Build an Ultrasonic Ranger

This multi-purpose computer add-on device can be used to measure distances, dimensions, height of liquids and much more

The Ultrasonic Ranger described here is a complete distance-measuring device that connects to virtually any computer via an RS-232 serial port. With only a few lines of program code, it lets you measure room dimensions, liquid levels and particles in a tank; detect intruders in a home and visitors in front of a display; and measure the height of people standing under it, to name just a few of its many possible applications.

When a visitor stands under the Ultrasonic Ranger, it measures the distance from the ceiling to the top of his head. It then subtracts this distance from the distance between ceiling and floor and displays the result on the screen of the computer being used with it. The prototype of the Ultrasonic Ranger is being used at a science exhibit in Canada, running on an Apple Macintosh with Hypercard, though it can just as easily run on any other computer equipped with a standard RS-232 serial port and a BASIC language interpreter.

The Ultrasonic Ranger requires an RS-232 port with selectable baud rates between 300 and 4,800 bps, eight data bits, even parity bit, one start bit and one stop bit. As many as 127 Rangers, each individually addressable, can be connected to the same computer.

The Ranger emits 16 pulses at a time, at a frequency of 49.4 kHz. Its automatic digitally-controlled gain and variable-bandwidth amplifier minimizes false triggering that can be caused by noise and side-lobe detection. Sensitivity to objects is highly directional.

The Polaroid ultrasonic module around which the Ultrasonic Ranger is built has a range of 16 inches to 35 feet. Its resolution is limited to 0.15 inch by the wavelength of the ultrasonic pulses. Typically better than 1% in normal use, accuracy is limited only by the module's resolution, provided air temperature hasn't changed since last calibration.

About the Circuit

The Ultrasonic Ranger doesn't directly measure the distance to an object.

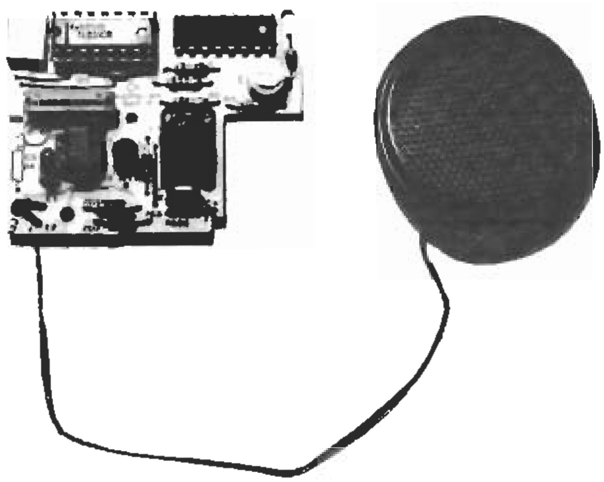
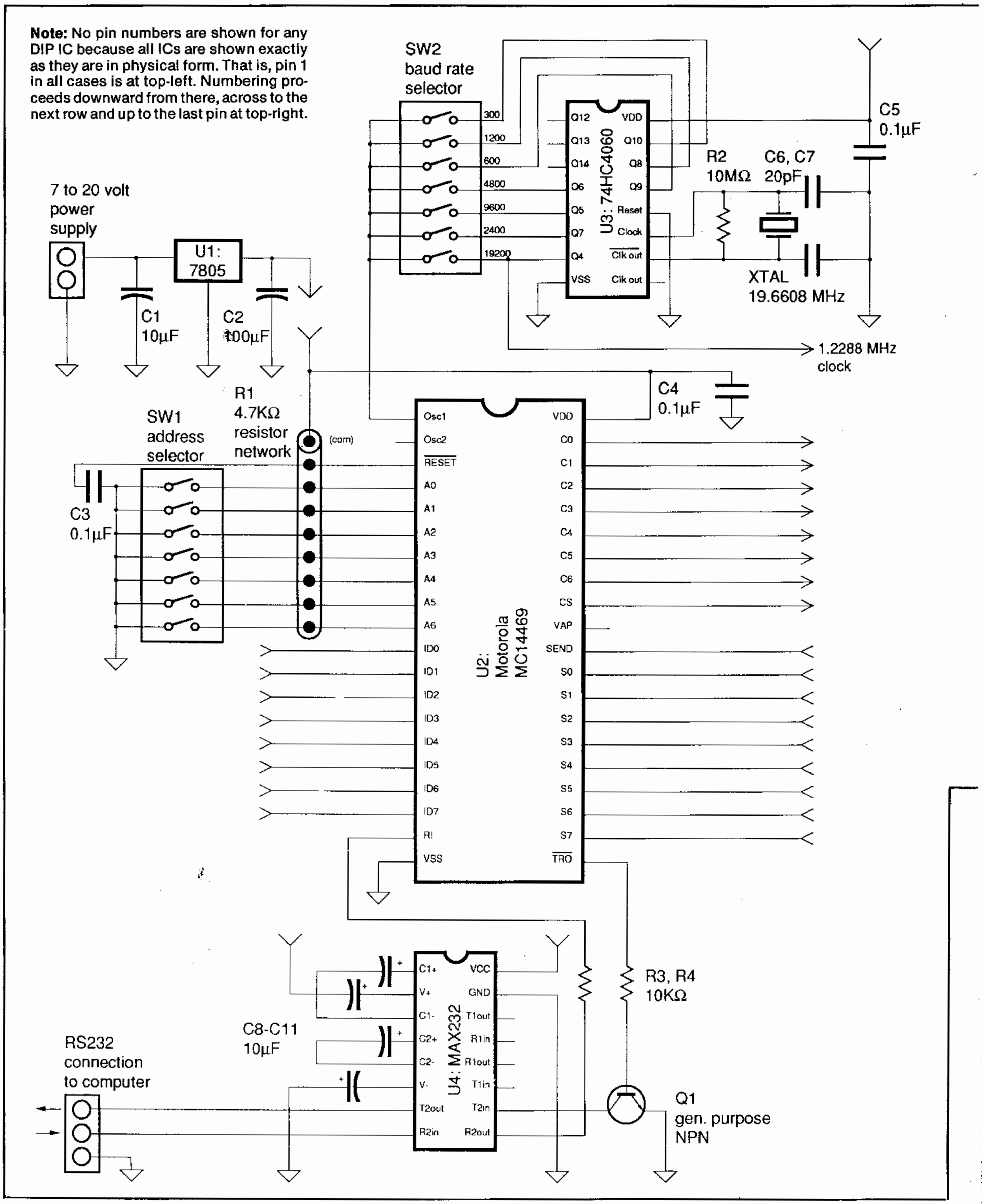


Fig. 1. Polaroid's factory-assembled ultrasonic ranging module and transducer greatly simplify building this project.



Note: No pin numbers are shown for any DIP IC because all ICs are shown exactly as they are in physical form. That is, pin 1 in all cases is at top-left. Numbering proceeds downward from there, across to the next row and up to the last pin at top-right.
SW2 baud rate selector
300
1200
600
4800
9600
2400
19200
U3: 74HC4060
Q12
Q13
Q14
Q6
Q5
Q7
Q4
VSS
VDD
Q10
Q8
Q9
Reset
Clock
Clk out
Clk out
R2 10MΩ
C6, C7 20pF
C5 0.1µF
XTAL 19.6608 MHz
1.2288 MHz clock
7 to 20 volt power supply
U1: 7805
C1 10µF
C2 100µF
C4 0.1µF
R1 4.7KΩ resistor network
(com)
SW1 address selector
C3 0.1µF
U2: Motorola MC14469
Osc1
Osc2
RESET
A0
A1
A2
A3
A4
A5
A6
ID0
ID1
ID2
ID3
ID4
ID5
ID6
ID7
RI
VSS
VDD
C0
C1
C2
C3
C4
C5
C6
CS
VAP
SEND
S0
S1
S2
S3
S4
S5
S6
S7
TRO
R3, R4 10KΩ
U4: MAX232
C1+
V+
C1-
C2+
C2-
V-
T2out
R2in
VCC
GND
T1out
R1in
R1out
T1in
T2in
R2out
C8-C11 10µF
RS232 connection to computer
Q1 gen. purpose NPN

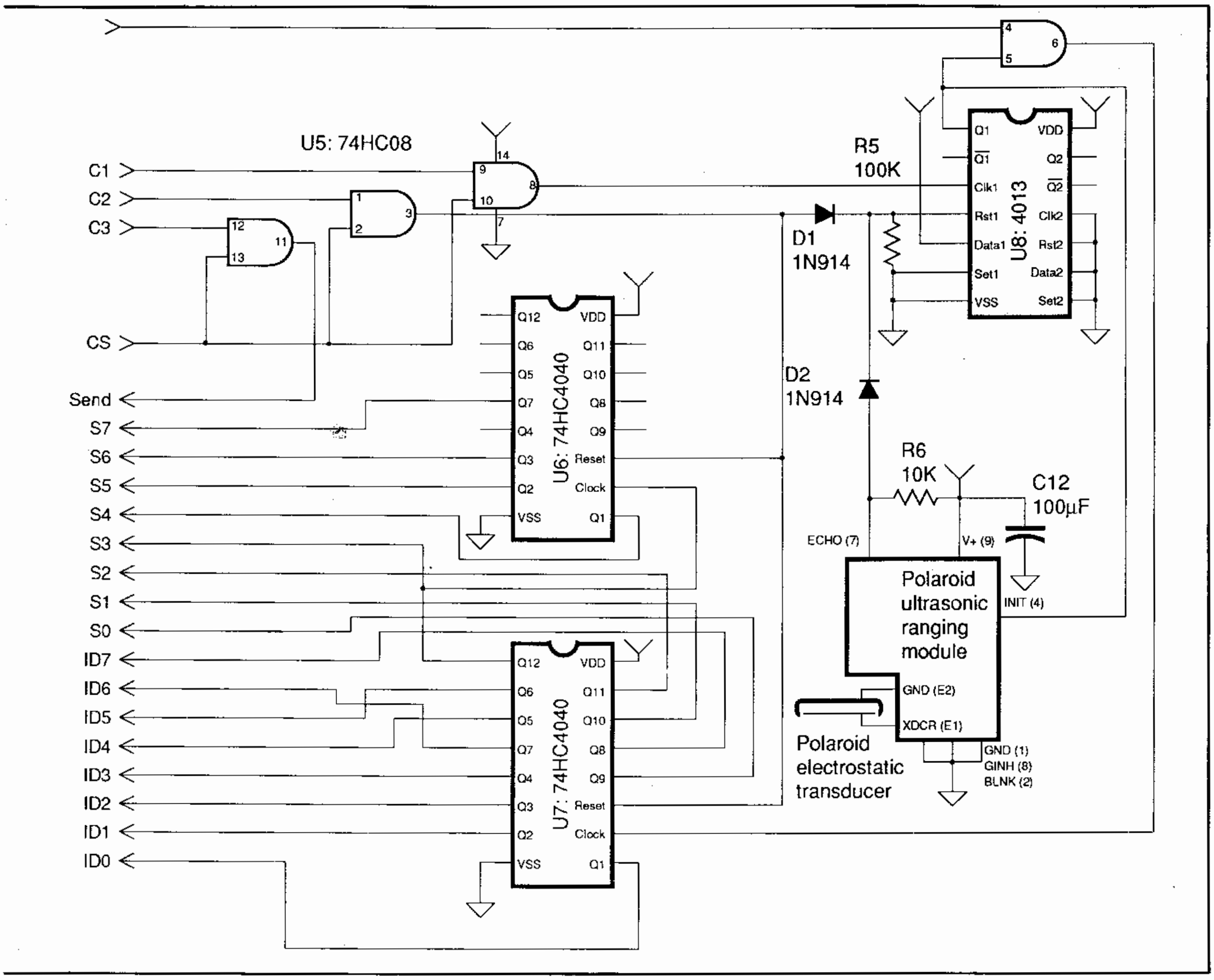


Fig. 2. Complete schematic diagram of the circuitry used in the Ultrasonic Ranger.

It measures the time it takes for sound waves to make the round-trip circuit from its transducer to an object and back again. It can obtain quite accurate measurements using sound waves because the speed of sound in air is relatively constant, except for its dependence on temperature.

Speed is calculated using the formula $331.4 \sqrt{T/273}$ meters/second, where *T* is ambient temperature in °K. Within the 0° to 40° C range over which the Ranger will most likely be used, the speed of sound varies by approximately 14%.

The best way to deal with this variation is to measure temperature every time you wish to measure distance and make an appropriate compensation or measure the temperature once and recalibrate the Ranger only when the air temperature has changed appreciably.

The program that controls the prototype Ranger at the science exhibit mentioned above is set up to automatically calibrate at start-up in the morning and then calibrate later in the day when a button is pressed. The Ranger is typically re-calibrated once or twice later in the day to accommodate the slight temperature rise that occurs in the building.

It would be difficult to design and build an ultrasonic transmitter and receiver from scratch. Fortunately, Polaroid Corp. has a nifty module (Fig. 1) that obviates the need for this. This ultrasonic transmitter/receiver ranging module requires only a 5-volt dc power supply. It accepts a logic-level pulse to initiate transmission and responds with its open-collector output when an echo is received. External circuitry need concern itself only with triggering the module, detecting the module's response and timing the interval between these two events.

Shown in Fig. 2 is the complete

schematic diagram of the Ultrasonic Ranger's circuitry. Regulator *U1* is the heart of a simple 5-volt dc power supply, which accepts 7 to 20 volts dc as its input. Most of the current drawn by this circuit goes to the Polaroid ranging module, which draws less than 100 milliamperes continuously and has a peak current requirement of 2.5 amperes when it transmits. Even though *U1* is rated to deliver only 1 ampere continuously, it can easily power this circuit because most of the 2.5 amperes drawn by the ranging module is supplied by *C12*.

The most sophisticated chip in the system is addressable asynchronous receiver/transmitter *U2*. On power-up, *U2* is reset by the momentary low that *C3* impresses on its RESET pin. It's then ready to accept serial data applied to pin RI.

Chip *U2* expects to receive one or two 11-bit words from the host computer. The first word should contain the address. If the address matches the binary number applied to pins A0 through A6, *U2* transmits back to the computer the information it reads from pins ID0 through ID7 and S0 through S7 in two 11-bit word data streams. Each 11-bit word contains eight data, even parity, one start and one stop bits.

If the first 11-bit word received by *U2* doesn't contain the address programmed onto pins A0 through A6, *U2* does nothing. This would occur if two MC14469s were connected to the same data line and the other chip was being addressed. The second 11-bit word received by *U2* contains a seven-bit word that's latched onto pins C0 through C6 for controlling external devices, provided *U2* has received a valid address.

Rather than go through every possible way of communicating with the MC14469, a subject covered in detail by the application note mentioned at the end of the Parts List, we'll discuss only what you must know to use the MC14469 with the Ultrasonic Ranger or similar circuit.

You must first initialize the serial port of your computer with the correct baud rate, eight data bits, even parity, one stop bit and one start bit. This done, a typical send/receive cycle, as seen from the point of view of the computer controlling *U2* is as follows:

PARTS LIST

Semiconductors
D1,D2—1N914 diode
Q1—General-purpose silicon npn transistor (2N2222, 2N3904 or similar)
U1—7805 fixed +5-volt regulator
U2—MC14469 addressable asynchronous receiver/transmitter (Motorola; see Note 2 below)
U3—74HC4060 CMOS oscillator/divider
U4—MAX232 single-supply RS-232 transceiver (Maxim or Intersil)
U5—74HC08 CMOS quad AND gate
U6,U7—74HC4040 CMOS divider
U8—CD4013 CMOS dual-D flip-flop
Capacitors
C1,C8 thru C11—10-µF, 16-volt electrolytic
C2,C12—100-µF, 16-volt electrolytic
C3,C4,C5—0.15-µF ceramic or Mylar
C6,C7—20-pF ceramic disk
Resistors (¼-watt, 5% tolerance)
R1—Eight-element SIP 4,700-ohm resistor network (see Note 3.)
R2—1 megohm
R3,R4,R6—10,000 ohms
R5—100,000 ohms
Miscellaneous
SW1,SW2—Seven-position DIP switch (see Note 3)
XTAL—19.6608-MHz crystal
Polaroid ultrasonic ranging module and instrument-grade electrostatic transducer (see Note 4); power supply; cables and connectors to attach to RS-232 port; experimenter boards (see text); sockets for all IC chips; suitable enclosure; machine hardware; hook wire; solder; etc.

Notes 1. Some programming languages have trouble handling the number 0 and can't send it over serial ports. To get around this problem that occurs when you want to toggle low control pins, send a command word that toggles high an unused control pin, rather than sending 0.
2. The MC14469 isn't commonly used; so it may help to contact Motorola and obtain Application Note 806: "Operation of the MC14469" (Motorola Semiconductor Products, 5005 E. McDowell Rd., Phoenix, AZ 85008).
3. If you don't think you'll frequently have to change the address of a particular node, you can tie high or low pins 4 thru 10 of U2, to permanently set an address, and eliminate R1 and SW1. Likewise, if you don't anticipate changing baud rates, connect the appropriate output of U3 to pin 1 of U2 and eliminate SW2.
4. The Polaroid ultrasonic ranging module and electrostatic transducer are available from Polaroid Corp., Ultrasonic Components Group, 119 Windsor St., Cambridge, MA 02139 (Tel.: 617-577-4681). Parts used in this device are the 6500 Series module (No. 615077) and instrument-grade transducer (No. 604142). Polaroid's $99 OEM Kit contains two of each of these.

(1) Send the first number over the serial port: first number = 128 + A6*64 + A5*32 + A4*16 + A3*8 + A2*4 + A1*2 + A0, where *A6, A5, A4, A3, A2, A1* and *A0* are either 1 or 0, corresponding to the logical status of those pins on the MC14469 to be addressed.

(2) Send the second number over the serial port: second number = C6*64 + C5*32 + C4*16 + C3*8 + C2*4 + C1*2 + C0, where *C6, C5, C4, C3, C2, C1* and *C0* are either 1 or 0, corresponding to the logical status you want latched onto those pins of the MC14469. At this point, *U2* will briefly take its CS (Command Strobe) pin to a logic high.

If you want to receive data from *U2*, you must arrange the circuit so that the pulse on CS brings high SEND. This can be accomplished with a hard-wired connection, a switch or an AND gate in this circuit. If a valid address has been received by *U2* and its SEND pin is brought high within seven bit times of CS, it returns two numbers to the host computer. The task of the computer will be to:

(3) Receive an eight-bit number over the serial port. This number corresponds to the number present on ID0 through ID7, where *ID0* and *ID7* represent the least- and most-significant bits, respectively.

(4) Receive a second eight-bit number over the serial port. This number corresponds to the number present on S0 through S7, where *S0* and *S7* represent the least- and most-significant bits, respectively.

For the above to work, the baud rate to which your computer's serial port is initialized must match that at

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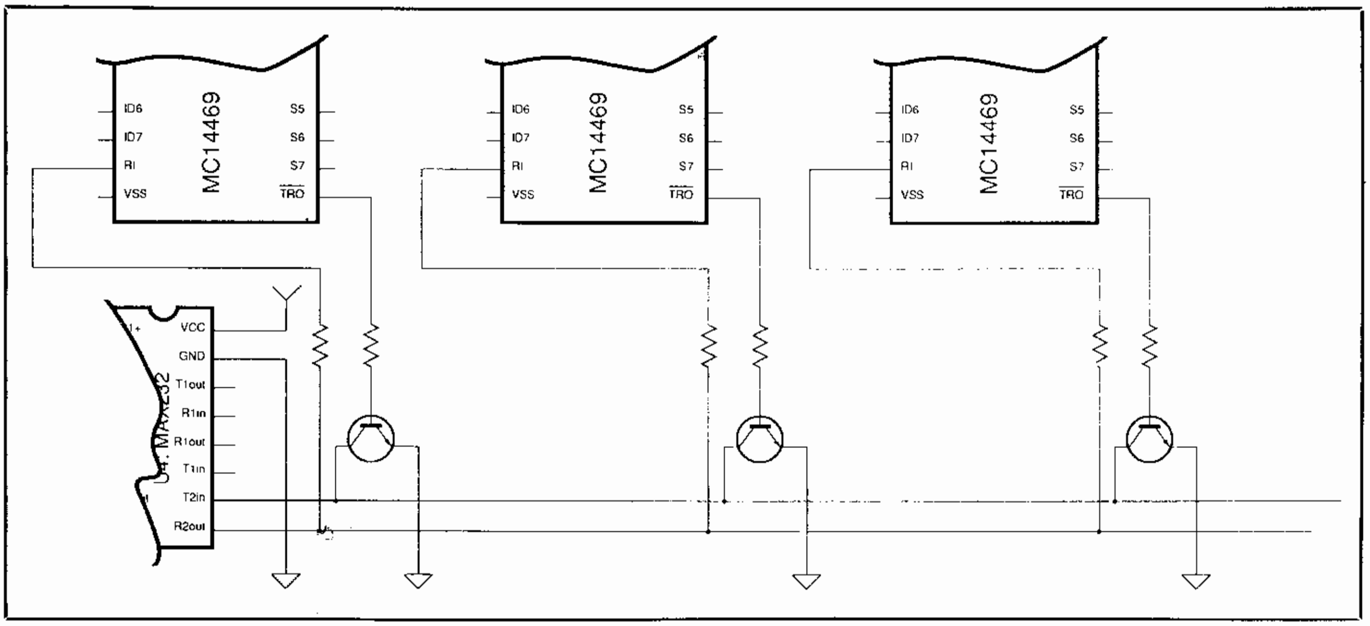


Fig. 2. Complete schematic diagram of the circuitry used in the Ultrasonic Ranger.

which *U2* is running. This equals the frequency present at OSC1 divided by 64. For example, to operate at 1,200 baud, you'd initialize your computer's serial port to 1,200 baud and drive OSC1 with a 76.8-kHz signal. The easiest way to obtain 76.8 kHz is to divide a higher frequency by a multiple of 2. In conjunction with a readily available 19.6608-MHz crystal, oscillator/divider *U3* provides the proper frequencies for 1,200 baud and other commonly used rates.

Figure 2 shows DIP switch *SW2* connecting OSC1 to one of the outputs of *U3*. If you don't anticipate frequently changing the baud rate of your system, you might prefer to hard-wire OSC1 directly to one of *U3*'s outputs and save on the cost of a DIP switch. Besides generating the correct baud rate, *U3* also produces a 1.2288-MHz clock signal for use by another part of the circuit.

Chip *U4* contains two transmitters and two receivers that translate between RS-232 levels and the logic levels used by *U2*. There are many different transceiver chips that could be used instead, but the MAX232 specified was chosen because it's readily available and operates from a single 5-volt supply. Transistor *Q1* and a pull-up resistor inside *U4* form an inverter between transmit output TRO of *U2* and the T2IN input of *U4*.

Additional MC14469 chips can be added to *U4*, as shown in Fig. 3. Up to 127 Ultrasonic Ranger circuits can be connected to a single computer, provided each has a different address. To all of the Rangers, the computer will send an address and command word, but only the chip that receives its own personal address will respond.

You can best understand the functions of *U5* through *U8* by stepping through the sequence of events that occurs each time the computer requests the Ranger to take a measurement. First, you must initialize the serial port and establish the address of the Ranger with which you wish to communicate. In BASIC, this could be accomplished by keying in:

```
ADDRESS = 255 'This corresponds
   to A0-A7 held high
OPEN "COM1:1200,E,8,1" AS #1
```

To initiate a measurement, it's best to start by resetting *U6*, *U7* and *U8*. This is done by toggling high C2, ensuring that a CS pulse is generated by *U2*, and then toggling low C2. In BASIC, a subroutine to perform this sequence of actions might be as follows:

```
PRINT #1, CHR$(ADDRESS)
PRINT #1, CHR$(4) 'Toggle C2
   high and send CS
PRINT #1, CHR$(ADDRESS)
PRINT #1, CHR$(16) 'Toggle C2 low
   by toggling C4 high (see Note 1)
```

Having reset the flip-flop and counters, you want to tell the ultrasonic ranging module to initiate a measurement. This is accomplished by bringing high the INIT pin of the module. At the same time, you want to begin timing how long it takes until the ultrasonic signal bounces back from its target. You can do this by toggling high C1, ensuring that a CS pulse is generated by *U2* and then toggling low C1. The code for this is:

```
PRINT #1, CHR$(ADDRESS)
PRINT #1, CHR$(2) 'Toggle C1 high
   and send CS
PRINT #1, CHR$(ADDRESS)
PRINT #1, CHR$(16) 'Toggle C1 low
   by toggling C4 high
```

When C1 is toggled high and the CS pulse that follows reception of the second word by *U2* is ANDed with C1, a pulse is generated at the CLOCK input of D-type flip-flop *U8*. This causes the flip-flop's output to latch high, causing the ranging module to emit an ultrasonic signal because its INIT pin was taken high and the output of the flip-flop opens an AND gate to allow the 1.2288-MHz clock pulses from *U3* to start incrementing *U7* and *U8* (*U7* and *U8* form a 16-bit binary counter).

When the ultrasonic signal is received by the ranging module a few milliseconds after it was emitted, the module allows its ECHO pin to be pulled high by *R6* (it has an open-collector output). This resets the flip-flop, forcing low its output and stopping the 16-bit counter.

At this point, *U6* and *U7* have on their output pins a 16-bit number that corresponds to the number of clock cycles that have elapsed while the ultrasonic signal traveled from the transducer to the target and back. This number is directly proportional to the distance to the target.

All that remains is to read the number off *U6* and *U7*. To do this, you issue another command to *U2*. This time, you toggle high *U3* to allow the CS pulse that follows to briefly take high the SEND pin. This tells *U2* to read the 16-bit number on pins ID0 through ID7 and S0 through S7 and send them to the computer. This is accomplished as follows:

```
WHILE B$ <> " "
B$ = INPUT$(1,#1)
WEND 'This loop clears the serial
  port buffer

PRINT #1, CHR$(ADDRESS)
PRINT #1, CHR$(8) 'Toggle C3 high
  and send CS
```

The numbers have been sent from the Ranger to the computer, but you must still read them from the computer's serial port buffer using a subroutine like:

```
BYTE1$ = INPUT$(1,#1)
BYTE2$ = INPUT$(1,#1)
COUNT = ASC(BYTE1$) + ASC
  (BYTE1$)*256
```

At this point, the variable "count" holds the number (0 through 65,535) of clock cycles that elapsed while the ultrasonic signal traveled to the target and back. "Count" is directly proportional to the distance to the target. From here on, the program code should be dictated by your application. In the prototype, what follows is computing the distance from the total count, subtracting the measured distance from 2.400 meters to find the visitor's height and various procedures to display and vocalize that height.

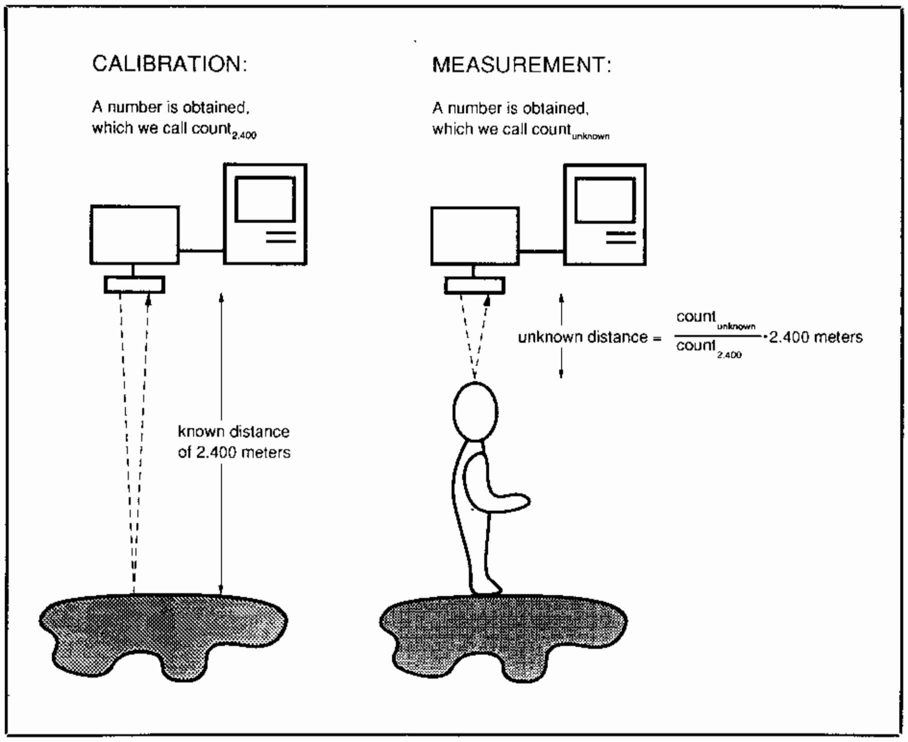


Fig. 4. Illustrated here is the ratiometric approach to calibrating and measuring distance in the application for which author's prototype is used.

Construction

The ultrasonic transducer is supplied by Polaroid with a short two-conductor cable for connecting it to the ranging board. If you wish to extend this wire very much, use shielded cable.

The ranging module has a connector for a supplied nine-conductor foil ribbon cable. If you can't locate a matching connector (Burndy No. SLP9s-2) for the other end of the special cable, you have two options. The simpler is to unsolder the Burndy connector from the module and replace it with your own ribbon cable soldered into the holes left by the connector.

If you don't want to tamper with the Polaroid module, you can use the Burndy connector and foil ribbon cable by modifying the end of the ribbon cable. To do this, separate the foil ribbon into its separate conductors and carefully insert the conductors into a DIP socket. This method seems to work best with AMP DIP sockets.

Decide now whether to include *SW1*, *SW2* and *R1* (for convenience when connecting multiple Rangers to the same computer) or omit them and hard-wire baud rate and address. Eliminating these components simplifies assembly and is something you can probably get away with in most applications. If you eliminate *R1* and *SW1*, be sure that pins A0 through A7 are either grounded or connected to V_{DD}, rather than leaving them floating.

The circuit is simple enough that it can be built on a few experimenter boards. No pin numbers are shown in Fig. 2 because the ICs are drawn exactly according to their physical packaging. Hence, pin 1 is at the top-left and the last pin number is at the top-right of each DIP IC. This makes it relatively easy to work between schematic and board layout.

You may want to build the left and right halves of this circuit on separate boards because the circuit half centered around the *U2* has considerable utility apart from the Ultrasonic Ranger and might at some point be used elsewhere.

There's nothing critical about component layout. Just make sure to locate bypass capacitors *C4* and *C5* physically close to pin 40 of *U2* and pin 16 of *U3*, respectively. Connect *C12* close to the ranging module because its function is to supply the brief pulses of current needed by the module.

You can use any type of enclosure into which all elements fit to house your Ultrasonic Ranger. Machine the selected enclosure as needed to mount the circuit-board assemblies, using ½″ spacers and suitable machine hardware. Mount the transducer that comes with the Polaroid ranging module outside the enclosure.

Using It

There are two ways to convert the number returned by the Ultrasonic Ranger into a usable distance measurement. One is to measure the temperature of the air, calculate the speed of sound at that temperature and then calculate distance based on the speed of sound and the clock frequency, using the equation: distance = [counts/frequency (Hz)] $\times 331.4\sqrt{(T/273)}$ = meters/second. Here, T is temperature in °K and clock frequency is 1.2288 MHz.

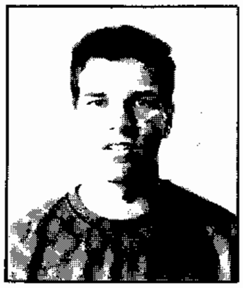
A far easier method to compute distance is to forget about directly measuring the temperature and calibrate the Ultrasonic Ranger in such a way that temperature is taken into account. Do this by having the project measure a known distance and then use the number obtained to calculate unknown distances, utilizing the linear relationship that exists between counts and distance.

At the science exhibit in Canada, for example, the Ultrasonic Ranger starts each day by counting the number of clock pulses it takes the ultrasonic signal to travel the distance from transducer to floor (2.400 meters). Actually the average of three successive measurements, this number is stored as a variable the computer uses throughout the day to make measurements of unknown distances per the formula given in Fig. 4.

If you anticipate a relatively constant temperature in your environment, and if it's feasible to calibrate the Ranger by measuring a known distance, you can do as we did. On the other hand, if you expect the temperature to vary over a wider range, or if you can't calibrate by measuring a known distance, you can add a temperature sensor to your computer to mathematically compensate for temperature changes.

You may encounter situations in which the Ultrasonic Ranger is slightly late in giving an echo pulse when directed at such acoustically "soft" targets as carpeting and heads of hair. In our science-exhibit setup, we determined that the echo pulse was 0.32 to 0.38 milliseconds late, making our distance measurements a few centimeters too large.

It appears that only the last of the 16 pulses emitted by the ultrasonic transducer are reflected from our targets with enough strength to register with the Ranger as an echo. (The Polaroid ranging module increases its gain with time to compensate for sonic attenuation with distance to give later pulses a better chance of being detected.) Subtracting 0.38 ms from every measurement corrected the problem.



Joseph O'Connell