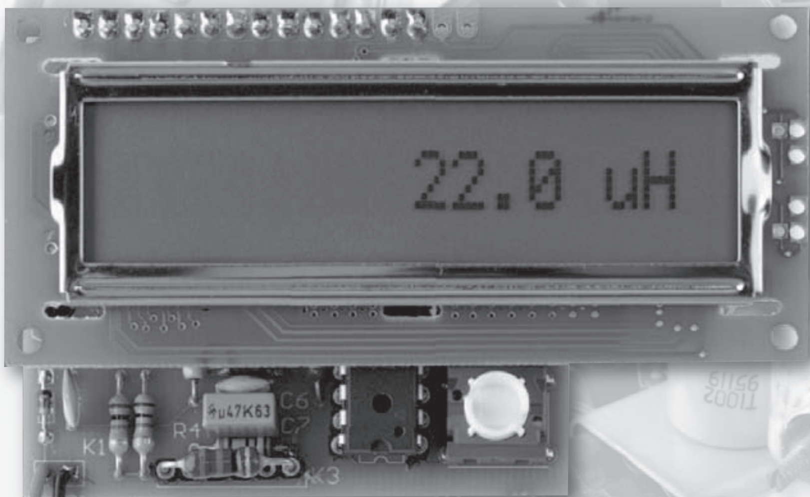
Coil Clinic



Coil Clinic is the name of this 100nH to 100mH single-range inductance meter with LCD readout. Reprinted, with permission, from *Elektor Electronics*, 6/2007.

Building the Device

This article originally appeared in *Elektor* magazine which is famous for providing a wealth of support for builders of their projects. The hard-to-find parts for this unusual inductance sleuth are available. The circuit card, processor, and a disk with the project software will all be available through Old Colony. For the remainder of the parts, contact Digi-Key, Mouser, and All Electronics as possible sources first. I suggest you access the various European suppliers for other unfamiliar parts.—E.T.D.

Atmega48-20PU, fully programmed
(Part # 060195-41)................................$9.75
PCB, bare
(Part # 060195-1)................................$14.25
***CD-ROM, project software**
(060195-11)..$9.75

*This software is also available free as a download from **www.elektor-electronics.co.uk**.

The inductor with its property "inductance" (symbol: *L*) is one of three lowdown passive components around which all electronics has evolved, the other two being the resistor (symbol: *R* for resistance) and the capacitor (symbol: *C* for capacitance). Of the three, the inductor is the one that seems to divide whole communities in two: you either love it or hate it. The latter opinion is held by many of the younger generation who get frustrated by inductances being present literally everywhere in circuits—but totally invisible! These "stray inductances" you need to develop a keen eye for. No problem for the seasoned radio amateur, but a source of confusion and headaches for newcomers cheerfully installing a 50cm long wire to carry a high-impedance millivolt AF signal from one board end to the other, and then wondering why Vatican Radio blesses their construction at nightfall, or (with less interesting stuff to listen to) mum's hairdryer!

Other skills most "simulation-generation" enthusiasts have difficulty mastering in relation to inductors include guesstimates of the inductance (i.e., the inductor's self-inductance and from there, its operating frequency) and winding one's own coils. The latter job is fraught with pitfalls and hassles: knowing the core and wire properties, number of turns, finding a suitable core, and understanding the difference between nano-, micro-, and millihenries (nH, μH, and mH, respectively).

To add to all the misgivings, few, if any, digital multimeters support inductance measurement. And to cap it all, the fixed and adjustable inductor industry is mostly Asian and Japanese (Toko, Murata, *et al.*) with a solid tradition of producing quirky type-designations and a lot of unbranded no-name aftermarket components.

In the end, most head bashing and objections against the humble inductor can be sussed out if help is available to "find out the value of the thing." And that's where Coil Clinic comes in.

Coil Clinic Quick Specs

- Measures 100nH to 99.9mH in one range
- 2% resolution (approximately)
- Direct readout on LCD
- Battery powered
- Battery status indicator
- 35mA current consumption
- ATMega48 microcontroller

PRINCIPLES OF THE MEASUREMENT

After some research, resonance-frequency measurement was found the best method available to make Coil Clinic work over the stated inductance range. Another method was abandoned but needs to be mentioned here for the sake of completeness.

Due to its self-inductance property, an inductor supplies a voltage that's proportional to the *variation* of the current it carries. Consequently, an inductor supplies a square wave when fed with a ramp (triangular) current.

The amplitude of the square wave is proportional with the rate of rise of the current and likewise with the inductance we're hoping to measure. In practice, an effect called "ringing" (damped oscillations) spoils the accuracy of the proposed method, not forgetting the inductor's series resistance wreaking havoc at lower frequencies.

The resonance frequency f_r of an *LC* network is not too difficult to calculate from

$f_r = 1/(2 \pi \sqrt{L\,C})$

Now, if C has a fixed, known value, then we can isolate L as

$L = 1/C\,(2 \pi f_r)^2$

and deduce it from the resonance frequency measured by a suitable circuit such as a microcontroller.

To prevent any kind of range switching, an oscillator was developed capable of covering a wide frequency range using one and the same, fixed, capacitance *C*.

The output of the wide-range oscillator is then fed to the microcontroller set up to "gate" its internal counter for 100ms before being disabled again. The result in this case is the output frequency divided by 10. Using the above formula (in software!) the microcontroller converts frequency to inductance value and shows the latter on a display.

PRACTICAL CIRCUIT

The theory (almost) over, we can have a look at the circuit diagram in **Fig. 1**. Not much there, really.

Because the microcontroller runs at "just" 20MHz, the highest frequency that can be accepted from the oscillator is about 8MHz. A normal Colpitts oscillator configuration cannot be used because the *Q* (quality factor) of the *LC* circuit will be low if small inductances are measured with a relatively small (fixed) *C*. After all, the internal gain of the oscillator has to be greater than unity (1) not just to overcome *LC* losses but also to afford the required high bandwidth of about 8MHz without stalling or trouble starting.

The AD8099 fast op amp from Analog Devices has a high open-loop gain coupled with a high input impedance to minimize the load on the *LC* network. In this special configuration, oscillation occurs not chiefly because the *LC* network impedance maximizes at resonance (as the textbook will tell you), but rather because the phase shift is zero degrees at resonance. This interesting characteristic affords quite accurate measurements as will be seen later.

Finally, the circuit is powered by a lowdrop low-power 5V regulator, which takes its input voltage from a 9V PP3 battery. Preset P1 is the LCD contrast adjustment.

SOFTWARE AND THE MICRO

The oscillator output is directly fed to the PD4 (counter) input of the ATMega48 microcontroller. This input is gated for 100ms under software control, and the resultant ÷10 signal (i.e., $f_r/10$) is “slow” enough for measuring, again in software. In fact, about 95% of the functionality of Coil Clinic is due to carefully designed firmware running in the ATMega chip.

Measurements and calculations were programmed in assembly language.

The source code (.asm) and object code (.hex) files for the project are available free of charge from our website (www.elektor-electronic.co.uk) as archive file **# 060195-11.zip** (June 2007). You may want to have the .asm listing available to be able to follow the discussion below.

Of two internal timers available in the ATMega48, one is used as a frequency counter, and the other to govern the 100ms gate signal. Use is made of the counters’ ability to generate internal interrupts on an overflow condition. The timer used as a counter has a width of just 8 bits. However, by incrementing a 16-bit register by 1 on each overflow, the effective width becomes 24 bits, which is ample for our purposes.

The timer “doing” the gate time is set up as an up-counter and features a prescaler. A fairly accurate gate timing is achieved by clever use of the prescaler and pre-load parameters.

Computing the L value from the measured frequency represents a heavy load to the micro. Sure, it can add, subtract, and multiply, but you will look in vain for assembly code instructions to do divisions. Like it or not, at some point it is required to divide a 24-bit number by another 24-bit number. A workaround was found in the use of the “long division” method we learned at school many moons ago. Here, it is done at bit level!

As the author discovered, writing a long division in assembler language is not accomplished during tea break, in fact it forced him to call in the help of the internal debugger in AVRStudio 4.0. The debugger was found to be an invaluable aid in tidying up the code, weeding out minor errors, oversights and the odd bungle, and generally tweaking the code.

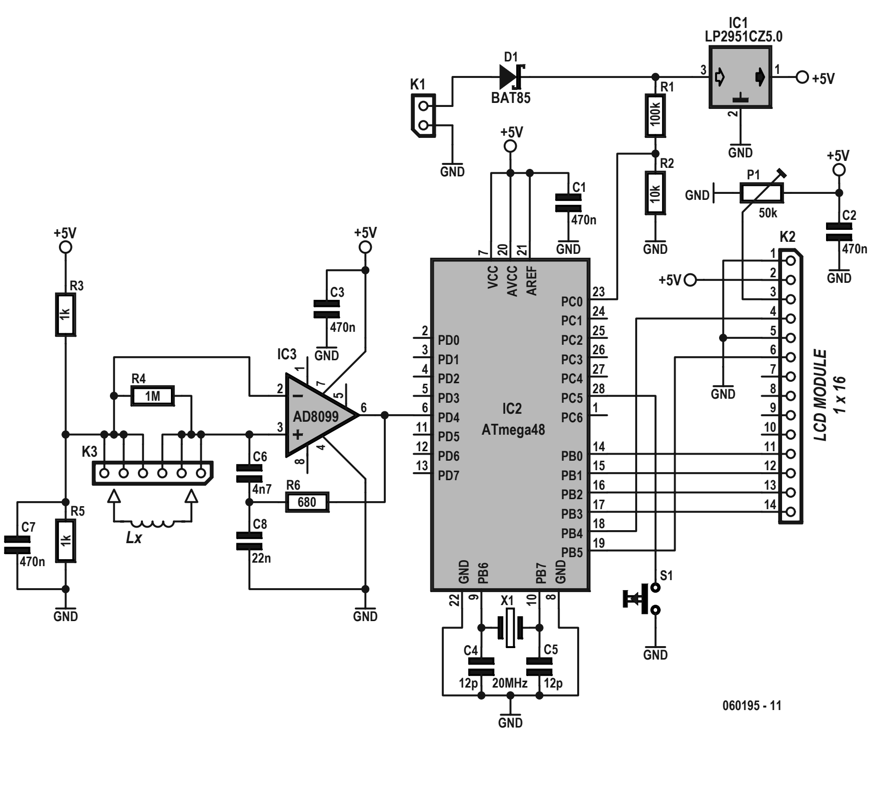


FIGURE 1: Hardware-wise, this is all there is to Coil Clinic—an ATMega driven inductance meter with direct LCD readout and no range switching. The crux of the circuit is the wideband oscillator around the AD8099 op amp.

CONSTRUCTION

Luc at Elektor Labs has again succeeded in designing a PCB for the project that’s so nice and clean we can safely print the copper track layout on our website and the component mounting plan in **Fig. 2**. As you can see, the board is double-sided with plenty of copper pour at the solder side to act as a ground plane.

The 8-pin AD8099 is an SMD component which will require the most attention when wielding the soldering iron. After the 8099, it’s all plain sailing as only through-hole parts are involved. The ATMega48 micro is best fitted in a 28-pin narrow-DIP socket. . . come again?. . . which is made from two strips of SIL pin receptacles cut to 14-way length.

Although the LCD is operated in 4-bit mode, the PCB has a 14-way connector, as we also need to cater for E (enable), RS (register select), contrast, and the LCD supply voltage.

The LCD may be a general-purpose device with 1 × 16 characters, as long as it has the HD44780 controller (or equivalent). For the lab prototype we used an MC16011A-STR from Farnell, order code 1ZZ0423, which can be plugged directly onto K2. Make sure you know the connections of the LCD module you intend to use.

Photo 1 shows the last prototype of the meter. Preset P1 was improvised, but its footprint is correct on the final PCB layout. The unknown inductor is inserted into K3, a piece of SIL receptacle strip cut to 6-way length. Another piece may be stacked on top so you can easily replace it when it wears out or gets damaged. Two sets of three receptacles are in parallel to allow several lead pitches for these components. If you have to use wires between the board and “L_x,” keep them as short as possible. Do not touch the leads while measuring, on penalty of incurring a lot of stray inductance.

The finished board and LCD module should be easy to fit in a compact plastic or metal case with a battery compartment and an LCD window.

CALIBRATION

Do not attempt to calibrate the instrument if it does not work yet. With the microcontroller up and running you will see "OVER" on the LCD. Did you get the LCD contrast right with the preset? Good, continue. Short-circuit the L_x inputs and check that "NO VALUE" appears.

The calibration calls for two reference inductors, one 22µH and one 220nH (yes, that's 0.22µH). The first is for the correction factor measurement, which is required to level out the tolerance on the ceramic caps in the oscillator. The 220nH inductor, then, serves to compensate the length of the connecting tracks to L_x (and wires, if any).

From a batch of 5 to 10 220nH inductors (E12-series miniature chokes), select the one that comes closest to the *average* value of the batch (measured with Coil Clinic). The same is done for the 22µH inductor also needed for the calibration. If you find large deviations from 22µH (i.e., below 16µH or above 26µH), then the 12pF ceramic caps need to be reviewed. Best results are obtained if the uncalibrated meter achieves an accuracy of about 10% at this stage already.

Switch off the meter, depress S1, switch on again, and release S1. You will see the message: "Place L1 = 22.0µH" on the LCD. Connect the calibration inductor and press S1 again. Disconnect L_1 and connect the 220nH inductor (L_2). Press S1 again. With this inductor also checked and measured, Coil Clinic will display: "Calibration OK."

The correction factor and offsets so established are stored in the EEPROM in the ATMega chip and will be recalled and applied every time the instrument is switched on. Calibration is required only once, and afterwards the meter is ready for instant use.

The LCD will show an error message if L_1 or L_2 is not connected up, or if an out of the blue value is measured. Calibration data is then ignored until, during a proper calibration, values are available that do make sense.

ACCURACY AND RESOLUTION MATTERS

A deviation of 0.1µH equals only 0.45%,

ATMega48 Fuse Settings

This is a tricky one mainly because of the clock setting. If you get it wrong, the software will run so slow characters can be seen typed one by one on the display like an old fashioned RTTY. Screendump shows the settings on the Elnec SmartProg2 programmer in the Elektor Lab.

```
BOOTSZ = 11
BODLEVEL = 1
CKSEL = 1111
SUT = 11
```

which is negligible considering the total error of up to 2% caused by number rounding. The 2% resolution, in turn, is insignificant if you look at the tolerance stated for cheap off-the-shelf E12-series chokes, which is another way of saying that Coil Clinic can be pretty accurate, but it all depends on the accuracy of the calibration process.

PRACTICAL USE

KISS applies here: connect up the mystery inductor and read the value on the display! No range switching or estimating required.

Now try this at home:

- What happens if you spread the turns of an air–cored inductor?
- What if you insert a core (ferromagnetic or metal)?
- What if long connecting wires are used?
- Wind a coil loosely on a ferrite core, measure L_1, and then remove the core. Measure L_2. Hey, presto! The "μ_r" parameter of the core material equals L_1/L_2.

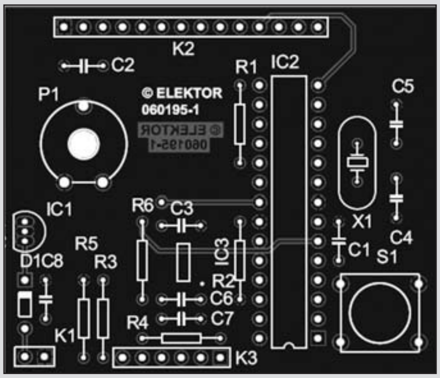


FIGURE 2: Double-sided PCB for the inductance meter.

COMPONENTS LIST

Resistors
R1 = 100kΩ
R2 = 10kΩ
R3, R5 = 1kΩ
R4 = 1MΩ
R6 = 680Ω
P1 = 50kΩ preset

Capacitors
C1-3, C7 = 470nF
C4, C5 = 12pF
C6 = 4nF7
C8 = 22nF

Semiconductors
D1 = BAT85
ICl = 78L05
IC2 = Atmega48-20PU (order code 060195-41)
IC3 = AD8099ARDZ

Miscellaneous
S1 = pushbutton, e.g., RA3FTL6 (Multimec)
X1 = 20MHz quartz crystal, low profile
Alphanumerical LCD module, 1 × 16 characters, HD44870 compatible (see text)
K2 = 14-way SIL pinheader
K3 = 6-way SIL receptacle strip (see text)
PCB, ref. 060195-1 from Elektor SHOP

Source and hex files for ATMega48, free download from www.elektor-electronics.co.uk

- Slide a small ferrite bead up a length of wire and see what happens.
- Measure the L value of a window or rhombic antenna and use it to calculate C required to tune for resonance in a specific frequency band.
- Find out the crucial A_L spec of an unmarked ferrite ring core—wind 10 (n) or so turns evenly on the core. Measure L, from which: $A_L = L/n_2$.

A special case exists with inductors larger than 100mH ("OVER" readout). These can be measured indirectly with the help of a reference inductor, as follows. First, measure the known inductor, note its value, and call it L_1.

Now connect the unknown specimen in parallel with L_1 and repeat the measurement, noting the value as L_2. The value of the large inductor, L_x, is calculated from

$L_x = 1/(1/L_2 - 1/L_1)$

For example, with L_1 = 47.5mH and L_2 = 45.0mH on the display we get

$L_x = 1/(1/45 - 1/47.5) = 855$mH.

In principle, inductors smaller than 100nH can be measured, too—simply connect a known inductor in series. However, the inductance of the connecting wires may cause problems; just remember that a wire piece with a length of just 1cm easily represents 10nH. "NO VALUE" is displayed if the meter "sees" a short-circuit or an inductance only UHF and SHF technicians care about.

The message "LOW BATTERY" will flash every 10 seconds or so if the battery approaches the "flat" state. The voltage measurement is performed by an ADC on board the ATMega48 chip.

Although measurements are still possible for a while, replace the PP3 as soon as possible. Fortunately, inductance measurements normally take little time to perform, so the battery should last for years. aX

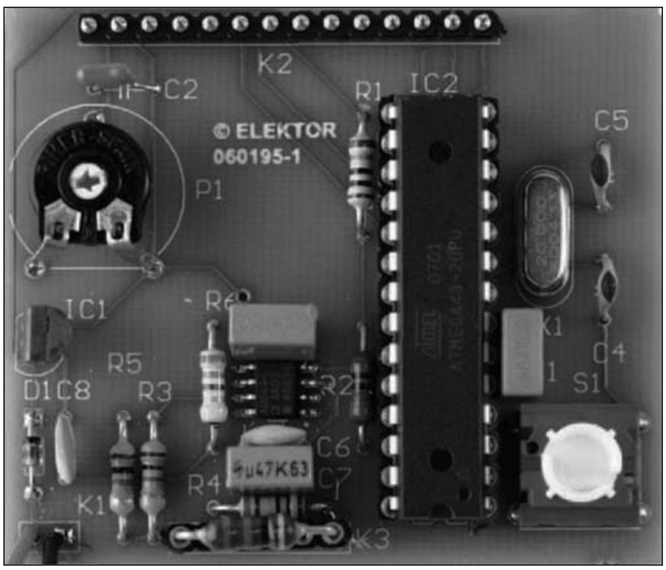


PHOTO 1: Prototype of the board. The footprint for P1 has been corrected in the final PCB artwork.