LCFesR 3.0 precise, wide range measuring unit

LCFesR 3.0 unit is a precise, wide range meter that can measure inductivity, capacity, frequency and equivalent series resistance of a capacitor in-circuit, which can be easily built with homemade one- or double-faced PCB and available electronic components.

During a project of my hobbies (building a dog/cat alarm unit) I had to check the value of an inductivity of a little transformer that I winded, but I could not because I had no such meter. So I tried to build an inductivity/capacity/frequency (shortly LCF) meter for my own use, which followed by the capability of measuring the Equivalent Series Resistance (shortly ESR) of capacitor inside an electronic circuit.

On the internet I found formulas of L and C calculations with the help of building LC and RC oscillator circuits around CMOS IC inverters. John Becker in his article in Everyday Practical Electronics Magazine - 2004 February dealt with the theory of the calculations and gave a practical application that used PIC processor. On the Internet I found some application of measuring ESR as well and liked bob Parker’s the best. His application used the Z86 processor. I used this information as a theory to make my new instrument that use AVR ATMega8-16PU processor. The unit is now named LCFesR 3.0. It took a lot of energy and some monthly works to design, redesign hardware, write, test and rewrite the software.

The measurement range:

- C: 1pF – 100000 µF (accuracy in 1-100 pF: 1-10%, from 100 pF: 1-5%, in calibration range: 1-2%)
- L: 10 nH – 30 H (accuracy: 10-100 nH: 1-10%, from 100 nH: 1-5%, in calibration range 1-2%)
- F: 0.1 Hz – 8 MHz (accuracy: 0.1-1%, 5V logic, 5-30V signal is measurable as well at 1-10 mA current restriction)
- ESR: : 0.020 Ohm – 30 Ohm (accuracy: 1-5%, from 1 uF)

<u>The base of L/C measurment:</u>

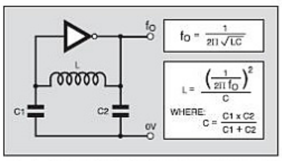


Fig.1. A basic inductance and capacitance (LC) oscillator.

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

where:

F = frequency

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

L = inductance

π = 22/7

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

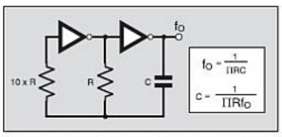


Fig.2. A basic capacitance and resistance (CR) oscillator.

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

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

The formulas speak for themselves. The microprocessor in the circuit measures the frequency of LC and RC oscillating circuits, from these data it calculates the inductivity, or the value of the capacitor.

The base of F measurment:

The instrument is able to measure a logic signal 5 V till 8 Mhz. In the case a bigger signal is required to be measured, **the current of the measured signal is needed to be restrained to 1-10mA** by using a current-restrained resistor (I measured a 30 V signal through a 30 KOhm serial resistor). The processor has got signal-processing units (spit, edge-detector, etc.) hence 0,1-1% accuracy is available.

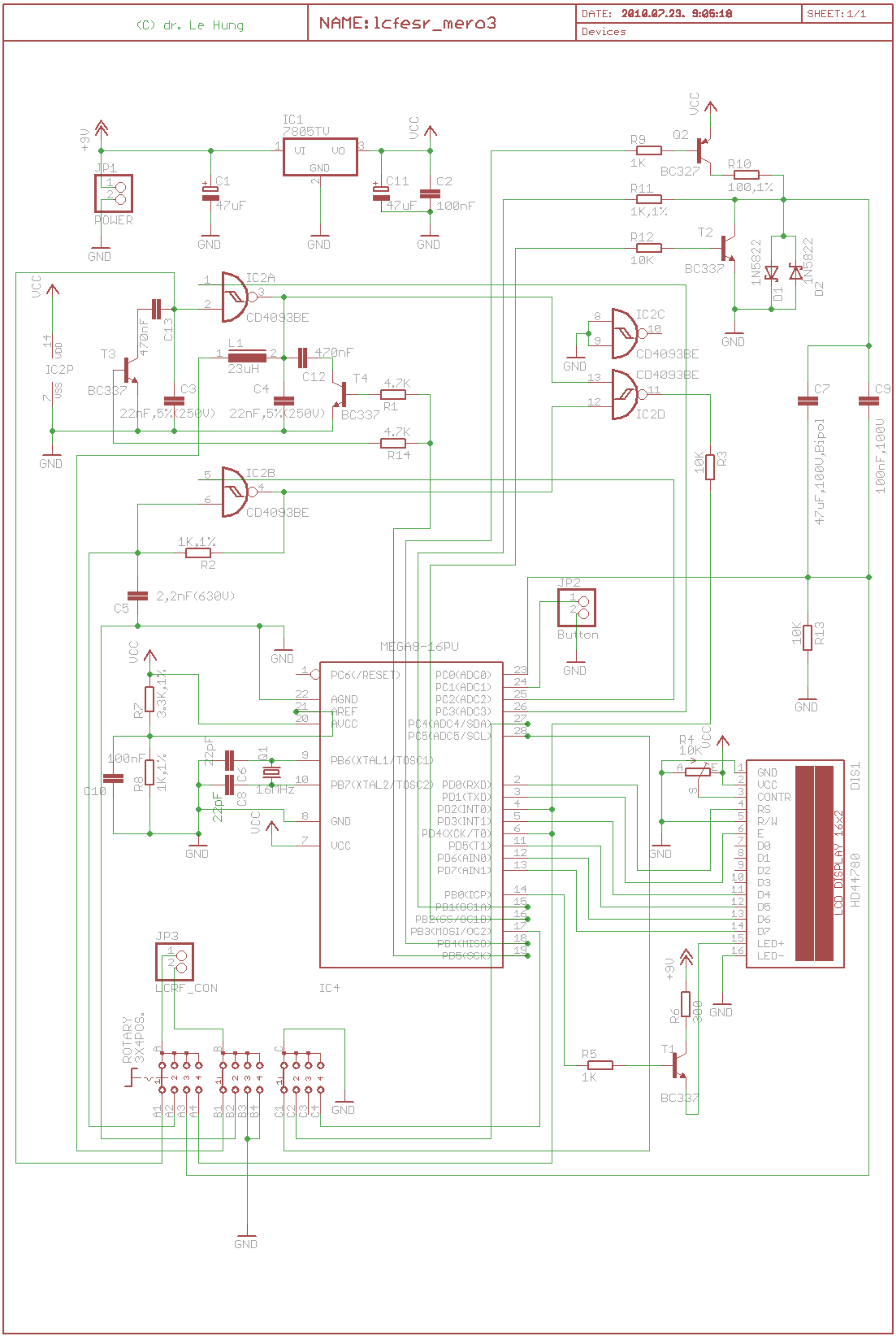
The base of ESR measurment:

Electrolyte capacitors using in environment with higher temperature or big current signals can run dry or hole, therefore they become useless. In this case their equivalent serial resistances (ESR) will become bigger. By measuring this value, it is ascertainable if the capacitor is still useable or if it should be replaced.

When developing the ESR-measurement function the aim was to assure that not only the ESR of a capacitor standing alone, but the **ESR of capacitor in an un-powered electrical circuit** should be measurable too. The in-circuit measurements can be simulated the simplest, if we bind 1-1 diode (the best is if we bind Schottky diode) abreast to the measured capacitor (or resistor) and measure them together. If this result and the ESR of the lonely measured capacitor are the same, then the meter was made for **in-circuit measurements**. To assure this, the measuring voltage should be reduced so much that the semiconductor in the circuit during the measurement should not conduct, so it may not affect the measurement. In case of LCFesR meter, the peak-peak voltage on the oscilloscope is about 300mV. Meanwhile at such low voltage like this, the capacity of the capacitor can not be measured accurately. So it is understandable that in commercial trade „ESR-meters” can be found without the ability of measuring capacity of capacitor. Consequently the ESR measuring function of LCFesR meter had to be designed so that the ESR measurement happens in a separate function and additional components also are used.

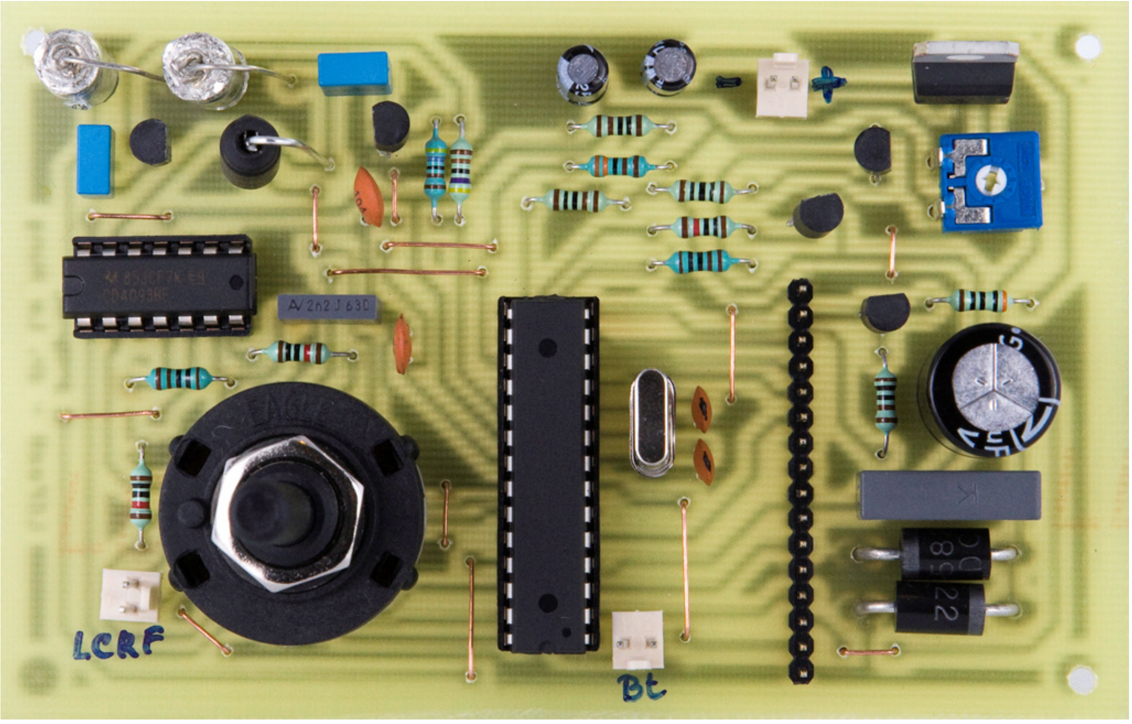
Before each measurement the meter tries to discharge the capacitors in the measuring circuit for a half second. Afterward by giving a 5mA or 50 mA current-pulse that holds about 10-12 us, the meter measures the voltage that falls on the capacitor or on the measured resistance. From this it calculates the value of ESR. Since this electricity impulses are so short that during it the capacitor with value as big as uF or bigger will charge very little, so it is negligible compare to ESR. The 10 us current pulse is followed by the 490 us discharge, which ensures that the capacitor will discharge. If the capacitor does not discharge perfectly the result will be false, because the meter is measuring the ESR and the voltage of the charged capacitor cumulatively. At case of measuring a charged capacitor, it is noticed that the initial high ESR values are continually decreasing, after a while it takes up a permanent value. The stably readable ESR is the fair value, because the capacitor this time has totally discharged and it has no effect on the measurement. **For this reason it is recommended to discharge every capacitor before measuring its ESR.** It should be noted that ESR is dependent on the measuring frequency, different meters may result a little different ESR measuring values. It is because meters can measure with different frequencies. In my opinion, the most important is not the absolute conformity, but to ascertain the quality of the capacitor. By measuring ESR, the same type capacitors but in much worse state are easily determined. Similarly the different ESR tables available on the internet should be used only as information guide, because the different ESR values depend on producer and measuring techniques. Different meters may measure a little different ESR values; however all of them may be able to filter out bad capacitors.

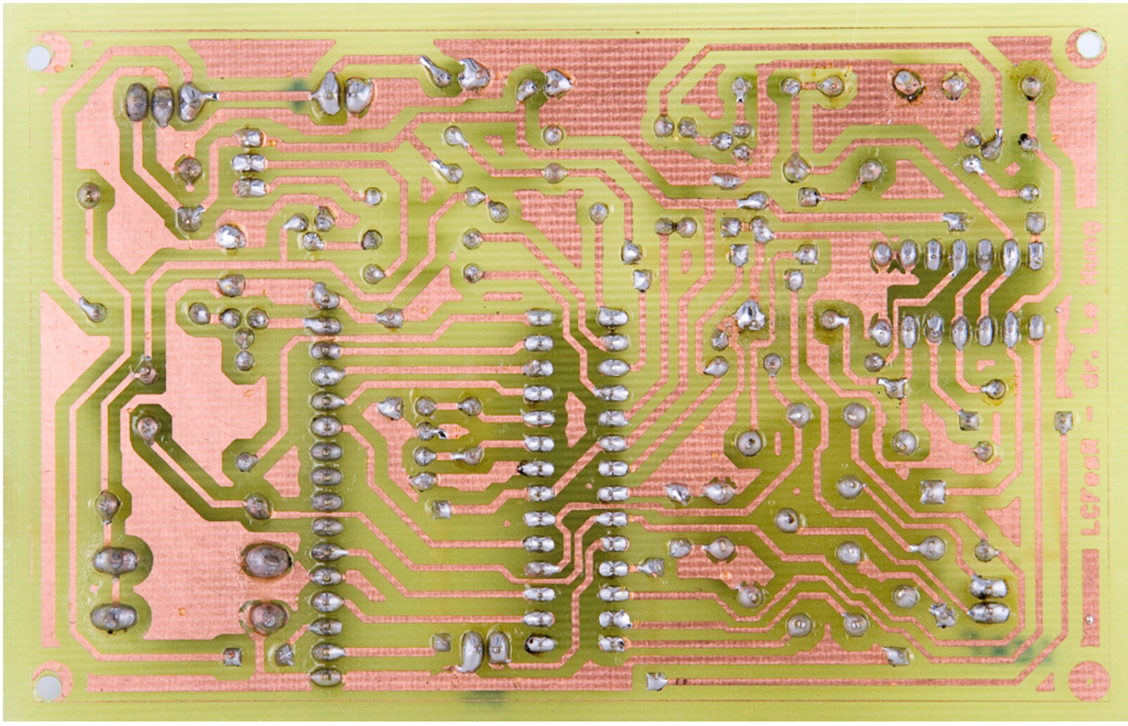
The circuit plan:



How to build the measuring instrument?

The instrument can be built from 1 or 2 sided PCB board. The meter built from 1 sided board is visible on the following 2 pictures:





Because of the easier availability, in the circuit plan 2 pieces of critical C3 and C4 capacitor has been given for 5% accuracy, however by using 1% accuracy heat-stable capacitors, the calibration of the instrument becomes simpler, or even without calibration it is accurate and stable. 5-10% capacitors are also useable; however in this case the instrument has to be calibrated. Using non heat-stable components it is possible that the NULL value in 10-100 nH range is unstable. Also the R2 resistor has been given for 1%, however if we use 0.1% heat-stable resistor, the C-measurement will be more stable in 1-100 pF measuring range.

The software nevertheless gives possibility to modify the reference value, so after calibration the instrument becomes more accurate. ***Attention! If there is a possibility, write down the values of C3, C4 components or measure them before soldering for the calibration later (including the values of C12 and C13 as well).***

While soldering the components, 2 things should be considered: **If axial inductor is used, it is better to solder it in a vertical position,** because in a horizontal position the tracks of the PCB board may disturb the retention of the stable resonance-frequency, simply because it's too close to the coil. Otherwise experiences show that stability of ESR-measurements can be enhanced, if one separate ESR-measuring cable is soldered out straight from the left exterior leg of the rotary switch and the other one is from GND.

On the circuit plan it is visible that C7 is a bipolar capacitor which can not be replaced with a polar capacitor. The reason is that if the measured capacitor is already charged by accident, then C7 will charge easily (D1/D2 help in it) and not go to ruin. Even so it is important to remember to measure ESR of discharged capacitor in an un-power circuit. Capacitor charged with high voltage may damage the instrument.

How to use/calibrate/zero the instrument?

On one hand, to assure accurate measurement, the "reference" components marked with % in the circuit or their resultant should be setup or adjusted. The process when these values are adjusted is called calibration. Otherwise in order to eliminate the impact of change in environment / temperature and measuring cables some times it is necessary to zero the meter. This process is called zeroing.

In opposition with some other instruments where usage of precise components is requirement, LCFesR does not require the application of them. It's because ***the software gives possibility to modify the reference values without using any further hardware***. The meter can be calibrated in two ways: we can setup the known values of the built-in components or in better way we can modify these values so the meter will shows the value of a known external component.

In my opinion stability of components (its value should not change radically when temperature changes) during functioning is more important than they should be 1% accurate. Of course the best is if the component is accurate and stable. In case of less stable components but in every case where a component with small value is being measured, zeroing the instrument can prevent the impact of temperature change.

It's extremely easy to use the instrument. The meter switches automatically to the correct measuring mode according to the position of the rotary switch: L / C / ESR or F. The instrument measures automatically and continuously in all mode. However if it senses that the frequency is less than 30Hz, it will automatically switch to period-time measuring mode, which takes a bit more time, but it produces a bit more accurate frequency, therefore more accurate L/C measurements too. In such cases at L/C measurements only one result is visible (by pushing the button or changing the component, new measurement can be started), and at F measurements it will wait for the push of the button.

When turning on the instrument for the first time it will warn the user to zero the meter (the instrument warns until the zeroing has been done).

If reference components were 1%, maybe calibrating is unnecessary or very little change in their values is needed. In case of using non-precise components or using components with different values the next process has to be executed. Press and hold the button for **11-13** seconds. The instrument shows the actual reference value or after a short time it displays the next value. **By push and release the button some times or pushing and holding it the actual value is changeable in steps or continually**. In case the meter is not sensing push for some seconds, it will store the value into the permanent memory that does not forget. Then it shows the next reference value and in some seconds it is waiting for being modified or exit from the calibration mode at the end.

The C reference value (REF_C) applied for measure L inductor is calculated from C3*C4/(C3+C4) formula. The result of calculation has to be adjusted in the REF_C parameter. Basically **REF_C = 11 nF** is the result of 2 pieces of 22 nF capacitors resultant: 22*22/(22+22)=11 nF. Instead of 22nF C3-C4 capacitors, 10nF-25nF capacitors also can be installed, so REF_C value could be changed between 4.9-12.5 nF. When measuring inductor with inductivity higher than 120 mH, in order to have a more accurate result the processor draws in C12-C13 capacitors to the measuring circuit. Resultant of C12, C13, C3 and C4 capacitors are about 230-246 nF. These values should be adjusted in parameter **REF_C+.**

R reference value (REF_R) applied for C measurement is changeable among 900-1100 Ohm range. Basically it is **997 Ohm.**

After calibration in L- or C-mode the instrument has to be zeroed. It's done by pushing and holding the button for 5-6 seconds.

Calibration of ESR measurement: By modifying the values of current restrictive R10 (100 Ohm), R11 (1000 Ohm) resistances, we can compensate the impact of different components, leading tracks, inaccurate of ADC reference-value, etc. Possibility of adjusting ADC reference-values is also ensured by the software.

ESR calibration has to be executed this way: push the press-button for 5-6 seconds to zero the measuring cables. After this, by measuring **1 Ohm 1%**, and **5.1 Ohm 1%** exterior resistors, we will see how much the values showed by the instrument differ from these values. If there is no difference the calibration is unnecessary, otherwise it has to be done. The 1 Ohm 1% resistor is needed for smaller (0-2.5 Ohm) and the 5.1 Ohm 1% resistor is needed for higher (2.6-30 Ohm) ESR-measurement's calibrations. First cramp the 1 Ohm 1% resistor, then press the button for 11-12 seconds, now we have entered the calibration mode. Here change the value of 98 Ohm showed by the software by pushing or pushing and holding the button. Depending on the early known deviation, adjust a few or more +- Ohms and wait some seconds till the software exits from calibration mode and start measuring. Check again the digression from 1 Ohm. Possibly the measurement will be good some adjustments. To calibrate 5.1 Ohm ESR-measurement we should modify the **995 Ohm** value. By entering the calibration mode again, do not change the first value that was adjusted previously. Wait until the software offers **995 Ohm** for modification. Now change this value. If it is ready, zero the meter, and then check 1 Ohm, 5.1 Ohm measurements again. So the calibration that should be executed once is now complete. During the calibration a third number can be visible too (base value: 4.3). This is important for **reference-voltage ratio for ADC-measurement. The value 4.3** concerns for 3.3 K (R7) and 1 K (R8) voltage-divisor ratio: (3.3 K + 1 K) / (1K)= 4.3. Mostly it is unnecessary, but by changing this value, calibration becomes more powerful in whole measuring range (at high and low values also).

Zeroing the instrument: ***in mode C leave the measuring cables (crocodile clips) open. In mode L and ESR close them and push and hold the button for 5-6 seconds***. If the process is successful the instrument will say OK. Zeroing process may be executed anytime, especially if a component with very small value is required to be measured. It is recommended to be done if environment / temperature / cables are changed. Values measured at zeroing process are also stored in EEPROM.

After calibration and zeroing process, the instrument is ready to be used. Using L/C/ESR measurements cables may be mixed without consequence; ***however at F measurements using correct poles is important***.

Basically the LCD panel is illuminated, but it can be switched off by pushing the button for 8-9 seconds. The meter remember this state even after it has been turn off. By pushing the button for 8-9 seconds, the LCD illumination can be switched on again.

I have made 2-2 minutes long videos about L/C/F/ESR measurements of the instrument that can be found on my site: ***http://members.upc.hu/lethanh.hung/LCFESRmero/en/***

Software has to be burnt into the AVR microprocessor installed in the instrument. A DEMO version is available to try out the meter. The DEMO is a fully functional version; however it allows measuring only for 5 minutes. After that the meter has to be turn off and on. With DEMO version the meter can be tried and checked out.

For those who can not burn AVR EPROM I can be contacted on my e-mail hutale@gmail.com. I can help in burning process. Who needs the full software that also can contact me on my e-mail.

The development of the meter required lots of work (a few months) so I can not give the full version of the software to the public.

Attention: both of HEX files have to be burnt (software in flash, data in EEPROM)!!!

Information and AVR burning tools can be found on the internet. Extremely simple LPT, COM and complicated USB devices can be made at home or bought from shops / web-shops.

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