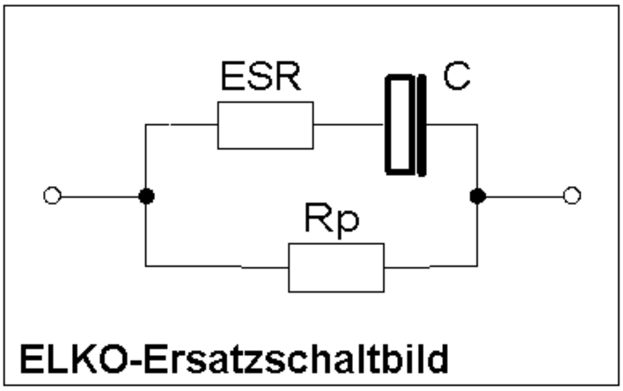
Measuring device for electrolytic capacitors

with PIC16F883

Prototype

This project was on hold for 7 years. It is now time to reopen it.

General



	Measuring range	Tolerance / Error
Capacity:	10µF ... 65 000µF	10 %
ESR (at 100 kHz):	20 mOhm ... 1 Ohm	10 %
Leakage current:	1 uA ... 22 uA	10 %
Measuring time:	<1 s / s 1000 uF + 2	

The aim was to develop a device with which to make the most important parameters of electrolytic capacitors easily determined.

Introduction:

The ideal capacitor doesn't exist. If you buy a capacitor with it's capacitance and maximum voltage, you also buy its equivalent series resistance and its parallel resistance.

Rp: thats the parallel resistance and causes the leakage current in the capacitor. At an healthy capacitor the resistance is very high (>> 1 MOhm).

ESR: this value is much more important. it' responsible for losses in the capacitor and loweres the ability to smooth voltages.
Measuring ESR is important for those who build SMPS. The ESR can be some 10mOhm to some 100mOhm.

C: measuring the real capacitance is also interesting. because this value changes by aging while storage and use. It tells about the healthiness of the capacitor

Measuring Capacitance "C"

You can determine the capacitance of an electrolytic capacitor with it's charging-behaviour.

For this purpose the capacitor is charged (via a 250 ohms resistor and a supply voltage of 5V) from 0 to 2.5V. The charging time is proportional to it's capacity.

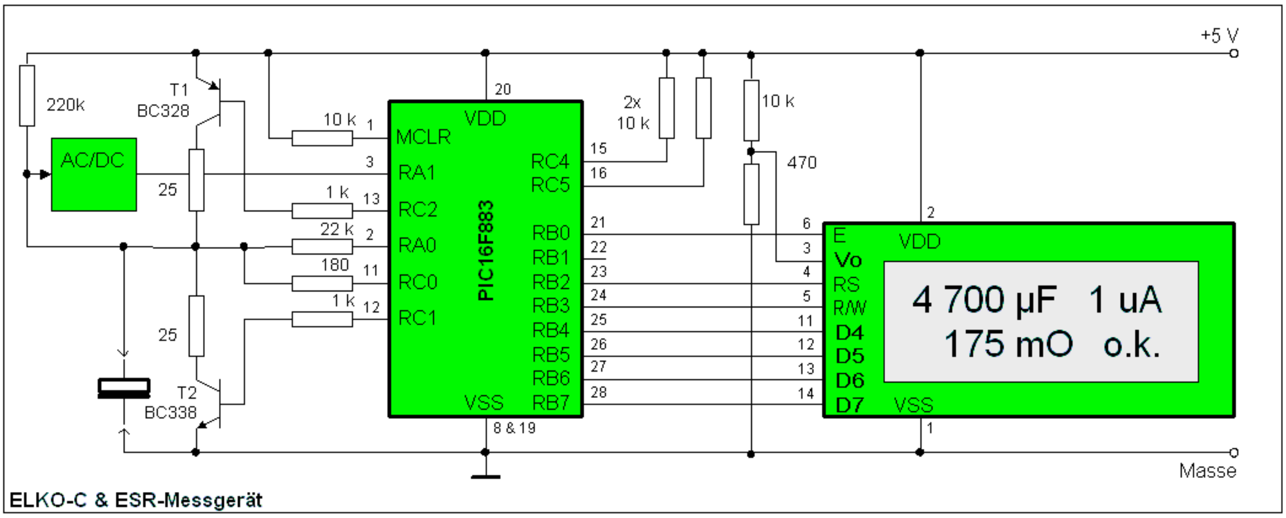
It is: C = 0,005771 * T

One μF means a charging time of 0,1733ms. 10000μF means 1.733 seconds. While charging a 16-bit counter is incremented with 5771Hz. When the voltage across the capacitor reaches 2.5V, the value of the counter is read (by the microcontroller). The counter-value corresponds the capacitance in μF.
The voltage of the capacitor can be recognized by a comparator or a ADC. i've chosen the ADC.

In the example which you can see in the picture below the PIC charges the elko via RC0, while it's voltage is observed by the adc via RA0. The pin RC0 has a FET-driver. At high-level a P-FET connect Pin RC0 with Vdd. This FET has an resistance of about 70 ohms, which is in series with the external charging-resistor.
Thats why the external charging-resistor must only be 180 ohms.

Before the measurement the capacitor has to be discharged to 0V, thats done by T2 which is controlled by RC1. To keep the discharging time short, the capacitor will be discharged only down to 40mV.
This principle of measurement is also used in this educational exercise http://www.sprut.de/electronic/pic/programm/elkoc/elkoc.html .

The impedance of the RC0 final stage is problematic. It has manufacturing tolerances and raises with the temperature. (at 70°C it doubled it's value at 20°C).
A external driver would provide a higher accuracy and better temperature stability. On the other hand, the temperature in the hobby-lab is mostly constant.



Measurement of the equivalent series resistance

especially for usage in SMPS you need capacitors with a low ESR. It's important to measure the ESR at a decent high frequency (100kHz) because it's changing by frequency.
Values for lower frequencys are useless for a lot of purposes.

Measuring the ESR is complicated because the capacitors impedance Z is in series with the ESR. The best method is to measure the overall impedance Rg (ESR+Z) at 100kHz and then subtract the Z (which is calculated with f and C). The overall impedance is about 20...1000mOhm (at 100kHz).

A measurement resolution of 1 Ohm is therefore decent.

For the measurement a 100kHz AC-voltage (5Vpp, rectangular) is applied to a series circuit of a resistor (25 ohm) and the elco. The overall impedance is calculated by the voltage drop across the electrolytic capacitor. A high current makes the measurement easier. At a current of 100mA AC the voltage drop is about 2...100mV AC. To measure this voltage with a resolution of 0,1mV AC you need a precision-rectifier which rectifies the voltage and amplifies it with factor 49.
After this you can measure the voltage with the PIC's ADC. Now you can measure overall impedances of Rg = 0 ..1000 mOhm.

The measuring amplifier is designed that the adc-value corresponds with the overall impedance. For this purpose a input signal of 100μV AC pp has to be ampified to 4.9mV DC. (ampification factor 49)

To calculate the impedance Z:

$$Z = 1/ (6,28 \times f \times C) = 1/(628318 \times C)$$

simplified:

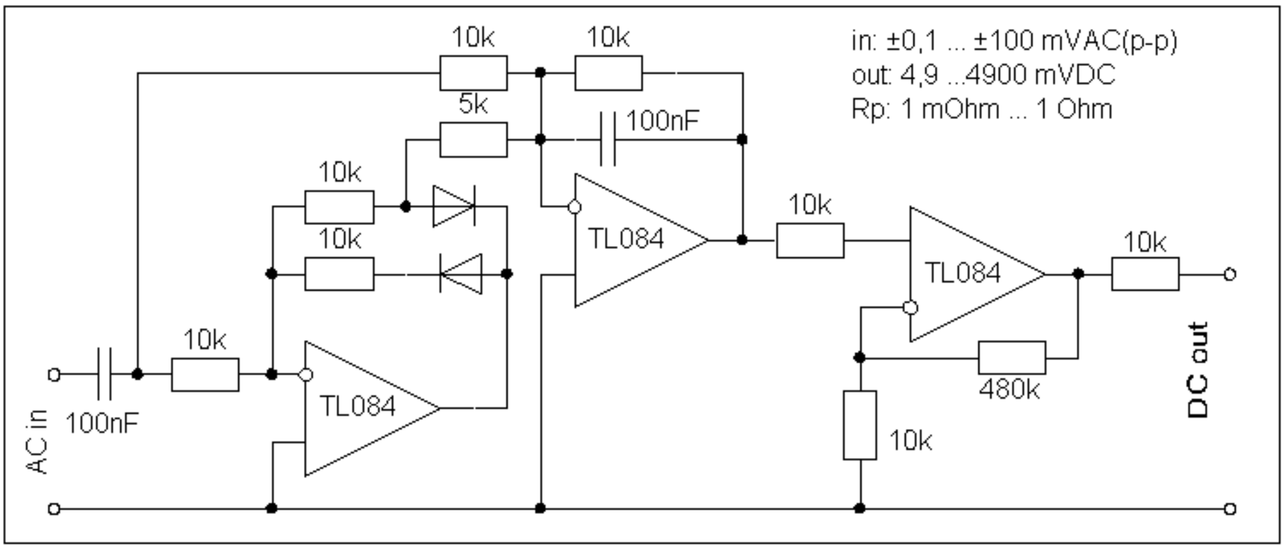
$$Z\ [mOhm] = 1591 / C\ [\mu F]$$

Subtracted from the overall impedance:

$$ESR = Rg - Z$$

The 100kHz Ac voltage is generated by the PIC (RC1, RC2) and amplified by a push-pull driver (T1, T2) and 25 ohm resistors (R8, R9) to 100mA.

The precision rectifier consists of 3 operational amplifiers. The first one uses the positive half-waves of the input signal and inverts them. The second stage doubles the levels of the inverted half-waves and adds them to the input signal.
By that all half-waves are now in the positive voltage area. The capacitor transforms the half-waves into a positive DC (lowpass filter). The third OPA amplifies the rectified voltage by factor 49.



Measuring the leakage current with Rp

A hight leakage current is an indication for a defective cap or capacitor which has been stored for a long time and needs to be "trained" again. The leakage current can be measured with the voltage drop at a high-value resistor.

The capacitor is charged to 5V and connected to 5V (charging voltage) via a 220kOhm resistor. The leakage current flows through the resistor and causes a voltage drop which can be measured.

$$I = UI / R$$

For a 220kOhm resistor:

$$I[\mu A] = UI[adc] / 45$$

whereas UI is the difference between the ADC value with active T1 and deactivated T1.

The highest measurable leakage current is 22µA and the measurement isn't linear. But a value higher than 5µA means a defective capacitor and till 5µA the linearity is good enough.

PIC model:

You need an ADC for the ESR measurement and a lot of pins, so the PICs with 8 or 14 pins are not usable. The author found a usable PIC 16F883 in his parts-box .
A 16*2 LCD display is connected to PortB.

Measurement sequences

Measuring of the capacitance:

1. Discharge the capacitor with a 25 ohms resistor until the voltage at RA0 is below 0,04V
2. Set the capacitance counter to zero
3. start charging the capacitor via 250 ohms (RC0)
4. measure the voltage across the capacitor every 0,1733ms and increment the capacitance counter till the voltage at RA0 reaches 2,5V
5. Process and show the counter-value in the display

Measuring ESR

1. charge the cap to 2,5V (has been done at capacity measurement)
2. connect the cap via 25 ohms alternating at 100kHz to Vdd or Vss
3. measure the ac-voltage across the capacitor via rectifier/amplifier
4. calculate overall impedance with the ADC-value
5. calculate impedance Z with the measured capacitance
6. Calculate ESR (ESR = overall impedance Rg - impedance Z) and show it on the display (second line, left hand side)

Measuring leakage current

1. connect the cap via 25 ohms to 5V
2. wait till the cap is charged to 5V
3. keep the cap connected to 5V via a 220kOhm resistor
4. measure the voltage drop across the 220kOhm resistor
5. calculate the leakage current and display it on the display (first line, right hand side)

Schematic in Detail

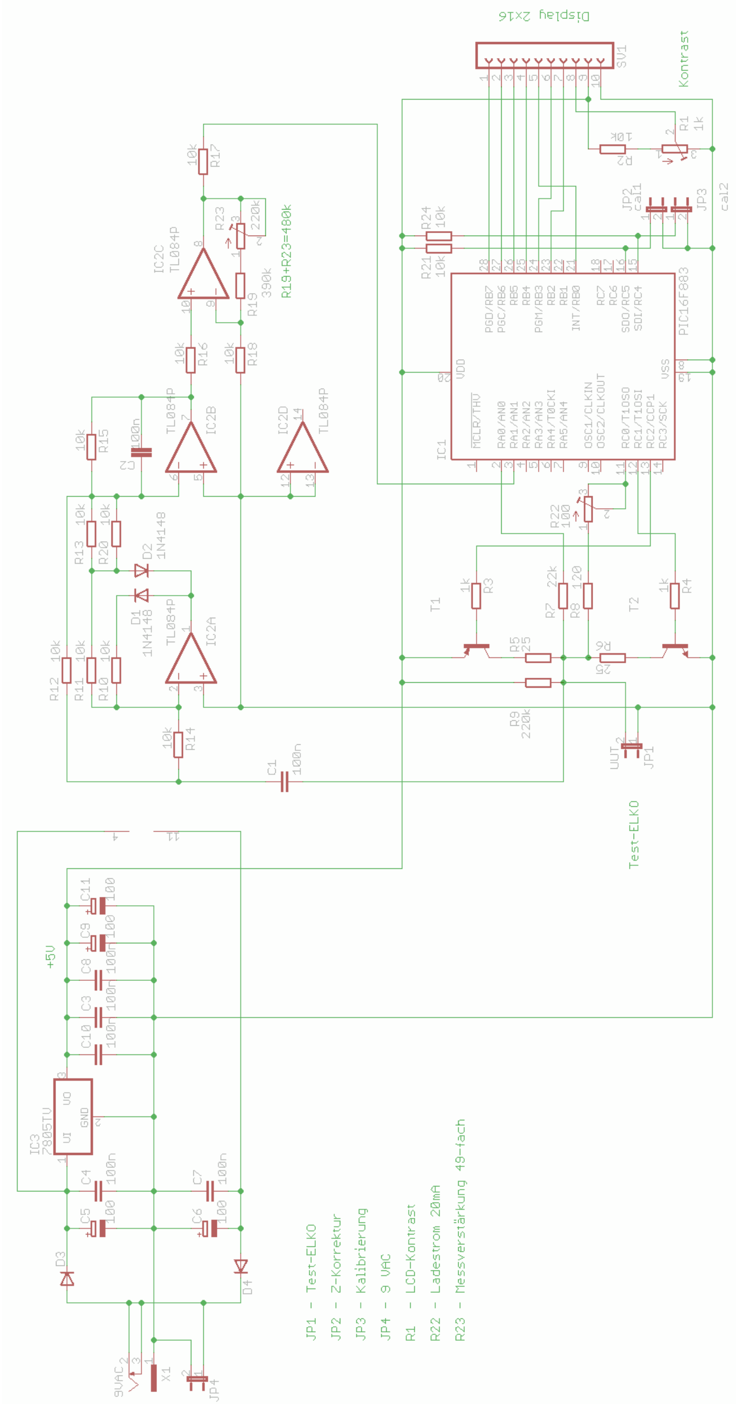
Here is the complete circuit.

Power supply
The PSU has to provide +5VDC and at least 140mA for the PIC. A positive and negative voltage is also needed for the ADC.
If you use a rail-to-rail OPA, you could use the +5Vdc for the positive OPA supply. But the used TL084 needs a higher voltage.

precision rectifier
The PR requires 3 OPAs. The first two must be capable to process a 100kHz rectangular signal so the bandwith should be at least 3MHz. The author used a TL084 which contains 4 OPAs. The diodes D1 and D2 should have a low barrier capacitance and should be usable for high frequencies. The connections from C1 to the capacitor under test as well as from pin 3 of the TL084 to the ground connection of the capacitor under test should be designed that they don't have to conduct any other current (except the currents you need to test the cap). Especially the charging and discharging currents from T1 and T2 must not use these traces on the pcb, otherwise you would measure teh ESR plus the resistance of the traces.
R23 is used to set the amplification factor. Presetting is middle-position. It's going to be trimmed to the right value while the calibration.

PIC & ect.
R23 is used to set the charging current for capacitance measurement. First it should be set to 60 ohms. It's going to be trimmed to the right value while calibration. Jumpers JP2 and JP3 are used to calibrate the instrument. In regular used they aren't connected.

JP2 (at RC5) has a additional function. If you close this jumper you are measuring the overall impedance of the capacitor instead of its ESR.
R1 is for setting the contrast on the LCD



Calibration

Two steps of calibration are necessary. Therefore you need a current-meter and a exact low-ohm-resistor with some 100mOhm (for example 470mOHm)

For the first step you have to close J3, open J2, and connect the current meter to J1 before switching on the supply voltage. After switching on you can see K:20mA on the LCD. With R22 you can set the current measured by the current meter to 20mA. (Display shows voltage across JP1). Then you have to switch off the device.

For the second step you have to close JP2 and JP3 and connect the exact low-ohm resistor to JP1 before switching on the device. After switching on you can read K:mOhm on the display. The

device measures the resistance and shows the value in the display (second line, left hand side). With R23 you can set the displayed value to the real value of the resistor.
Be patient while doing this, the display is updated only every 2 second.
Then JP1 have to be shorted. The displayed resistance should be below 10mOhm.

Now you have to remove both jumpers.

State of development

capacity
Measurement of the capacity was proofed and works fine.

ESR
Measuring the ESR is much more critical. The precision rectifier/ amplifier has to rectify and amplify 2...100mV at 100kHz. Thats much more complicated than it sounds. The OPV needs positive and negative supply. In addition the precision rectifier has a small offset error, but this can be compensated by the software.

leakage current
Measuring the leakage current showed to be uncomplicated. But it's only makeshift because the lC is always measured at 5V.
The lc should usually be measured at the maximum voltage of the capacitor.

Download

Hier liegt

- the assembler source along with the finished assembled HEX file (8 Kbytes)
- Stromlaufplan und Platinenlayout im Eagle-Format
- Placement plan
- Representation of the board (Eagle-3D/Povray)

possible extensions

- Revision of the measuring rectifier
- Detection of a missing ELKOs
- automatic detection of errors ELKO

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translation by kripton2035 - september 2011 with google help...

far better translation by Richard W. from eevblog october 2011