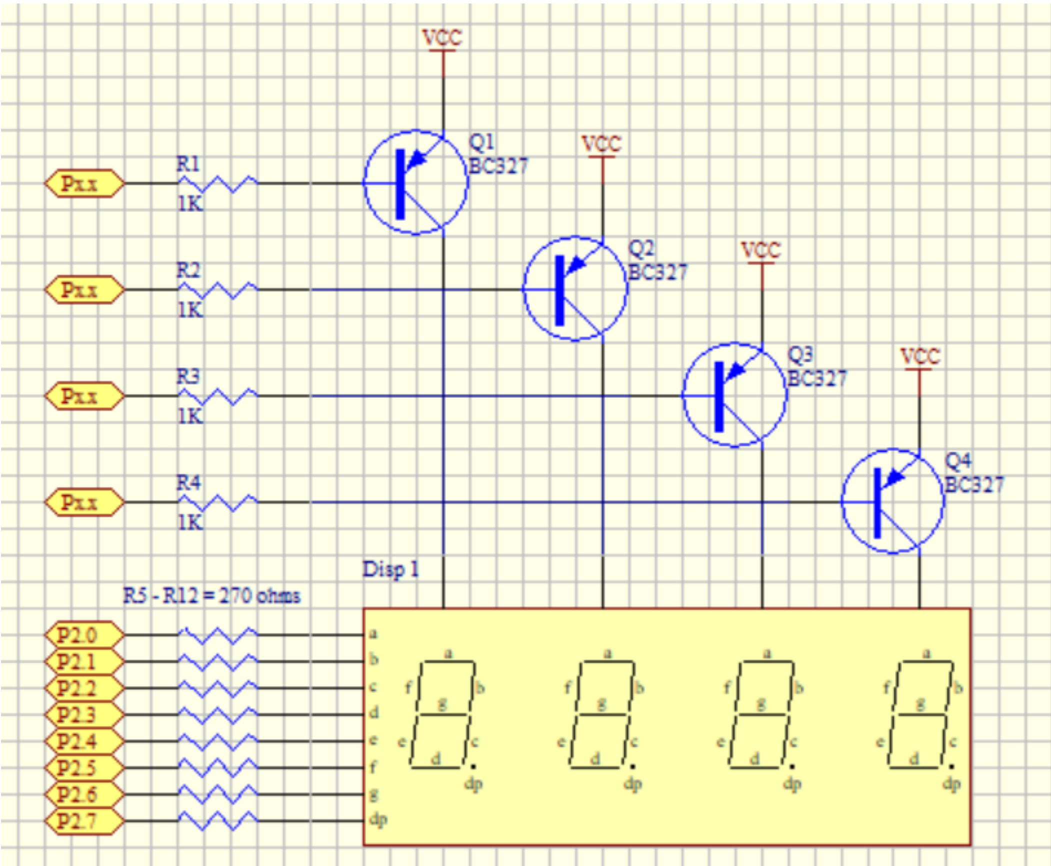


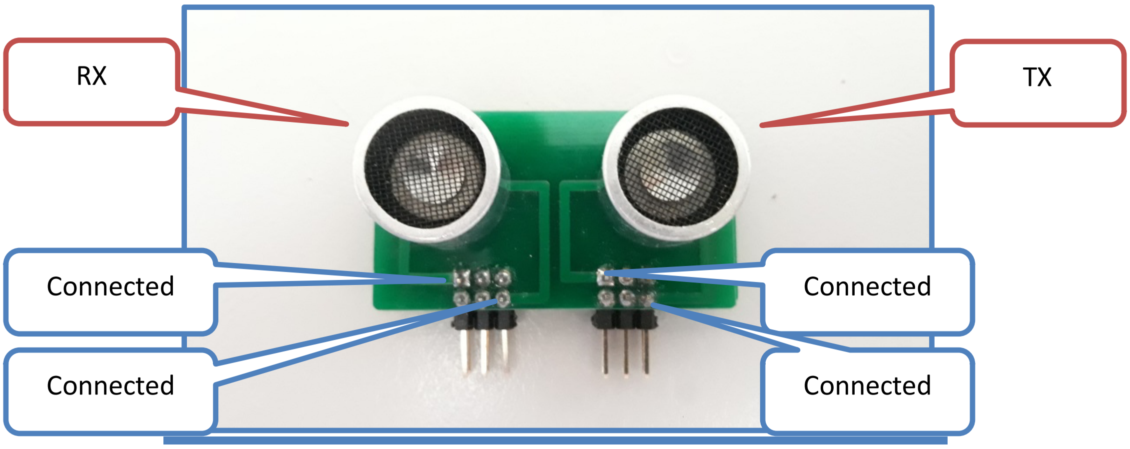
Above: Strongly suggested display circuit

Please see the document titled "Electrical notes" for a more detailed description on how to multiplex the displays using software.

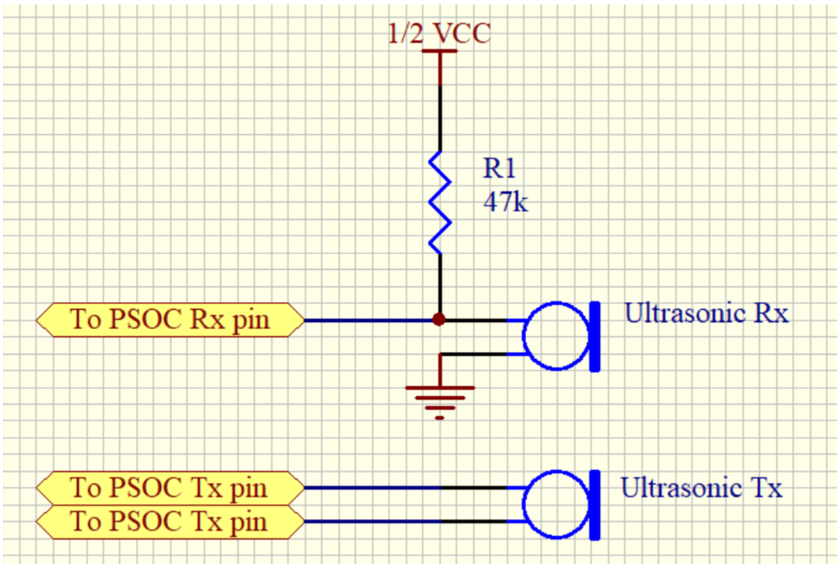
Step 4: Ultrasonic transducer sub-board

(This may be pre-assembled already). For your unit to work reliably, you will need to secure your ultrasonic transducers to a sub-board. This can be pre-made and then plugged into the breadboard as shown below. If you are required to solder the modules into some form of board, care should be taken not to over-heat the leads of the transducers, as you will damage them. You may be provided with either a small PCB or some Vero board to complete this section.

Important: Below the transducers there are two groups of six pins which are mainly provided for physical support when plugged into the bread board. However there are only two on each side that are connected to the ultrasonic modules. These can be seen on the front of the PCB as they have tracks going to them.



Above: Complete ultrasonic PCB ready for use
Note: Only selected pins are connected to the transducer

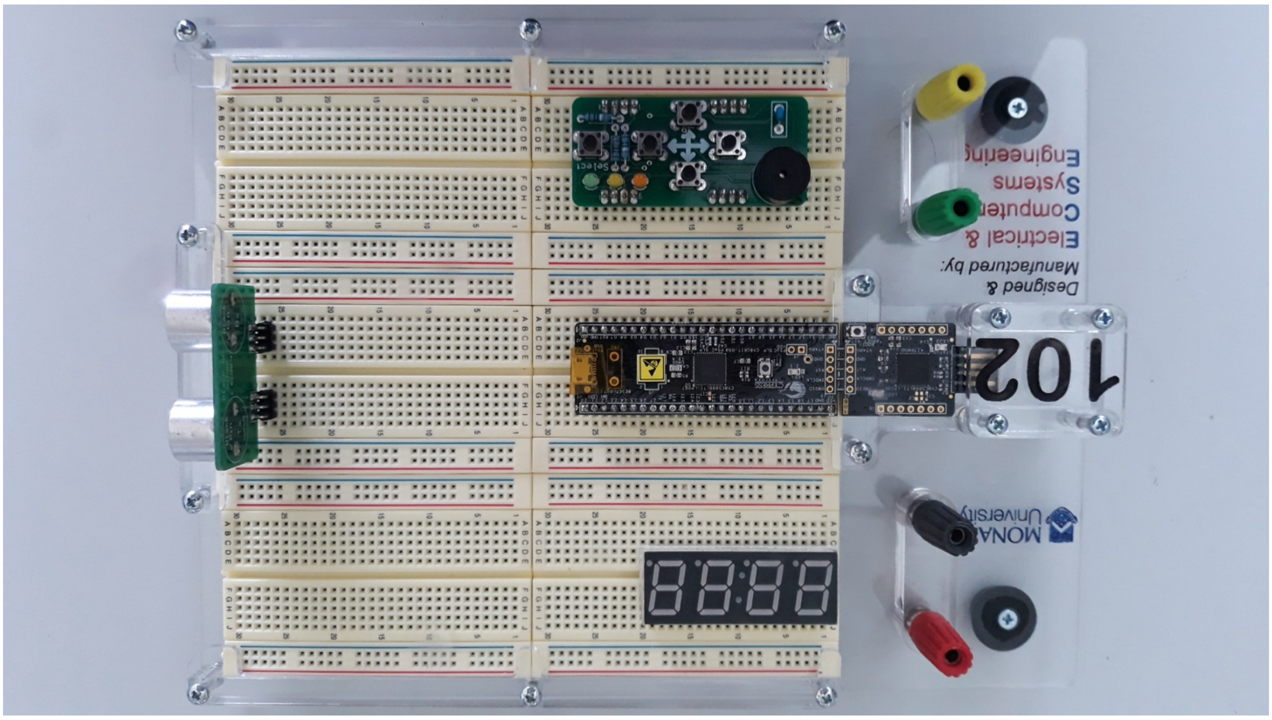


Above: Possible interface circuit for Ultrasonic modules. Note that the resistor is tied to ½ VCC, which will be about 2.5V. This will be provided by the PSOC

Step 5: Design

Do an initial design on paper of your circuit and layout showing the following:

1. The complete circuit.
2. Show all pin numbers of IC's
3. Show all components including capacitors, resistors, LED's etc
4. Do a layout of your breadboard before starting construction. Shown below is a typical layout. Note that the keyboard is close to the user and that the ultrasonic module is facing right and has a clear path.
5. ***You may have large or small display and their pinouts are different. Make sure you use the correct data sheet.***



Above: Suggested layout of your components

Step 6: Construction

Place all of the components on the breadboard and wire it up. Make your circuit as neat as possible so if you need to debug it goes as easily as possible.

Step 7: Creating the 40 KHz.

You need to create a 40 KHz square wave on two (2) of the PSOC's port pins. This can be achieved in several ways:

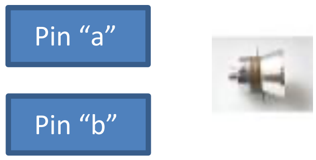
1. Software loop that turns the port pins on and off.
2. Interrupt driven loop (Better)
3. Internal hardware inside the PSOC

Type 1 Software

Use software and a delay routine to toggle pins. Note that you still need to see if a returned signal has been detected. During the Wait(12.5uS) delay routine, you could be checking for this signal.

Note: When one of the Tx pins is high, the other must be low!

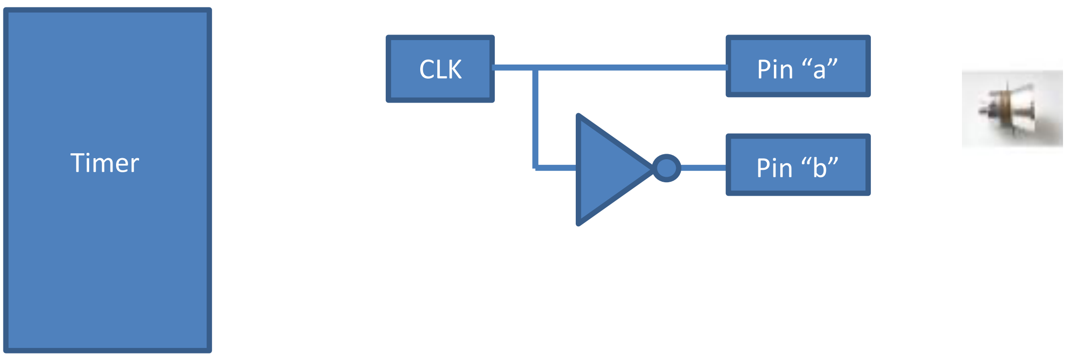
```
For (i=0;i<10;i++)
{
        Pin"a" = 1
        Pin"b" = 0
        Wait(12.5uS)
        Pin"a" = 0
        Pin"b" = 1
        Wait(12.5uS)
}
```



Keep checking for the returned signal for a while

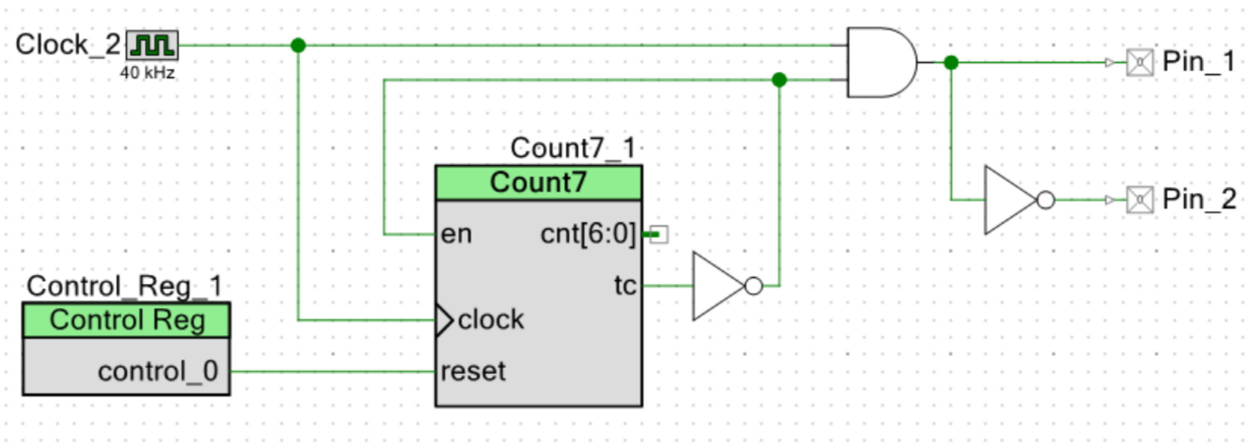
Type 2 Software/Hardware

1. Create PSOC circuit with clk and inverter. Set clock to 40kHz
2. Set countdown timer to 250uS
3. Start countdown timer
4. Start CLK
5. Keep checking for returned signal
6. When timer reaches “0” which will be 250uS after you start it, an interrupt is asserted.
7. Processor interrupt routine stops CLK
8. Keep checking for returned signal for a while



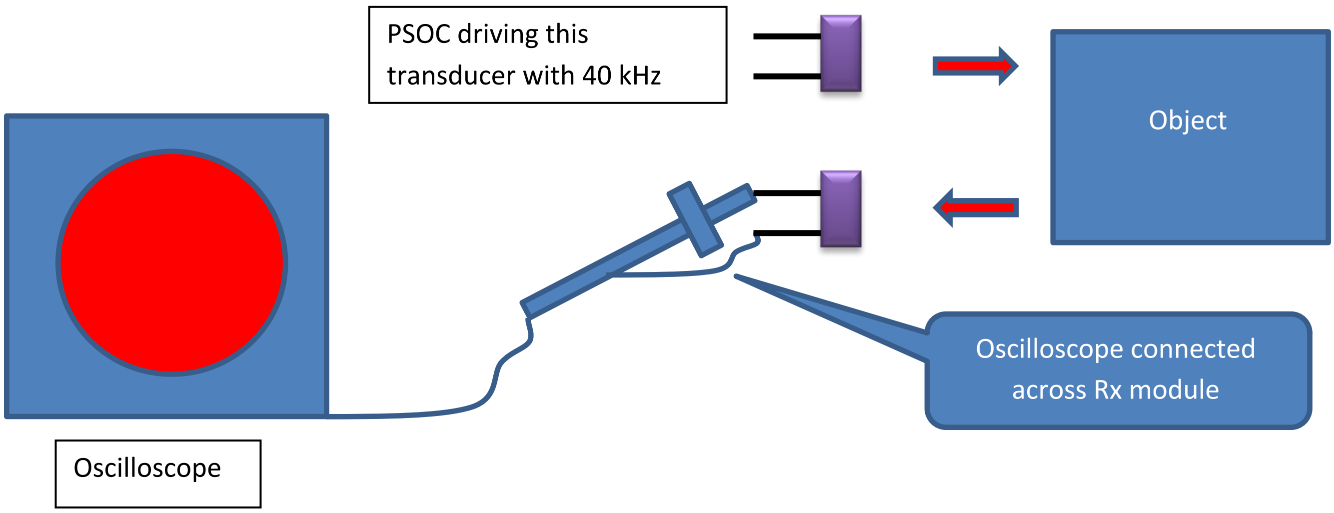
Type 3 Hardware

1. Ten (About 10) pulses created in hardware and then automatically turns off until a software restart occurs.
2. Set counter to 10
3. Start counter and oscillator
    a. Terminal count (tc) pin output is normally low which is inverted and sends a high to en pin which enables the counter and also the “and” gate.
    b. After 10 cycles have been sent to the “And” gate and clock input to counter, the counter tc pin will go high which sends a low to the en pin disabling it as well as disabling the and gate function.
    c. 40kHz is now stopped and will not run again until software reinitialises this block.



Step 8: Initial detection of echoed signals.

As a first step, create the 40 kHz for the Tx module and make sure its transmitting. Connect an oscilloscope directly across the RX transducer without any circuitry connected and set the Volts per division to 20mV. Select a number of objects and use them to reflect the ultrasonic waves. Observe the range and size of the signals received and write them down for your guidance.



Step 9: Using the returned signal

Once you have determined that you can receive a returned signal you will notice that as objects move further away, the returned signal becomes smaller.

The document "Module 2 PSOC Analogue" has some valuable information on how to amplify the returned signal. The rest of the electronics and software we will leave up to the student to complete.

Tips & Tricks

Here are some tips you may wish to implement.

What we know.

- The required frequency to drive the Tx module is 40kHz
- 1/40,000 = 25uS per cycle

- We should send a burst of about 10 cycles in one measurement
- Thus 10 x 25uS =250uS transmission time.
- The object under test should not be able to move around and so use something like a block of wood. (Do not hold it)

A typical measurement happens in this way.

1. User locates an object at a distance from unit.
2. User pushes a button
3. A timer is started and a burst of 10 cycles each 25uS long is sent to the Tx module where they are converted to sound wave pulses.
4. Sound waves travel out and bounce off target and return.
5. Microcontroller detects returned sound waves and stops timer.
6. Travel time of sound = (Start time – Stop time = result)
7. Result is stored

To guarantee accuracy, steps 3 to 7 may happen 6 times and then the average is taken.