Testing Our Voltmeters:
The Syscomp REF-101 Voltage Reference

Peter Hiscocks
syscomp-support@magma.ca
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Introduction

It's natural to assume that our voltage measuring equipment is reading correctly. But is that really the case?

Here at Syscomp, we needed a voltage reference for calibrating our oscilloscopes. It used to be that a voltage reference was an expensive device. These days, it's an inexpensive integrated circuit. Once we had a reference, it was a natural extension to test our voltmeters (shown below) to see how accurate they are.

Simpson 260

AVOMeter 8

Fluke 8100A

Tektronix DM502A

Metex 3530

DT830-D

HP6920B

Mastech MAS344

Mastech MS8226

Mastech 9803

The Reference

The reference circuit is shown in figure 1. The reference device is the 2.5V variant of the National LM4132. The quiescent reference current is only 60μA, much less than the current in the indicator LED (about 14mA), so battery power is quite feasible. The 2.5V output is divided down to provide a second outputs, 250mV. For convenience, both outputs are available at pin headers and BNC connectors.

The initial output accuracy is $\pm 0.05\%$, or ± 1.25mV on the 2.5V output. The temperature drift is 10ppm/°C, or 25μV on the 2.5V range. Typical long-term drift is ± 75ppm, or ± 0.18mV. (These specs apply at 25°C).

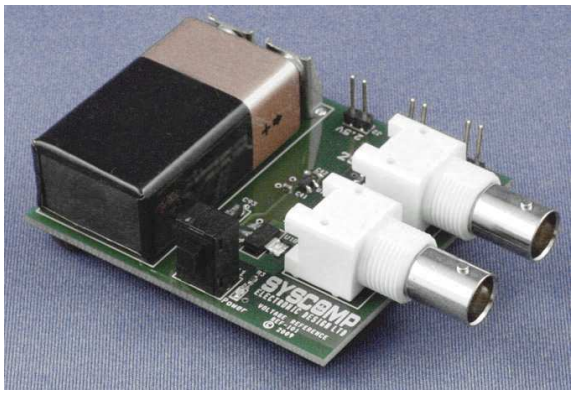

Figure 1: Voltage Reference

The Tests

We tested each meter on both ranges. Digital voltmeters can automatically correct for polarity, and so we checked the reading with the polarity reversed. The results are shown in the following table. They were surprising in some respects.

Simpson 260

This is an analog (moving coil) VOM (Volt-Ohm-Milliameter). In its heyday, it was a very popular unit and it's available on Ebay for a few dollars. This unit has an error of about 9% (on this scale), which is rather serious. The Simpson 260 is about 60 years old, so we have to cut it some age-related wiggle room, but it's no longer useful with that kind of accuracy. See:
`http://reviews.ebay.com/Simpson-Meters-260_W0QQugidZ10000000007543567`

Avometer 8

The AVO (Amps-Volts-Ohms) was a standard analog multimeter for many years. First introduced in 1923, it was discontinued in 2008. That's a *very* long run for a product. At the university where I worked (Ryerson, in Toronto) the AVO was valued for its ability to read AC amperes, which is unusual in a multimeter. As well, it has a circuit breaker that protects the instrument from overcurrent. The AVO has a reputation for ruggedness - it's claimed that one was dropped from the Toronto Channel 9 TV broadcasting tower, and survived.

The specification for DC readings is 1%. This one is within 2%, much worse than run-of-the-mill digital instruments. The AVO was very expensive: toward the end of its life, it sold for 585 British pounds. Like the Simpson 260, it's frequently available on Ebay.
`http://en.wikipedia.org/wiki/Avometer`
`http://www.richardsradios.co.uk/avo8.html`

Model	250mV Range	2.50V Range	2.5V Error, mV	2.5V Error,%
Simpson 260	+220mV	2.27V	230	9.2
Avometer 8	+240mV	2.45V	50	2
Fluke 8100A	+249.5mV	2.499V	1	0.04
	-249.6mV	-2.497V	3	0.12
Tektronix DM502A	+250mV	2.51V	10	0.4
	-249mV	-2.49V	10	0.4
Metex 3530	+250mV	2.49V	10	0.4
	-249mV	-2.49V	10	0.4
DT-830D	+248mV	2.48V	20	0.8
	-248mV	-2.48V	20	0.8
HP6920	+2475mV	2.445V	55	2.2
Mastech MAS344	+249mV	2.496V	4	0.16
	-249mV	-2.496V	4	0.16
Mastech MS8226	+250.2mV	2.501V	1	0.04
	-250.5mV	-2.501V	1	0.04
Mastech 9803R	+249.7mV	2.499V	1	0.04
	-249.7mV	-2.499V	1	0.04
Rapid/Mastech M9912		2.501	1	0.04
(see Postscript)		2.492	8	0.32

Fluke 8100A

Produced in 1967, the Fluke 8100A was an early digital voltmeter. This predates the invention of the LED, and the readouts are Nixie tubes[1].

This unit has excellent resolution (4 1/2 digits[2]) and accuracy to match. This is especially impressive considering that it's 43 years old.

Tektronix DM502A

The DM502A is one of a large number of instrument modules that make up the Tektronix TM500 measurement system[3]. This one dates from 1979. At 3 1/2 digits, the resolution is somewhat limited, but it's useful as a general

[1] `http://en.wikipedia.org/wiki/Nixie_tube`

[2] The four digits are the usual decimal digit. The 'one half' is an extra 1 digit, so the range of the display on this instrument is 00000 to 19999.

[3] `http://web.mit.edu/johnston/www/tek-7000-tm500.html`

purpose instrument. Allowing for that, the accuracy is fine. The TM500 series is a very convenient arrangement on a test bench.

Metex 3530

The Metex 3530 is an early example of a Hong Kong import. It appeared in Toronto about 20 years ago for a retail price of about $70. It has gotten extensive use and is now somewhat frayed around the edges, but the accuracy is still fine for a 3 1/2 digit unit.

DT-830D

The DT-830D showed up in a local surplus store for $10 retail price. The accuracy of this 3 1/2 digit unit accuracy is comparable to the Tek DM502A. It's *very* cheaply made, as one would expect, and therefore of unknown reliability.

Hewlett Packard 6920B Calibrator

The HP6920B dates from 1967. It is not actually a voltmeter, it is an adjustable power supply intended for the AC and DC calibration of ammeters and voltmeters. The dial at the centre of the front panel is a 10-turn potentiometer with 3 mechanical digit readout. The full-scale range can be set between 1 and 1000 volts, AC or DC. It can also produce a calibrated output current between 100μA and 10A.

The accuracy specification is 0.2%. This unit needs re-calibration, the error is currently 2%.

Mastech MAS344

With the MAS344, we enter a more modern era. The MAS344 is currently in production (November 2009), available for about $50. The display is described as '3 3/4' digits, which means the leading digit can be 0 through 3. This is also described as a '4000 count' meter (0 to 3999). There is a rather strange front-panel socket that allows connection of the meter to a host computer for data logging.

The autoranging puts it within 1mV on a 250mV reading (0.4% accuracy) and 4mV on a 2.5V reading (0.16% accuracy). This is very respectable for this class of multimeter.

Mastech MS8226

The MS8226 is similar to the MAS344. It's a '3 3/4' digit display with a similar accuracy specification (± 0.5%). We actually measured a very respectable 0.04% error. The MS8226 has a much nicer opto-isolated cable for data logging, RMS measurement on AC voltage, temperature probe and auto-shutoff.

The software supplied by Mastech only runs on a Windows operating system and is closed source. We will be reselling this unit with open-source software than runs on the Windows, Linux and Mac operating systems. The software will have the same functions as the Mastech software, plus additional features, all at a very competitive retail price.

Mastech M9803R

Not that we need more voltmeters, but this model became available at a very attractive price. It's a bench model, higher accuracy with fewer features than the MS8226. The display is 4 1/2 digits, that is 00000 to 19999, or one part in 20,000. The DC volt accuracy specification is ± 0.3%, plus or minus one count. We measured a one-count error (2.499V for 2.5V). That could easily be an error in the reference itself.

Conclusions

- The Simpson and AVO analog meters have a retro charm, but their DC accuracy leaves a lot to be desired. There is something to be said for the moving needle display. It can be much easier to interpret a trend from a moving needle. On the other hand, recognizing that as a problem, some digital voltmeters have a bargraph display to help indicate the direction and speed of readings.
- The Fluke 8100A cost about $700 new in 1969[4]. Accounting for inflation[5] that's equivalent to $3300. A modern digital meter with comparable precision and accuracy is about 50 times lower in cost. Whether these modern meters will still be functional and accurate in 32 years - as is the Fluke – is an open question.
- Modern digital multimeters appear to meet their accuracy specifications, so they can be relied upon. Reversing the polarity has essentially no effect on the reading accuracy.
- The REF-101 is a very simple, low-cost way to check the DC accuracy of an oscilloscope or voltmeter.

Postscript

John Foster reports on his use of the reference:

> I used the Syscomp voltage reference to check my Rapid M9912 meter[6], which claims a DC accuracy of 0.8% +- 1 digit. The results were well within the spec whichever way round it was connected. Thanks to the voltage reference I now know that at low voltages I will get results better than the spec by more than an order of magnitude if I make sure to connect positive to positive instead of relying on the auto-polarity function.

Figure 2: Rapid/Mastech M9912

[4] See `http://www.eetimes.com/anniversary/designclassics/gauging.html`, an account of the history of the digital voltmeter in the USA.

[5] Inflation averages about 5% per year, so the inflation factor is 1.05^y, where y is the number of years.

[6] The Rapid M9912 appears to be a rebranded Mastech M9912.