V & I Calibrator

Have faith in your measurements

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It's difficult to be sure that your digital multimeter (DMM) is taking accurate measurements especially if it's a few years old. This handy calibrator gives full scale reference levels of both voltage and current, designed specifically for the scale ranges used by DMMs.

DMMs which claim to have a basic accuracy better than 1% can these days be found for less than £20. Even instruments with better than 0.5 % accuracy are selling for less than £100.

At the other end of the scale you can find low-spec 'no name' digital multimeters for just a few pounds at 'bargain basement' outlets and jumble sales. You may have doubts about the accuracy of these instruments. Even the better known brands do not give any figures regarding long term accuracy. Periodic recalibration is recommended. You can of course blindly trust the display readings but as they say 'confidence comes with calibration'. This calibration circuit is small enough to find a space on any workbench and will facilitate speedy and precise multimeter (re)calibration.

Voltage reference devices

The basic requirements for the calibration circuits are that it must supply a known stable DC reference voltage level. The multimeter to be calibrated is connected to the reference supply and adjustments are made to its calibration preset (see **Figure 1**) until the displayed value is the same as the known voltage level. Both the DC volt-

Figure 1. A simple low-cost multimeter with the back removed to reveal the calibration preset (red arrow).

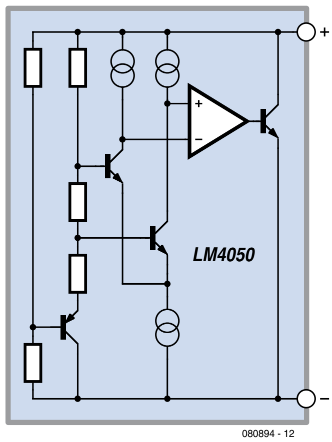


Figure 2. Block diagram of the LM4050 precision zener.

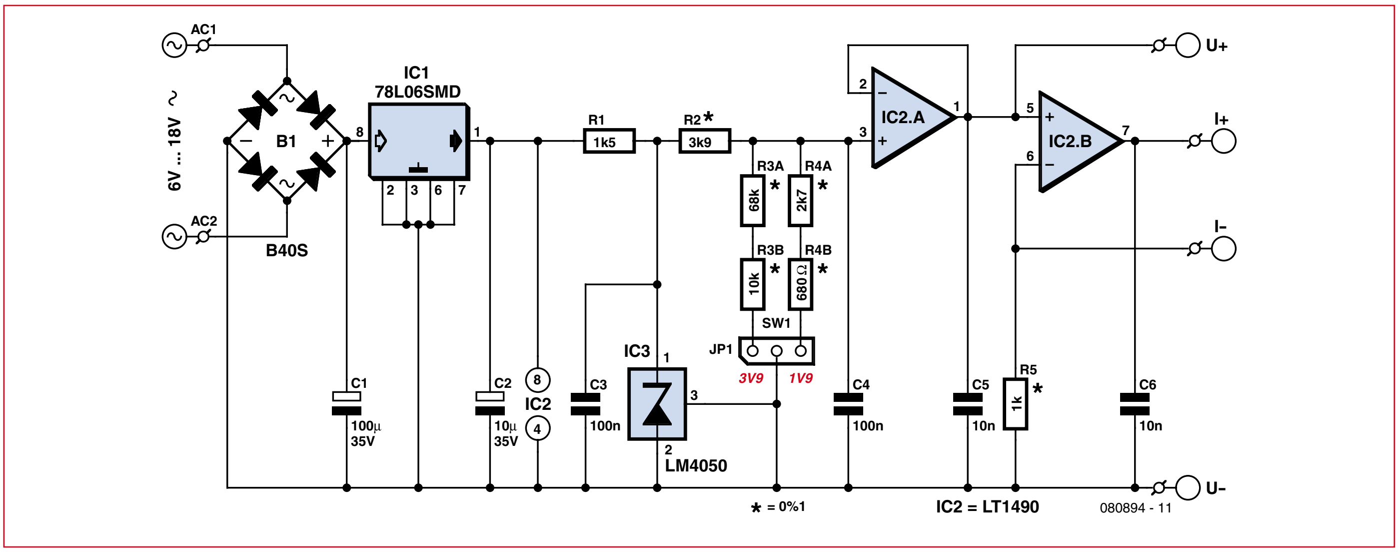


Figure 3. The volts calibrator has a voltage regulator, voltage reference, switchable voltage divider networks and a dual op amp used as a buffer and voltage/current converter.

age range and current range can be checked. The most important component in this circuit will undoubtedly be the device which generates the stable reference voltage. Fortunately there are a number of suitable ICs available which offer good precision at low cost. The LM4050 from National Semiconductor [1] was eventually chosen for this application. The LM4050A-4.1 acts as a high-precision zener diode producing a 4.1 V reference with an accuracy of 0.1%, the device is priced at around £2.00 and is available in a two-pin SMD-SOT23 package. The internal block diagram of the LM4050A is shown in **Figure 2**.

In its simplest form the calibration circuit can be made by connecting the LM4050 in series with a suitable resistor across a supply voltage (higher than the reference voltage). The multimeter to be tested then measures the voltage produced across the IC and its calibration preset is adjusted. The 10 to 20 MΩ input impedance of the multimeter will not impose a significant load on the reference voltage. OK, job done…I knew this was going to be a short article.

Reference voltage level

That certainly would do the job but to make a more useful universal calibration device requires a bit more thought and planning. High precision voltage reference ICs are available with a range of fixed reference voltage outputs. The part number suffix usually indicates the reference voltage. A typical range of standard voltage references would include 1.024, 1.200, 1.240, 2.000, 2.048, 2.500, 3.000, 3.300, 4.096, 5.000 and 10.000 V, none of which are ideally suited to our needs here. Reference levels of 1.000 V, 2.500 V and 5.000 V are fine for analogue multimeters but for digital multimeters it is necessary to produce a level just below full-scale. To find the optimum voltage reference we need to look more closely at the way DMM scale ranges work.

Technical Specfication

- 0.1 % accuracy at 25°C
- Temperature stability: 50 ppm/°C
- Output voltage: 3.9 V/1.9 V switchable
- Output current: 3.9 mA/1.9 mA switchable
- Power requirements: 6 to 18 VAC or 9 V battery
- Current consumption: 5 mA

A standard 3½ digit DMM can display readings in the range from 0 to 1999 while a better 3¾ digit device can show 0 to 3999. Using a meter with manual range selection and a reference value of 2.000 V (or 4.000 V for 3¾ digit) will cause the DMM display to indicate an overflow. This is not too much of a problem; you can turn the calibration adjustment on the DMM until the display is on the point of alternating between full scale and overflow. The DMM will then be calibrated with sufficient precision. Meters with automatic range select however will switch up to the next range, so a reference level of 2.000 V (or 4.000 V) will be displayed as 02.00 V (or 04.00 V). The resulting reduction in measurement resolution caused by the loss of a decimal place amounts to 1/200 = 0.5% (or 1/400 = 0.25%). This would significantly reduce calibration precision; the reference voltage has an accuracy of 0.1%.

Testing various makes of autoranging DMMs showed that they do not all behave identically as the measured voltage approaches full-scale. Some of them switch up to the next range at 1.950 V (or 3.950 V) while others display up to 1.999 V (3.999 V) before they switch. This influences the choice of reference voltage level, it was found that all the meters tested remained stable in the lower range (giving best resolution) with a voltage level of 1.900 V (or 3.900 V). The resulting resolution at this level now shows an improvement to the more acceptable figure of 1/1900 = 0.053% (or 1/3900 = 0.026%).

Precision circuitry

The circuit diagram (**Figure 3**) shows that precision resistors are used in two voltage divider networks to derive the 1.900 V and 3.900 V voltage levels from a reference voltage of 4.096 V produced by the LM4050A-4.1 (IC3). An AC mains adapter with an output voltage in the range of 6 to 18 V will make a suitable supply for this circuit. Regulator IC1 produces the 6 V supply voltage. Full wave rectifier B1 on the input ensures that the polarity of the

supply voltage is not important. The circuit draws low current so for occasional use a 9 V battery is also a suitable power source.
Jumper JP1 is used to select between the two different output levels to cater for both 3½ and 3¾ digit meters. The current through R1 is 1.27 mA. The current through IC3 is either 1.22 mA or 0.71 mA depending on the position of JP1 but both of these values lie around the middle of the optimum operating curve specified in the IC3 data sheet.

It can be difficult to find a supplier who stocks the complete E96 series of 0.1% tolerance resistors so R3 and R4 are both made up of two resistors in series. This allows resistor values from the more popular E12 series to be used and also makes it easier to select resistor combinations to give exactly the right output voltage.
The resulting reference voltage is now filtered by C4 and connected to the noninverting input of IC2A. This Rail-to-Rail Input and Output op amp features a low input offset voltage typically less than 0.2 mA. It is configured here as a buffer for the voltage reference [2]. The second op amp in the package (IC2B) with the help of R5 is configured as a voltage to current converter. The position of JP1 not only switches the output reference voltage but also switches this precise reference output current generator between 1.900 mA and 3.900 mA. This feature allows you to check the meter's current measurement accuracy; it is often the case that the current ranges are less accurate than voltage ranges.

C5 and C6 are used to attenuate any RF signals which may be picked up by the circuit. The author's home lab is situated quite close to several sources of radio frequency interference which can sometimes be troublesome.

Construction and use

IC3 is only available as an SMD outline so with the exception of the precision resistors and both electrolytic capacitors all the remaining components use SMD packaging. The finished PCB is just 40 mm square (**Figure 4**). To make it easier to mount the SMD components R1 and C3 to C6 use the larger 1206 package outline.
The author recommends using the following procedure to mount the ICs and B1: firstly tin just one of the pads on the PCB where the IC will be fitted. Move the IC into position over the pads, clamp it down tightly with one fingernail then using the other hand bring the soldering iron tip in contact with both the tinned pad and IC leg until a joint is formed. Once cool the IC will now be correctly fixed in position. Now after double-checking the IC orientation, solder the remaining leads. Lastly check that you have not accidentally created any solder bridges between pads.

Once the board is fully populated and you have carried out a careful visual check of your soldering handiwork it is time to test the circuit. Connect the supply input pins to the output of an AC mains adapter capable of supplying 6 to 18 V (the circuit consumption is less than 10 mA) or alternatively use a 9 V battery. A DMM can now be connected between 'U+' and 'U–' where either 1.900 V or 3.900 V can be measured. Connect the multimeter leads to 'I+' and 'I–' and switch the range to DC current to measure 1.900 mA or 3.900 mA.
Calibrating the DMM is just as simple: Open-up the DMM case and identify the scale calibration preset (**Figure 1**). Select the correct scale on the DMM and switch it on. Connect the calibrator output to the DMM inputs and adjust the preset until the DMM display value is correct. It is usually sufficient to calibrate just one range, all the measurement ranges are normally linked by cascaded resistor networks and it is very difficult to make any individual changes. Once the voltage range is calibrated the current reference can be used to test the DMM current reading. It is usually not possible to make any adjustment to the displayed current value. You will at least get an indication of how accurate the current readings are and how far the meter readings can be trusted. This also applies to the AC measurement ranges of voltage and current which are not calibrated. To calibrate resistance ranges there are no prizes for guessing that a precision resistor of value 1.8 k or 3.9 k can be used as a reference.

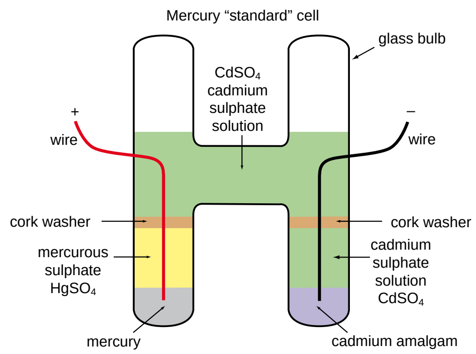
Variations

The circuit will also work with a 5 V voltage regulator in place of the 6 V version used for IC1. In this case it will be necessary to reduce the value of R1 to 820 Ω. This modification will however prevent the circuit from supplying the reference current to test the current ranges. A current of 4 mA produces a voltage drop of more than 400 mV. The author has a 3¾ digit DMM in his possession which (curiously) produces a voltage drop of just over 1 V at this level of current. In this case the supply voltage to IC2B will be too low. The component values given in the circuit

The Weston standard cell

Reference voltage sources have traditionally been called 'standard cells'. Similar to a battery, they use a combination of galvanic materials to produce a precise reference voltage which is relatively stable and temperature independent. The Weston cell (1893) was the work of the American physicist Edward Weston (1850–1936) and was adopted as the international standard for EMF (electromotive force) in 1911.

Like all galvanic elements the cell has two electrodes suspended in an electrolyte solution. The cathode is mercury and the anode is a cadmium/mercury amalgam while the electrolyte is a solution of cadmium sulphate (see illustration). The Weston cell produces a nominal voltage of 1.01865 V at 20 °C. It has a very low temperature coefficient of less than 10^{-4} V/°C.



The photo at the beginning of the article shows a cell which was made in the second half of the last century. According to the label it produces a voltage of 1.0193 V with an accuracy of 0.1 %. This is better than we have achieved here with our low-cost silicon alternative but it has to be said that our version is less toxic, more robust and much more versatile.

COMPONENT LIST

Resistors
R1 = 1kΩ5, SMD R1206
R2 = 3kΩ9, 0.1%
R3A = 68kΩ, 0.1%
R3B = 10kΩ, 0.1%
R4A = 2kΩ7, 0.1%
R4B = 680Ω, 0.1%
R5 = 1kΩ, 0.1%

Capacitors
C1 = 100μF 35V, radial electrolytic
C2 = 10μF 35V, radial electrolytic
C3,C4 = 100nF, SMD C1206
C5 = 10nF, SMD C1206
C6 = 1nF, SMD C1206

Semiconductors
B1 = B40S, SMD bridge rectifier, 40V/1A
IC1 = 78L05SMD, SO08
IC2 = LT1490, SO08
IC3 = LM4050A-4.1, SOT-23, e.g. Farnell # 1468851

Miscellaneous
JP1 = 3-way SIL pinheader, lead pitch 2.54mm (0.1”) with jumper
PCB, # 080894-1

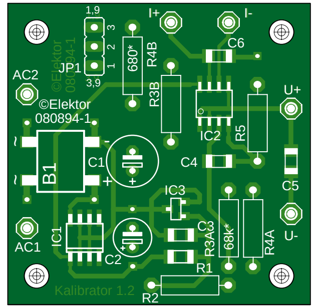


Figure 4. At 40 mm x 40 mm the Volts Calibrator PCB is very compact.

diagram will be suitable to cater for the majority of situations. If you really want to cover every possible case you can use an 8 V regulator for IC1, R1 will now need to be 3.3 kΩ and a minimum AC input supply of 9 V will be required.

In many cases a less precise reference is acceptable; the B version of the LM4050 can be used here. It has a precision of 0.2 % but the price difference between the two chips is only a matter of a few pence. Alternative op amps for IC2 (the LM4050) are the OPA2343 from Burr-Brown or the AD822 from Analog Devices.

The circuit can be fitted into an enclosure; a single pole changeover switch can be wired to the pins of JP1 to replace the jumper. Those of you who would prefer the volts calibrator to produce the more traditional reference values of 1 V and 1 mA can use a value of 750 Ω for R3A and 510 Ω for R3B. Both 0.1%, of course.

(080894-I)

Internet links & Literature

[1] www.national.com/mpf/LM/LM4050.html

[2] www.linear.com/pc/productDetail.jsp?navId=LT1490