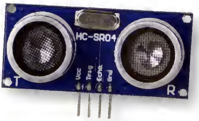
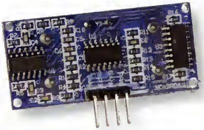




Using Cheap Asian Electronic Modules Part 2

The HC-SR04 Ultrasonic Distance Sensor Module

In the second article on cheap pre-built electronics modules, we're focusing on the HC-SR04 ultrasonic distance sensor module. We describe how the module works and show how it can be used as a hallway monitor or door sentry.

By JIM ROWE

IF THE HC-SR04 module shown in the picture looks familiar, that's because it has already been used in Geoff Graham's Ultrasonic Garage Parking Assistant, published in the March 2016 issue. But this module doesn't have to be used with a microprocessor module like a Micromite or an Arduino, it can also be used with much simpler circuitry, as we'll see later.

Before we get to how it works, we should note these ultrasonic sensor modules have been around for about six years, beginning life as an add-on "shield" for the Arduino. Since then, they have gone through a number of iterations, all bearing the same HC-SR04 label but with various minor circuit and component changes. We suspect this has been due to various manufacturers working out ways of reducing costs, rather than seeking to achieve better performance.

The bottom line is that although some of these slightly different HC-SR04 modules are still being sold, they all seem to function and perform much the same. So don't worry if the module you buy looks a little different from that shown in the photos. The odds are that if your module carries the label HC-SR04, it will work just like any other HC-SR04.

Current HC-SR04 modules are based on a PCB measuring 45 x 20mm. On the top side of the PCB are a pair of small (16mm diameter) ultrasonic transducers with a 4MHz crystal between them.

All the components on the other

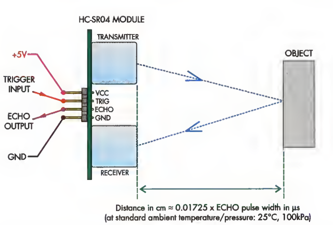


Fig.1: one ultrasonic burst is sent out from the transmitter transducer. The receiver transducer will detect this burst if it is reflected off an object in front of the module. Once detected by the receiver, an output pulse is produced with a width in microseconds of (distance in cm) ÷ 0.01725.

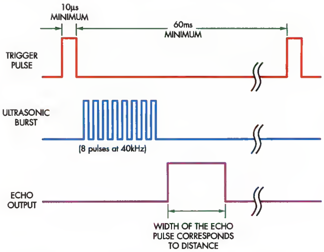


Fig.2: there must be a delay of 60ms between trigger pulses to prevent late echoes from affecting successive readings.

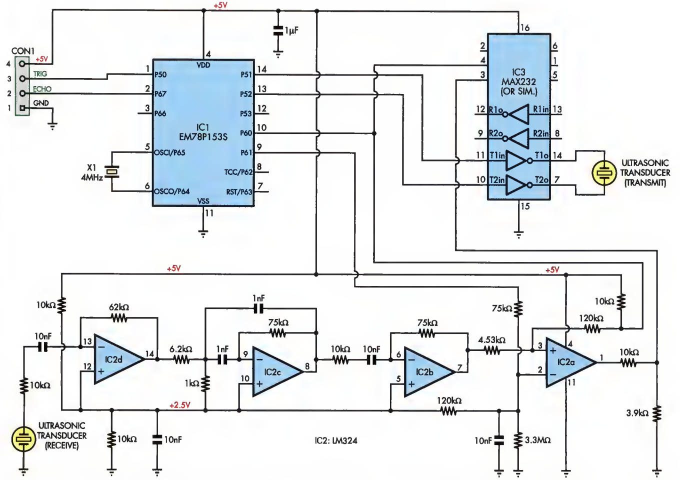


Fig.3: complete circuit diagram for the HC-SR04 ultrasonic sensor module. When IC1 detects a TRIG pulse at pin 1, a 40kHz burst signal of eight pulses is generated at pins 13 and 14 of IC1. This is taken to pins 10 and 11 of IC3 respectively and output at pins 7 and 14 connecting to the transmit transducer.

side of the PCB are surface-mount types, apart from the 4-pin right-angle header at bottom centre. Fig.1 shows how it's used. It sends out a burst of ultrasonic energy from the transmitter transducer (the one marked T, on the left) and then listens via the other receiver transducer (marked R, on the right) for any echo that may be reflected back from an object in front of the module (see Fig.1).

If it detects this ultrasonic echo, it produces an output pulse with a width approximately proportional to the distance between the module's sensors and the object producing the echo.

The ultrasonic frequency used is very close to 40kHz, roughly double the highest frequency that can be heard by human ears. The burst of transmitted energy consists of eight pulses at 40kHz, so the transmitted burst lasts for only 200µs, as shown in Fig.2.

Since the speed of sound in air at 25°C and 100kPa (ie, 1 bar) is close to 345m/s (= 0.0345cm/µs) and the distance travelled by the ultrasonic burst energy corresponds to double the distance between the transducers and the reflecting object, we can calculate the distance from the delay as follows:

$$\textbf{distance in cm} = \frac{\textbf{0.0345 x echo pulse width (µs)}}{\textbf{2}}$$

$$= \textbf{0.01725 x echo pulse width (µs)}$$

As shown in Fig.2, each measurement cycle begins when a positive trigger pulse of at least 10µs duration is applied to the HC-SR04 module's trigger input pin. When the echo has been detected, it then produces a pulse at the echo output pin. Note that there should be at least 60ms between trigger pulses, to prevent late echoes from one cycle from causing false readings on the next. So in practice, it's a good idea to limit the trigger pulse frequency to no more than 16Hz.

Circuit details

The full circuit for the HC-SR04 module is shown in Fig.3. It is based on an EM78P153S microcontroller (IC1), a low power 8-bit CMOS device made by Elan Microelectronics in Hsinchu, Taiwan. This device has a 1024 x 13 bits one-time programmable (OTP) ROM plus 32 bytes of on-chip SRAM, and comes in a 14-pin SOIC package. It runs here with a 4MHz crystal between pins 5 and 6.

When a TRIG pulse arrives at pin 1 of IC1 (from pin 3 of CON1), the controller generates a 40kHz burst signal of eight pulses at pins 13 and 14, with one pin 180° out of phase with the other. These go to pins 10 and 11 of IC3, a bus driver IC very similar to the MAX232. The outputs from IC3 (pins 7 and 14) connect across the transmitter transducer, effectively driving it in bridge mode to emit the bursts of ultrasonic energy.

Echoes picked up by the receive transducer pass through the four sections of IC2, an LM324 quad op amp. These provide amplification, bandpass filtering and phase detection, with the result that a received echo

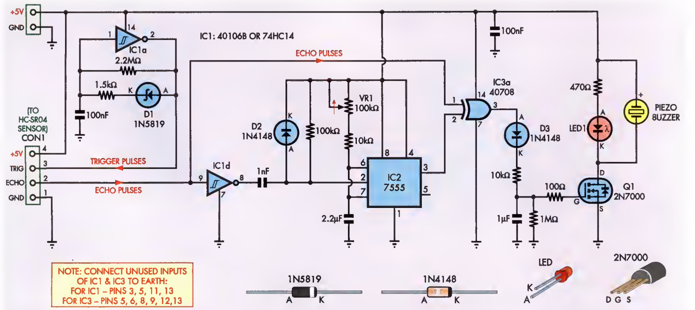


Fig.4: complete circuit for an ultrasonic intruder alarm using an HC-SR04 module. IC1a generates 60µs-wide trigger pulses at 12Hz, which are fed to pin 3 of CON1. The echo pulses trigger monostable multivibrator IC2 and IC3a then compares the width of the resulting pulse to the echo pulse. If these differ, LED1 lights and the piezo buzzer sounds.

pulse is fed back to pin 10 of IC1. The micro then compares the timing of the leading edge of this received echo pulse with the leading edge of the transmitted burst fed to IC3 and the transmit transducer, and produces an echo output pulse at pin 2 with its width equal to the time difference. This echo output pulse appears at pin 2 of CON1.

How it's used

If you want to use the HC-SR04 module to actually measure the distance to an object or wall in front of it, the best way to do it is to hook it up to a microprocessor module like an Arduino, a Micromite or a Raspberry Pi. The micro's program generates the trigger pulse to the HC-SR04, then measures the length of the echo pulse and calculates the corresponding distance.

There's no need to worry about writing a program to do these tasks for you, because many people have already produced programs to do this. A quick search on the Arduino website (www.arduino.cc) or by using Google will find a sample program for the micro you're using in short order.

If you want to use the HC-SR04 with a Micromite, Geoff Graham has already built a DISTANCE function into his MMBasic programming language for the Micromite family to make it really easy.

All you have to do to get the Micromite to trigger the HC-SR04 and then calculate the object distance from the echo pulse is use this one-line function call:

d = DISTANCE(trig, echo)

Where "d" is the distance in centimetres, "trig" is the Micromite's I/O pin connected to the HC-SR04's trigger input pin and "echo" is the I/O pin connected to the HC-SR04's echo output pin.

The only extra step is to connect the HC-SR04's +5V and GND pins to the corresponding pins of your Micromite.

If you want to display the result "d" on an alphanumeric LCD, you can do this using commands like:

LCD INIT ...
LCD 1, 2, "Distance = "
LCD 2, 6, STR$(d)
and so on.

You can get a good idea of what's involved in using the HC-SR04 with a Micromite from Geoff Graham's article describing the Ultrasonic Garage Parking Assistant, in the March 2016 issue of SILICON CHIP.

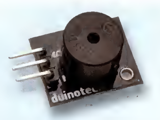
But say you want to use this module without a microcontroller at all. That's fairly straightforward, as we'll now demonstrate.

A simple intruder alarm

For example, to use it as an ultrasonic intruder alarm, have a look at the circuit shown in Fig.4. It uses three low cost CMOS ICs, a 2N7000 Mosfet, three diodes, one LED, a piezo buzzer and some passive components. This circuit and the HC-SR04 operate from a common 5V DC power supply, which can be from a USB plugpack or USB power bank.

IC1 is a hex Schmitt trigger inverter package and we're using just two sections of it, IC1a & IC1b. IC1a at upper left is connected as a relaxation oscillator, to generate a stream of 60µs-wide pulses at a frequency of about 12Hz, ie, with a pulse spacing of about 83ms. These form the trigger pulses which are fed to the HC-SR04 via pin 3 of CON1.

The rest of the circuit monitors the width of the echo pulses sent back from the HC-SR04 via pin 2 of CON1. If this varies significantly (indicating that something has moved between the sensor and the nearest object, like



This tiny active piezo transducer module from Jaycar can be used in the intruder alarm instead of the piezo buzzer.

the opposite wall of your entry hall), it sounds the alarm by switching on LED1 and the piezo buzzer connected across it.

This section is a little more complex. First, the incoming echo pulse passes through inverter IC1d, so that its leading edge is negative-going. The 1nF capacitor and 100kΩ resistor then form a differentiator circuit, which develops a narrow negative-going pulse from the negative-going leading edge of the inverted pulse.

This is then used to trigger IC2, a 7555 CMOS timer chip connected as a one-shot multivibrator. When IC2 is triggered, its output pin 3 switches high for a short time, determined by the 2.2µF capacitor connected from pins 6 and 7 to ground and the resistance connected between the same two pins and the +5V line.

As shown, this resistance is the series combination of a 10kΩ resistor and VR1, a 100kΩ pot. So by varying VR1, we can vary the width of the pulse generated each time the one-shot is triggered.

The output of IC2 is connected to pin 2 of IC3a, one section of a 4070B quad XOR (exclusive-OR) gate. The echo pulses from the HC-SR04 are fed to pin 1 of IC3, the second input of the same XOR gate. Since the output of an XOR gate is high only when one of its inputs is high and the other low, it forms a pulse width comparator.

Consider the situation where the HC-SR04 sensor is facing a wall say 1.5m or 150cm away. The echo pulses fed back from the sensor will be very close to 8.7ms wide and these are fed to input pin 1 of IC3a.

If we adjust VR1 so that IC2 also produces 8.7ms wide pulses, since they start at virtually the same instant as the start of the echo pulse, both inputs of XOR gate IC3a will rise and fall at the same time. As a result, the output of IC3a (pin 3) will remain low at all times.

But if someone moves in front of the HC-SR04, this will cause the echo pulses to shorten, because the ultrasonic energy reflected back by the person or object will be travelling over a smaller distance. So the echo pulse width will drop briefly to say 5-6ms, and as a result the inputs of IC3a will no longer be synchronised.

Although the pulses fed to pin 2 will still be high for 8.7ms, the echo pulses being fed to pin 1 will drop low after 5-6ms, so the output of IC3a will switch high for the remaining 2.7-3.7ms. These positive-going pulses will very quickly charge up the 1µF capacitor in the gate circuit of Mosfet Q1, via diode D3 and the 10kΩ series resistor, and this will turn on Q1, causing LED1 to light and the piezo buzzer to sound the alarm.

Then when the intruding person or object moves away again and the echo pulses return to their original width of 8.7ms, the pulses fed to the two inputs of IC3a will be again be synchronised. There will be no more output pulses from IC3a and the 1µF capacitor will be discharged by the 1MΩ resistor connected across it. So within a couple of seconds, the buzzer and LED will switch off.

The circuit is quite easy to set up, too. All you need to do is wire it up and connect it to the HC-SR04 module using a suitable length of 4-conductor cable. Then mount the sensor module on one side of the hall or doorway to want to monitor, facing either a wall or a large fixed object such as a dresser, a chest of drawers or a filing cabinet.

Next, set pot VR1 to its fully anticlockwise (ie, minimum resistance) position and turn on the 5V power supply. You'll find that LED1 will immediately light, and if you have a piezo buzzer connected as well, it will sound. That's because the pulses being generated by the one-shot IC2 will be shorter than the echo pulses coming from the HC-SR04.

Now slowly turn pot VR1 clockwise until LED1 turns off and the piezo buzzer goes silent. Your intruder alarm will then be set up and ready to detect the presence of a "foreign body" in the space between the sensor and its reflecting wall. So we've done all this without a microprocessor – apart from the EM78P153S micro inside the HC-SR04 sensor module itself, of course. **SC**

Parts List

1 HC-SR04 ultrasonic sensor (Jaycar XC4442)
1 active piezo transducer module (Jaycar XC4424) ***OR***
1 piezo buzzer
1 100kΩ trimpot (VR1)

Semiconductors
1 1N5819 diode (D1)
2 1N4148 diodes (D2)
1 LED, any colour (LED1)
1 2N7000 mosfet (Q1)
1 40106B or 74HC14 CMOS IC (IC1)
1 LM7555 CMOS timer IC (IC2)
1 4070B quad XOR gate IC (IC3)

Capacitors (16V)
1 2.2µF
1 1µF
2 100nF
1 1nF

Resistors (0.25W, 5%)

1 2.2MΩ	1 1MΩ	1 100kΩ
2 10kΩ	1 1.5kΩ	1 470Ω
1 100Ω		