500 ppm LCR Meter (3)

Part 3: PCBs, BOMs, assembly, calibration

After the flood of theory, design considerations and software descriptions in the first two installments we are ready to tackle practical matters.

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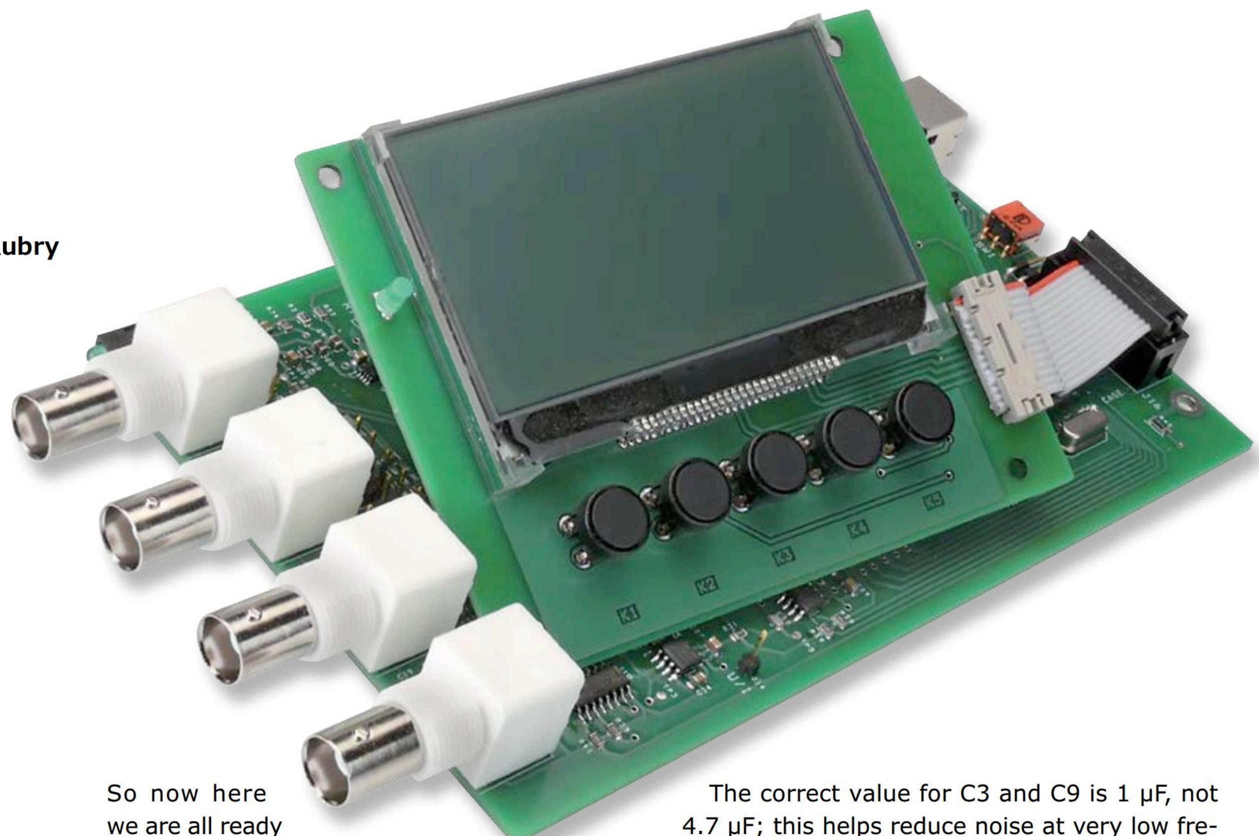


So now here we are all ready to start building the 500 ppm LCR meter. Most of this article is taken up describing the two boards, but before we finally get down to the nuts and bolts, we need to look again at the circuit diagram.

Inconsistencies and accuracy

We actually noticed a number of differences between the circuit published in the March 2013 edition and the final component list in this article. As so often, where there is a doubt, the component list is the one to believe, but as it hadn't yet been published, no-one was able to tell!

In **Figure 3** of the first installment [1], the value for crystal Y1 was missing: 24 MHz.

The correct value for C3 and C9 is 1 µF, not 4.7 µF; this helps reduce noise at very low frequencies, attributed to the operation of the MAX7404 itself and revealed when measuring high-capacitance capacitors (1,000 µF and over): on the oscilloscope, looking at the ADC input signal, the mean value of low frequency fluctuates more and more as the capacitor value increases.

For U2, we need a normal MAX7404**C**SA (the extended temperature range of the MAX7404ESA is unnecessary here). For U10, we need an LM40**4**0 (and not the LM4050 that I happened to have to hand, and which will also do). The amplifier used for U6 is an OPA3**65** and not an OPA354, which has too high an offset voltage. And lastly, for U19, it should be an FT23**2**RL and not FT235RL (just a typo).

Specifications

The 500 ppm LCR Meter is an automatic impedance measuring bridge. The two guiding principles in designing this unit were maximum measuring accuracy and ease of construction. It measures resistance, capacitance, and inductance for components with impedances from 1 mΩ to 1,000 MΩ. Measurements can be made at three frequencies: 100 or 120 Hz (50 or 60 Hz power line), 1 kHz, and 10 kHz.
Two configurations are possible:

- Basic unit, with no display or keypad Works only when connected via USB to a computer running the user program. This program, developed from the *Qt* libraries, has been tested under *Windows XP*, *Windows 7, Linux* (*Ubuntu 11.04*), and MacOSX (*Snow Leopard*, *Lion*, and *Mountain Lion*).
- Basic unit + display & keypad extension. Also works stand-alone (without a PC) with an external 5 V supply via the USB cable (which can also be connected to a computer for the power).

Finally, we observed that to make one of the adjustments easier, a 10 Ω resistor must be fitted for R17, incorrectly shown on the circuit diagram as not fitted (NC). The other components marked NC should only be fitted if the calibration procedure requires it — we'll come back to this later.

Before plugging in your soldering iron, we suggest you make these corrections carefully on your circuit from the first article. A corrected XL version of this diagram will be put on line for download [3] along with the software and the other documents, including the PCB designs.

Construction

The layouts for the two PCBs that make up the LCR meter are given in **Figures 1–3**. Remember that **you only need the extension board for the standalone version of the device**; otherwise the main board is all you need. If you have the right tools and good experience in soldering SMDs manually, you can solder the components onto the bare boards yourself. You'll be all the more satisfied with the result. However, even though there's no special difficulty, it is a job for a specialist which you should only undertake if you know what you're doing.

Adhere scrupulously to the component list — not for the order of the components, of course, but for their values and tolerances. Apart from the four precision resistors, the rest are all standard 1% tolerance. R50 is indeed a 0 Ω resistor that makes it possible to link the digital and analog grounds in a single, precise spot; a solder bridge will also do! The tolerances of the various capacitors is stated in the component list. Make sure you adhere to the dielectric types specified, particularly for the NP0 capacitors.
Alongside the crystal, you'll notice a point marked XTAL CASE on the board. This must be connected to the crystal case using a short piece of wire, as the metal screening is only effective if it is grounded. Above all, don't take too long with the soldering iron, to avoid damaging the crystal.
Attention: If you solder in the components yourself, the microcontroller will be blank. You'll need to load it with the boot program; to do this, you'll have to use the USB DEBUG ADAPTER from *Silicon Laboratories* [3].

If you go for the standalone version, do pay attention as well to the full part number for components like the HE10 connector for the flatcable that is soldered directly into the display board (**Figure 4**). The height of a normal type would stop you mounting the module into the recommended case. The graphics display is soldered by a row of fine pins flanked by two normal-sized pins, but this isn't enough to keep it in place; to avoid its lifting accidentally, we secured it at the side opposite the pins with the help of a few spots of hot-melt glue.

In order to avoid any misunderstandings about the choice of components, we are making available to you on our site [3] the BOM (bill of materials) which supplements the component list given here. The size of the components and their pin spacing is what will determine the order in which you fit them. Don't forget the components mounted beneath the main PCB.

Those components marked NC will only be fitted (perhaps) later, for the calibration.

However, if you are not happy about soldering SMDs or if you don't have the time, all you need do is order the ready-to-use modules from www.elektorPCBservice.com, our professional production service: you will receive the modules through the mail, and all you'll then have to do is fit them into a case before calibrating them.

Like many electronic devices, an LCR meter is sensitive to electromagnetic radiation, in particular from the power line @ 60 or 50 Hz. So you'll need to use a metal case, e.g. the Hammond 1455L1601, which is perfect for a 160 × 100 mm board plus the extension, if used. Dimensioned mechanical drawings are available from our website [3].

Preparations

Drilling the holes for the BNC chassis sockets and LED D6 on one of the small sides presents no problem. For the USB connector and switch SW1 on the opposite side, you'll need a square-section tool… or a good file and some elbow-grease; in fact, for a tidy result, you'll need at least two files, a flat and a rat-tail, and possibly a triangular-section one too.

For grounding the main board to the case, you'll also need to drill a hole (3.2 mm Ø) in the bottom of the aluminum case, in line with the hole in the PCB located next to J16; use a 12 mm (0.5") M3 machine screw with washer and nut in conjunction with a 5.5 mm (0.2") spacer.

COMPONENT LIST Main circuit

Resistors

(default: SMD 0805 1%)

R1,R16,R17,R28 = 10Ω
R2,R34 = 820kΩ
R3,R5,R11,R13 = 8.2kΩ
R4,R10,R47,R55,R56,R71,R72,R78,R81,R82,R94,R95 = 10kΩ
R6, R58, R59 = 1.8kΩ
R7,R100 = 5kΩ trimpot (Vishay-Sfernice TS53YJ502MR10)
R8, R60, R62 = 16kΩ
R9,R23,R25,R35,R38,R39,R41,R52,R68,R69,R70,R87,R88,R96 = 56Ω
R12,R14 = 5.6 kΩ
R15,R97 = NC (not fitted)
R18 = 10kΩ 0.05% 10ppm (Panasonic ERA6ARW103V)
R19 = 1Ω
R20 = 1kΩ 0.05% 10 ppm (Panasonic ERA6ARW102V)
R21 = 100Ω 0.05% 5ppm (Vishay-Dale TNPU0805100RAZEN00)
R22 = 100kΩ 0.05% 10ppm (Panasonic ERA6ARW104V)
R24,R26,R27,R29,R33,R36,R37,R40,R44,R57,R64 = 100Ω
R30,R61,R76,R77,R80,R101 = 20kΩ
R31 = 750Ω
R32,R42,R49,R66,R93 = 100kΩ
R43,R84,R85,R86,R89 = 2.2Ω
R45,R73 = 39kΩ
R46,R90,R91 = 680Ω
R48,R51,R74 = 4.7kΩ
R50 = 0Ω
R53,R65 = 470Ω
R54 = 1kΩ
R63,R98 = 1.6kΩ
R67 = 62Ω
R75 = 5kΩ trimpot (Bourns 3266W-1-502LF)
R79 = 4.3kΩ
R81 = 7.5kΩ
R83 = 30kΩ
R92 = 430Ω
R99 = 2kΩ

Capacitors

(default: SMD 0805)

C1,C2,C4,C10,C11,C12,C20,C26,C27, C28,C29,C31,C33,C34,C35,C36, C37,C40,C41,C43,C44,C45,C46, C47,C48,C49,C50,C51,C53,C54, C61,C63,C65,C78,C80,C86,C87,C88 = 100nF 10% X7R 25V
C3,C9,C62,C64,C90 = 1µF 10% 25 V X7R
C5,C13,C18 = 15nF 5% 50V NP0, SMD 1206
C6, C7, C14, C15, C16, C56 = 47nF 5% 50V NP0, SMD 1206
C8, C73, C89 = 1nF 5% 50V NP0
C17,C21,C23,C55,C60 = NC (not fitted)
C19,C25 = 150pF 5% 50V NPO
C22,C52,C58,C59 = 1.5nF 5% 50V NPO
C24,C32,C69,C72,C74,C75,C81,C85 = 2.2µF 10% 16V X7R
C30,C57 = 4.7nF 5% 50V NP0
C38,C39,C83,C84 = 33pF 5% NP0
C42,C70 = 33µF 6.3V, tantalum case A (Vishay Sprague 293D336X96R3A2TE3)
C66,C71, C82 = 10nF 10% 50V X7R
C67,C77, C79 = 4.7µF 10% 10V X5R
C68,C76 = 470µF 6.3 V tantalum case D (Kemet T495D477K006ATE100)

Inductors

L1 = 20µH dual coupled (Bourns PM3602-20-RC)
L2, L3 = ferrite bead, SMD 0805 (Murata BLM21PG221SN1D)

Semiconductors

(default: SMD)

D1,D2,D3,D4,D5 = BAV199 (SOT23)
D6 = LED, green, 3mm, leaded, horizontal mounting (Dialight 551-0207F)
D7 = MBR0520 (SOD123)
D8, D9 = LED, red, SMD 0805 (e.g. Kingbright KP-2012SURC)
D10 = BAT54A (SOT23)
U1 = OPA725AIDBV (SOT23-5) (TI)
U2 = MAX7404CSA (SOIC-8) (Maxim)
U3 = 74HCT4052D (SOIC-16)
U4, U20 = TLC2274AID (SOIC-14 (TI)
U5 = INA128U (SOIC-8) (TI)
U6,U11,U14 = OPA365DBV (SOT23-5) (TI)
U7 = PGA103U (SOIC-8) (TI)
U8 = 74HCT4053D (SOIC-16)
U9 = C8051F061-GQ (TQFP-64) (Silicon Laboratories)
U10 = LM4040D25IDBZ (SOT23) (TI)
U12 = DAC8811CDGK (MSOP-8) (TI)

To accommodate the display & keypad extension, the extruded aluminum lid will have to be machined and marked up (silk-screened or engraved) with the functions of the buttons (**Figure 5**). Then use four M3 screws (12 mm / 0.5", countersunk) with nuts and washers, and four 7 mm (0.3") spacers.

Note: for fixing the extension, in the absence of spacers, you can use other nuts (and washers):
4 for fixing the 4 screws onto the lid,
4 for setting the 7-mm (0.3") spacing,
and lastly 4 more to secure the extension board.

Two final remarks about the jumpers: Normally, the firmware is updated by the main program on the computer. Straight afterwards, the circuit ought to work, but if for some reason the firmware didn't respond (e.g. in the event of a bug in the new firmware that's just been loaded), it will then be necessary to intervene at the bootloader stage and tell it that we want to perform an *unconditional* update. Jumper J17, accessible by removing the back panel, is used to give this information.
The update procedure is described in the downloadable documentation [3].

To make sure the measuring probe is firmly connected to the measuring point pins J4, J5, J14, it's perhaps not a bad idea to bend them at an angle.

All the other jumpers are described in the online documentation.

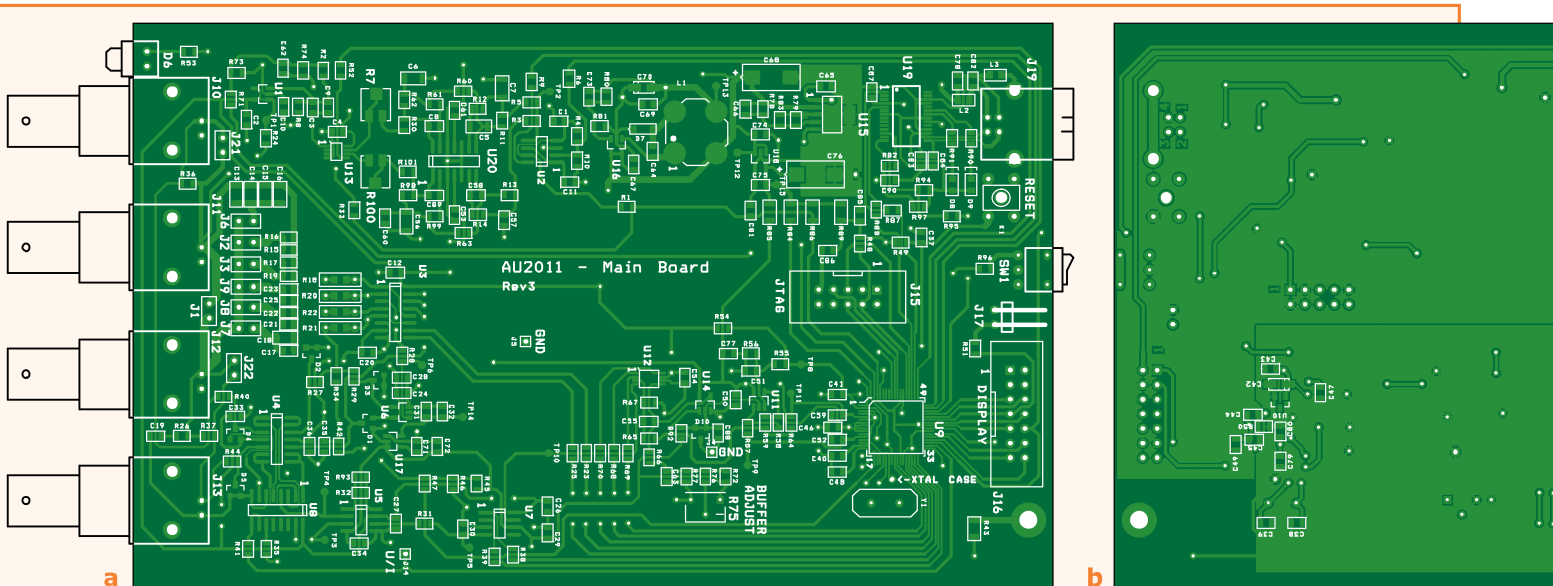


Figure 1. The LCR Meter's double-sided main board; component side (a). Don't forget the dozen or so components to be fitted **at the underside** of the board (b). The absence of silk screen print under the board is deliberate; it is not an oversight or an error.

U13 = SN74LVC2G53DCT (SM-8) (TI)
U15 = REG102GA-A (SOT223-5) (TI)
U16 = LT1611CS5 (SOT23-5) (Linear Technologies)
U17 = TPS72325DBV (SOT23-5) (TI)
U18 = TLV70030DDC (SOT23-5) (TI)
U19 = FT232RL (SSOP-28) (FTDI)

Miscellaneous

Y1 = 24MHz quartz crystal, fundamental resonance (e.g. Euroquartz 24.000MHz HC49/4H/30/50/40+85/18pF/ATF)
SW1 = rocker switch (RS Components 4US1R1020M6RNS, code 734-6934)
J1,J2,J3,J6,J7,J8,J17,J21,J22 = 2-pin pinheader, 0.1'' pitch (2.54mm)
J4,J5,J14 = 1-pin pinheader, bent (see text)
J10,J11, J12,J13 = BNC socket, horizontal mounting, isolated (e.g. TE Connectivity 1-1337543-0)
J15 = 10-pin pinheader HE10 (e.g. Multicomp MC9A12-1034)
J16 = 14-pin pinheader HE10 (e.g. Multicomp MC9A12-1434)
J17 = 2-pin pinheader, 0.1'' (2.54 mm), bent (see text)
J19 = USB connector, type B, horizontal (e.g. TE Connectivity 292304-1)
K1 = pushbutton (Omron B3F-10xx series)
PCB, bare, # 110758-1
alternatively, preassembled module # 110758-91
Case (Hammond 1455L1601 + machining + lettering)
Screws, nuts, spacers, misc. hardware

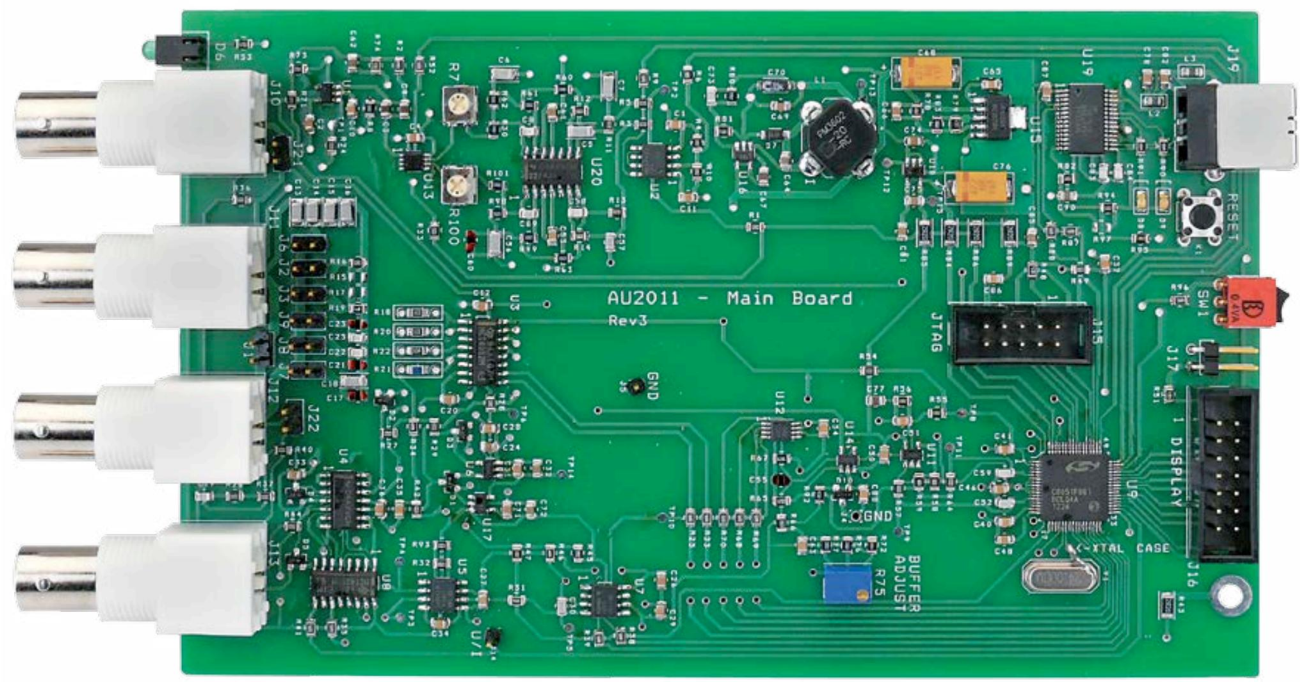


Figure 2.
Photo of the prototype.

Semi-automatic adjustment

Contrary to what we might be afraid of in the light of the devices remarkable accuracy, the adjustment procedure does not require any special skill or equipment. Apart from a multimeter for checking the supply voltage, no measuring device is required! The software takes care of the semi-automatic calibration. The user has only to carry out a few adjustments themselves, for which they are guided step by step by the program that

COMPONENT LIST

Display / Keyboard module

Resistors

(SMD 0805 1%)
R1,R2,R3,R4,R10,R11 = 4.7kΩ
R5,R6,R7,R9 = 56Ω
R8 = 1kΩ

Capacitors

(SMD 0805)
C1,C2,C3,C4,C5,C6,C7,C8,C9,C10 = 1µF 10% 25V X7R

Semiconductors

D1,D2,D3,D4 = BAT54A (SOT23)
D5 = LED, green, 3mm, leaded, (e.g. Kingbright L-424GDT)
Q1,Q2 = N-channel MOSFET (SOT23) (e.g. Fairchild FDV303N)

Miscellaneous

U1 = 64128M-FC-BW-3 graphic display (Displaytech)
J1 = 14-way HE10 transition header, **max. height 5.4mm** (Harting 09 18 114 9622)
K1,K2,K3,K4,K5 = pushbutton (Multicomp TS0B22)
14-way flatcable connector (e.g. Multicomp MC6FD014-30P1)
14-way flatcable, length (4 in. / 10cm) (3M 3365-14)

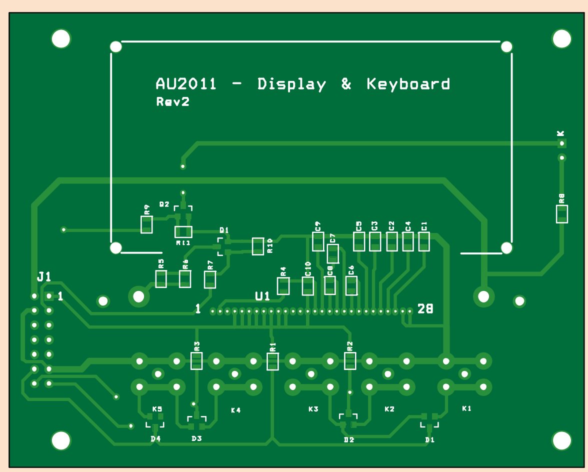


Figure 3. The design for the double-sided display extension PCB (optional).

PCB, bare, Elektor #110758-2
Alternatively, preassembled module, Elektor # 110758-92

performs all the measurements. The procedure is carefully described in a downloadable document [3], including fitting the NC components when necessary and the jumper configuration. All it takes is a little screwdriver, a little bit of judgment, and patience, as you must read the documentation right through and follow all the instructions to the letter, without skipping over any of them.

In the first article, we saw the importance of the measuring cables and their effect on the accuracy. So depending on what you want to use the LCR meter for, you may use Kelvin clips (**Figure 7a**) and/or a measuring box with four BNC connectors like the type TH26001A, "4 terminal test fixture" from TONGHUI (**Figure 7b**). They're easy enough to find via an Internet search (keywords LCR test clip, Kelvin clip, TH26001A).

Once you have the board you've built, you can power it using a USB supply and check the supply voltages. Since the microcontroller is blank, all its ports are at high impedance and it won't do anything! So there are no signals to measure. You can connect the board briefly to a PC and should see diodes D8 and D9 light: that's the FT232R (U19) communicating with the PC. Once the bootloader has been loaded into the microcontroller by the FlashUtil program using the DEBUG ADAPTER USB module (**Figure 8**) connected to J15, the microcontroller is operational. This operation and all those that follow are described in

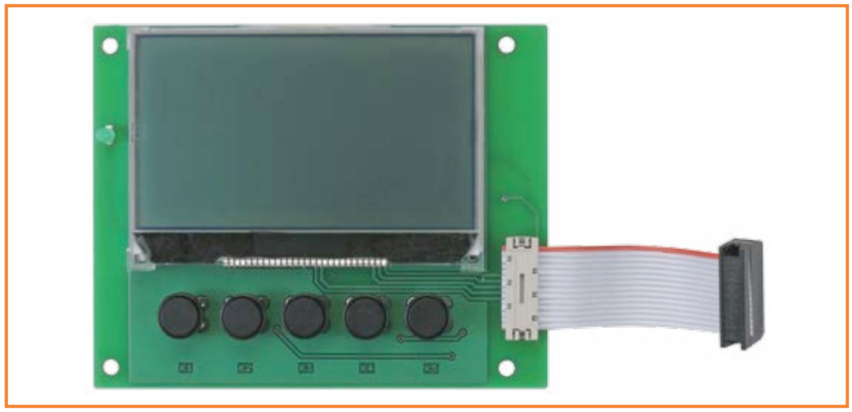


Figure 4a. Pay attention to the exact type of the HE10 connector for the display.

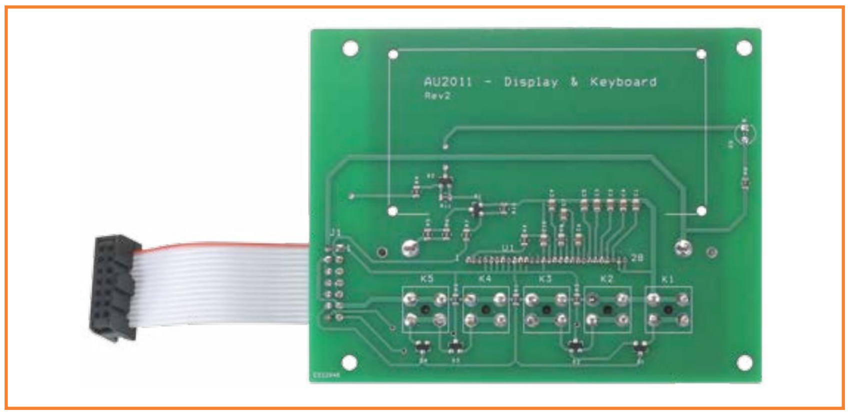
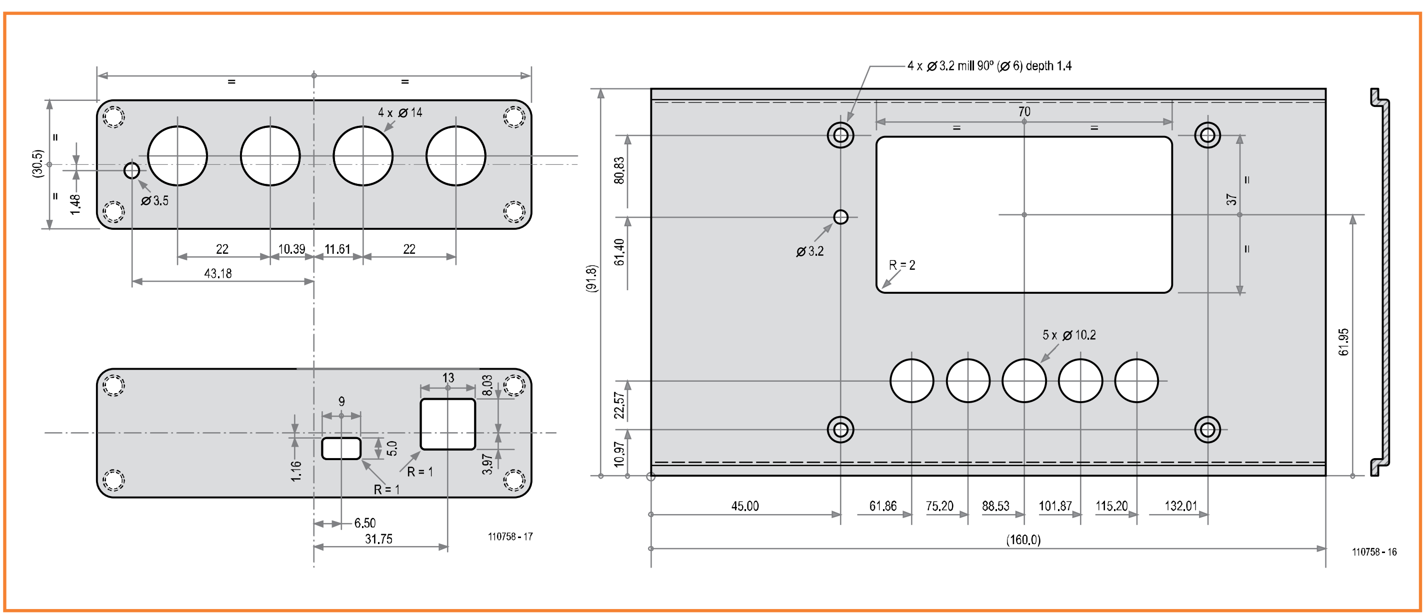


Figure 4b. The extension seen from below.

Figure 5. Dimensioned mechanical drawings.



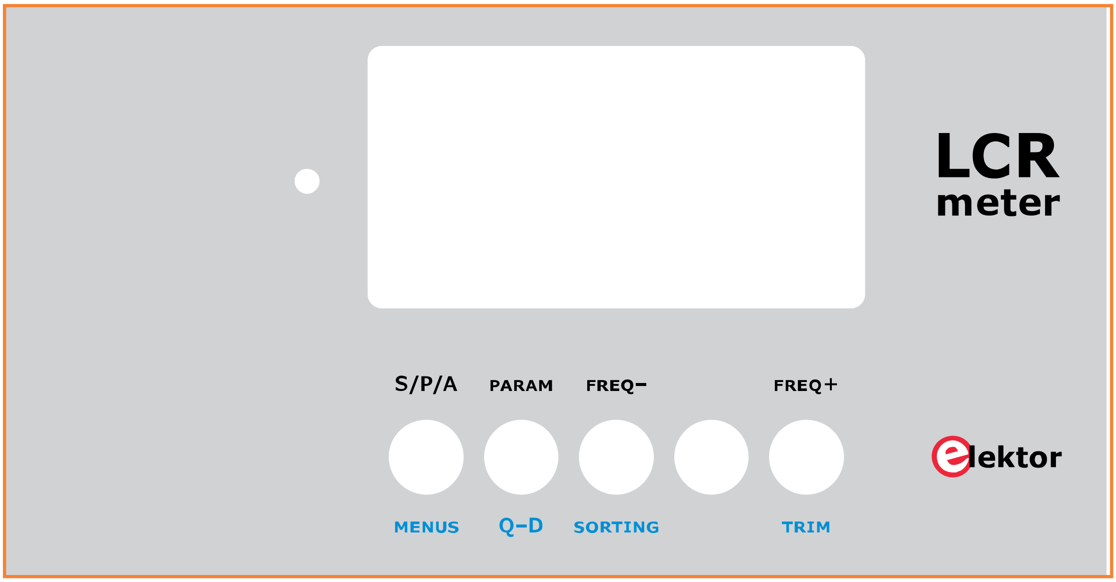


Figure 6.
Suggestion for front panel, to be engraved or silk-screened.

detail in the online documentation.
The AU2011 program installed on the PC must then establish the software link by opening the port; is it working? Then you're on the right track! All that remains is to load the *firmware* from the PC via the AU2011 program's Tools/Program update menu.
After that, when you re-boot the LCR meter, you should see the (semi-)automatic offset adjustments taking place normally as described in the

Figure 7a.
This set of Kelvin clips with four BNC leads can be found for around $10.

Figure 7b.
This test fixture fitted directly to the LCR meter case can be found for around $50.

Set-up manual [3]. If yes, there's a 95% chance that everything's OK. Then you will run the measurements by clicking on the Start menu on the PC. If the parameters of an open circuit before TRIM are displayed (**Figure 9**), then your almost 100% sure of success!

(130093)

Links & References

[1] 500 ppm LCR meter Part 1
www.elektor-magazine.com/110758

[2] 500 ppm LCR meter Part 2
www.elektor-magazine.com/130022

[3] 500 ppm LCR meter Part 3
www.elektor-magazine.com/130093

Online documentation

- software (bootloader, firmware, and main program)
- designs for PCBs 1 & 2
- component overlay, top 1 & 2
- component overlay, underside 1 & 2
- complete BOM
- XL version of circuit diagram
- mechanical drawing (standalone version with extension)
- front panel (standalone version only)
- Set-up and Operating Instructions documents

Figure 8.
To load the program into a blank microcontroller, you'll need this accessory.

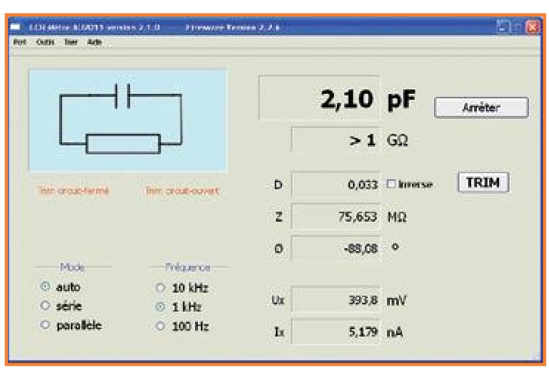


Figure 9.
If this window with the parameters of an open circuit before TRIM appears, it confirms that the circuit is working correctly.