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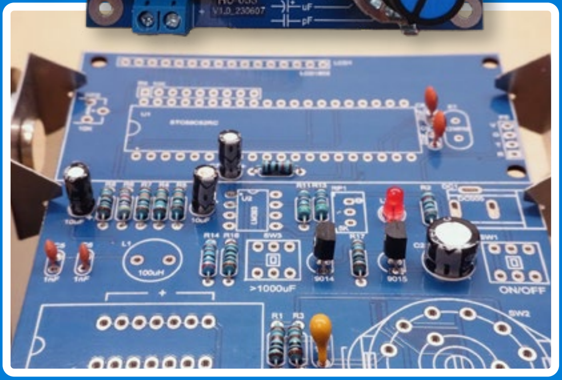
REVERSE ENGINEERING

AN LC METER KIT

Improvements in Performance

$$F_1 = \frac{1}{2\pi\sqrt{L_1(C_5 + C_6)}}$$



$$F = \frac{1}{2\pi\sqrt{L_1(C_5 + C_6 + C_x)}}$$

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$$F_3 = \frac{1}{2\pi\sqrt{(L_1 + L_x)(C_5 + C_6)}}$$

Reverse Engineering an LC Meter Kit

Improvements in Performance

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By Jean-François Simon (Elektor)

The HU-053 is an inexpensive and fun LC Meter Kit available online. It features easy-to-solder, through-hole components and a transparent acrylic box. The HU-053 kit measures capacitance, inductance, and frequency, making it a great Sunday afternoon project! Let's reverse engineer it and explore its functionality, performance, and potential improvements.

Figure 1: The HU-053 LC meter.

The HU-053 kit consists of a double-sided PCB, around 40 components, and a set of six pre-cut transparent acrylic plates, plus all the screws and nuts required for assembly. The result is the small device shown in **Figure 1**, measuring 91 mm × 106 mm with a height of 28 mm. The most recognizable components are, of course, the classic two-row, 16-character LCD, the STC89C52RC microcontroller in its large DIP-40 case, a three-pole, four-position (3P4T) switch for selecting functions, and a zero insertion force (ZIF) socket for connecting the components to be tested. The unit is powered by a 5-V supply (e.g., from a phone charger). A USB to DC barrel 5.5 mm cable is supplied.

Functions and Ranges

The four functions of the device are: capacitance measurement of small non-polarized capacitors (1 pF to 2200 pF), capacitance of electrolytic capacitors (1 µF to 12000 µF), inductance (1 µH to 1 H), and frequency meter (20 Hz to 400 kHz). The ranges shown here are those indicated on the vendor's product page, but it seems that the first range is actually much larger. I've successfully measured capacitances of over 1 µF in this mode. Probably a typing error on the measurement unit, which was never corrected! I didn't check the other ranges, as I didn't have large enough capacitors and inductors at hand.

That said, measurement accuracy, as we'll see later, can leave something to be desired. This device is more of an educational and entertaining kit on measurement techniques and oscillating circuits than a real tool. If you already own an LC(R)-meter, you can have fun comparing the measurements given by the HU-053 with those given by your own device.

Assembly

Assembly is straightforward, and illustrated instructions are supplied. As usual, the manufacturer's Chinese-to-English translation is imperfect, but photos can help. An online manual is also available at [1]. Start by soldering the smallest components (**Figure 2**), such as resistors, and install components in order of increasing size. The kit contains one more resistor than necessary per value, which is a little misleading, but nothing to worry about. Inspect the solder joints with a magnifying glass before powering up. Make sure your power supply delivers 5 V, as there is no voltage regulator on the board; any higher input voltage will destroy the microcontroller. Adjust the RP2 potentiometer to obtain the correct contrast on the display. Finally, adjust potentiometer RP1 until you obtain a voltage of 3.16 V on pin 5 of comparator U2.

Houston, We Have a Problem

During initial testing, the small capacitor range seems to have a significant measurement error. Although the unit has been calibrated by pressing the SW3 button until the display shows *Complete* and then releasing it, the unit has measurement deviations of over 30% compared with my trusty DE-5000. For example, it shows a 100 pF capacitor as 64 pF, 1 nF as 650 pF, 100 nF as 73 nF, etc. (**Figure 3**). What's going on?

Problem Solved!

More on this later, but for now, here's a quick solution. It turns out that capacitors C5 and C6, two ceramic capacitors of 1 nF each, are connected in parallel and serve as a reference for the measurement. They're thus the first suspects. Their value is checked using a DE-5000 LCR meter, and the result is shown in **Figure 4**. As can be seen, they are much larger than 1 nF; 1.5 nF for one and almost 1.8 nF for the other. These are probably very inexpensive Z-class tolerance capacitors (–20% to +80%). They may also be factory rejects for other tolerance classes which have been relabeled. Plus, their dielectric type is very sensitive to temperature changes; you can see the value shifting when holding the component between your fingers. All this makes them poor candidates for reference capacitors. Alas, the manufacturers of these kits pay little attention to these things.

Once I replaced these two by a single 2 nF, C0G, 5%, by Kemet, the meter is now usable: see **Figure 5** where a 100 nF cap is measured. The C0G class gives it much better temperature and frequency stability. Of course, it could be further improved by choosing a tolerance of 1% or even better, but I didn't have any on hand. This capacitor will do for now.

How Does It Work?

We've retraced the schematic, shown in **Figure 6**. A parallel LC circuit is built, using the reference inductor L1 and reference capacitors C5 and C6 (themselves in parallel, so they act as a single capacitor). Like all LC circuits, this circuit can oscillate, and its resonant frequency is:

$$F_1 = \frac{1}{2\pi\sqrt{L_1(C_5 + C_6)}} \quad \textit{(Equation 1)}$$

The SW2 rotary switch contacts are used to modify this reference LC circuit:

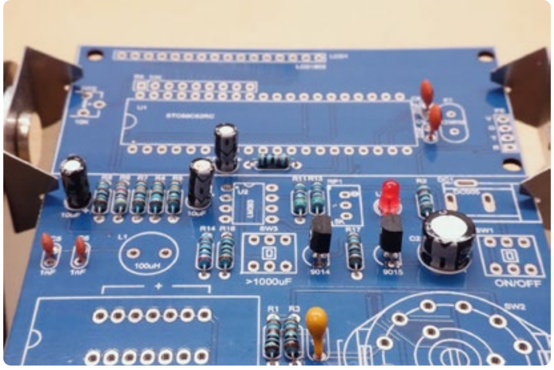

Figure 2: Start with the smallest components.

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Figure 3: Measuring the same component with two meters, something is wrong!

Figure 4: These reference capacitors of 1 nF each are not the best.

◀

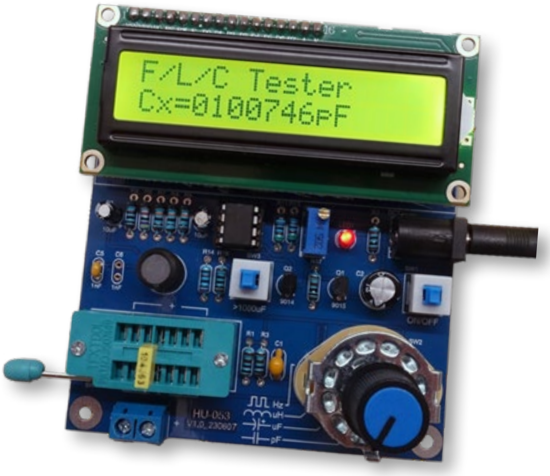

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Figure 5: With a new reference capacitor, the unit is usable.

- In *pF* mode, the capacitor to be measured Cx is put in parallel with reference capacitors C5 and C6. The oscillation frequency changes and becomes:

$$F_2 = \frac{1}{2\pi\sqrt{L_1(C_5 + C_6 + C_x)}} \quad \textit{(Equation 2)}$$

- In *μH* mode, the inductance to be measured Lx is connected in series with the reference inductance L1. The frequency changes to:

$$F_3 = \frac{1}{2\pi\sqrt{(L_1 + L_x)(C_5 + C_6)}} \quad \textit{(Equation 3)}$$

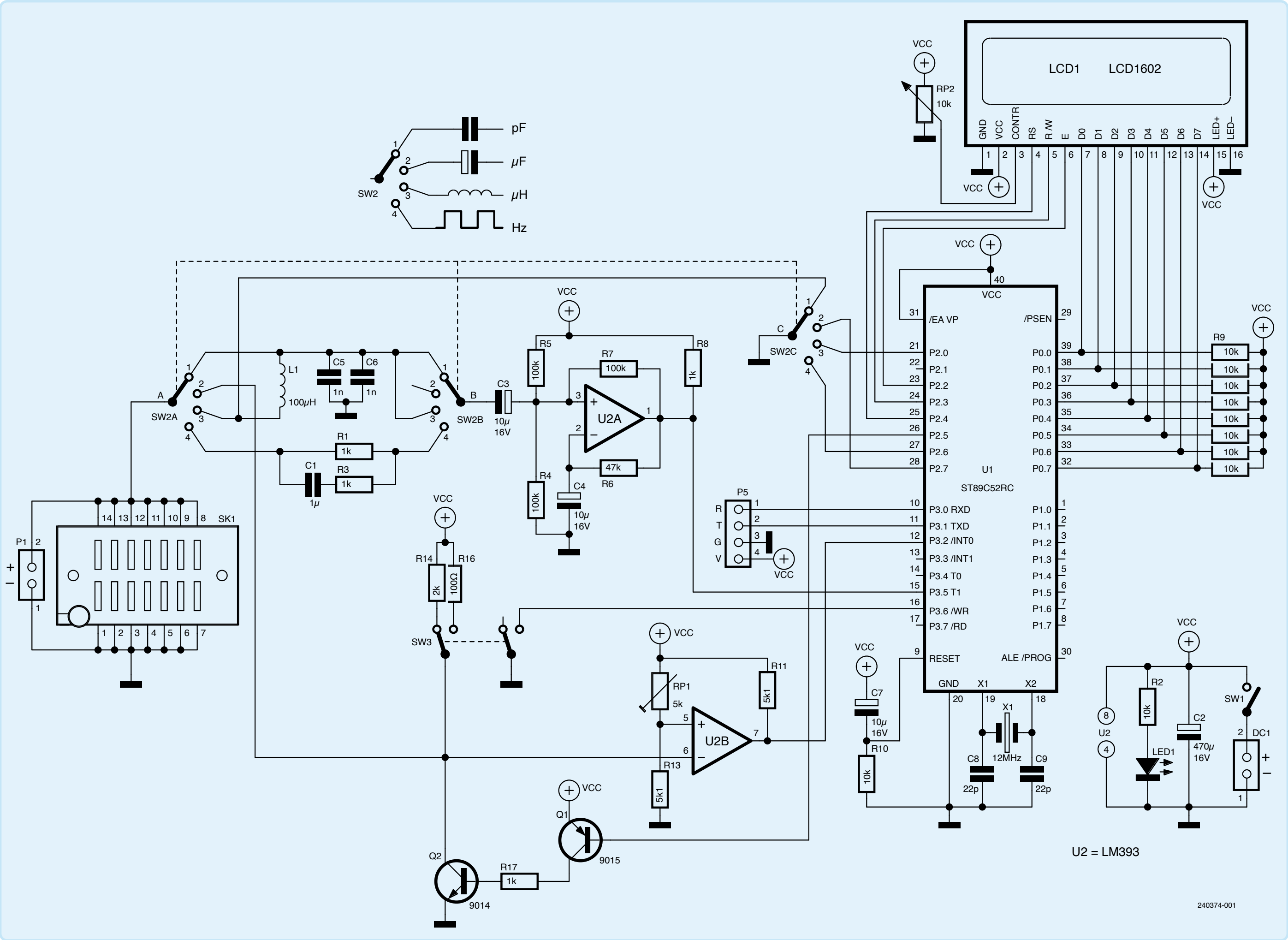

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Figure 6: Circuit diagram.

As the values of L1, C5 and C6 are known in advance, all that is needed is to measure the frequencies F1, F2 or F3 to calculate the values of Cx or Lx. The circuit formed by the first half of the U2 comparator (an LM393) is responsible for maintaining oscillations at the resonant frequency and producing a square wave signal of the same frequency on its output pin. This signal is sent to the ST89C52RC microcontroller, which measures the frequency, calculates the corresponding capacitance Cx or inductance Lx values and displays them on the LCD.

An Oscillating Comparator

The circuit using the first half of the comparator U2 is responsible for maintaining oscillations, at the natural frequency of the RC network. When the circuit is powered up, the voltage at pin 3 is 2.5 V, due to the R4/R5 divider. At this point, however, capacitor C4 is discharged (0 V). The output voltage of U2A is therefore 5 V. This charges capacitor C4 through resistor R6 until the voltage at pin 2 is equal to 2.5 V.

At this point, the output of U2A goes low. This, via resistor R7, causes the voltage at pin 3 to drop sharply to around 1.7 V. This transient is coupled, via C3, to the oscillating LC circuit, causing it to resonate at its natural frequency. This oscillation is itself coupled, again via C3, to the non-inverting input of U2A, causing a square-wave signal to appear at the output of U2A. This output signal, via R7 and C3, maintains the oscillations. This clever circuit was introduced by the late Neil Heckt in 1998 for his now unavailable and much-copied LC-meter [2].

Frequency Measurement Mode

In this mode, the LC circuit no longer oscillates, as the second terminal of L1 is left floating. Instead, an external signal whose frequency is to be measured is injected via the C1/R1/R3 network. A signal of identical frequency is created on pin 1 of U2A, and the microcontroller measures and displays this frequency on the LCD.

µF Mode

A completely different approach is used for polarized capacitors. Electrolytic capacitors are not really suitable for making oscillators, as their quality factor is between 10 and 100 times lower than that of ceramic or film capacitors. Consequently, the designers of this circuit opted for a simple, textbook method: DC measurement.

The capacitor is charged by a fixed voltage (5 V) through a fixed resistor (2 kΩ or 100 Ω, depending on the range). U1 controls the start of charging via transistors Q1 and Q2, which connect the positive pole of the capacitor to ground, or leave it floating. When U1 turns Q2 off, the capacitor starts charging and U1 starts a timer. When the voltage at its terminals reaches 63% of Vcc, the output of comparator U2B goes low, signaling the event to U1, which stops the timer. This measures the charging time at constant voltage up to 63% of the supply voltage. By definition, this time is equal to $\tau = R \times Cx$. The microcontroller computes $Cx = \tau / R$ and displays the result. Two ranges are available (0 to 1000 µF and >1000 µF), chosen with the switch SW3. The multiturn potentiometer RP1 is used to set the 63% ratio, and to fine-tune the measurement if you own a reference capacitor.

Going Further

The HU-053 is an interesting kit: it's easy to assemble, with a good quality PCB made of epoxy (FR-4) and accessible solder pads. I like the fact that it's modular: pluggable LCD, socketed ICs, and an acrylic case held by screws. It nicely illustrates concepts like converting physical measurements to time/frequency measurements, LC oscillators, and comparators with positive feedback. For more information about using comparators as oscillators, see for example Application Notes 41 and 74 from the Linear Application Handbook [3]. It's also an excellent opportunity to imagine possible improvements. Here's a non-exhaustive list, so don't hesitate to think about other ideas.

- Replace capacitors C5 and C6 with proper, high-precision reference capacitors.
- Designing a small board to replace the microcontroller with an Arduino and rewrite a new open-source program.
- Rework the measurement algorithm. Currently, inductance measurement depends on the inductance of inductor L1, and its inaccuracy produces a measurement error. However, by using the equations 1 and 3 in a different way, it is possible to express L1 as a function of C5, C6 and F1. This enables the microcontroller to calculate the precise value of L1, rather than treating it as a "magic number" in the program. This technique is used in most variants of this LC-meter, such as Jiri Recek's version [4]. It allows the use of any inductor, of any tolerance, without affecting accuracy. In all cases, however, the accuracy of the capacitor value still determines measurement accuracy.
- Modify the program to use the first line of the display, which doesn't currently show very useful information.
- Add a voltage regulator and/or reverse polarity protection to give greater flexibility and safety in terms of supply voltage.
- Find resistor values to fix U2B comparator tripping at 63% of VCC without relying on manual adjustment.
- Mitigate the error introduced by Q2's threshold voltage V_{CE} in *µF* mode.

Currently, the capacitor charging doesn't start at 0 V, but at 0.2 V. This is left as an exercise for the reader, as are the previous ideas. Good luck!

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Questions or Comments?

Do you have technical questions or comments about this article? Email the author at jean-francois.simon@elektor.com or contact Elektor at editor@elektor.com.

A Bit of Math

How are Cx and Lx calculated? By reworking Equation 1, we can write L1 as a function of F1, C5 and C6. Then, by replacing L1 by its expression in Equation 2, we can show that $Cx = (C5+C6)(F1^2/F2^2 - 1)$. When the HU-053 starts up, before any component to be measured has been inserted, the device measures the frequency F1. Then, when the capacitor to be measured is inserted, the device measures F2 and displays the result for Cx.

Similarly, by reworking Equation 1, C5+C6 can be written as a function of F1 and L1. Then, by replacing C5+C6 by its expression in Equation 3, Lx is written as $Lx = L1(F1^2/F3^2 - 1)$. As the value of L1 is known in advance, the device measures F1, then F3, and finally displays the result. Note that in pF mode, the SW3 button can be pressed to calibrate the zero point; in doing so, F1 is measured and stored in memory. This stored calibration value is also used in µH mode.

Related Products

- **LC Meter Kit**
  www.elektor.com/20868
- **DER EE DE-5000 LCR Meter (100 kHz)**
  www.elektor.com/20675

WEB LINKS

[1] Product Manual from Manufacturer: https://tinyurl.com/5hxvcxy3
[2] LC Meter from Neil Heckt: https://tinyurl.com/mv65tzc2
[3] Linear Applications Handbook: https://tinyurl.com/2hfmyr2c
[4] LC Meter from Jiri Recek: https://vyvoj.hw.cz/teorie-a-praxe/konstrukce/lc-metr-s-89c2051.html