# Constructional Project

# PIC LCF METER

## JOHN BECKER

*Simple monitoring of inductance, capacitance and frequency values*

**T**HIS simple PIC-based unit was designed to measure and display the values of inductors and capacitors. As a by-product of the technique used, it can also display the frequency of an external 0V/+5V signal source.

The ranges are approximately:

| | |
|---|---|
| *Capacitance:* | 1pF to 6500$\mu$F |
| *Inductance:* | 1$\mu$H to 10H |
| *Frequency:* | 0·05Hz to 5MHz |

## OSCILLATOR CONCEPTS

The design is based upon the concept that oscillators can be constructed from CMOS NAND gates or inverters, and that their oscillation frequency depends on the values of inductance, capacitance and resistance in their feedback paths. The principles were discussed by George Hylton in his two-part series *Logic Gate Inverter Oscillators* of Sept/Oct '02.

Using a suitable microcontroller, such as one from the PIC16F62x or PIC16F87x families, software can read the frequency of an oscillator and calculate the value of an unknown component if the values of the other components are known. In this design, a PIC16F628 is used and the results are output to an alphanumeric liquid crystal display (l.c.d.).
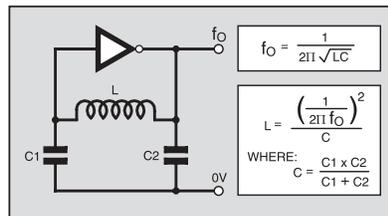


Fig.1. A basic inductance and capacitance (LC) oscillator.

One technique for using an inductor in a CMOS oscillator circuit is that shown in Fig.1. Here the oscillation frequency is determined by the formula:

$$F = \frac{1}{2 \times \pi \times \sqrt{(L \times C)}}$$

where:

F = frequency

$$C = \frac{C1 \times C2}{C1 + C2}$$

L = inductance
$\pi$ = 22/7

Using this formula, if any two values are known, the third can be readily calculated. For instance, if C and F are known, then L can be calculated using the formula:

$$L = \frac{\left(\frac{1}{2 \times \pi \times F}\right)^2}{C}$$

Similarly, using the capacitance-resistance oscillator configuration shown in Fig.2, the output frequency can be calculated for known values of R and C. Several formulae exist for this calculation and the one used in this application is:

$$F = \frac{1}{\pi \times R \times C}$$

from which the value for C can be calculated if R and F are known:
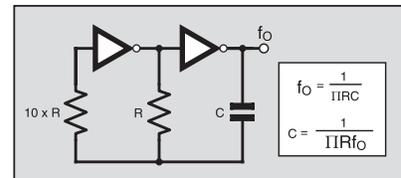
$$C = \frac{1}{\pi \times R \times F}$$



Fig.2. A basic capacitance and resistance (CR) oscillator.

## FREQUENCY TO PIC

Referring to the full circuit diagram for the PIC LCF Meter in Fig.3, two independent oscillators are used, one based on inductance and capacitance (LC) values, the other on capacitance and resistance (CR) values.

The LC oscillator is formed around NAND gate IC3a. The inductance is provided by inductor L1, used in series with the external inductor whose value needs to be measured. The external inductor is connected across probe clips P1 and P2 and switched into circuit by rotary switch S2 in position 1. The capacitance is provided by capacitors C5a, C5b, C6a and C6b.

Two pairs of capacitors are used so that the value of C in the LC formula is simple for the software to process. The values for each of the four capacitors is set at 10nF.

Fig.3. Complete circuit diagram for the PIC LCF Meter.

Therefore the parallel value of C5a/b = C6a/b = 20nF (a value not obtainable in standard capacitor ranges). In the formula, as expanded above, the value for C is thus 10nF.

A preset potentiometer, VR2, is also included in the feedback path. Its principal purpose is to ensure that oscillation starts reliably and then continues in a stable manner. The effect is due to its relationship with capacitors C6a/b, which impose a more pronounced phase shift on the signal being fed back through the inductor than the output of the gate itself can allow.

Potentiometer VR2 also has the side effect of providing a degree of frequency control, although this is not important in this application.

In use, the inductor whose value is to be measured is placed in series with L1. The latter provides a minimum inductance value against which the circuit is "nulled" prior to taking measurements. Its use minimises the effect of stray fields within the physical circuit assembly.

The CR oscillator is formed around NAND gates IC3b and IC3c. The maximum frequency at which the oscillator runs is basically set by resistor R4 and capacitor C7. The external capacitor whose value is to be measured is connected between the probe clips and switched in parallel with C7 by switch S2 in position 2. As with L1, C7 provides a minimum reference against which the circuit is "nulled".

Because the reference value has been set to be high enough to effectively "swamp" stray capacitance into an unimportant role, the software is capable of discerning very small capacitance differences, typically from 1pF upwards.

It should be noted that the value of resistor R3 also has an effect on the oscillation frequency. In this circuit it has been chosen to be ten times the value of R4 and is ignored in the frequency calculation formula.

## GATE CONTROL

The use of NAND gates in this circuit allows the oscillators to be selectively turned on and off by the PIC microcontroller, IC1.

The LC oscillator becomes active when IC3a input pin 12 is taken high by PIC pin RA0. When RA0 is low the oscillator is inhibited, with IC3a output pin 11 being held high.

The CR oscillator is similarly controlled. PIC pin RA1 when high allows the IC3b/c configuration to oscillate. When RA1 is low, the oscillator stops with IC3b output pin 4 held high.

The outputs from IC3a and IC3b are jointly fed to the inputs of NAND gate IC3d. When IC3a is oscillating, its frequency is passed through IC3d via pin 9 since its other input, pin 8, is held high by IC3b's output pin 4. Conversely, when IC3b/c is oscillating, its frequency is passed through IC3d via pin 8 since pin 9 is now held high by IC3a's output pin 11.

As only one oscillator can be selected at any time, there is no conflict of frequencies passing through IC3d. The output from IC3d pin 10 is fed via resistor R5 to PIC pin RB6. This pin is used as the input to the PIC's TMR1 16-bit counter/timer.

## FREQUENCY CAPTURE

For high frequency monitoring, the PIC is set for non-synchronous input to TMR1 and input rates in excess of 5MHz can be registered correctly. It is this fact that also makes this circuit suitable as a frequency counter up to about 5MHz.

For external frequency counting the signal is input directly to PIC pin RB6 via socket SK1, with resistor R5 providing a buffer between the signal and the output of IC3d. The resistor also provides a buffer when the PIC is programmed in-circuit from a system such as *PIC Toolkit TK3* (Oct-Nov '01) – see later.

The frequency output from IC3d can be connected via R5 and socket SK1 to an external frequency counter suited to accepting normal logic-level signals.

## MODE SELECTION

As stated earlier, the function of switch S2 is two-fold. The component to be measured, either inductor or capacitor, is connect via crocodile clipped leads (P1 and P2) to the poles of S2a and S2b. The switch is set so that the component is connected to its appropriate oscillator circuit. There is no danger of component or circuit damage if the wrong switch setting is selected. It will be obvious from the measured results if the wrong path has been chosen!

The second function of switch S2 is to inform the PIC which type of component it is to measure. This is controlled by S2c. When in position 1, S2c connects the +5V line to PIC pin RA4. In position 2, RA4 is held at 0V via resistor R6. Software monitors the logic on RA4 and reacts accordingly.

Switch S3 is a push-to-make type and is used to "null" the circuit prior to taking measurements. It is monitored by PIC pin RA2, which is biased low by resistor R2 when S3 is not pressed.

Switches S2 and S3 are also used to set "corrective" factors should any be found necessary, as discussed later.

## OTHER COMPONENTS

The results of component value calculations are output to the 2-line by 16 characters per line l.c.d., X2. Preset VR1 sets the l.c.d.'s screen contrast.

The system is operated at 3·2768MHz, as set by crystal X1 in conjunction with capacitors C3 and C4. It can be powered at between +7V and +12V d.c., at about 9mA for a 9V supply.

Regulator IC2 reduces the input supply voltage to +5V, to suit the PIC and the l.c.d. Capacitors C1, C2 and C8 help to ensure additional power line stability.

Connector TB2 is in the author's standard configuration for programming PICs *in-situ* should readers wish to modify the software. Brand new PICs should *not* be programmed via this option due to the configuration settings installed during manufacture (adverse LVP setting). Such PICs should only be programmed on the board of a dedicated PIC programmer.

Diode D1 and resistor R1 prevent the programming and unit supply voltages from interacting. (They must be retained even if on-board programming is not required.)

## CONSTRUCTION

Component position and track layout details for the PIC LCF Meter's printed circuit board are shown in Fig.4. This board is available from the *EPE PCB Service*, code 434.

In order to obtain the best potential accuracy from this unit, components C5a, C5b, C6a, C6b, R3 and R4 should have the best

tolerance that you can obtain. Ideally all should be 1% devices, although capacitors having such close tolerance are not widely available and you may have to accept 2% or 5% for them. The software has an offset compensation facility should you need to correct displayed values upwards or downwards in the light of experience.

Assemble in your own preferred order – that preferred by the author is wire links, i.c. sockets, and then in ascending order of component size. Ensure that electrolytic capacitors and the semiconductors are inserted the correct way round, but do not insert IC1 and IC3, or connect the l.c.d. (whose p.c.b. connections are in the author's standard order, also see Fig.4), until the correctness of the power supply has been checked. The latter should only be done once you are sure that everything else is correctly positioned and soldered.

Note that inductor L1 is mounted vertically on the board, with its other lead trimmed to serve as a terminal pin. In the prototype it was originally mounted flat on the board but it was found that this caused instability in the oscillation frequency due to the proximity of a signal-carrying p.c.b. track running in parallel with the inductor.

The switches and socket SK1 need only be temporarily connected at this stage, wiring them permanently once the case has been prepared and assembled. Adjust S2's lugged washer so that only positions 1 and 2 can be selected.

In the test model, extra-flexible wire was used for the probe leads, about 15cms long, terminated in miniature crocodile clips with different coloured insulating covers indicating their polarised identities.

For the prototype, a plastic case (the author's "orange box" again!) measuring 150mm × 80mm × 50mm was used, having been suitably drilled for the panel-mounted components (see photograph). Note that the author did not use 0V socket SK2 (see later).

## TESTING

When initial checks have been made, connect the l.c.d., insert IC3 and the pre-programmed PIC microcontroller.

Switch on power and recheck that the +5V supply voltage is still correct. Then adjust preset VR1 until the l.c.d. screen contrast is satisfactory. Switch off power and then go through the following main check routine:

Set switch S1 to position 2 (capacitance). Leave the probe clips unconnected (open circuit). Switch on the power. The screen will first briefly display an opening message on line 1, EPE LCF METER, followed by CAPACITOR, with WAITING TIMING on line 2.

The software then assesses the frequency generated by the CR oscillator in relation to capacitor C7 and any stray capacitance present around the assembled unit.

Sampling is done at approximately one-second intervals, so that the frequency monitoring is in Hertz (cycles per second). After each sampling period, the frequency is displayed on screen line 1. Below it is



CAPACITOR
WAITING TIMING

shown the interpretation of that frequency in terms of capacitance. It will be wrong at this time, until the circuit has been nulled. With the prototype, the frequency at this stage is typically about 247000Hz with a displayed capacitance value of 1227pF.

This is the value which results from the exact value of capacitor C7 and any stray capacitance in relation to the values of resistors R3 and R4. When taking active measurements of a capacitor connected
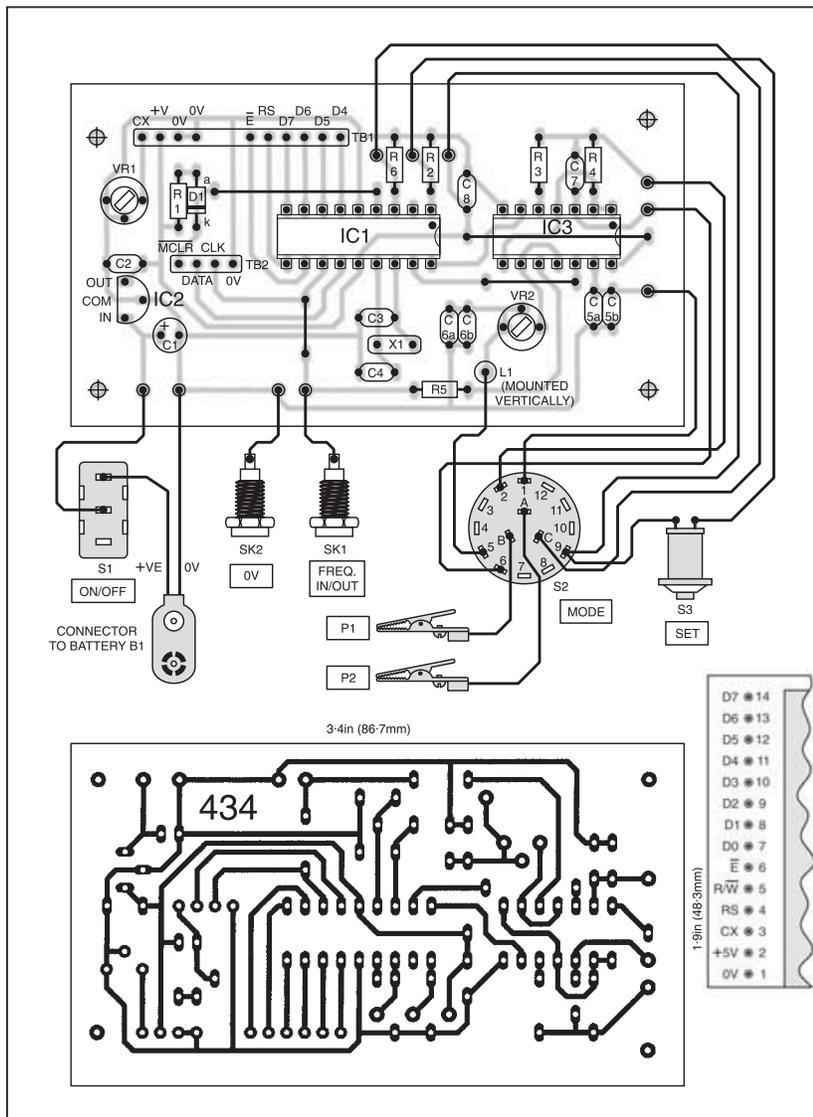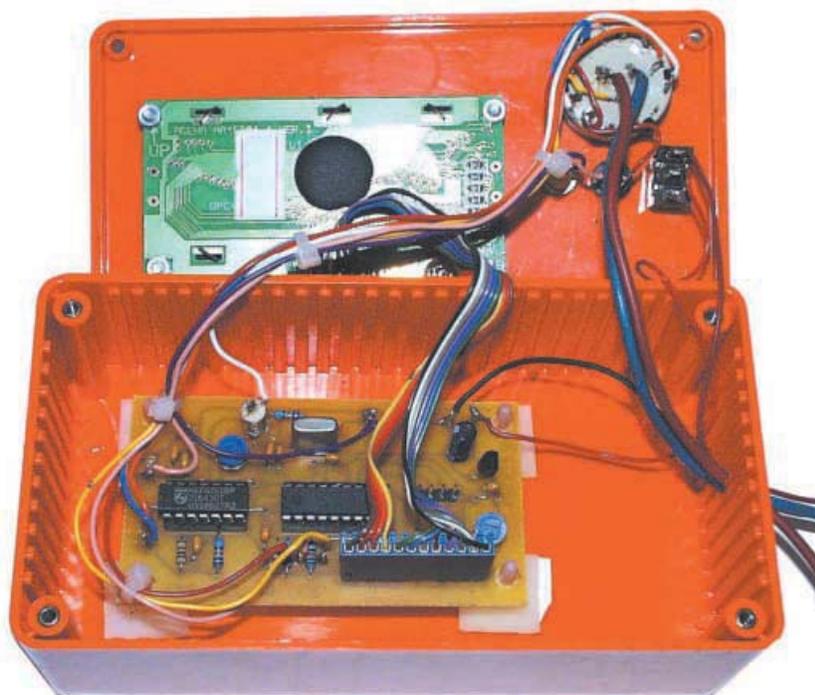
94

Fig.4. Component layout and master track pattern for the PIC LCF Meter. Typical l.c.d. pinouts are shown to the right.



between the probe clips, this "reference" value is subtracted from the result of the measurement. However, the PIC must be "told" that this is the value to use. At present it is subtracting zero from the value, as set when the power is switched on.

Pressing switch S3 sets the reference value into temporary memory within the PIC. This is confirmed by the word NULLED being shown on line 1, followed by the capacitance value being reset to zero on line 2.

Having released switch S3, the next sample value should also read zero until the capacitance across the probes is changed. Clip the probes to a capacitor nominally specified as, say, 1000pF and its actual value will be displayed on line 2. Note that the frequency value on line 1 is always the actual oscillation frequency and is not affected by the "nulling".

Be aware that the act of touching the probe leads with your hands will introduce additional capacitance across the probes, so do not hold them while taking value measurements.

A 470pF ceramic capacitor being monitored while this text is being written is producing a frequency of 177653Hz and, after the reference value has been subtracted by the software, is shown as having a real value of 492pF, well within its catalogue-stated tolerance of ±5%.
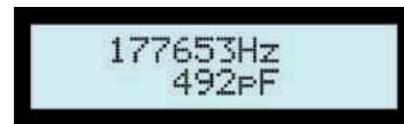


Now clip an electrolytic capacitor in place of the previous one, say a value of 1$\mu$F, correctly connecting the positive clip to the positive capacitor lead – an important point to note when measuring electrolytic capacitors, which are polarity sensitive, of course.

Observe the capacitor's displayed value on screen. Using a test capacitor while writing this, the screen shows a frequency of 311·138Hz and a value of 0·974$\mu$F (not a bad value for a 1$\mu$F capacitor whose tolerance is nominally ±20%!).

Two points are worth noting in relation to this displayed value. First, a different timing technique is used for frequencies that are below 1024Hz, in order to obtain better accuracy than with pulse counting for low frequencies.

In this mode, which is entered automatically if a frequency below 1024Hz (a binary "round" value) is detected, the PIC assesses the logic status of the signal on its RB6 pin. It then waits until this logic phase changes. It then starts a timing counter (TMR1) which runs until the pin status has changed twice more, representing a complete cycle of the waveform. At the end of this cycle the counter is stopped.

The count value, which is in relation to the 3·2768MHz crystal used, is converted into microseconds (T), and then converted into the equivalent frequency (F) for that timing (F = 1/T). In this mode the reference value is too low to be of interest and is ignored.

Secondly, this mode produces frequency results that have three places of decimals and a decimal point is displayed

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0.141Hz
2257.336uF
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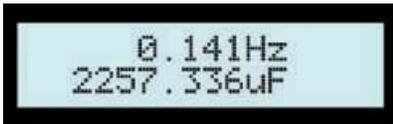
accordingly. Additionally the value is now expressed in microfarads ($\mu$F – but shown as "uF").

Now, if you have a capacitor to hand of, say, 220nF (0·22$\mu$F), clip it to the probes and examine the result. Taking one at random, the prototype displayed a frequency of 1305Hz, representing a value of 231·210nF. Note the "nF" suffix – the software, when registering a calculated value of less than 10000 (but which has not been obtained by the "uF" route), gives an "nF" suffix, but otherwise shows "pF".

Note that with larger values of electrolytic capacitor, you need to be patient while the values are assessed, since up to three logic half cycles may need to be processed – the initial logic level change, followed by one complete cycle. For instance, a random test with an electrolytic monitored as 5055$\mu$F had a full cycle period of 0·060Hz.

## INDUCTANCE TEST

To test the LC oscillator, switch S2 to position 1 (inductance) and clip the probes to each other (as a short circuit). In this configuration inductor L1 completes the feedback circuit for IC3a, which oscillates accordingly.

Adjust preset VR2 until the oscillation rate appears stable, as indicated by the frequency value shown on screen line 1. The setting will be obvious if an oscilloscope is used. If a scope is not available, try VR2 at various wiper settings and chose the best – it is not critical. In the prototype the author set the wiper for approximately three-quarters clockwise rotation (about 7k5).

Again the frequency and calculated results are shown on the upper and lower lines of the screen. In the prototype typical un-nulled values are 468608Hz and 11.492$\mu$H. Pressing "null" switch S3 the inductance value should read 0·000uH

Now clip an inductor of, say, 10$\mu$H between the probes. A typical display might then be 342348Hz, 9·969uH. In this case showing that the external inductor is pretty close to its marked value.

As with the capacitance mode, the pulse width assessment technique is used when the monitored frequency is below a certain value, 16384Hz for inductors. Again the frequency value is shown with three decimal places.

On the normal frequency counting range, values less than 100$\mu$H are displayed with a "uH" suffix, otherwise they are shown in millihenries (mH), i.e. 100.801$\mu$H would be displayed as 0·100801mH.

Values obtained using the pulse width technique are displayed in henries, with a suffix of "H", for example 7.305H.

Be patient when monitoring higher values of inductance, for the same reason as for larger values of capacitance.


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33490Hz
9.458uH
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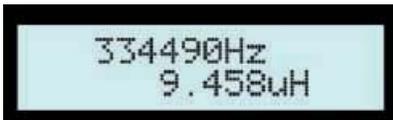
## FREQUENCY COUNTING

To monitor an external frequency, which must conform to normal logic levels (swinging between 0V and +5V), connect the signal source to socket SK1. Switch S2 may be in either position.

Resistor R5 prevents the signal from being adversely affected by the running of either internal oscillator.

Frequencies from about 0·05Hz to greater than 5MHz can be monitored.

Because switch S2 does not cause the internal oscillators to be inhibited during external frequency input, the displayed frequency will always be accompanied by an inductance or capacitance value on line 2.

Socket SK1 may also be used to feed the internal oscillator frequencies to an external frequency counter.

Note that if the LCF Meter is not powered by the same power supply source as the external signal source or frequency counter, then a common 0V (ground) connection between them must be provided via socket SK2.

In the prototype SK2 was omitted as the author always uses a common workshop power supply for all circuits.

## ALIGNMENT

In the event that the component values used with the oscillators are not exactly those for which the software has been written, compensation is possible through a routine selectable when the LCF Meter is first switched on.

With power switched off, set switch S2 for the capacitance or inductance mode you want to modify. Press switch S3 and hold it pressed while the power is switched on. On recognising the pressed status of S3 during its initialisation routine, the PIC's software jumps to the appropriate correction routine selected by S2.

This will be confirmed by a screen message on line 1 stating which correction mode has been accessed, for example CAP CORRECTION. On line two the existing correction value will be displayed. The default is 100.


```
CAP CORRECTION
100
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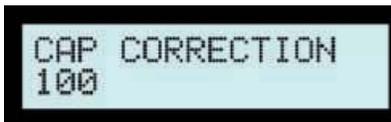
In normal running mode the calculated capacitance and inductance values are multiplied by the correction value and then divided by 100. For instance, if the correction value is 100, then there is no correction applied, since multiplying by 100 and then dividing by 100 is the same as multiplying by 1, so leaving the value unchanged.

If the correction value is 101, however, the effect is to multiply the value by 1·01 (a 1% increase). Conversely, if the correction is 99, then the effect is a multiplication by 0·99 (a 1% decrease). The range of correction values is 1 to 199, i.e. a multiplication range of 0·01 to 1·99.

When the screen shows that correction mode has been entered, release S3. Wait briefly for the software to exit a switch debounce routine (about 0·5 seconds). The correction value can now be changed using both S2 and S3.

If S2 is in position 2 (capacitor) then each press of S3 causes the correction value to be incremented. On the other hand, if S2 is in position 1 (inductance) then each press of S3 causes the correction value to be decremented.

Each press of S3 causes the new value to be stored to the PIC's internal non-volatile (EEPROM) memory, where it remains even after power has been switched off. (The "nulling" factors referred to earlier are not stored beyond switch-off.)

Each time the unit is switched on, the correction values for the two oscillator modes are recalled from memory and applied to each value calculation.

It would have required an extra switch to allow the software to be told to exit correction mode and the only way out of it is to switch off and then switch on again, leaving a suitable pause before doing so to allow the circuit's power line capacitors to discharge.

Correction for the other oscillator's routine is entered in the same way, first setting switch S1 to the opposite position prior to power-up.

## STABILITY

A point to appreciate is that this simple unit has no temperature compensation circuitry. The oscillator frequencies can and will drift with temperature changes. For higher capacitance and inductance values, especially those in the "$\mu$F" and "H" ranges, the drift is insignificant. For lower component values (i.e. higher oscillation rates), though, you should always "null" the meter prior to taking a measurement.

For capacitance nulling the probes must be open; for inductance nulling they should be closed (shorted).

Finally, **never** try to measure the values of components that are "in-circuit". At best, the existence of other components within that circuit is likely to result in incorrect readings. At worst, if the other circuit is powered, it and the PIC LCF Meter could be damaged.

## RESOURCES

The software for the PIC LCF Meter is available from the *EPE PCB Service* on 3.5in disk (for which a nominal handling charge applies). It is also available for *free* download from the *EPE* website, accessible via the Downloads click-link on our home page at **www.epemag.wimborne. co.uk** (path **PICs/LCFmeter**).

Read this month's *Shoptalk* page for information on component buying for the PIC LCF Meter.

## ACKNOWLEDGEMENT

```
1712.328Hz
0.846H
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