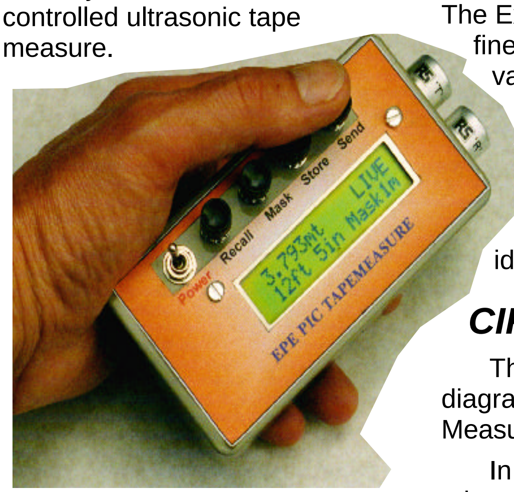
PIC TAPE MEASURE by JOHN BECKER

Microcontrolled ultrasonic distance calculator with data recording and foreground masking.

Quite naturally, many of you will be wondering how PIC devices can be used to update some of your favorite designs. PICs are, as we are proving on frequent occasions, extremely versatile devices and can be used in many circuits to replace quite a few conventional logic chips.

Recently, the author's eye fell on his earlier *Ultrasonic Tape Measure* (*EPE hard copy magazine Sept 92*) and began to speculate about how it too could be simplified using a PIC. The result (after about an hour with a soldering iron and *many* hours at the computer), is before you now – a PIC16C84-controlled ultrasonic tape measure.



Not only is it an update on the previous design, it is a quite significantly more advanced instrument. Taking advantage of the PIC16C84's internal EEPROM (electrically erasable programmable read only memory), a data store and recall facility have been programmed in as well. There is also a masking option that allows foreground echoes to be ignored.

The device can record and recall 30 or 32 (see later) distance measurements, allowing several readings to be taken before copying them to paper – ideal when taking measurements in difficult to access locations!

There is a choice of two software programs for the unit. The Standard program requires no adjustment to the timing and calculation factors and assumes a rigidly fixed speed of sound. The Extended program allows fine tuning of the calculation values and requires a small amount of setting up to be done via the software and the panel function switches. The electronics hardware is identical for both programs.

CIRCUIT DIAGRAM

The complete circuit diagram for the PIC Tape Measure is shown in Fig.1.

In a nutshell, the PIC microcontroller (IC2) is the mastermind that controls the whole operation. When prompted by the pressing of Send switch S2, the PIC transmits a series of 40kHz pulses via the ultrasonic transmitting transducer TX1.

The pulses are accurately generated in software at a rate determined by the controller's operating frequency (4MHz as set by crystal X1) and the number of commands that are processed between each phase of the output signal.

PIC output pins RA0 and RA1 are used as the push-pull source which drives the transmitter transducer. One pin alternates between high and low, while the other alternates between low and high.

Solid objects within the path of this signal reflect it back to the ultrasonic receiving transducer, RX1. The echo signals are at a considerably lower amplitude than those transmitted and require a fair amount of amplification in order to be recognizable by the PIC as logic signals.

AMPLIFICATION

The 40kHz echo signals receive two stages of a.c. amplification. A gain of 100 is provided by opamp IC1a, as set by resistors R1 and R4. Opamp IC1b provides a further gain of about 47, as set by R5 and R6.

Capacitor C6 then feeds the amplified signal to transistor TR1, whose purpose is to provide logic-level pulses to the PIC at pin RB7. Between them, resistor R7 and preset VR1 set a basic d.c. bias on the base (b) of TR1, determining the response sensitivity.

The output from TR1's collector normally rests at 5V, but swings between 5V and 0V in the presence of suitably strong echo signals. Immediately the PIC has finished transmitting the brief chain of 40kHz pulses, it starts a 2-byte counter (16-bits) which increments at a known rate. When the PIC recognizes that pin RB7 has changed its logic state from high to low in response to an output from TR1, the counter is stopped.

CALCULATIONS

The software now goes into its calculation routine, in which it converts the count value into two distance values, one in metric (meters to three decimal places) and one in imperial (feet and inches). These measurements are displayed on the X2 16-character 2-line LCD (liquid crystal display module). Meters are shown top left, followed by letters “mt”. Feet and inches are shown bottom left, complete with letters of “ft” and “in” (see photographs).

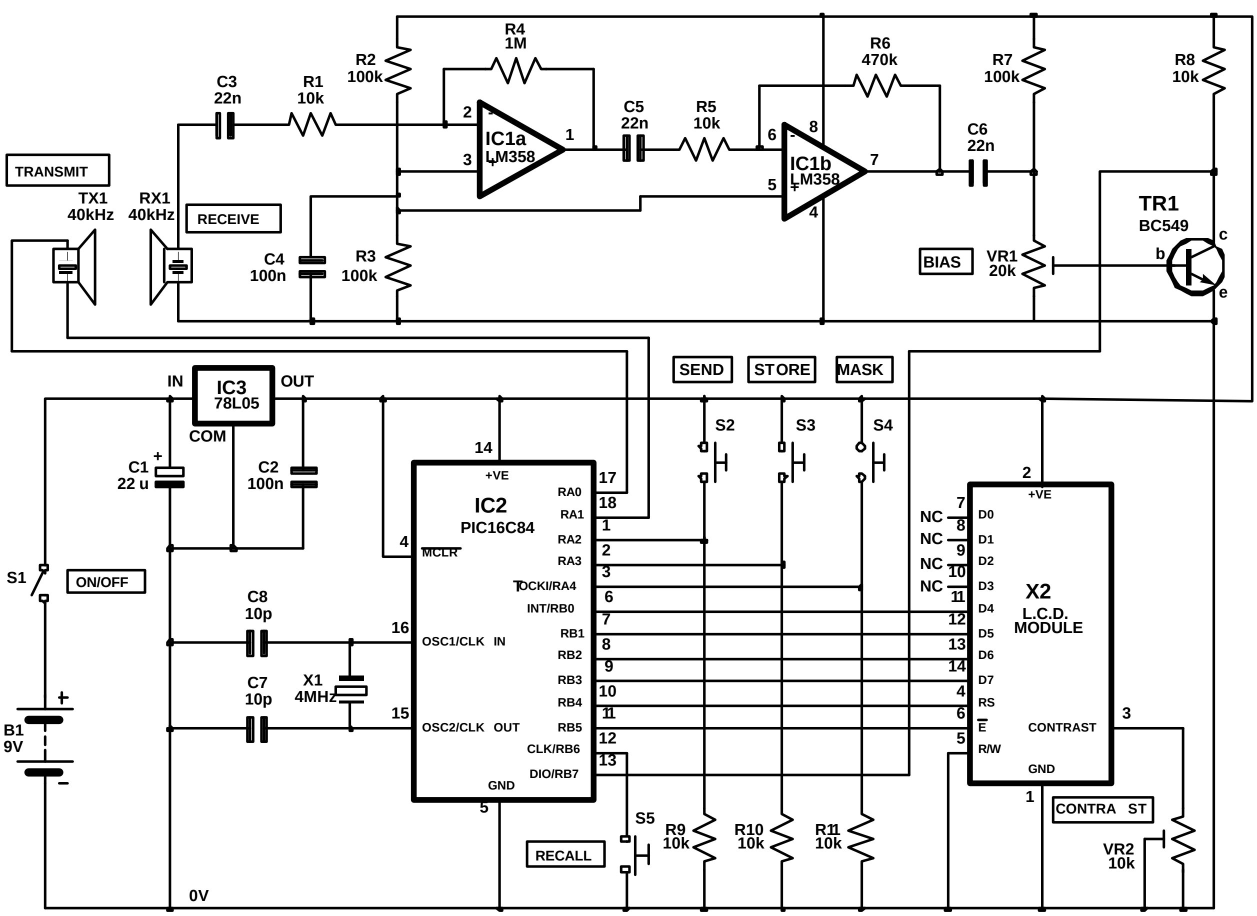
The transmission and echo conversion process continues for as long as the Send button remains pressed. You can, therefore, pan around a room and just generally view its dimensions until you are ready to accept a measurement. At this moment, releasing the switch will cause the last measurement read to stay on the LCD screen. It will remain there until Send is pressed again, or Recall switch S5 is pressed, or the unit is switched off.

While Send is pressed, the sampling rate is normally a little under once per second – depending on the mask and distance values.

Front panel display window and function buttons. A recalled measurement is shown.

MEASUREMENT RECORDING

The measurement shown on the display is not yet recorded in the PIC's EEPROM memory. That action occurs when Store switch S3 is pressed. Since the switch status is only read by the PIC when it has finished its calculation and display, the measurement recorded is always the one just completed. This ensures that an



incomplete measurement is never stored (i.e. one caught in the middle of transmission).

The information is stored as the count value achieved, not in meters or feet. Consequently, only two bytes of EEPROM memory are used. The PIC has 64 bytes of this memory available and up to 32 measurements can be recorded with the Standard program.

With the Extended program, 30 measurements can be stored, the other bytes being reserved for timing and counting values.

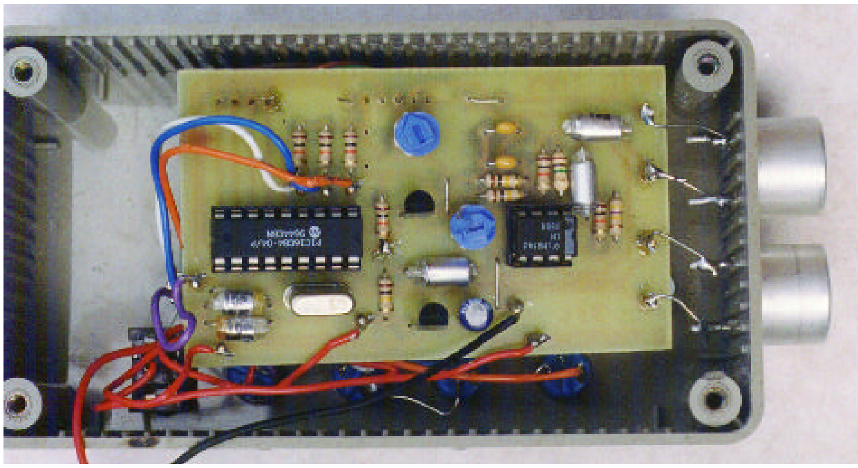
Each time a measurement is stored, a record counter is incremented. This is displayed on the top right of the LCD so that you know how many readings you have taken. Immediately in front of this value the message "SAVED" appears.

It is not possible to step the counter back in order to store another measurement at this count location. Thus, if you make a recording in error, you must remember that the value at this location is to be disregarded when you examine the recordings later.

PLAYBACK

To play back the stored recordings, the Recall switch is used. Each time it is pressed, a Recall counter is incremented. The 2-byte data from the EEPROM at the equivalent address to the count (count × 2) is read and converted to metric and imperial as before.

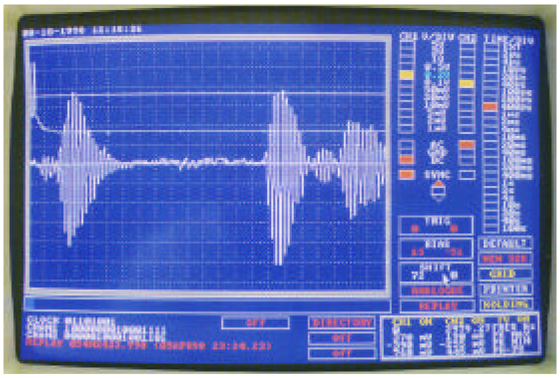
The Recall counter value is also displayed at the top right in place of the Record counter value. Immediately in front of it the message "SHOW=" appears.



Prototype PCB mounted "below" the display module.

EEPROM RESET

A facility to reset the Record and Recall counters to zero during normal use has not been included. With the Standard program, they are automatically reset at the moment of switching on the unit. With the Extended program, the Recall counter is reset at each switch on, but the Record counter is only reset when the full EEPROM measurement data contents are reset. The EEPROM measurement data remains intact until intentionally reset. This can be done at switch-on. If the Store button is pressed and held down immediately prior to and during switching on, all stored measurements are cleared, and the Record and Recall counters set to zero.



Screen photo 1. Without masking, the center line "echoes" could be interpreted as measurement signals.

MASKING

The masking facility allows foreground echoes to be ignored within a timing/distance range set via the Mask switch S4. This allows you, for example, to read the distance of a far wall when a clutter of furniture is between you and the wall. Without this facility, the echoes from the furniture would be those read by the "tape measure."

To an extent, however, this facility has to be used with discretion, since it is possible that too long a masking distance could allow multiple reflections to be read, i.e. those that ricochet around the room before returning to the unit.

Inclusion of a gain control was considered in order to reduce this possibility, but it was concluded that having both a mask and a gain control might be confusing to use in practice, and the idea was dropped. If you would like an external sensitivity control, replace VR1 with a case mounted potentiometer of the same value (you may need a bit bigger case, though).

The software is written so that the masking

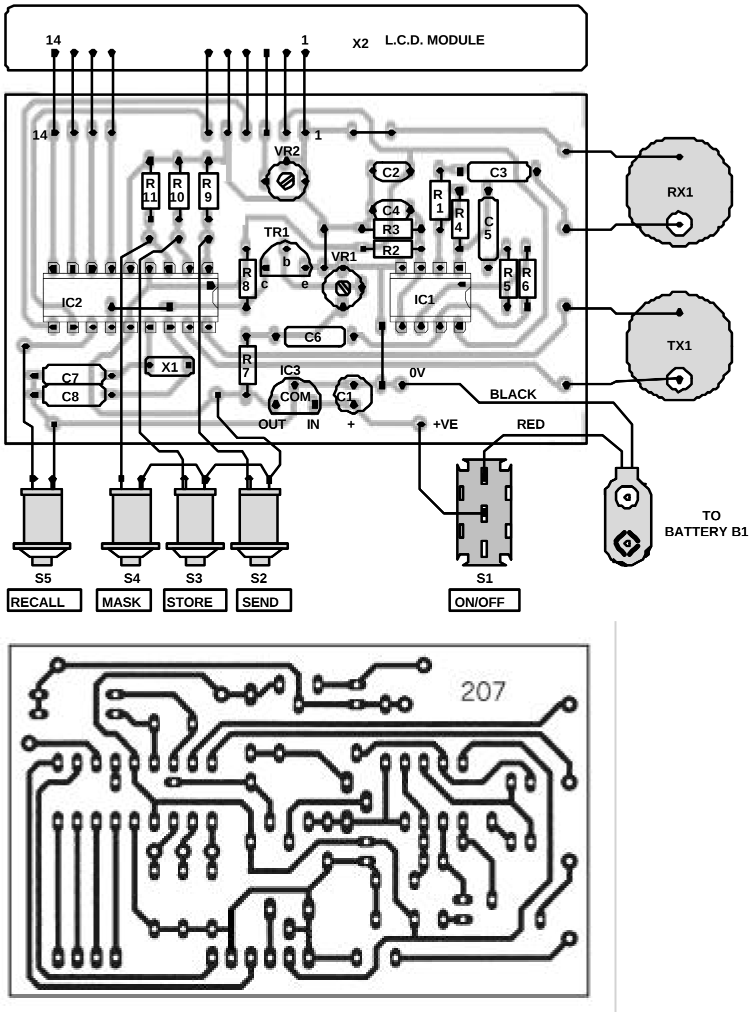


Fig.2. PIC Tape Measure PCB topside component layout, interwiring, and copper foil master pattern.

COMPONENTS

Resistors
R1, R5, R8 to R11 10k (6 off)
R2, R3, R7 100k (3 off)
R4 1M
R6 470k
All 0.25W 5% carbon film or better

Potentiometers
VR1 20k miniature round preset
VR2 10k miniature round preset

Capacitors
C1 22u radial electrolytic, 16V
C2, C4 100n ceramic disc (0.2in spacing – 2 off)
C3, C5, C6 22n polystyrene (3 off)
C7, C8 10p polystyrene (2 off)

Semiconductors
TR1 BC549 *npn* transistor
IC1 LM358 dual opamp
IC2 PIC16C84 (or PIC16F84) pre-programmed microcontroller – see text
IC3 78L05 +5V 100mA voltage regulator

Miscellaneous
S1 miniature s.p.s.t toggle switch
S2 to S5 miniature push-to-make switch (4 off)
RX1 miniature 40kHz ultrasonic receiver
TX1 miniature 40kHz ultrasonic transmitter
X1 4MHz crystal
X2 16-character 2-line alphanumeric LCD display
B1 9V PP3 battery and clip

Printed circuit board available from the *EPE Online PCB Service*, code 207; plastic case, 120mm x 64mm x 40mm; 8-pin DIL socket; 18-pin DIL socket; self-adhesive rubber feet (3 off) (see text); nuts and bolts, M3 x 12mm (2 off) (see text); connecting wire, solder, etc.

See also the SHOP TALK Page!

Approx. Cost Guidance Only **$53**

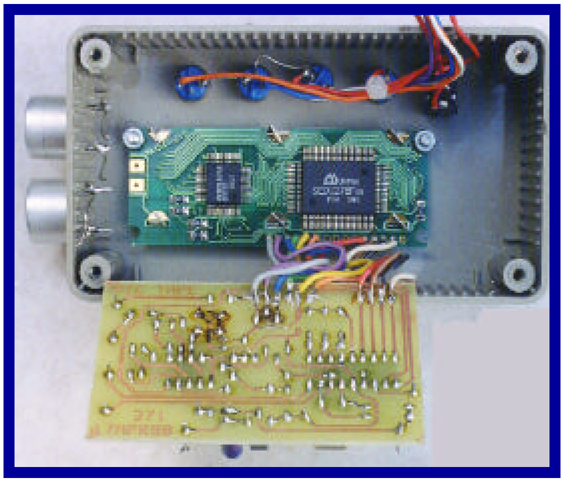
distance progressively increases while Mask is pressed, ranging (in steps of one) from zero to nine with the Standard program and one to nine with the Extended program, rolling over to zero again following nine. The mask value is displayed at the bottom right of the screen, prefixed by the word Mask. It represents an approximate (but not precise) distance in meters. If the value shown is above zero, it is followed by the letter “m” for meters.

Switch S4 increments the mask value at two digits per second, The rate may be slower when the value is greater than zero and the Send button is pressed at the same time. In this situation, if an echo is not being received the software waits until a time-out occurs before it again examines the switch. It is normally better to press Mask when Send is not pressed.

MASQUERADE

Screen photo 1 illustrates why a mask is useful. The final pulse of the transmission signal is seen top left, and centrally five echo signals are seen at different amplitudes. The first echo is (normally) too small to be accepted as a valid echo. The second echo, though, is large enough for the software to accept it as the trigger signal, reacting to it about half way above its central (d.c.) position, and it will do so if no response delay is included.

By inserting a suitable delay in the software before it starts looking for echoes, the second echo can be ignored, with the third echo being the one that is accepted. Extending the delay a bit further, the response can be timed to only accept the fifth echo.



PCB folded back to reveal the layout, interwiring and full size copper foil master pattern.

As illustrated, the fourth echo is too small to be recognized. However, if the bias level on transistor TR1 were to be suitably increased, effectively increasing the gain, both the first and fourth echoes could be responded to if the delay was set appropriately.

Note, though, that the first echo is probably the residual ringing of the receiving transducer rather than a true echo. Without any response delay, this undesirable signal would trigger the unit, preventing it from responding to any of the subsequent pulses. This is why a minimum masking value of one (about one meter) is necessary with higher bias settings.

The display seen in Photo 1 was created by coupling the *EPE Virtual Scope* (*Jan/Sept '98*) to the transmitting transducer and the output of opamp IC1b. For the sake of illustration, the conditions were set up slightly unnaturally in that the echoes are those from small items deliberately placed only a few inches in front of the transducers. The data was recorded on disk some months before being recalled to the screen for photography.

Although the pulses have a 40kHz content, the frequency shown at the bottom right of the screen (2979·27Hz) has resulted because the transmission and return pulses are not continuous, the *V-Scope* assessing frequency from the number of pulses occurring in one second.

POWER SUPPLY

The PIC Tape Measure runs from a 9V PP3 battery. Current drawn is normally about 6mA, rising to about 7mA (average) during transmission.

Regulator IC3 drops the 9V supply down to 5V to suit the PIC and the LCD.

CONSTRUCTION

Details of the printed circuit board (PCB) component layout and tracking are shown in Fig.2. The board is available from the *EPE Online PCB Service*, code 207. It is essential to use a socket for IC2, and recommended for IC1. Fit the on-board link wires first, then assemble the board in any order you find convenient.

The LCD module may be connected to the PCB by rigid wires (20 s.w.g. tinned copper wire – although resistor offcuts might be suitable), or short lengths of flexible insulated connecting wire may be used.

Using rigid wires, the LCD can be mounted above the *rear* of the PCB at a height of about 7mm, i.e. clear of any danger of the soldered joints and trimmed component leads touching any part of the LCD. To ensure this could not happen if the two units were squeezed, two rubber spacers (self-adhesive feet) were inserted between them.

The viewing window slot for the LCD is in the *base* of the plastic case. It can be cut in the time-honored method of drilling a series of holes and then filing down to the correct size to accept the friction-fitting of the LCD's metal frame. Ensure that the positioning of the LCD and PCB allows room for the battery at one end, yet does not allow the corner pillars in the case to interfere with the mounting of the assembly.

Drill two holes in the case to allow the LCD to be secured with two nuts and bolts via its own mounting holes (those furthest away from the LCD/PCB connections).

It is preferable to insert thin spacers between the case and LCD (another nut on each bolt), so that the ends of the soldered connecting wires do not prevent the LCD from sitting comfortably against the case. Any distortion of the LCD module could prevent it from working.

Once the display slot has been completed, and before the LCD is mounted in the case, drill holes alongside and above the slot for the five switches. Also drill holes in the end of the case for the ultrasonic transducer pins. Use a drill bit of about the same size as the transducer pins so that a friction fit occurs. Wire-up the switches as shown in Fig.2, and in the order seen in the photographs, using ordinary multistrand connecting wire. The transducers should be connected with solid wire, to secure them rigidly in the case. Ensure that the transducers are in good alignment with each other, to optimize the signal transmission and return paths.

It is imperative to ensure that there is no chance of the 9V power connection on the PCB (or the 9V track underneath) coming into contact with the tags of the switches. Such an occurrence could kill the PIC and the LCD. Use two or three layers of insulating tape on the switch tags and rear of the PCB.

Another self-adhesive rubber spacer may be attached to the inside of the lid to prevent the battery from rattling when the unit is fully enclosed.

FIRST TESTS

Having thoroughly checked the completed assembly for shorts etc., plug in opamp IC1, but not microcontroller IC2. Switch on the battery supply and check that the output from regulator IC3 is at 5V.

Adjust preset VR1 so that the bias on the base of transistor TR1 is about 0·3V.

If all is well, switch off and plug in the PIC16C84 (or PIC16F84), which must be preprogrammed (see later).

Switching on again (without any of switches S2 to S5 being pressed), the PIC will start running. The first thing it does is to initialize the LCD, setting it to 4-bit control mode and then, on two lines, displays the opening message:

EPE PIC TAPE BOX

PRESS SEND KEY

You may need to adjust the Contrast preset VR2 to make the message visible.

ALIGNMENT ROUTINES

At this point with the Extended program version, there are some alignment routines to be performed via the switches. These will be discussed later at the section headed "Extended Program Version." Until then, the following paragraphs refer to both versions.

In normal use, when the unit is first switched on the opening message is displayed and the soft-ware goes into a loop in which it waits for any of the function switches S2 to S5 to be pressed.

Point the PIC Tape Measure at a nearby wall, without any other object in the signal path. Press the Send switch S2. The distance that the wall is away from the front of the unit should be displayed on the LCD in meters and feet plus inches.

The words LIVE and Mask, plus the mask value will also be shown. Keep Send pressed and move backwards and forwards with respect to the wall, observing the change in distance readings. Ensure that the signal is not reflected off the hand pressing the switch.

DISTANCE EXTREMES

The minimum distance readable with a mask value of zero and transistor TR1's bias at 0·3V, is about 55mm (2in). The maximum depends on a number of factors. The transmission power of transducer TX1 is one factor. This is likely to vary between different units of the same type, due to manufacturing tolerances. Similarly, the sensitivity of the receiving transducer (RX1) is equally likely to vary between units. The relative alignment accuracy of the two transducers also plays a part.

Another factor is the nature of the surface from which the ultrasonic beam is being reflected. Hard surfaces will provide stronger echoes than soft ones.

Typical screen display in the Mask set-up mode

Additionally, if the unit is being used outside (don't let it get wet) the wind may deflect or impede the transmitted and reflected signals, reducing the echo signal amplitude received by the unit.

BIAS LEVEL

The most crucial factor, though, is the bias level on TR1. With the bias set at 0·3V, a maximum measuring distance of about six meters is a reasonable expectation. Increasing the bias to about 5·5V (using preset VR1), distances in excess of 10 meters should be achievable.

The bias could, perhaps, be raised to about 0·6V, allowing really low amplitude echo signals to trigger transistor TR1. The danger of making it too sensitive, though, is that multiple echoes from around the room will be picked up, resulting in false readings.

Also, increased sensitivity makes the system susceptible to being triggered by the "ringing" of the receiving transducer, caused by its proximity to the transmitter. The mask facility, though, will usually allow this effect to be ignored, except at excessively sensitive settings of VR1/TR1.

Use discretion and ensure that the triggering is always reliable in normal measuring situations, at the expense of its long distance abilities.

MASK TESTING

To test the masking facility (initially with a bias of about 0·3V), place the unit on the edge of a table facing a wall and place a dining chair (with a normally-high back) slightly in the signal path. With the Send button pressed, position the chair until its distance is displayed rather than the wall's. Now press Mask while still holding Send pressed.

When the masking distance is equivalent to that just beyond the chair back, the chair echo should cease and the wall value become that displayed. The mask can be used on any occasion that foreground items interfere with the desired target reading, as long as a good strength of signal still reaches the target.

In normal use, without foreground echoes and with the bias below about 0·4V, keep the mask value at zero. With higher bias levels on transistor TR1, it is likely to be preferable to normally use the mask value set to one. (In normal use of the Extended version, the minimum mask value is automatically set to one.) It is suggested that you experiment to find the best bias level that suits your own assembly.

DATA RECORDING

To record a displayed reading, press Store switch S3. Note that the reading displayed must be one that has just been acquired by taking a measurement. A reading which has been recalled for display will not be re-recorded over itself.

So that you know whether you are looking at a real or recalled reading, the messages "LIVE" and "SHOW" are displayed accordingly. You can only record if "LIVE" is showing. The record number of the newly stored measurement is displayed on the top right of the LCD. Separate EEPROM address pairs are used in ascending order each time Store is pressed. When roll-over beyond the maximum count permissible occurs, the counter is reset and recorded data now overwrites that previously recorded at the same ensuing addresses.

DATA RECALL

Data recall occurs when the Recall button is pressed. A separate counter is used for this routine, incrementing each time Recall is pressed. Again, when roll-over beyond the maximum count occurs, the counter is reset. Note that the record displayed is not normally that which has just been recorded. To view the latest record, the recall counter number has to match the stored counter number.

In a practical situation both counters should be set to zero prior to taking a series of measurements (see "EEPROM Reset" earlier).

PERMANENCE

Recorded data remains in the PIC's EEPROM data memory even when the power is switched off, remaining there until overwritten (be aware of this in other situations if you use a previously programmed PIC '84 for another program).

As stated earlier, the data can be overwritten by zeros when the Store switch is held down while switching on.

With the *Standard* software program, note that each time you switch on the unit, the Store (Record) counter is reset to one, consequently you should *not* switch off during a sequence of measurements.

However, the Extended program records both the measurement data and the counter value in the EEPROM, and with this version you may switch off between readings.

COMMENTS

Of likely interest to PIC programming readers is the way in which the ultrasonic transmitter (TX1) is driven in push-pull mode by Port A pins RA0 and RA1 (see Listing 1).

In the general initialization routine at the start of the program, Port A is set with these two pins as outputs, and with RA2 to RA4 as inputs. Port A is then cleared.

On entry into the transmission routine (at label TXIT), a loop value is set at ten, a 2-byte counter is cleared, and RA0 is set high, so setting one side of TX1 high. There is then a pause as set by eight NOP (no operation) commands.

Then the command COMF PORTA,F is given. This inverts (*complements*) the value on Port A from binary 00001 to binary 11110 (Port A only has five usable pins). Pin RA0 is thus set low and RA1 set high, an action which reverses the current flow through TX1. The other three pins (RA2 to RA4) are of no interest since they are set as inputs.

A further delay now occurs, of 12 NOP commands, after which COMF PORTA,F is again given, returning Port A to the first value, 00001. The loop value is decremented and if it is not yet zero, the routine jumps back to the first of the eight NOPs (at label BEAMIT) and the process is repeated.

At the end of the loop, transmission ceases and Port A is cleared. Consequently, 10 pulses are transmitted and the time taken to transmit them is equivalent to a frequency of 40kHz.

The transmission routine is shown in abridged form in Listing 1 (the BSF SAVE,0 command sets a flag which allows the measurement to be recorded if required).

Listing 1

```
TXIT:   MOVLW 10
        MOVWF LOOPB
        CLRF COUNT0
        CLRF COUNT1
        BSF PORTA,0
        BSF SAVE,0
BEAMIT: NOP (by 8)
        COMF PORTA,F
        NOP (by 12)
        COMF PORTA,F
        DECFSZ LOOPB,F
        GOTO BEAMIT
        CLRF PORTA
        CALL RECEIVE
```

Whilst there may appear to be a significant imbalance in the mark-space ratio of the output pulses, the presence of other commands in the loop evens out the timing. ***Do not change the commands in this loop — to do so would upset the 40kHz frequency and the duration of transmission.***

The RECEIVE routine is too lengthy to reproduce here, but in it the 2-byte timing counter is repeatedly incremented until a change in the status of Port B pin RB7 is detected (from high to low), at which point the count stops.

DISTANCE CALCULATION

Sound travels through air at a rate of 331·4 meters per second (at standard temperature and pressure – s.t.p.), so say the text books. In other conditions its velocity varies accordingly. Over short distances, though, such changes are negligible as far as this unit is concerned. Conseq-uently, they are ignored (making this a far simpler and cheaper device to design and build).

The speed of sound is thus taken as a constant – that encountered in the author's workshop during prototyping! Tests and measurements revealed that a reception count value of 618 represented a target distance of 1000mm i.e. one meter (the value is adjustable in the Extended version). Dividing 1000 by 618 equals 1·6181229, and so it seemed reasonable to multiply the count value by 1·618 to convert it into a meters value.

Two bytes are used to represent 1·618 as a binary value, the MSB holds the value of 1 and the LSB holds a value of 158 ($256 \times 0{\cdot}618$ = integer 158). An additive technique is then used to divide the count by this binary value.

The answer is decimalised and output to the LCD as a meters reading. (Although the answer is to three decimal places, the accuracy is realistically only within a centimeter or so.)

The binary meters value is also divided by the binary representation of 25·4 (MSB 25, LSB 102 – because $256 \times 0{\cdot}4$ = integer 102) to obtain an inches value. This, in turn, is converted to feet with the remainder in inches. Both are decimalised and displayed on the LCD.

EXTENDED PROGRAM VERSION

The original program for this PIC Tape measure was called TAPE99, but several months elapsed between designing the project and writing this text.

During the writing of this article, the author decided that the addition of fine "tuning" options would be beneficial, allowing minor corrections to be made to the values used for calculating distance and the masking offset.

The following paragraphs discuss how these adjustments are made. The software prog-ram to which they refer is coded TAPE100. How to obtain it is detailed at the end of the article.

TIMING ADJUSTMENTS

In most instances, it is unlik-ely that any further adjustment to the default timing values will be necessary, and will only be minor if they are needed. The first stage of alignment, though, must always be carried out on a newly assembled unit.

Stage 1

When the LCD contrast has been set and the opening message is clearly seen (as described in "First Tests" section earlier), switch off.

With Recall pressed, switch on again and then release Recall. At the top right of the opening message, "BOX" will be replaced by "CLR." This action clears the entire contents of the EEPROM data memory and places the timing default LSB values into the final two bytes.

The default values are 158 for Basic timing at EEPROM byte 62, and 234 for Mask timing at EEPROM byte 63.

Stage 2

The bias on TR1 must be about 0·3V for the second stage of alignment, to minimize the echo sensitivity.

Switch off, and with the Send button pressed, switch on again and release Send. The screen will change from the opening message to the distance display with the top line showing “TEST158” preceded by a flashing “S”. In this mode the ultrasonic pulses are repeatedly transmitted and the target distance displayed. Mask is automatically set to a value of zero.

Typical screen display during normal measurement mode.

The value of 158 can now be changed upwards or downwards by pressing the Store or Recall buttons respectively. The rate of change is about one digit per second.

Place the unit facing a wall at *exactly* one meter distance from the front of the transducers. Press Store or Recall until the displayed meters reading shows 1000 meters. Store increases the LSB value and the distance shown; Recall decreases them. The change of the distance value is much slower than that of the LSB.

The Basic timing is now set. Switch off.

Stage 3

With Mask pressed, switch on again and release Mask. The LCD screen will change from the opening message to the distance display with the top line showing “TEST234” preceded by a flashing “M". In this mode the ultrasonic pulses are again repeatedly transmitted and the target distance displayed. The Mask value, though, is automatically set to one.

Adjust the bias on transistor TR1 to about 5·5V, giving greater echo sensitivity.The value of 234 can now be changed upwards or downwards by pressing the Store or Recall buttons, respectively. The rate of change is still about one digit per second.

Place the unit a few meters away from a wall, without intervening furniture in the way.

Note the distance reading. Now repeatedly press Mask and note the reading at each mask sett-ing. If the Mask alignment value is correct, the readings should be just about identical. If nec-essary, use Store or Recall to change the value accordingly.

That completes the alignment. The new values are automatically stored in the EEPROM during the process and will be those used for future measurements. You may change them at a later date if you wish to, using the same techniques.

SWITCHES SUMMARY

In summary, during the alignment procedures the switches have the following roles:

Switch pressed while switching on:

- Send – Basic correction mode
- Store – EEPROM measurement clear (timing factors untouched)
- Mask – Mask correction mode
- Recall – Clear entire EEPROM data and set default timing factors

While in Basic and Mask correction modes:

- Store increases displayed timing value
- Recall decreases displayed timing value

SOFTWARE SOURCING

The source code text files (.ASM) show all the routines, with comments where appropriate. They were written in TASM.

The files for TAPE99 (Standard program) and TAPE100 (Extended program) are available for free download from the EPE Online Web Site at **www.epemag.com**

The pre-programmed PIC, available from Magenta Electronics, contains the TAPE100 program.

For more information about obtaining the software and pre-programmed chip, also see the Shop Talk page in this issue.