LCFesR 4.5 precise, wide range measuring unit

LCFesR 4.5 unit is a precise, wide range LC / LCF / LCR / ESR meter (tester / checker) that measures inductance (L), capacity (C), frequency (F), small resistance (R) and equivalent series resistance (ESR) of a capacitor inside an electronic circuit (in-circuit). It can measure the internal resistance of a battery / rechargeable battery too. The meter can be built easily with one- or double-sided throughole PCB and available electronic components (DIY). It's functions are base on an further developed AVR ATMega88PA-PU microprocessor. An assembled, thoroughly tested and calibrated meter with 2-side professional SMD PCB together with an assembled LCD display is available.

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 ATMega88PA-PU or ATMega88P-20PU processor. I wrote the software from scratch and did not use any other source. The unit is now named LCFesR 4.5. It took a lot of energy and some monthly works to design / redesign hardware, write / rewrite and test the software. Especially ESR measurement mode has been implemented with several additions to increase the protection of the meter from charged capacitor, to discharge capacitor faster and so to speed up measurements. In the 4.5 version I introduced the LM311 IC (another type LC resonance) and with its help the meter can measure small value inductors in nH range more stably. However, the CMOS IC remained for the measurement of big inductance, because he is simply better in that area!

The measurement range:

Range	Accuracy	Notes
10nH - 1000nH	<5%	
1uH - 200mH	<2%	
200mH – 4H	<3%	
4H – 30H	<5%	
30H-100H	Informative	
0pF - 100pF	+-1pF	
100pF - 470nF	<1%	
470nF - 4700uF	<2%	
4700uF - 22000uF	<5%	
22000uF - 100000uF	Informative	
0 - 250mΩ	+-5mΩ	ESR / R (ESR of an electrolytic capacitor in-circuit is measureable too, from 1 uF)
250mΩ – 1Ω	<2%	
1Ω - 25Ω	<1%	
25Ω - 30 Ω	<4%	

0.01Hz – 6MHz	<0.1%	
6MHz - 8MHz	<2%	

The base of L/C measurment:

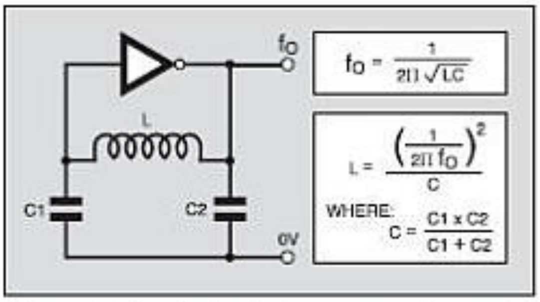


Fig.1. A basic inductance and capacitance (LC) oscillator.

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

where:

F = frequency

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

L = inductance

$\pi = 22/7$

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

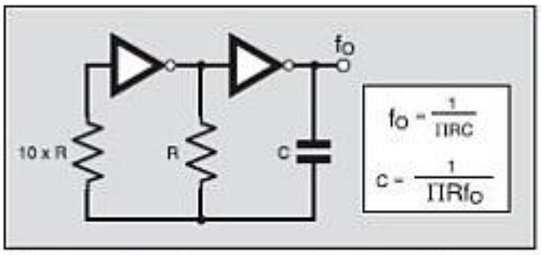


Fig.2. A basic capacitance and resistance (CR) oscillator.

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

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

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.

At L measurements the resonant frequency of the LC resonant circuit is also shown, making it possible to calculate the Q factor: Q = 2 * Π * f * L / R, where f and L are values the meter provides. R, however, the coil DC resistance can be measured with a simple multi-meter.

The LCFesR 4.5 meter can measure coils having value between 0.2H - 4H in two modes: **“'L>! "** and **“ L <! "** (See later). The difference between the two measuring modes is the resonance frequency (a few 100 Hz and few kHz). It is known that the permeability of some coils (transformers) depends strongly on the used (test) frequency, so that this property can be checked by comparing the results the two measuring modes give : the less different the two values from each other, the less dependent the permeability on the frequency.

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 KΩ serial resistor). The processor has got signal-processing units (spit, edge-detector, etc.) hence 0,1-1% accuracy is available.

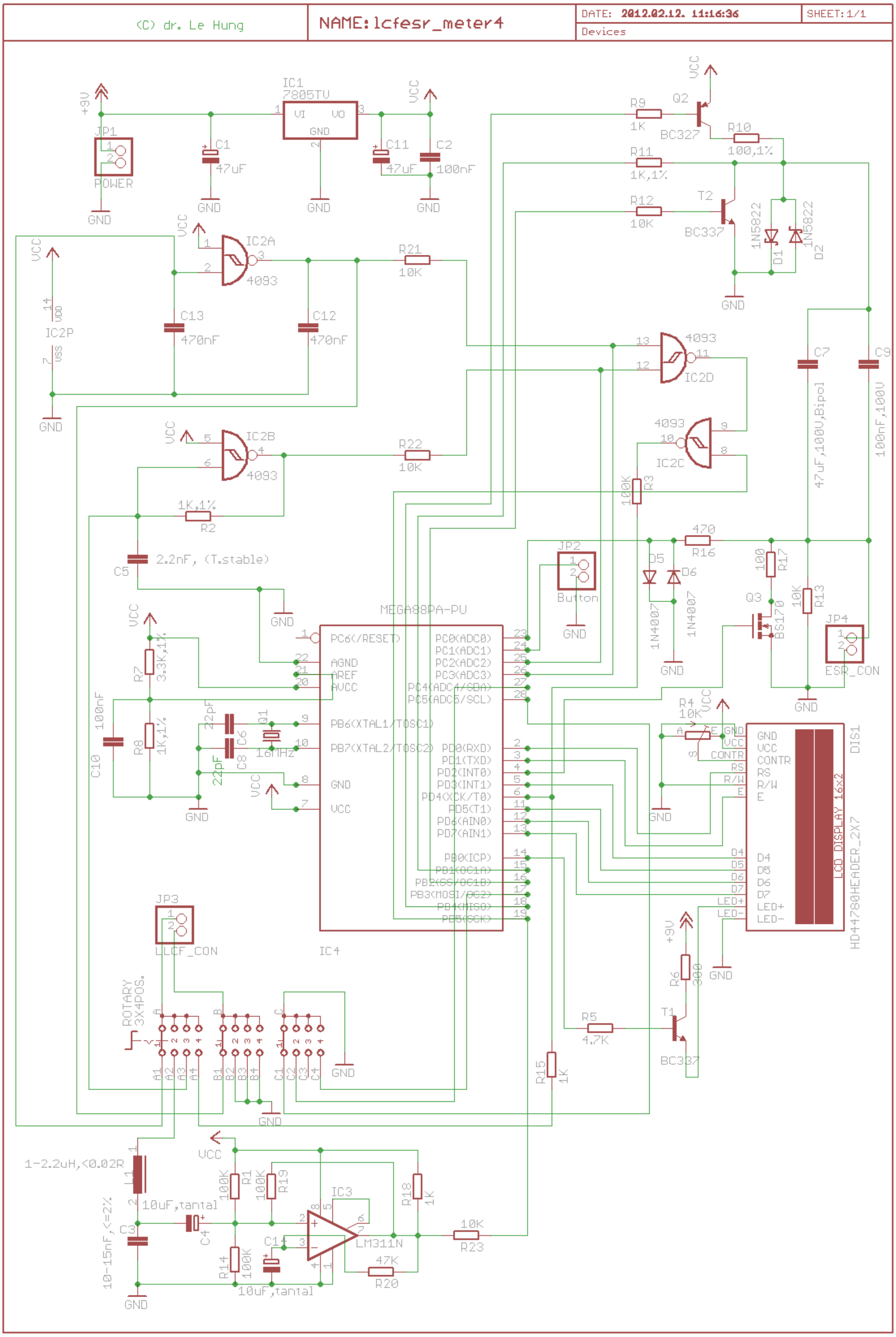
The base of ESR measurment:

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, on the one hand 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). Secondly to assure **polarity-independent ESR measurement** and to **protect the circuit under measurement as well as the meter itself** we should detach the DC component from the measuring sign. However by using small measuring voltage (max. 300 mV) and de-coupling capacitor the capacity of any capacitor can not be measured accurately under ESR-measurement. 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.

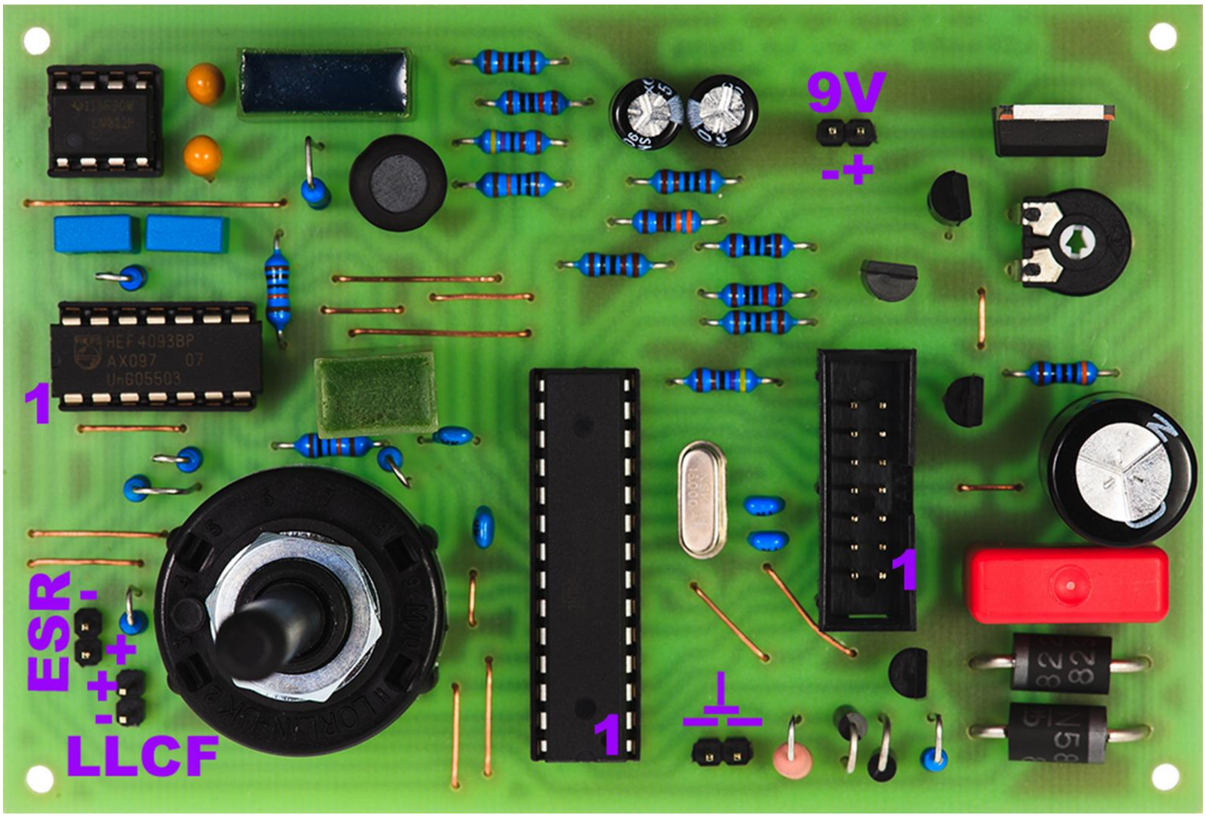
Before each measurement the meter tries to discharge the capacitors in the measuring circuit for a half second. Afterward by giving a 5mA or 50 mA current pulse that holds in very short time (matched to 100 kHz measuring frequency), the meter measures the voltage that falls on the capacitor or on the 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 current pulse is followed by the 500 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.

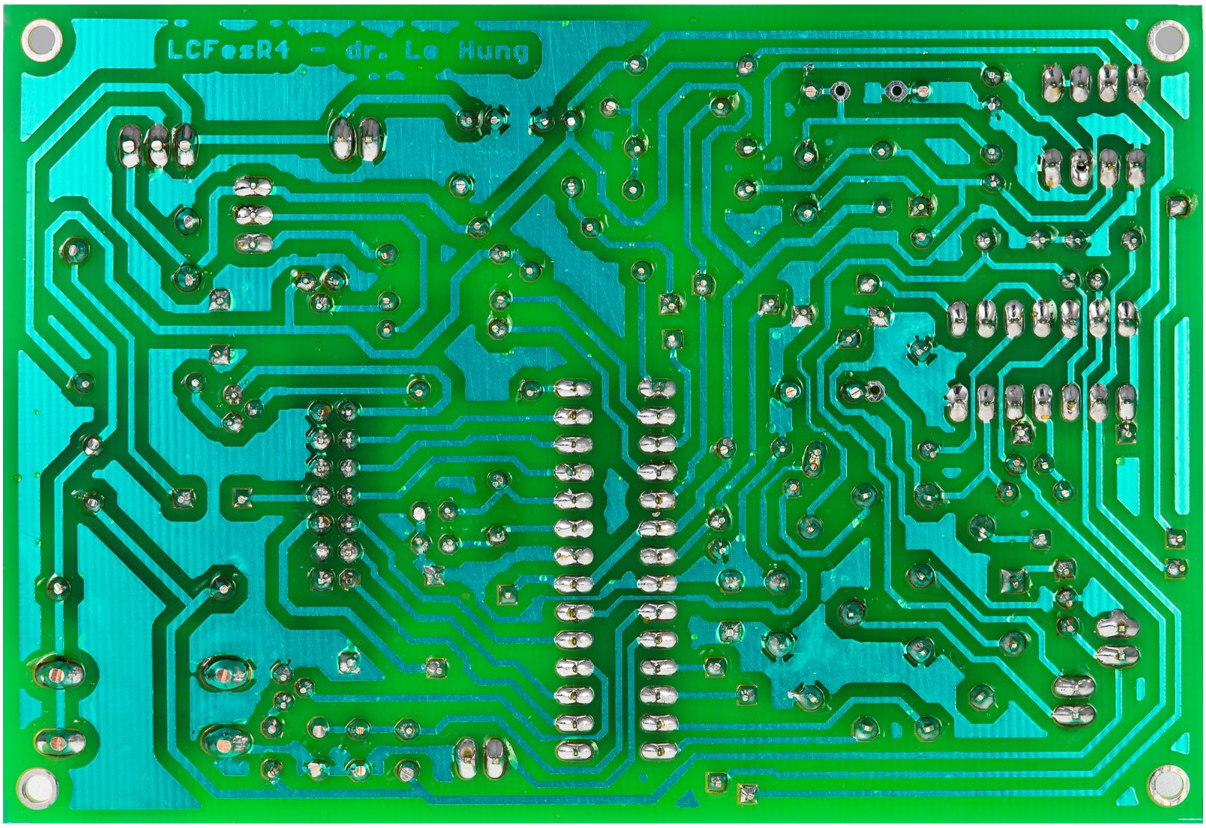
The circuit plan:



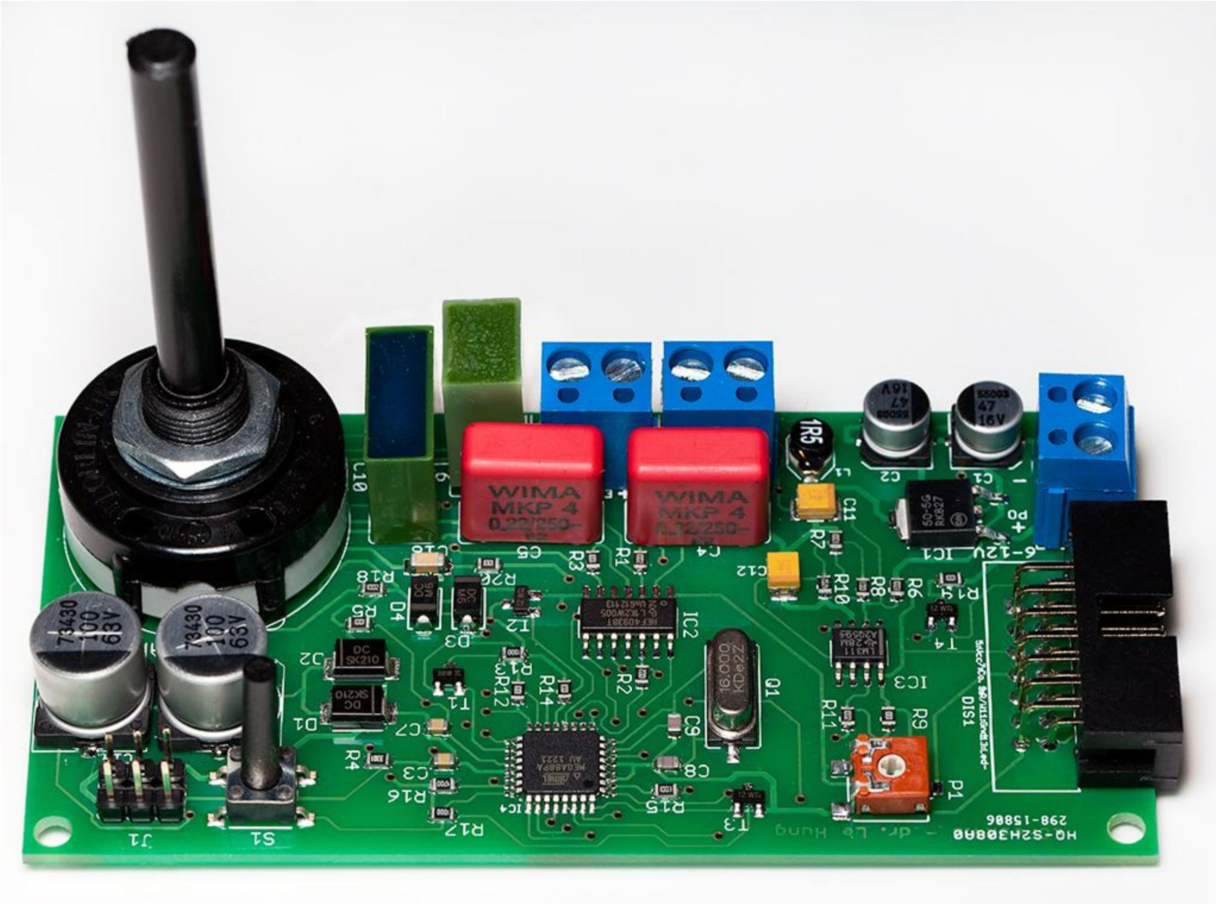
How to build the measuring instrument?

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:





The SMD version was built too. Both the through hole and the SMD version have the same functionality. The picture of the SMD version is the next:



In the circuit plan for small L measurements the critical **C3** capacitor has been given for 2% accuracy, however by using **0.5-1% accuracy heat-stable capacitor** (**best is polystyrene** but polypropylene is useable), 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. If using non heat-stable components, it is possible that the ZERO value and / or the measurements in 5-100 nH range is unstable. Likewise, it helps if the inductor **L1 has high Q factor and low resistance** (but no need to be precise). For C measurements the **R2** resistor has been given for **1%**, however if we use **0.1% heat-stable** resistor, the measurement will be **more stable** in 1-100 pF measuring range. Similarly, in the place of the capacitor **C5** it’s recommended to use heat-stable type! (No need to be precise).

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. Experience shows that **for stable ESR measurements, the test leads needs to be soldered to the connector pins ESR_CON on PCB! So do the same for the LLCF_CON connector!**

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, even with reversed polarity (D1/D2 help in it) and **not go to ruin**. The **D5/D6** also **protects the ADC input** of the processor from charged capacitor. Even so it is important to **remember to measure ESR of discharged capacitor in an un-power circuit**. Capacitor charged up to high (>100 V) 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 and easier 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> / L< / C (ESR) / F**. These are explained as next:

- **L>** : **200mH - 30H** inductance measurement mode. The meter is capable of measuring up to 100 H, but the accuracy may be degraded. At small (<0.2H) inductance’s measurement it outputs "**L<0.2H**" - then we should turn to the **"L<"** test mode! If there is no measurement, or if meter senses low frequency (when measuring big inductance), it displays **"Cyc.T?"** and **"L>!"** text alternately. Then simply **start to measure** any inductor or when measuring big inductor **press the button once** to start measuring the time period!
- **L<** : **10nH – 4H** inductance measurement. At big (>4H) inductance’s measurement it outputs **"L>4H"** - then we should turn to the **"L>"** test mode! If there is no measurement, or if meter senses low frequency (when measuring big inductance), it displays **"Cyc.T?"** and **"L<!"** text alternately. Then simply **start to measure** any inductor or when measuring big inductor **press the button once** to start measuring the time period!
- **ESR or C**: Basically meter is in a **1pF - 100,000 uF** capacitor (**C**) measurement mode. The **ESR** measurement mode (**0-30 Ω**) can be activated by *<u>pressing and holding the button for 2-3 seconds</u>*. The **C** measurement mode can be switched back by using the same method (pressing and keeping the button for another 2-3 seconds).
- **F** : **0.01 Hz – 8 MHz** frequency measurement mode. If there is no measurement, or if meter senses low frequency, it displays **"Cyc.T?"** and **"F!"** text alternately. Then simply **start to measure** any frequency or when measuring small frequency (<40 Hz) **press the button once** to start measuring the time period!

The instrument measures automatically and continuously in all mode. However if it senses that the frequency is less than 40Hz, 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). **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 4-6 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.

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 **7-11** seconds. The instrument shows the actual reference value matched to the actual mode or after a short time it displays the next value. **By push and release the button a few times or pushing and holding it, the actual value is changeable in steps or continually**. Now in the LCFesR 4.5 version **we can increase or decrease the value**. We do this by **choosing the operation in 2 s**, when meter asks us to do. Meter will shows **text "++>"** that means: the "next operation will be the **summation**" or the **text "--<"** that means: the "next operation will be the **subtraction**". By pushing right away the button we can change the operation. If we do not touch button in 2 s, then meter proceeds and shows the value. Here if **we push button** then meter **will add or reduce** the value **according to what operation we have chosen.**

If the meter is not sensing any 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 value of **C3** used in measurement of small inductances (LM311 IC + LC resonance), **REF_C =** can be between **10-15 nF**. The resultant value of **C12+C13** used in measurement of big inductances (4093 IC + LC resonance), **REF_C+ =** can be about **235 nF (**half of 470nF).

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

After calibration in L</C or ESR mode the instrument has to be zeroed. It's done by pushing and holding the button for 4-6 seconds.

Calibration of ESR measurement: By modifying the values of current restrictive R10 (100 Ω), R11 (1000 Ω) resistances, we can compensate the impact of different components, leading tracks, inaccurate of ADC reference-value, etc.

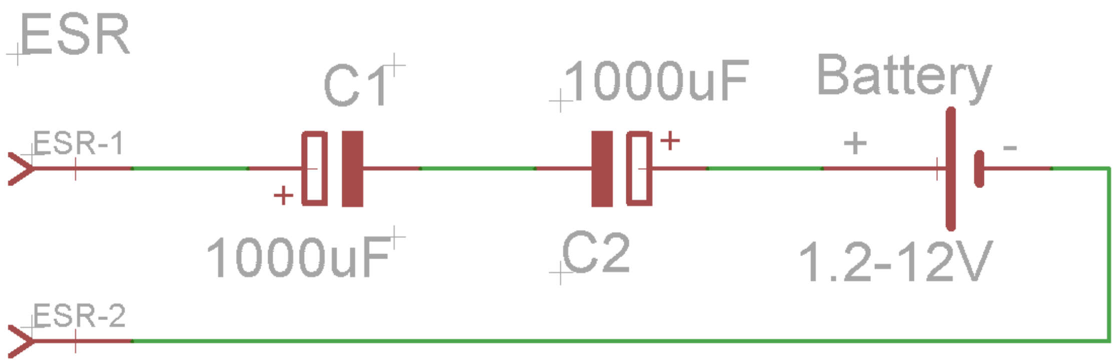
ESR calibration has to be executed this way: push the press-button for **4-6** seconds to **zero** the measuring cables. After this, by measuring **1 Ω 1%**, and **5.1 Ω 1%** exterior resistors, we will see how much the values showed by the instrument differ from these values. If there is no difference the calibration is unnecessary, otherwise it has to be done. The 1 Ω 1% resistor is needed for smaller (0-2.5 Ω) and the 5.1 Ω 1% resistor is needed for higher (2.5-30 Ω) ESR-measurement's calibrations. First cramp the 1 Ω 1% resistor, then press the button for **7-11** seconds, now we have entered the calibration mode. Here change the value of **100 Ω** showed by the software by pushing or pushing and holding the button. Depending on the early known deviation, adjust a few or more +- Ω and wait some seconds till the software exits from calibration mode and start measuring. Zero the meter and check again the digression from 1 Ω. Possibly the measurement will be good after some adjustments. To calibrate 5.1 Ω ESR measurements we should modify the **1000 Ω** value. By entering the calibration mode again,

do not change the first value that was adjusted previously. Wait until the software offers **1000 Ω** for modification. Now change this value. If it is ready, zero the meter, and then check 5.1 Ω measurements again!
When calibrating ESR we can see the 3. parameter (**ESR_Cal**) that gives possibility to set the length of the measuring current pulse so that it precisely matches 100 KHz (properties of electric items can vary because of manufacturing process) or by increasing it's value we can increase the measuring frequency (this is a **possibility** if some one would like to use).

After calibration and zeroing process, the instrument is ready to be used. When measuring **L/ESR** the **measurements cables may be used in any way**; ***<u>however at C and F measurements using correct poles is important</u>***!

Basically the LCD panel is illuminated, but it can be switched off by pushing the button for **12-15** seconds. The meter remember this state even after it has been turn off. By pushing the button for **12-15** seconds, the LCD illumination can be switched on again.

With **<u>meter in ESR mode we can measure internal resistance of battery, rechargeable battery</u>**. Because battery is a power source we need to use 2 pcs 1000uF 16V capacitors to isolate the DC power (we need 25V, if we want to measure batteries having bigger voltage). So we use the next measuring schema:



For the first time we have to Zero the new cables with 2 caps <u>soldered</u> on them (so we measure and zero the cables by closing them – do not connect cables to any battery this time). Then we can measure the resistance of any battery. The battery is worn when its ESR is about twice or much bigger than the ESR of a new battery).

I have made some minute's long videos about L/C/F/ESR measurements that can be found on my site: http://lcfesr.atwebpages.com/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. I can burn and send full software in an AVR ATMEGA88PA-PU.

The development of the meter required lots of work (some months) so I can not give the source of the software to the public or any.

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.

Hungary, 2018-10-21

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