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ESR - Meter ESR 1

English translation

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ESR Meter – ESR 1

This useful little helper facilitates debugging in modern electrical appliances, such as TVs, monitors, video recorders, etc. The meter determines the equivalent series resistance (ESR) of an electrolytic capacitor (in short: Elko) ; even in circuit, without desoldering. The ESR gives information about the state of aging or the "quality" of an electrolytic capacitor. Especially in switching power supplies, electrolytic capacitors age faster than "normal" due to the high switching frequency or high working temperatures. When capacitors are used for filtering the output of a power supply, if the ESR increases too much, the power supply may not be able to operate properly. Of course, the ESR 1 can also be used to measure ohmic resistances in the specified measuring range.

Aging capacitors

In general, most electronic components, (such as semiconductors, resistors and others) have an almost unlimited life, provided that they are not overloaded and operated in their designated working environment. However, there is one exception - the electrolytic capacitor (in German: "Elko"). When an electrolytic capacitor is used with its temperature being kept within the specified operating range (usually, max. 85°C or 105°C), the average service life is 1000 to 3000 operating hours. The storage itself causes a steady loss of capacity over time. Therefore, it is not recommended to use electrolytic capacitors that have been stored for more than 10 years when building your new projects. One of the main reasons for this is that the liquid electrolyte inside the capacitor dries out, thus reducing its capacity and performance.

Technical data	
Power supply:	9-V-Battery
Current draw:	8 mA
Measuring range:	0,01 to 19,99 Ω
Accuracy:	± 5%
Miscellaneous:	Low batt. indicator Auto-Power-Off
Dimensions (Housing):	140 x 60 x 26 mm

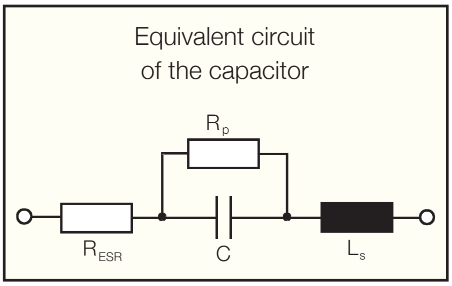


Fig. 1: The AC-equivalent circuit diagram of the capacitor illustrates the term ESR (Equivalent Series Resistance).

The operating temperature is a critical parameter in the dessication process. It is determined by the ambient temperature and the heat generated by the circuit itself. A rule of thumb says that a 10K increase in temperature halves the life of an electrolytic capacitor.

If a capacitor is used for voltage stabilization in a conventional linear power supply, a capacity reduction of say 4700 uF to 3300 uF is usually still tolerable.

The situation is different with modern switching power supplies. Here the Elkos are exposed to extreme loads. Due to the relatively high switching frequency and the high, partly rectangular pulsed currents, the electrolytic capacitors heat up, which leads to a rapid decrease in the service life. It's no coincidence that power supplies in computers are one of the most common causes of failure. These switching power supplies are increasingly finding their way into modern consumer devices.

A trend can be observed: many of these electronic devices such as TVs, VCRs, monitors, etc. already fail after a relatively short time. The cause of the fault is often a defective electrolytic capacitor in the switching power supply. If you measure such electrolytic capacitors with a capacitance meter, you will notice with astonishment that they have only slightly lost their capacity. Why did the device or switching power supply fail?

This is where the internal resistance of the capacitor comes into play, which is also called ESR (Equivalent Series Resistance). Rather, this resistance represents the sum of all the serial losses of a capacitor. The internal resistance is also directly related to the state of aging of the electrolytic capacitor, it increases with the age of the electrolytic capacitor. The effect of high ESR on power supplies is predominant at high frequencies. As a consequence, the switching power supply no longer works properly. Usually the device only seems to work flawlessly for a short time, but soon switches off or goes in standby mode. To avoid this problem, the manufacturers use so-called low-ESR electrolytic capacitors, which have an extremely low internal resistance and are designed especially for high temperatures. These electrolytic capacitors are usually recognizable by the imprint "105 ° C" - a standard electrolytic capacitor is only suitable for temperatures up to 85 ° C. But even these low ESR types are not excluded from the aging process. However, for financial reasons, manufacturers often use normal capacitors instead of low ESR ones in switching power supplies, leading to early failures.

Easy ESR measurement

With the ESR measuring device presented here, the internal resistance (ESR) of an electrolytic capacitor in the circuit can be measured without having to desolder it. As a result, the annoying and time-consuming desoldering process is avoided, together with the subsequent measurement of capacity. Moreover, in such cases, as already stated, the ESR is more meaningful than the capacitance measured with a capacitance meter.

Before going on to the circuit description of the "ESR 1", we briefly consider the theoretical basics of ESR measurement. Each capacitor is lossy due to its design. Electrolytic capacitors are particularly affected. For a better illustration, Figure 1 shows the equivalent circuit diagram of a capacitor operated with AC voltage. The parasitic components are characterized as follows:

R_{ESR} = Series loss resistance
R_p = Insulation resistance, or parallel loss resistance (caused by the leakage of the dielectric)
L_S = Series Inductance of the terminals and the electrodes

The ESR (R_{ESR}) is made of the resistances that form through the leads, the transition to the electrodes, and the resistance of the dielectric. This ESR can't be measured with a standard multimeter and needs an AC measurement. In order to find a suitable measuring method, we will only focus on the R_{ESR} component. Applying an AC voltage to the capacitor results in a phase shift of 90 ° between the voltages at "ESR" and at "C". The impedance (Z) of the capacitor (ignoring Ls and Rp) is composed of the two components reactance (Xc) and the ESR, defined in the following formula:

$$Z = \sqrt{Xc^2 + ESR^2}$$

$$Xc = \frac{1}{2 \cdot \pi \cdot f \cdot C}$$

The formula can be graphically represented using a phasor diagram that looks like this:

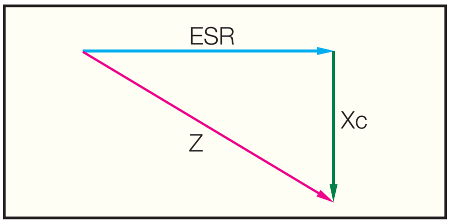


Figure 2: The phasor diagram illustrates the relationship between ESR, impedance and reactance.

If we can reduce the reactance of the capacitor to about zero, we could easily resolve the formula to ESR. The variable parameters for Xc are the frequency and the capacity. The capacity is determined by the DUT, so only the frequency remains. If we set the measurement frequency high enough, Xc tends to zero, as the following example proves:

Example: f = 60 kHz, C = 100 µF

$$X_c = \frac{1}{2 \cdot \pi \cdot f \cdot C} = \frac{1}{6{,}28 \cdot 60\text{kHz} \cdot 100\mu\text{F}} = 0{,}03\Omega$$

By this finding we can solve the formula for the impedance Z to ESR, which looks like this:

$$Z = \sqrt{Xc^2 + ESR^2} \approx \sqrt{0 + ESR^2} = ESR$$

With an AC resistance meter operating at a relatively high frequency (60 kHz in our case), we can determine the ESR of a capacitor.

There are basically two different measuring methods for such "ohmmeters": One measures with constant current and the other uses a constant voltage. We chose the variant with a constant voltage.

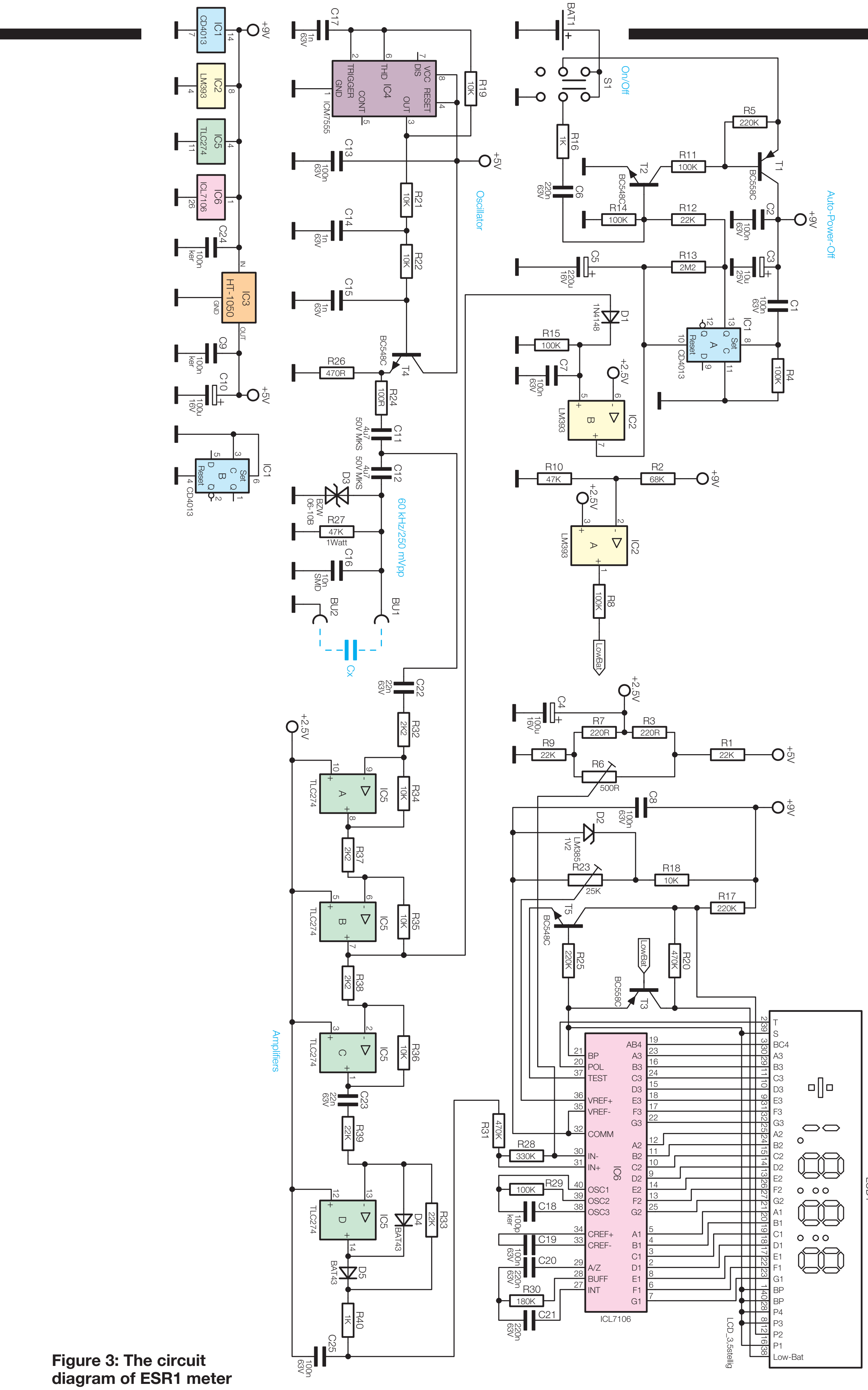


Figure 3: The circuit diagram of ESR1 meter

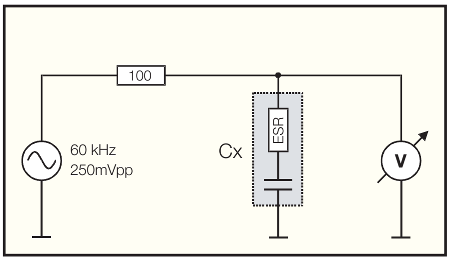


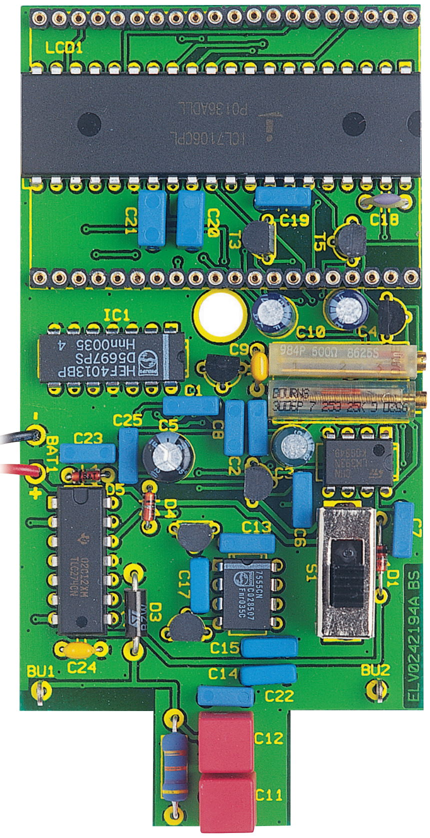
Figure 4: the measuring principle of our ESR meter

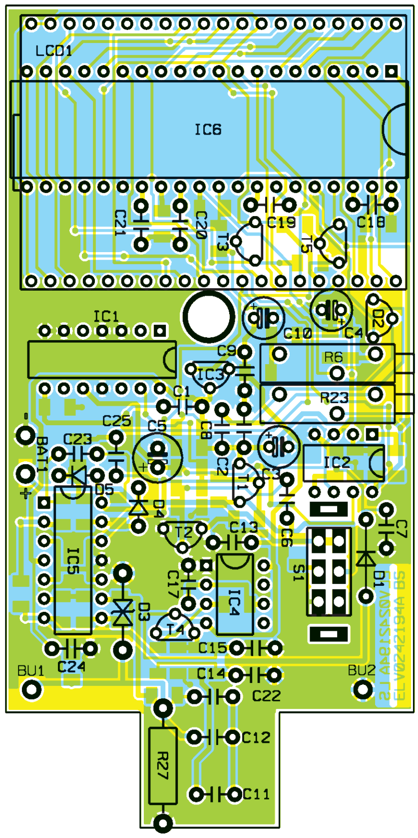
The measuring principle is shown in figure 4. Since the source voltage and the series resistor are known, the value of the ESR can be calculated by measuring the voltage at the leads of the capacitor under test. However, the disadvantage of this circuit should not be concealed: the relation between measured voltage and ESR is not linear. If you want to measure resistances in a wide range, the measurement method with a constant current is preferable, as it is the case with most ohmmeters. But since we only need a small range, namely from 0 to 20 ohms, the deviations are not too large. It is not supposed to be a highly accurate ESR meter, but a cheap and easy to set up circuit, with which one can detect defective electrolytic capacitors. In addition, the interpretation of the measured ESR value is purely a matter of experience, since one should primarily make comparisons with new electrolytic capacitors.

The circuit

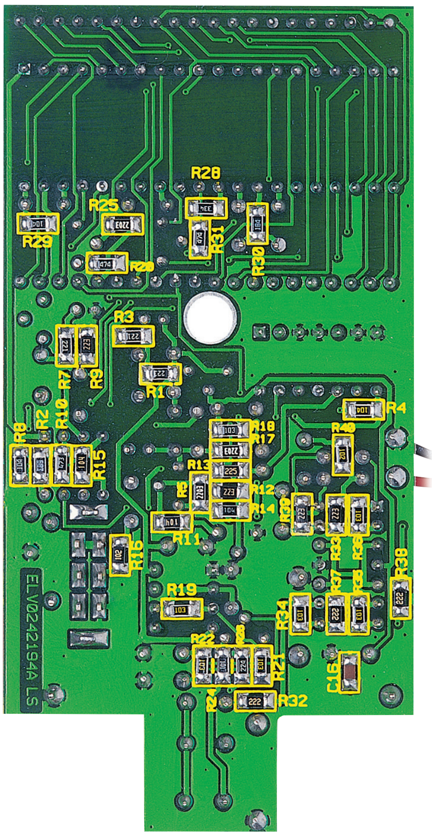
The circuit diagram of the ESR meter is shown in Figure 3. The lower left shows the oscillator, which is formed by IC4 with external circuitry. The frequency is determined by R19 and C17, it is about 60 kHz. The dual stage low-pass filter formed by R21, C14, R22 and C15 gives a clean sine wave, which is amplified to an amplitude of 250 mVpp at the emitter of the transistor T4. Via R24 and the two capacitors C11 and C12, the signal arrives at the measuring socket BU1. The Transil diode D3 protects the input of the measuring device (on pins BU1 and BU2) against voltage spikes. The resistor R27 discharges the capacitor to be tested, if necessary. At the node between C11 and C12, the AC voltage decreases during the measuring process; this is where the measurement is made. The three-stage measuring amplifier, formed from IC5A to IC5C, amplifies the signal by a factor of 94. With IC5D, the amplified signal is rectified and then smoothed with R40 and C25.

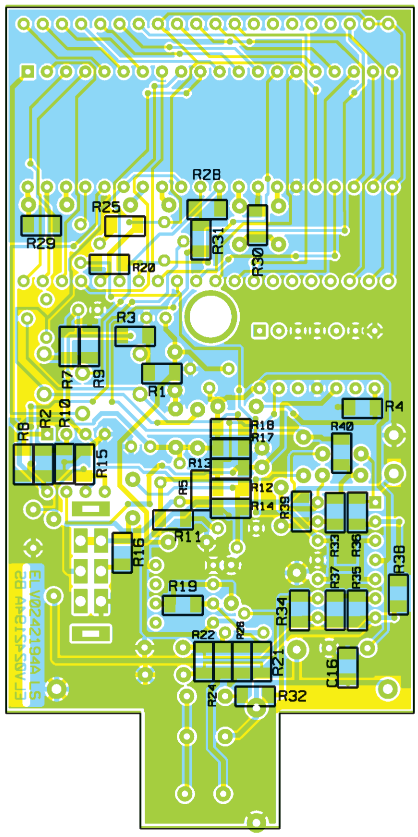
The rectified voltage is displayed with a 3.5-digit LCD display.





View of the assembled board of the ESR meter, top and bottom, with the corresponding component layout. The LCD meter is not fitted for better visibility.





Parts list

Resistors:

10 Ω	used for calibration
100 Ω/SMD	R24
220 Ω/SMD	R3, R7
470 Ω/SMD	R26
1 kΩ/SMD	R16, R40
2,2 kΩ/SMD	R32, R37, R38
10 kΩ/SMD/1 %	R18, R19, R21, R22, R34-R36
22 kΩ/SMD	R1, R9, R12, R33, R39
47 kΩ/SMD	R10
47 kΩ/1 W/metal oxide	R27
68 kΩ/SMD/1 %	R2
100 kΩ/SMD	R4, R8, R11, R14, R15, R29
180 kΩ/SMD	R30
220 kΩ/SMD	R5, R17, R25
330 kΩ/SMD	R28
470 kΩ/SMD	R20, R31
2,2 MΩ/SMD	R13
multi turn trimmer, 500 Ω	R6
multi turn trimmer, 25 kΩ	R23

Capacitors:

100pF/ceramic	C18
1nF/63 V/MKT	C14, C15, C17
10nF/SMD	C16
22nF/63 V/MKT	C22, C23
100nF/ceramic	C9, C24
100nF/63 V/MKT	C1, C2, C7-C8, C13, C19, C25
220nF/63 V/MKT	C6,C20, C21
4,7µF/50 V/MKS2	C11, C12
10µF/25 V	C3
100µF/16 V	C4, C10
220µF/16 V	C5

Semiconductors:

CD4013/Philips	IC1
LM393	IC2
HT1050	IC3
ICM7555	IC4
TLC274	IC5
ICL7106	IC6
BC558C	T1, T3
BC548C	T2, T4, T5
1N4148	D1
LM385/1,2 V	D2
BZW06-10B	D3
BAT43	D4, D5

Other:

LCD display, 3.5 digits	LCD1
4mm banana socket, red..	BU1
4mm banana socket, black	BU2
DPDT slider switch	S1
Soldering pin with eyelets..	BU1, BU2
9-V-Battery clip	BAT1
IC sockets and female pin headers	

1 plastic case
1 set of test leads
1 piece of adhesive foam tape

This unit consists of the display driver IC6 and the LC display LCD1. The dual-slope ICL7106 display driver with integrated AD converter is characterized by a very good performance and a relatively low price. The measuring input of IC6 consists of pin 30 (-) and pin 31 (+). Via the voltage divider R31 and R28, the voltage from the rectifier reaches the input pin 31 (IC6). For offset correction (zero point), the input pin 30 (-) is connected to the trimmer R6, with which one can make a small potential shift compared to the ref. voltage of 2.5 V.
The scale factor is determined by the voltage between pin 35 (Vref-) and pin 36 (Vref +), which can be adjusted with the trimmer R23.

On the LCD display are some additional required segments (decimal point and low-bat segment), which are not directly controlled by IC 6. In order to still be able to display these segments, T5 generates a square-wave signal which is in phase opposition to the backplane signal (BP) and passes directly from collector T5 to pin 12 (P2) of the LC display and activates the decimal point. The segment for the low-Bat indicator is switched by the transistor T3, which is driven by the low-Bat detector IC2A.

IC2A is a comparator that switches output Pin 1 to "High" when the operating voltage drops below 6.2 V. The switching threshold is fixed with R2 and R10.

Now, let's describe the auto-power-off circuit, which is shown in the upper left part of the diagram. The voltage from the battery goes through transistor T1 after the switch S1. The sequence when switching on is as follows: In the switched-off state, the resistor R16 is above the second switching contact of S1 to ground. After S1 is set to "on", R16 is connected to + 9V and a current pulse flows via R16 and C6 into the base of the transistor T2. This controls the switching transistor T1, which is the main switch for the whole device, via the base resistor R11. As a result, a voltage pulse passes through the capacitor C1 to the "set" input of the RS flip-flop IC1A. The flip-flop is now set, the "Q" output pin 13 carries high level and controls T2 whereby the circuit closes and the circuit itself "holds". Now the auto-power-off timer is activated, which actually only consists of the timer R13 and C5. The relatively large electrolytic cap C5 is now charging slowly over R13. If the voltage at C5 rises to approx. 2/3 of the operating voltage (corresponds to approx. 4 minutes), the flip-flop is reset via the reset input (Pin10). Since the "Q" output now changes to "low", T1 and T2 lock and the operating voltage is switched off. Only a new Off/On action on switch S1 activates the device again. If a measurement is made during the switch-on time, this is registered by the comparator IC2B, which discharges the electrolytic capacitor C5 via its output (pin 7) and thus the timer restarts. For this purpose, the AC voltage passes from the output of the second amplifier stage IC5 B to the rectifier diode D1. As soon as the voltage at the storage capacitor C7 drops below 2.5 V, the comparator detects it.

Building the kit

The circuit is assembled on a double-sided board. A large majority of components are through-hole devices, except the resistors which are SMD. It has been reported on the ELV website that newer versions of the kit are sold with all SMD components already soldered. If you own an early version of the kit and the SMD components are not pre-soldered, start by populating the SMD resistors on the bottom of the board. The resistors are made in one of the largest SMD form factors, "1206", in order to facilitate the work for everyone, including beginners. Basically, a soldering iron with a slim tip and medium power should be used for the soldering work. This allows a clean soldering of the SMD components and protects the sensitive components from overheating. Based on the parts list and the assembly plan, the resistors are positioned on the board with tweezers and soldered on one side at first. After checking the correct position of the component, the remaining terminal is soldered. After all SMD components have been fitted, the wiring of the wired components, starting with the smaller components (resistors, diodes, etc.), continues with the larger components, as well as mechanical components. The components are placed and soldered according to the silkscreen. On the underside of the board, protruding wire ends and component legs are cut off with a side cutter, without damaging the solder joints themselves.

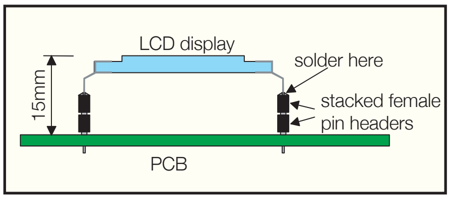


Fig 5: LCD panel assembly

For the semiconductors as well as the electrolytic capacitors, it is essential to pay attention to the correct mounting position and polarity.

Insert semiconductors according to component layout in page 5. Electrolytic capacitors are marked at the negative pole. The notch on ICs shows pin 1. As an aid, the board photo can also serve here. Pay attention during installation of the LCD display. To get the correct height, the display is placed on two row of pin headers, similar to IC sockets. To do this, two 20-pin sockets must be plugged together and then soldered onto the board. Now insert the LCD into the socket from the top until it is 15 mm away from the board (see Figure 5). This ensures that the display is located directly under the viewing window in the housing. The legs of the display are now soldered to the upper row of contacts to ensure a tight fit.

Finally, insert the slide switch and the solder pins. The battery clip is connected as follows: red cable to + Bat and black cable to - Bat. In the next step, we will prepare the lower housing shell.

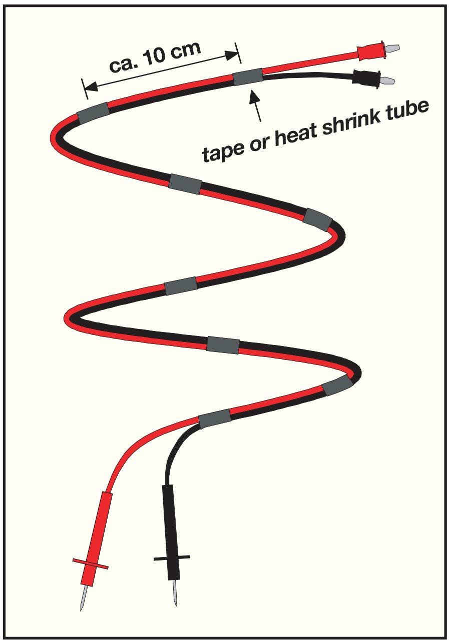


Fig. 6: This is how the test leads are prepared

The two 4-mm sockets are first unscrewed and soldered at the end of the metal sleeve about 2 cm long piece of wire. The disassembly of the socket before soldering is necessary because the plastic parts of the socket would otherwise be deformed when exposed to heat.

Now, the two jacks are reassembled, inserted into the lower housing part and screwed. Finally, the board is placed in the housing base and the wires connected to banana terminals BU1 and BU2 are soldered to the terminals on the PCB. Next, the transparent Plexiglas sheet is inserted from the inside into the upper part of the housing and fixed at the edges with a little plastic glue. Be careful not to spill glue on the visible surface of the lens.

In order to prevent the battery from rattling in the housing, a piece of foam tape is stuck in the upper housing shell (above the battery). After inserting a 9 V block battery and screwing the housing, the ESR meter is ready for use.

Adjustment and operation

Before you start, here are some important instructions that are necessary for the correct functioning of the measuring instrument: To minimize the inductive influence of the test leads on the measurement result, the two leads are kept close to each other at intervals of approx. 10 cm with electrical tape or heat shrink tubing. (see Figure 6).

The 4 mm plugs of the test leads should sit very tightly in the sockets on the meter. A loose fit could lead to incorrect measurements, so it is worth to pay attention to this connection.

Adjustment is necessary before the first start-up, but it is only necessary to do it once. If you need higher precision, the device may need to be readjusted once a year. No special gauges are required for adjustment, only a 10 ohm resistor with a tolerance <1% is required. After switching on the measuring instrument, hold both test probes together and match the display with trimmer R6 exactly to "0.00". A deviation up to ± 5 digits is still tolerable.

Next, place the 10 Ω resistor between the two probes and make contact with the leads. With the trimmer R23 (scale), the display is now set to "10.00". This completes the adjustment and the device is ready for operation.

When measuring in electrical devices, make sure that they are not switched on, and are disconnected from the mains. There are no definite figures that can be used to determine if an electrolytic capacitor is defective or not, solely based on its ESR value. Ideally, one should make comparisons with measurements of brand new capacitors of the same capacity. In most cases, if measured value is less than 1 Ω, it can be classified as "OK".

An ESR of more than 10 Ω is not uncommon for some capacitors, but these are usually not used in switching power supplies.

Here is the result of our experiments:

- For small caps in the range of 1 uF to 47 uF, ESR increases with the voltage rating, for an identical capacity
- The larger the capacity, the smaller the ESR.
- Electrolytic capacitors greater than 100 µF should in any case have an ESR below 1 Ω.
- An ESR with more than 20 Ω certainly indicates a defective electrolytic capacitor. The following table shows some ELV laboratory readings for different electrolytic capacitors.

	25 V	63 V	100 V	350 V
1 µF			3,86 Ω	
2,2 µF			2,76 Ω	
4,7 µF	1,68 Ω	1,25 Ω		2,37 Ω
10 µF	0,9 Ω	1,46 Ω		2,94 Ω
22 µF	0,74 Ω	0,95 Ω		
47 µF	1,1 Ω	0,4 Ω		
100 µF	0,12 Ω	0,47 Ω	0,12 Ω	
220 µF	0,23 Ω	0,16 Ω	0,1 Ω	
470 µF	0,36 Ω	0,4 Ω		
1000 µF	0,01 Ω	0,01 Ω		
2200 µF	0,01 Ω	0,01 Ω		

These values are of course not universal, but they can serve as a guide. Due to the different manufacturers of electrolytic capacitors, the test does not reveal a recognizable structure. It should also be considered that the ambient temperature has a significant influence on the ESR.

Finally, it should be mentioned that with the "ESR 1", purely ohmic resistances can also be measured, either in-circuit or on their own. The measuring voltage of 250 mVpp is small enough to prevent semiconductor junctions from turning on, and thus prevents them from altering the result. However, when there are very low impedance inductors in parallel with the device under test, the measured value may be inaccurate. ELV

Used batteries do not belong in the household waste! Dispose of them at your local battery collection point!

Disposal notes

Do not dispose of this device through domestic waste.
Electronic devices must be disposed of in accordance with the Waste Electrical and Electronic Equipment Directive at local collection points for old electronic devices!

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