Exploring the DMM: Applications and Techniques

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About the cover

The six DMMs shown are used as examples of the various aspects of the most used electrical instrument: The Digital Multi-Meter. The DMM is in contrast to the Analog Multi-Meter shown at the bottom left. All instruments were made in China. Three did not have serial numbers, SNs, on the back or in the battery compartment. The two identical machines made by ANENG have different (one longer) serial numbers. Is there information encoded in the serial number? The current price and source are also included. The user must shop carefully as the prices are crazy with Chinese sales the lowest. The delivery time may be weeks, however.

The calculated load on the 10-volt reference is: 6 machines @ 10 MΩ = 1-2/3 MΩ, Add the input for the analog meter at 0.2 MΩ for a total load of 129 KΩ. At 10 volts the current is 80 µA. This is well within the 10-mA maximum current rating of the 10 reference source.

1. The largest DMM is the ANENG model AN-870. This is a four and ½ digit, 19,999 count DMM that is an excellent higher resolution low-cost instrument in the ANENG product lineup. **No serial number.** The cost from Alibaba is $17.10. This performance and price is a real bargain.

2. Next to the AN-870 is "The" AN-8009. This is the primary subject of this writing project and HHC2025 presentation. SN 74404483. The cost from Alibaba is 16.50.

3. The next DMM is really an AN-8009, but sold under another name ZOTEK with a model number of ZT111. Examine them carefully. Do you see any differences? See Fig. N3 in the Notes section for a side-by-side comparison with the backs removed. SN 404018187. The cost from AliExpress is $27.98.

4. The yellow-orange DMM is a newer ANENG model the SZ 02. This machine replaces the function selector switch with a very large LCD display. The specifications are very similar to the AN-8009 at one half of the AN-8009's cost. SN 20230541736. The cost from Bangood is $15.00.

5. The penultimate machine is the no longer available Fluke model 101. I bought two of these on sale just to have a Fluke. This DMM is described in great detail using the DMMCheck Plus as an NIST traceable reference. Also see Appendix C. Here is what Google AI had to say. *"The Fluke 101 was available starting in 2013 and was listed as a current product by Fluke and other retailers as of September 2025, indicating a market presence of at least 12 years. However, some sources suggest the model may now be replaced by the Fluke 101+ (available since at least April 2015) or other models like the 107, suggesting it may no longer be the primary offering from Fluke." SN 55270220WS. The cost from Temu (?) $15.99 and from eBay $39.00*

6. The last DMM is the red no-cost seven function DMM sold by Harbor Freight and used for many promotions with a get-one-FREE coupon. It has an Item number 90899. **No serial number.** The cost from Harbor Freight is $7.99.

The analog meter value is "read" for greatest accuracy by copying the pointer/scale area and enlarging it as shown in the insert. Each minor scale is 0,2 volts. This portion is then printed on a full page and a Verner caliper is used to make the spacing measurement to the thousandths of an inch. This resulted in the 10.16 volt measurement so the Error = + 1.6% value could be calculated. This also demonstrates one of the reasons that digital instruments have outpaced analog instruments. Reading errors are greatly reduced. **No serial number.** The cost from amazon is $26.49.

At the lower right is an NIST traceable 10-volt reference source that each instrument reads. This is the latest, R9, extremely stable voltage reference available at: https://voltagestandard.com See Appendix I for more details.

Introduction

The term multimeter is broad and often the example of an analog multimeter comes to mind, especially for older readers/users. See Fig. 1. The battery used for an analog multimeter is used for measuring resistance. This more modern design has a 9V battery and two series AAA cells. The latter is for the resistance function. I do not know what the 9 V batter is for. Note the model number is VX-360TR$_{N\text{-}A}$ which is after the famous 360 Simpson design. AC versions, VTVMs, Vacuum Tube Volt Meters, used vacuum tubes, but due to design/performance constraints was only 10 to 11 megohms input resistance. Vacuum tubes are often thought of as having "infinite" input resistances.

Fig. 1 – Typical Analog multimeter with leads.

When analog to digital conversion technology improved the digital multimeter, DMM, became a practical and lower cost alternative. Also with semiconductor advancements custom integrated circuits, ICs, further reduced the costs so a DMM may be manufactured in China for just a few dollars. In years past Harbor Freight "sales promotions" gave a seven function DMM for free[(2), (5)].

The DMM, compared to analog meters offers greater sensitivity, accuracy, and resolution at a lower cost. The most used feature is the clarity of the display reading. Here is a list of typical DMM advantages.

1. Higher resolution with up to eight and one half digits to be displayed. See appendix B.
2. Higher sensitivity, typically 10 MΩ with a millivolt range usually exceeding 100 MΩ.
3. Being microprocessor, µp, based the user interface is more flexible. Unusual methods that require complex math operations are easily employed. It then becomes a matter of programming. Output interfaces for data recording are easy to implement as features.
4. Because the display and other circuits are all digital the size may be reduced for shirt pocket and palm sized models.
5. A digital µp may also use memory for time related functions such as maximum and minimum readings. The AN-870 has a max-Min feature working on nearly every function.
6. An auto range selection is a µp capability that is nearly impossible with analog meters.
7. True RMS is another feature example of DMM advantages.
8. Signal processing is also more easily implemented in a DMM.

The DMM is one of the most used, and powerful instruments used by the electrometer[(1)].

Manufacturer and model considerations

Modern DMMs are microprocessor based and controlled by a program that may even be updated – as a feature? For this reason, it may be important to be aware of the make, model, serial number, and software version whenever discussing a particular DMM. Only a few have this software update ability however.

DMMS may be divided into **three categories**.

A. **Low end range (cheap).** These are the lowest cost at about ten dollars. They are often powered by a nine-volt battery, and they are not very sensitive. These are bare bones models that may not even have an auto turn off feature. An example is the Harbor Freight [(2)] seven function DMM shown in Fig. N1 in the Notes section.

B. **Mid-range.** These are in the $15 to $35 price range and they have a wide range of features and functions. A $25 (or less) ANENG AN-8009 is "the" DMM implied in the title.

C. **Professional.** These are often the old school designed models that are especially rugged, are fully specified, fully supported, and are often marketed by instrument (oscilloscope, signal generator, etc.) companies. Fluke is an example. A full featured Fluke DMM may cost $300 or higher. They have excellent accuracy specifications. The accuracy specifications may take several pages to present.

The category of DMM that is most suitable for the reader [(3)] will depend on its intended use. Usually this will be between the low-end and mid-range categories. **Because price is a factor it is vital to shop.** The prices very greatly, especially the low prices during a sale direct from China. The professional category of models may be an ego issue as much as anything. In this situation cost may be less of an issue because the user "wants the best". **One of the objectives of this presentation is to challenge this thinking.** See the next section. Personally, I own and use close to 100 DMMs. This includes a few analog multimeters, i.e. the cover page. There are two models that I have a dozen or more of each [(4)].

What I Use

Because I do a lot of technical writing involving electronics measurements, I need a small DMM with a large display so I may include multiple instruments in one circuit photo. A Chinese manufacturer, ANENG, makes a complete line of DMMs, and their model AN-8009 is an excellent value for its handheld size, functions, features, and accessories. My needs may be unusual, but the AN-8009 [(4)] is still an excellent bargain at $25 with an even lower price if bought directly from China. See page 2.

Rather than buy an excellent Fluke DMM for $300 I prefer to buy three AN-8009s and a $225 NIST traceable DMM set of references/standards to check all of my DMMs. See Fig. 2 and Fig. 3. Also see Appendix D for its specifications – those provided and those I measured.

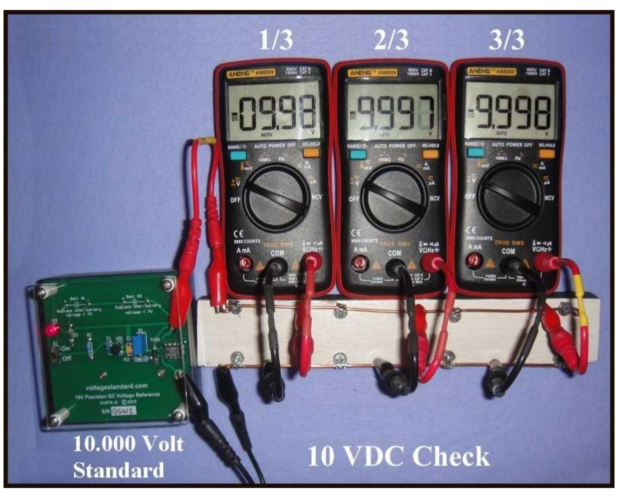


Fig. 2 – ANENG model AN-8009 DMM.

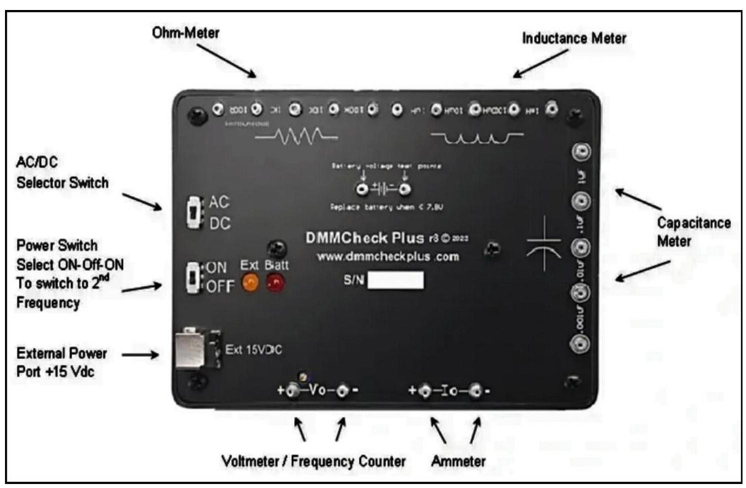


Fig. 3 – DMMCheck Plus r8, a recent more stable design.

This model is the reason for the use of the word "The" in the title. No DMM model is all inclusive with all the functions and features a user may desire. An example is the ability to record the high and low (max and min) values. This is especially important when making certain measurements such as a light intensity sensor. The light sensor must be normal to the source to read its value. This is usually physically difficult. Using the max/min feature you just tilt the sensor in each axis and the DMM will record the maximum (and the minimum). This is especially important for data recording and repeatability. This is a DMM feature that I wish the AN-8009 had. The AN-870 does have it however.

The next step up

If the resolution of the 9999 count AN-8009 is inadequate the next step up is the ANENG AN-870. This model is a physically larger DMM – the left most large machine on the cover – and it is in the $30 range with a 19,999 count. It has as good or better accuracy specifications as the AN-8009. See Appendix E for the details.

An interesting new development

ANENG has a very large range of models. They even have their own website. You cannot, however, communicate directly with them. They introduced a four-digit model, the AN-8008 in 2017. An improved model changed three functions (and is the AN-8009) in late 2017 or early 2018.

A relatively new model, the SZ02 is an interesting DMM that is designed to remove the expensive selector switch and have less than half the cost of the AN-8009. Its large display takes the whole face of the instrument. See Fig. 4. This machine – I have four of them (in two colors) and it is high on my list of writing projects to explore. It is a true RMS, 9999 count with similar specifications as the AN-8009. This may be a market test model. It is also an example of the company actively doing research and development to push the state of the DMM art ever forward.

Fig. 4 – Low cost DMM.

Common DMM functions

Here is a list of the more common DMM functions. Usually, a function is a position on the selector switch. An additional push button switch may toggle several functions with one rotary switch position.

1. **Voltage AC and DC.** The most common range will usually be millivolts to hundreds of volts. Usually, 1 KV is the upper range [7]. AC voltages are always less sensitive than DC voltages. Look closely at Fig. 1 at the lower left corner below the analog model number. It says "DC 20 KΩ/V" and AC 0 KΩ/V. Nearly every DMM will exceed this sensitivity.

2. **Current AC and DC.** The range is microamperes to 10 amperes. The 10-ampere range is usually for measurement and not for continuous monitoring because of overheating.

3. **Resistance.** Sub ohms to 10 MΩ. The AN8009 upper range is 100 MΩ. The highest resistance normally encountered is 10 MΩ. DMMs that have an upper limit of 10 MΩ will show OL for 1% 10 MΩ resistors that are on the high side. The Over Load display is often considered as an "open" condition.

4. **Non-Contact Voltage function.** This is very important from a safety perspective.

5. **Frequency and duty cycle.** These are usually together.

6. **Diode testing.** Usually, the forward bias voltage is displayed. Diodes have a surprising range,

7. **Continuity.** A (often specified) resistance or less causes a tone to be generated.

8. **Junction transistor testing.** You may determine NPN vs PNP transistors.

9. **Capacitance.** One or more ranges. Often nano-farads is the lowest value range, no pFs.

10. **Inductance.** One or more ranges. Not very common.

11. **High, low, and hold.** These are probably better thought of as a feature than a function.

DMM Applications

The applications for DMMs are practically limitless. Here are a few of the most common.

A. Household, commercial, and electrical power measurements and troubleshooting. A cheap DMM is easily justified by the homeowner even if used but once a year. Electricians are VERY expensive.

B. Component testing and grading.

C., Electronics/electrical device troubleshooting.

D. Car battery charging is an issue because the high Amp range may over heat and damage the internal shunt. The manual should provide this notice.

E. Research applications involving electrical parameters.

F. Measuring high voltages to 40 kV using a special probe [(7)].

G. Demonstrating various electrical phenomena.

DMM specifications

Most DMMs in the low-end and mid-range categories do not have all the necessary specifications the informed user requires. The unspoken assumption by the manufacturer is that we are just like the others. Some specifications are provided because the competition requires/provides them. These are usually accuracy specifications. See Appendix B for seven DMM accuracy specification methods compared side by side.

The accuracy specifications of a digital meter are different than that of an analog meter. The reason for this is the analog to digital converter that is required to allow a µp to process the inputs to have the value to process for the display. This additional processing adds another parameter to the accuracy specification. The two parts are the percent of the reading, and the second part is the least significant counts that are added. Here is the AN-8009 DC voltage specification. See Appendix B. This situation looks like a good application for a calculator program. Store the two parts of the specification and enter the meter value to get the accuracy range.

Where the first two categories exhibit the lack of specifications the professional category is just the opposite. An example of such a meter is seen in Fig. I1 near the end of this document. It practically takes an engineer's degree – and maybe a lawyer – just to read and understand all the details of these specifications. Spending $10,000 plus for a quality DMM is very easy.

Still, a hand-held quality DMM needs specifications. Specifications require extensive testing and maintenance. A DMM manufacturer is not going to add additional Quality control measures if they are not required. I measured all of the major specifications for the AN-8009 DMM and the results may be found in Appendix D. A sample is shown in Fig. 5. Notice that the DC voltage accuracy specification is twice as good as the AC.

Official AN8009 Specification. See Table l page 3. Where are the vital specifications?
▲ - Range values rounded up one LSD count. The red notations are mine for added clarity.

Function – switch rotation order	**Range▲ (highest value)**	**Resolution**	**Accuracy***	**MAX. Value**	**Other**
DC Voltage (V)	999.9mV **1V**	0.1mV	**DC Voltage** **±(0.5%+3)**	999.9V	
	9.999V **10 V**	0.001V			
	99.99V **100 V**	0.01V			
	999.9V **1 KV**	0.1V			
DC Voltage (mV)	9.999mV **10 mV**	0.001mV		99.99mV	
	99.99mV **100 V**	0.01mV			
AC Voltage (V)	999.9mV **1 V**	0.1mV	**AC Voltage** **±(1.0%+3)**	750V	40Hz-1kHz
	9.999V **10 V**	0.001V			
	99.99V **100 mV**	0.01V			
	750.0V **750V**	0.1V			
AC Voltage (mV)	9.999mV **10 mV**	0.001mV		99.99mV	
	99.99mV **100 mV**	0.01mV			

Fig. 5 – Official AN-8009 specification snippet.

The results are reproduced in Fig. 6.

Table 8 – Measured Missing AN8009 DMM Specifications

1	DC mV loading resistance . . . .>100[1] MΩ	7	DC Amp range resistance (burden voltage) . 0.0667[1] Ω
2	DC voltage loading resistance. . . . . 10 MΩ	8	AC µA resistance (burden voltage) . . . . .100 Ω
3	AC mV loading resistance. . . . . >100[1] MΩ	9	AC mA resistance (burden voltage) . . . . 0.0809[3]Ω
4	AC voltage loading resistance. . . . . 10 MΩ	10	AC Amp range resistance (burden voltage). . 0.0809[3]Ω
5	DC µA resistance (burden voltage) . . . . 100 Ω	11	Ohm's voltage or constant current. . . . . The constant current is 0.02 µA to 85 µA. See tables 9 & 10.
6	DC mA resistance (burden voltage) . 0.0667[2]Ω		

1, - The input resistance is very high and prone to noise (especially 60 Hz) pick up.
2, - This seems like an unusual value. Ten averaged measurements from 0.605A to 1.993A were made.
3, - This also seems like an unusual value. I expected/hoped it to be the same as the DC values.

Fig. 6 - *Missing AN-8009 specifications. These are just a guide with a measurement of a single machine.*

Because the accuracy values are a twostep procedure it is tedious to perform them. If the measured value is within the range of the first specification value there is no need to go further by adding the counts. This is usually the case in the measurements I have made. The reader may want to check the cover machine values. The AN-8009 passes. For a good explanation of the digital accuracy specification see Appendix D, Note 13. It is reproduced here for the readers convenience.

"(13) A digital meter has two specification values. Both must be applied to the measurement.
(1) A percentage of reading, and
(2) an additional number of counts to be added/subtracted to the least significant digit of the reading.

A four digit display may only show one to four digits depending on the value being read, and the range of the meter. The fewer the digits the higher the error due to the counts part of the specification. Good measurement/checking techniques are to always try to provide the maximum number of digits of resolution.

Table N3 – Interpreting a DMM Accuracy Specification

#	***Specification***	***Display***	***% Range***	***Range with ± LSD counts[1]***

1	*± 1 % +3*	*0.8*	*0.8 – 0.8*	*0.5 – 1.1*
2	*± 1 % +3*	*1.3*	*1.3 – 1.3*	*1.0 – 1.6*
3	*± 1 % +3*	*5.59*	*4.54 – 4.64*	*4.51 – 4.67*
4	*± 1 % +3*	*7.631*	*7.555 – 7.707*	*7.552 – 7.710*

1, If the meter reading is within this range it is within its specifications.

Suppose a resistor being measured is 1 ohm ±0.02%. This means that the actual value may be in the range of 0.9998 ohms to 1.0002 ohms. The DMM 8009 lowest resistance range (100 ohms) accuracy is specified as ±1% +3. The +3 is more accurately described as ±3 but is probably not shown that way to avoid confusion.

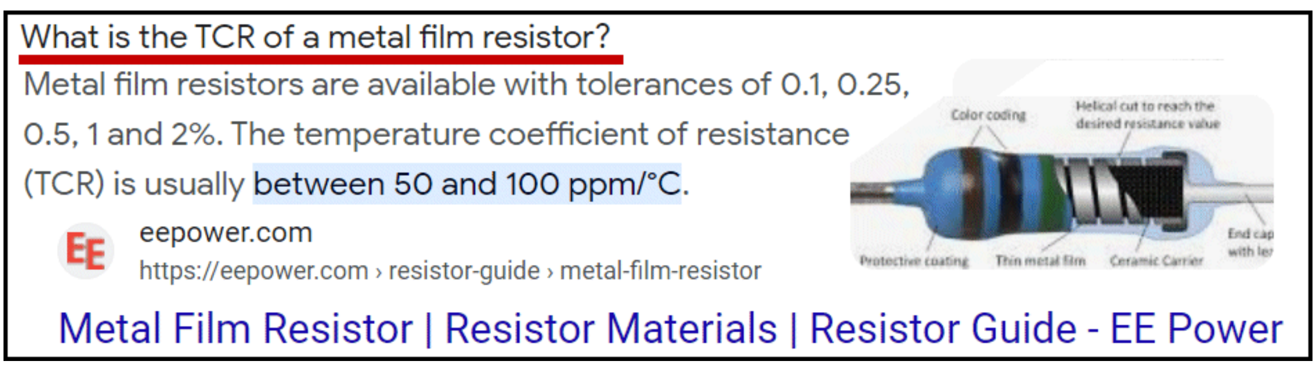
Since the displayed digits may be four digits or less depending on the range and value, the one-ohm value is at the low end of the lowest range. Table 5 shows 0.96/7. The 6 and 7 slowly alternate. For accuracy and computational purposes, we can consider it to be 0.96. Is this value incorrectly being read by the meter or is the resister "Out of Specification"? Let's assume that the resistor is just within specification and has an actual value of 0.9997 ohms. This is within its specified range and the meter reads this as 0.96 ohms.

The meter (Appendix A) has its specification as ±1% +3. This means that 0.96 ±1% is in the range of 0.95 ohms to 0.97 ohms (we can't use more digits just because the math provides them) MINUS the 3 least significant digits (counts). Because of the range and value, the meter is only able to show 0.96 ohms. Since this is the low side of the specification, we subtract the 3 least significant digits from the low (-) percentage range for 0.92 to 0.94 ohms. Since both the resistors and the meter is "new" factory calibrated the specifications of both the meter, and the resistor being measured, the meter reading is correct and within specifications.

DMM demonstrations

The ANENG AN-8009 DMM with its full four digits may be used to demonstrate many phenomena. Here is a partial list.

1. Light measurements using a CdS cell or solar cell.
2. Stray AC power line fields using a pick-up coil.



3. Temperature coefficients of resistors, TCRs. Fig. 7 shows what Google says. What is missing? My memory of reading data sheets, is that it may be either positive or negative depending on the manufacturer's technology.

Fig. 7 – Example of TCRs of 1% metal resistors.

4. 10 MΩ resistors. Many of the 3-1/2 digit DMMS only have an upper limit of 10 MΩs. If a 1% resistor is on the high side, but well within tolerance it will show as open with an OL display. Most users will interpret the display as the resistor being open – and being defective.

5. Generated voltages (AC or DC) from: A magnet and coil, Solar cell, or two dissimilar metals.

6. Measuring the output from a wide variety of sensors.

DMM Techniques

The utility of the DMM may be greatly expanded by using the right methods, techniques, and accessories. I will use the DMM applications section list to inspire a list of a few techniques.

1. **Measuring milliohm resistances**. Fig. 8 shows various electrical connectors that I DMM measured for their milliohm resistances.

Measurement Summary

I measured 12 of the 14 connection devices. Those I didn't measure are indicated with an em dash in the Fig. 39 Milliohms column. I didn't see the comparative value.

ID Device	Image	Milliohms	ID Device	Image	Milliohms
A - Alligator Clip, large		—	H - 1/4" Blade socket[4]		1.22 mΩ
B - Alligator Clip, Medium		2.42 mΩ	I - Pin Jack		0.97 mΩ
C - MiniGrabber Clip		19.9 mΩ	J - Banana Jack		4-8 mΩ
D - MicroGrabber Clip		—	K - E-Z-Hook Nailclip		0.18 mΩ
E - Pin Plug (0.080 dia.)		0.25 mΩ	L - Wire loop, 18 Ga.		0.532 mΩ Per inch
F - Banana Plug		4-8 mΩ	M - Fahnestock Clip		1.43 mΩ
G - 1/4" Blade[4]		See H.	N - #6-32 brass screw		1.79 mΩ Per inch

Fig. 39 – Various devices used to connect and terminate electrical conductors with comparative resistance.

Fig. 8 – Connecting device DMM milliohm measurement snippet.

2. **Measuring stranded wire** to determine its AWG size.
3. **Battery testing of cells and batteries**.
4. **Quickly measuring many values** without bending the leads or touching the component body by using the Grayhill special test connector shown in Fig. 9.

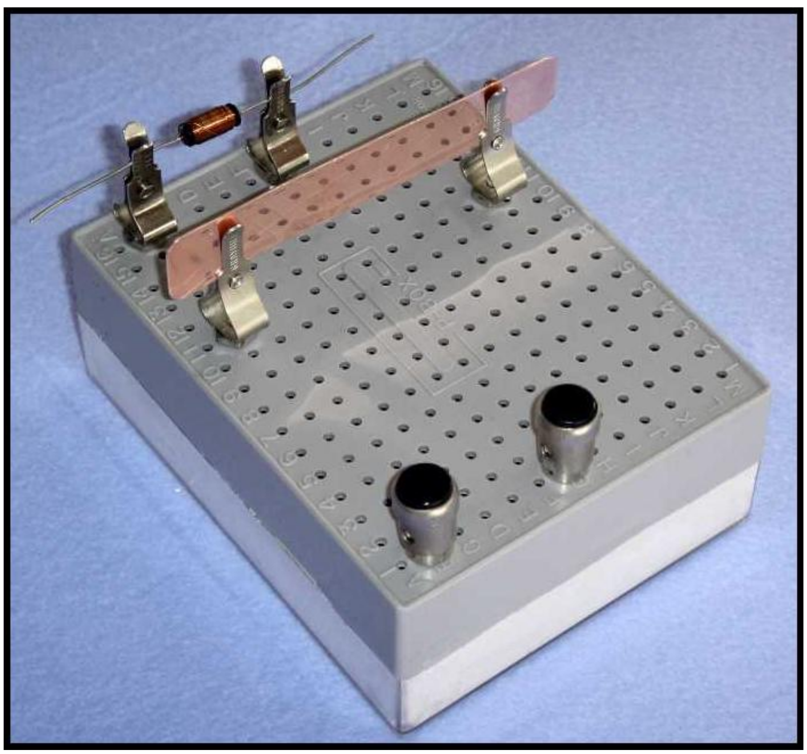


Fig. 9 – Special test clip used 20 years ago on this DIY test fixture.

The test Clip, P/N 02-1, is still being made by Grayhill and may be found at:

http://www.newark.com/grayhill/02-0/test-clip/dp/28F550

This wonderful test clip is now getting more expensive at $6.18 each in low quantities. I recently added plaster and nails inside to make it much heavier at 25 ounces (709 gr.). The two “posts” in the foreground are push to insert the DMM test leads on the side. These are also not commonly found these days. The large copper strap is a shorting bar to “zero” the resistance if required.

Fig. 10 shows the seven function DMM being used with the test clips. It also shows a DIY extension bar for longer parts. It is “plugged” into a base for stability. These photos are from a writing project called Home Brew test fixtures.

Fig. 10 – Low cost DMM with close test jacks.

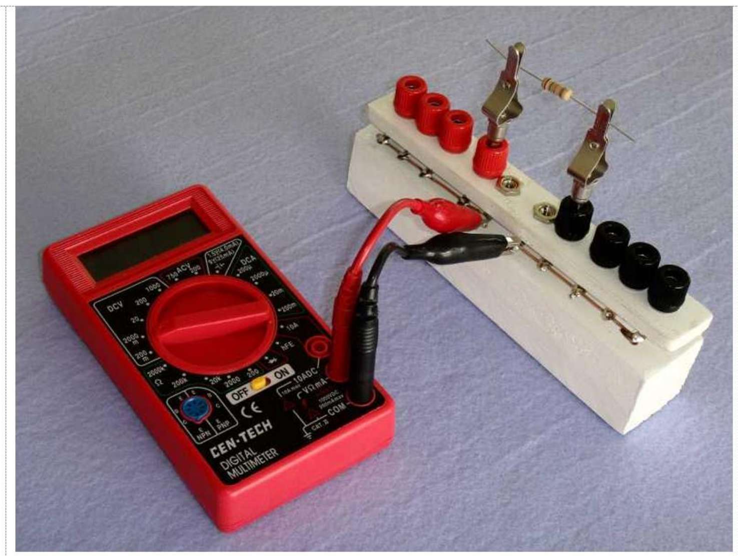


Fig. 11 – A support block with two holes drilled 3/4" spaced to accommodate the banana plugs facilitate the spacing extender. Use it with any meter.

Fig. 10a – Test clips in a low cost DMM. *Fig. 10b – Test clips with a DIY size extender.*

The seven Function DMM has non-standard banana jack spacing. They are closer than ¾" which is the standard. That is why the test leads have to be used in Fig 10b.

5. **Measuring high voltage**. See Fig. N4 in Note 7.

6. **Sorting resistors** (or any component) using #4.

7. **Use the r8 DMMCheck Plus** (especially the 1 mA constant current feature) for test and measurements.

8. **Justifying two DMMS** to make measurements such as power drawn from voltage and current or resistance from current and voltage.

9. **Ten stage voltage divider.** This DIY accessory is great for DMM calibration at other voltages higher and lower than the reference/standard.

10. **Using short and low resistance DIY test leads** instead of using a Kelvin connection. See Appendix G for additional details.

DMM Accessories

A DMM is similar to a microscope. Each is the core instrument, but the accessories often cost more than the core instrument. Most of these are DIY projects.

1. **Component test fixture** using the Grayhill blade connectors. See Fig. 9 above. This should include a set of component boxes to hold each value range.

2. **Ten stage voltage divider**. The 9999 count is a good starting place. The AN-860 is better with its 19,999 resolution. I use my bench 6-1/2-digit Siglent. The Siglent will match resistors to 0.1 PPM. For this DIY project resolution is far more important than accuracy. You need ten identical resistors. See Fig. 11.

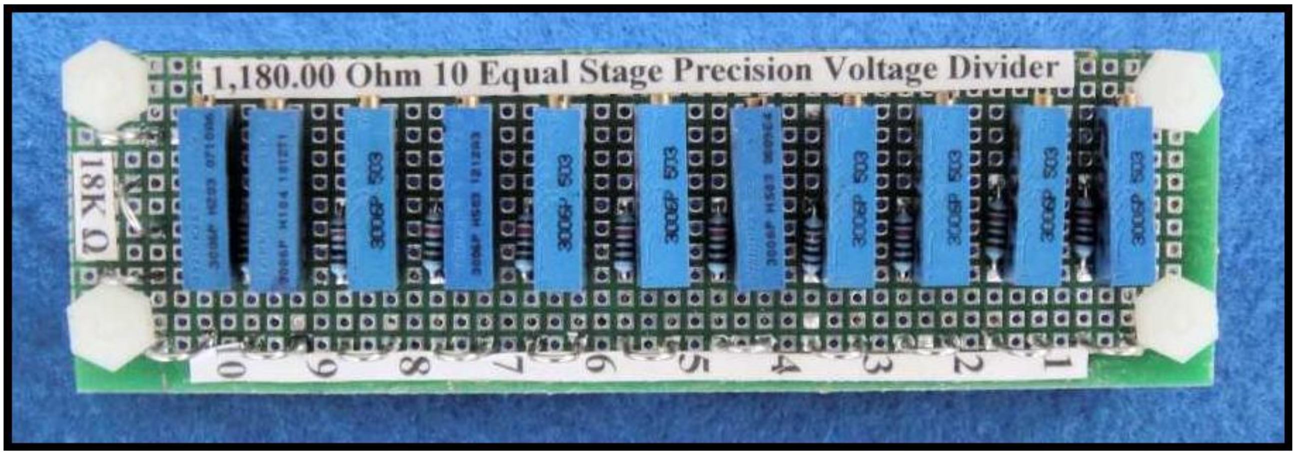


Fig. 11 – Ten stage voltage divider. Each stage has a 22-turn trim pot.to make every one the same value.

3. **High voltage adjustable spark gap**. See Fig. 12. Using spherical electrodes, it is possible to achieve ±3% accuracy. Table 1 shows the spacing vs peak voltage.

Table 1 - Voltages for various spark gap distances.

Maximum spark length [cm] between spherical electrodes in dry air at normal conditions.

U_{peak} [kV]	diameter [cm] 2.5	5	10	25	needle	U_{peak} [kV]	diameter [cm] 50	75	100
5	0.13	0.15	0.15	0.16	0.42	140	5.15		
10	0.27	0.29	0.30	0.32	0.85	160	5.95		
15	0.42	0.44	0.46	0.48	1.30	200	7.60	7.50	7.50
20	0.58	0.60	0.62	0.64	1.75	240	9.20	9.10	
25	0.76	0.77	0.78	0.81	2.20	250			9.55
30	0.95	0.94	0.95	0.98	2.69	260	10.0	9.95	
35	1.17	1.12	1.12	1.15	2.69	300	11.8	11.6	11.5
40	1.41	1.30	1.29	1.32	3.81	340	13.7	13.2	
45	1.68	1.50	1.47	1.49	4.49	350			13.5
50	2.00	1.71	1.65	1.66	5.20	360	14.7	14.1	
60	2.82	2.17	2.02	2.01	6.81	400	16.8	15.9	15.5
70	4.05	2.68	2.42	2.37	8.81	440	19.2	17.9	
80		3.26	2.84	2.74	11.1	450			17.7
90		3.94	3.28	3.11	13.3	460	20.6	18.9	
100		4.77	3.75	3.49	15.5	500	23.6	20.9	19.9
110		5.79	4.25	3.88	17.7	540	26.8	23.1	
120		7.07	4.78	4.28	19.8	550			22.2
130			5.35	4.69	22.0	560	28.5	24.2	
140			5.97	5.10	24.1	600	33.0	26.7	24.7
150			6.64	5.52	26.1	640		29.3	
160			7.37	5.95	28.1	650			27.3
170			8.16	6.39	30.1	660		30.5	
180			9.03	6.84	32.0	700		33.4	30.0
190			10.0	7.30	33.9	740		36.8	
200			11.1	7.76	35.7	750			32.8
210			12.3	8.24	37.6	760		38.5	
220			13.7	8.73	39.5	800		42.2	36.0
230			15.3	9.24	41.4	840		46.5	
240				9.76	43.4	850			39.3
250				10.3	45.2	860		49.0	
300				13.3	54.7	900		53.7	43.0

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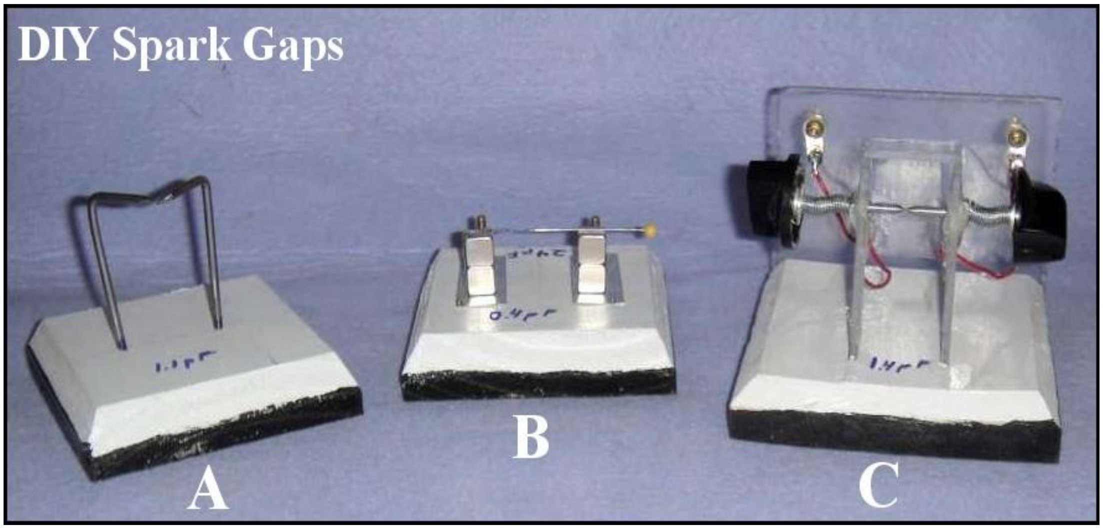


Fig. 12 - Spark gaps may be used to measure high voltages. "C" is more easily adjustable.

Fig. 13 -"0" Ω jack.

4. **High voltage transformers.** The best transformers are the old Neon Sign transformers. These will current limit and work well with spark gaps for measurement purposes.

5. **High voltage probe.** See Note **(7).**

6. **Stable and adjustable power supply** which allows the voltage setting to be easily millivolt set and stable so that measurements may be made and recorded.

7. **Dual banana plug with "zero" ohms** for checking DMMs. Actual resistance is 18 milliohms. See Fig. 13 above.

I plugged this dual banana plug into several of my DMMS. You would expect that the display would show 0.000 or 00.00 depending on the DMM. Most of them did, but two or three gave crazy results changing values from a fraction of an ohm to several ohms. I have no idea, but an exploratory writing project to investigate this unexpected behavior is on my to do list. In fact, this version is one I made to further trim the resistance by using gold plated contacts and a slightly larger shunt wire.

AN-8009 fuses

If you only have one DMM and you blow a fuse you are non-functional. Acceptable fuses may be ordered. The ones with wire leads are very reasonable by the bag. You should order some while it is fresh on your mind. You cannot easily find the small size locally. See Fig. 13.

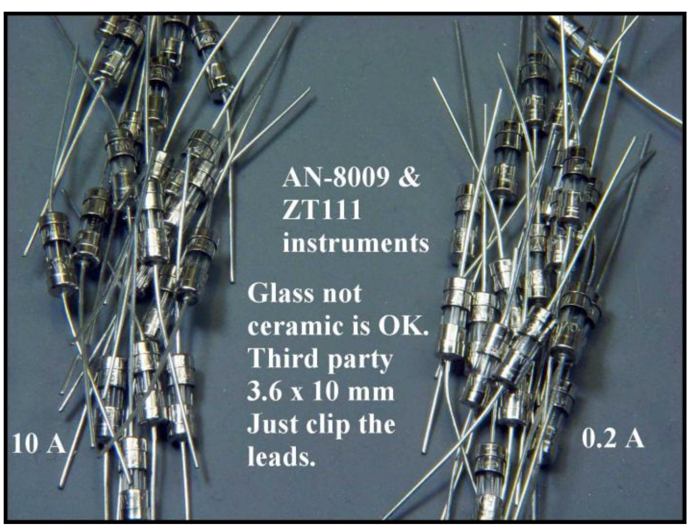


Fig. 13 – It really pays to buy the fuses in bulk/bag.

Notes for Exploring The DMM: Applications and Techniques

(1) *Electrometer is a term used in some circles that describes a person with a serious interest in electronics. It does not imply any level of ability, training, or education. I had once had a boss that called me a true electrometer.*

(2) *Low cost DMMs may range from FREE to the ten-dollar range. This very old design has been around for decades. See Fig. N1.*

***Fig. N1a** – Harbor freight lowest cost seven function DMM. Thie same model has been sold for nearly 30 years. I have over two dozen of the Free ones offered over the years.*

DMM description

Harbor Freight says: "The 7 function Digital Multimeter shown in Fig. 1 gives you accurate digital readings for 7 functions: AC/DC voltage, DC current, resistance, transistor test, diode test, and battery test, all easily read on the large, easy-to-read LCD digital display. This digital multimeter also has a positive set selector switch and two color coded 32" leads."

- Test AC/DC voltage, DC current, resistance, transistor and diode, battery test
- Features an easy-to-read 3-1/2 digit LCD display
- Resolution: 1999
- Automatic zero adjust

The 7 functions are:

AC voltage: 200-750V	Transistor test
DC voltage: 200mV-1000V	Diode test
DC current: 200µ-10A	Battery test
Resistance: 200 – 2000k ohms	

See appendix A for more detailed specifications.

Fig. 1 – Harbor Freight DMM, SKU 69096[2].

All DMM images have been enhanced by adding the white selector switch position dot. The machines photographed for this article have had the position indicating indentation enlarged by drilling and filling the indentation with white Liquid paper.

***Fig. N1b** – Harbor freights lowest cost seven function DMM. Here is a writing project snippet with additional details. It is not a high sensitivity model.*

DMMs are sold in hardware stores, Harbor Freight, and the internet. Good quality instruments are available from many retailers directly from China and will often have sales that have very low prices. It really pays to shop when you are on a tight budget;

(3) *I make a detailed technical comparison between the low-end fluke 101 and the ANENG AN-8009 in Appendix C. This is not intended as a review of the Fluke 101. The reader may be an HHC 2025 attendee or anyone interested in DMMs. There is much to be learned about this technology influenced subject*

(4) *Over the years I have made an effort to acquire most of the free and sale priced seven function DMMs. See Fig. N1. I especially use them whenever I am exploring high voltage circuits because any "mistakes" are costly. You hear a "pop" when you blow one of the SMT components. I also use them for special DIY projects. See Fig. N2.*

Fig. N2 *– A 7 Function DMM is used to display the millivolts from a 50-ampere shunt in this DIY writing project.*

(5) *An identical model to the ANENG AN-8009 is the ZOTEK ZT111. See the very minor differences in Fig. N3. I have nine of these and I have opened them and compared them to an opened AN-8009 and they are identical. The ZT111 box has two models listed with a check box. The other model is the AN8008. I stocked up on these when MPJA had their 50% off sale when going out of business in mid-2025. See Fig. N3 on the next page..*

(6) *Because measuring a light source any sensor orientation is critical using a DMM to read its output. Using the feature of MIN/MAX is vital for repeated and accurate measurements. The sensor is slowly tilted to cover the normal orientation of which the normal maximum value is saved.*

(7) *Higher voltages are easily measured using a high voltage probe accessory. The classic model is the Fluke 80K-49. It is a ±1% 1 GΩ 1000:1 voltage divider. See Fig. N4. This design has one very serious flaw. It uses coaxial cable between the divider output and the DMM. This shunt capacitance severely limits its frequency response*

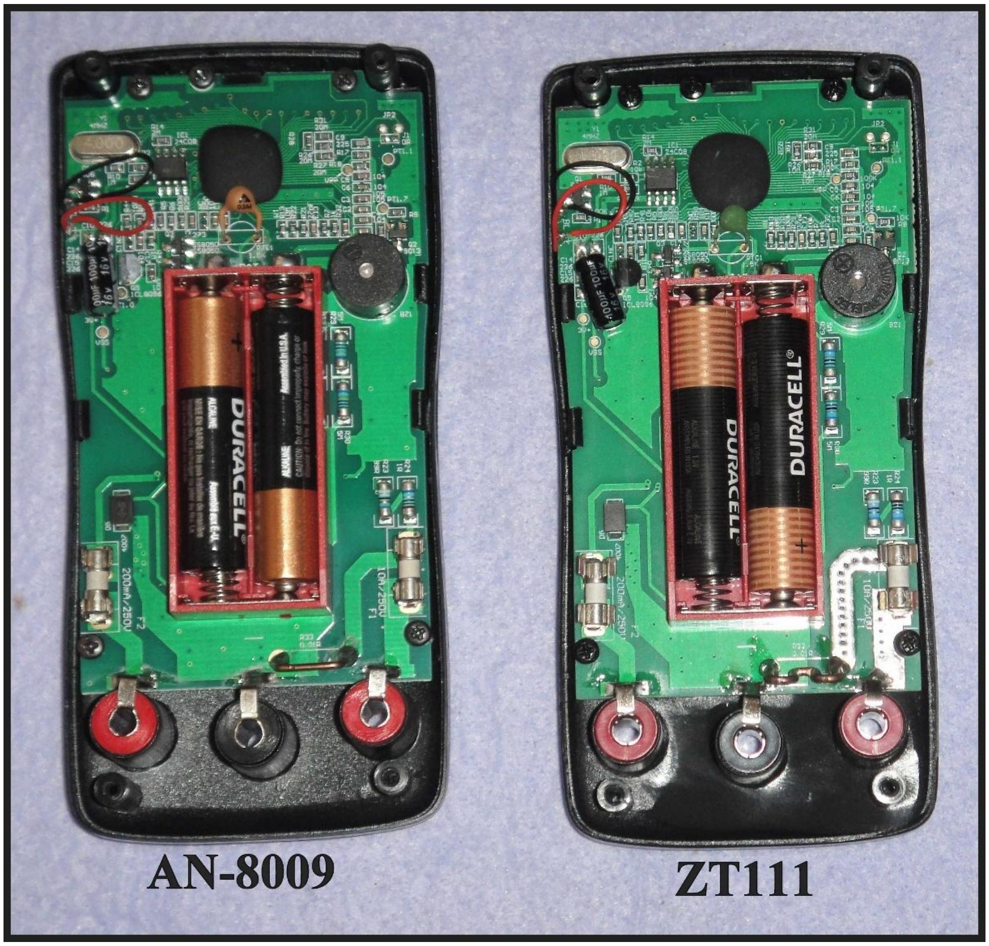


Fig. N3 – Comparison of the AN-8009 and the *ZOTEK ZT111. They are so identical that ANENG must have made them both. An obvious difference is the 10 Ampere shunt at the lower right.*

. I do a lot of measurements and some HV sources (e.g. Plasma balls) are also in the audio frequency range. I removed the voltage divider and mounted it as shown in Fig N4 b & c.

***Fig. N4a** – Fluke HV probe showing the DMM cable.*

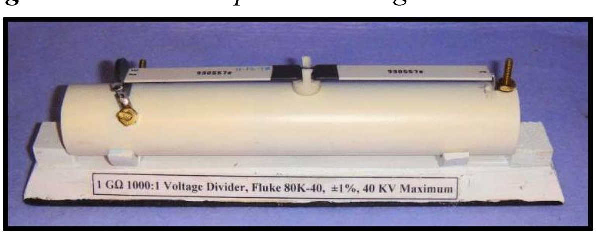


***Fig. N4c** – 1 GΩ resistor divider horizontal mount.*

***Fig. N4b** - 1 GΩ divider mounted for open clip lead use.*

Appendices

The Appendices include additional DMM related writing projects for the convenience of much of having everything related I have written on the subject in a single document. Because the various articles also have their own appendices I have prefixed these appendices with HHC2025 to avoid confusion with the Appendices in the articles themselves. I have used the same table/graph etc. in various articles and will be duplicated as it was a lot of effort edit each Appendix with possible duplication removal in mind.

The description in table 1 may not always be the same as the article title

Table 1 – List of HHC2025 Appendices with Page Numbers

Observations and conclusions

The digital multimeter, DMM, is the most widely used electronics instrument. The modern DMM is microprocessor based, and it has many functions and features. There are well over two dozen companies in the world wide DMM market, and the number of models is astounding. Most are made in China and one company, ANENG has a full line of models. The central model of this presentation is the ANENG AN-8009 handheld, 9999 count, leading edge design that first appeared in late 2017 or early 2018.

Six digital instruments, and one analog instrument are shown on the cover. The presentation explores the applications and techniques of the handheld DMM. The sections are:

Introduction
Manufacturer and model considerations
What I use
The next step up
An interesting development
Common DMM functions
DMM applications
DMM specifications
DMM demonstrations
DMM accessories
AN-8009 fuses
Appendices
Observations and Conclusions
E N D

HHC2025 Appendix A – Characterizing CCCs V2 (7 pages)

Richard J. Nelson

Introduction

A CCC is a Cheap Chinese Copy. Many Chinese business practices have a strong cultural and legal basis, and this article will characterize and provide some perspective and implications on the subject. This is a personal perspective and is not intended to be Anti-Chinese in any way.

The legal influences are really the lack of legal control and enforcement with regards to product designs copying. This has long been an issue with US businesses trying to operate in China. The attitude of individual recognition and respect for products is not a real part of the Communist run society. US patents are not recognized by the Chinese government so why should there be any issue of using a US patent disclosure to copy your own product? This political position also helps Chinese businesses grow.

Culturally there is a strong drive for individuals and small businesses to buy and sell products. Many Chinese also manufacturer products and the large network of small home style manufacturing is amazing. This situation alone makes it difficult to enforce or control because it is everywhere. There are some advantages to this "system", however, because a single large factory burning down is very disruptive. Standards and control, however, are nearly non-existent.

The copy process

If your driving interest and purpose is to simply make as cheap a product as possible and to sell as many as possible, you are not very interested, in or care about, user instructions, specifications, standards, product descriptions, or packaging. Packaging gets more attention when shipping half way around the world is involved. This is driven by necessity rather than over all good practice. CCC interest is in lowering costs to sell more. The providers cut corners on everything involved. I read about one solar panel manufacturer that changed a specific coating material because it was expensive. Their panels began to fail long before their foreign competitor's panels did.

It is easy to copy something. You start with a sample and you just duplicate it. Here is a simple easily understood example. Have you ever used a funnel? We all have one lying around because we have to transfer liquids from one container to another. A funnel makes it easier and faster to pour the liquid. A plastic funnel is cheap to make, and they are often sold with several sizes in one package.

Of course, you need to understand how a funnel works [1]. It is not complicated, but if you do not understand how, it works you could produce a funnel that doesn't actually work. From my perspective a funnel doesn't work if it does not provide a full flow. There is a bulge in the plastic to provide a space between the funnel inserted into the liquid receiving container. This allows the air to be pushed out to allow the liquid to flow in. That bump needs to be properly sized for full flow. Not understanding this you may save a little plastic if your funnel's bump is smaller.

This is a simple example of a simple product being made by a person who essentially does not understand the product and he is just copying it. It is a classical CCC.

Electronics designs

If cost reduction is the focus of all of your business activity you will do everything possible to cut costs.

Because you did not originate the product and you are simply copying it, you will use the products of the competition to make your own. You will copy their product descriptions, and use their photos, and specifications. You may not understand the technical aspects and you may make silly statements in your descriptions because of this. The internet makes all this copying very easy, and it is quite obvious if you pay attention comparing products when you are shopping. Electronics designs that use complex integrated circuits will use the manufacturer's circuits in their product. This is as intended and encouraged because of the complexity and the technology involved.

Because you do not completely understand what the product does or how it works you just copy. I bought a plasma globe and I noticed that some comments about its features involved magnetism. This is simply untrue and very obvious to a customer who does understand the electrostatic and capacitive principles involved. There is no magnetism. US customers accept this situation with all of its limitations because the product is a good working copy at a low price.

A successful CCC seller's description may get copied and bad information gets propagated. When many do this, it becomes more believable. An old saying: Once words are put into writing they become more believable.

Understanding how and the why the CCC is what it is, helps in making an optimal buying decision. There is no fraud intended[(2)]. You should not be disappointed when the seller doesn't relate to or even understand your question. The American public gets used to CCC shortcomings and becomes accepting of the results. **This places a heavy study and evaluation burden on the customer of a CCC.**

I was inspired to write on this subject when I was examining an electronics device I had bought five years ago. A friend had just bought one two months ago and we were discussing its applications.

A voltage reference example

A voltage reference is a small battery powered accurately known voltage reference integrated circuit used to check the calibration of volt meters. It provides a stable quite accurate voltage for you to measure. Most volt meters are in the range of 5 to 0.5% in their accuracy. A low end CCC voltage reference ($15) provides one or more voltages that are known to be accurate to 0.1% or better. The highest quality designs ($130) are NIST traceable with a specified voltage accuracy of 0.001%.

The CCC uses an integrated Circuit, IC, and is designed and made by a well-known American company, Analog Devices, in Massachusetts. Analog provides all the technical details, circuits, and even hardware suggestions. A voltage reference using this AD584 is simply a small circuit board, a battery holder, and perhaps a case.

Fig. 1 shows my 2018 AD584 voltage reference, and Fig. 2 – shows Don's 2023 AD584 voltage reference. His wife gave him the case. He provides the user interface, power source, wiring, and user controls. He elected to just use the 10V output and not the other three.

Because of the time difference the price difference is unknown, but comparing the current low-end pricing of the two designs the pricing is about $15 for the circuit board design that Don is using, and $30 for my "deluxe" design.

The point is that the internet offers the world many products and you may easily compare them. It is then that you will see how the CCCs even compete with different versions. Mine, for example is made by KKMOON and they use an undocumented version of the AD584. It is clearly stated on their case as the AD584-K. It is speculated that the IC that they bought had different voltage specifications, perhaps not complying with their data sheet. KKMOON compensates by using a 6-1/2 Digit Agilent 34401A Digital Multimeter and recording the reading on a label for each device. Perhaps this gives them a cost edge to help cover the additional cost of their very nice clear plastic case. Fig. 3 shows the result when I went to the internet to research the current price as sold by Amazon. Another issue with CCCs is that you are never sure who you are dealing with. Fig. 3 illustrates. Amazon is selling it in the US. The Brand is

Baugger,

Fig, 1 – Richard's packaged design – Nice!

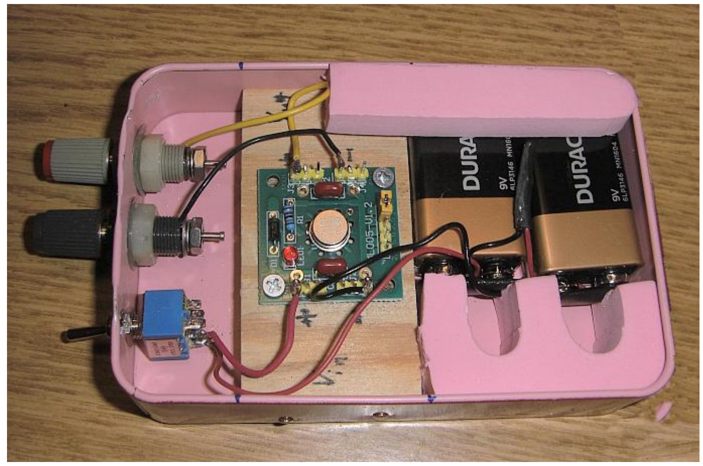


Fig. 2 – Don's bare bones circuit board design he packaged.

and the manufacturer is KKMOON. The latter two may actually be the same company. Because of the Chinese culture from a business point of view it is unimportant to provide any details. Here is what I have, and here is the price. Everything else is minimized.

Don wanted the minimal design[(3)] for his overall project needs. I researched the voltage reference to perhaps get another version for my approach to the overall project we both are working on. My current version is ideal for my DMM voltage checks, but perhaps another lower cost version might better provide multiple voltages by using several circuit boards connected. My packaged design would preclude this.

Part of the project includes a precision ten stage voltage divider. A voltage reference would be used in its calibration.

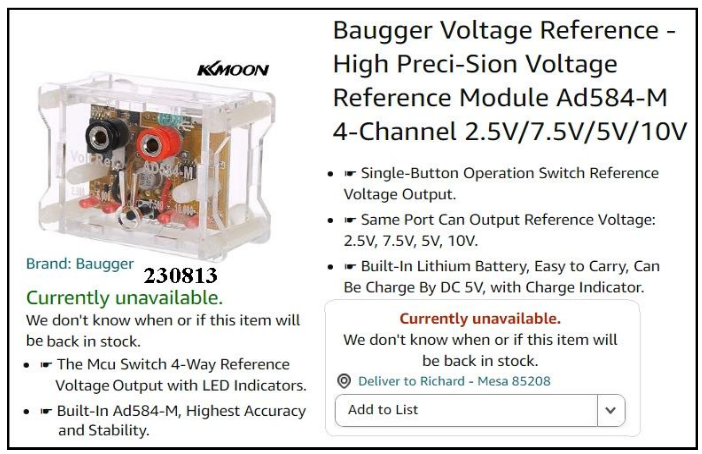


Fig. 3 – An outstanding design using the Analog IC.

Fig 4 - Fig. 6 show various versions of the "same"

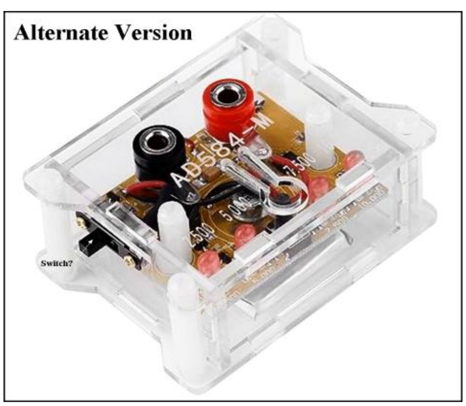


Fig. 4 – Alternate version has another switch ?.

Fig. 5 – Version with cheaper clear case & switch.

AD584 voltage reference. I only noticed the differences of my clear packaged version. If you search Amazon for this voltage reference you will see many different product offerings. You may even sort them by different criteria other than by price.

As you scan down the long list with nice photos you will notice that many look/are the same but they show different angles.

This simple product is a good example to illustrate how CCCs are sold. All the circuits are the same and taken from the original data sheet. If you study them, you might even discover that certain parts are even lower cost parts - smaller values of capacitance for example. These changes may have a subtle effect on the reference's performance.

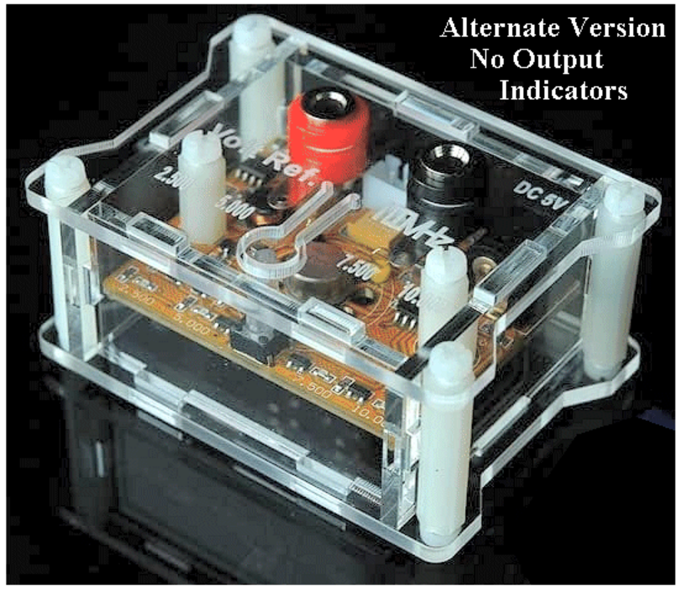


Fig. 6 – This has no voltage selection LED indicators.

Cost reduction is vital for sellers of CCCs. One design, very similar to mine, does not include the rechargeable battery. CCCs do anything to get a cost advantage. You must study CCC products very carefully.

An electrical connection example

CCCs should always be considered **Ca′veat′ Emp′tor**. Old timers experimenting with early radios and other circuits used a simple "breadboard" of actual wood with Fahnestock Clips screwed down. Here are a couple of examples on how they are used.

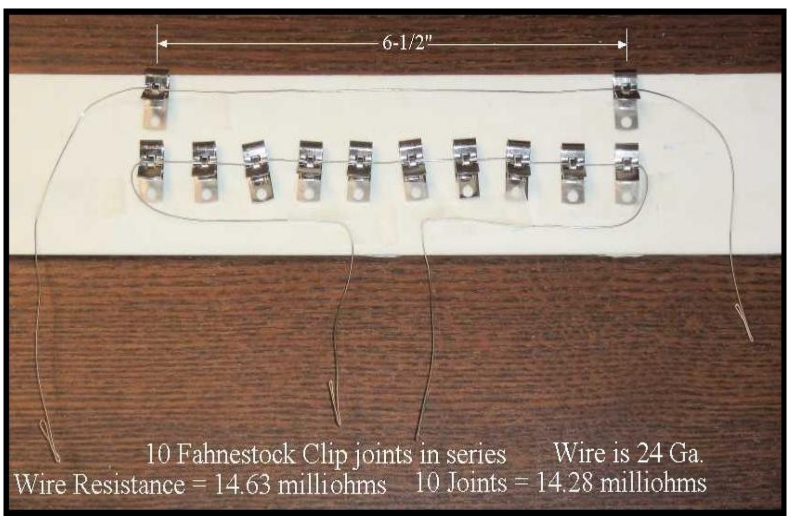


Fig. 7 – Fahnestock clips being tested for the quality of the electrical connections that they easily make.

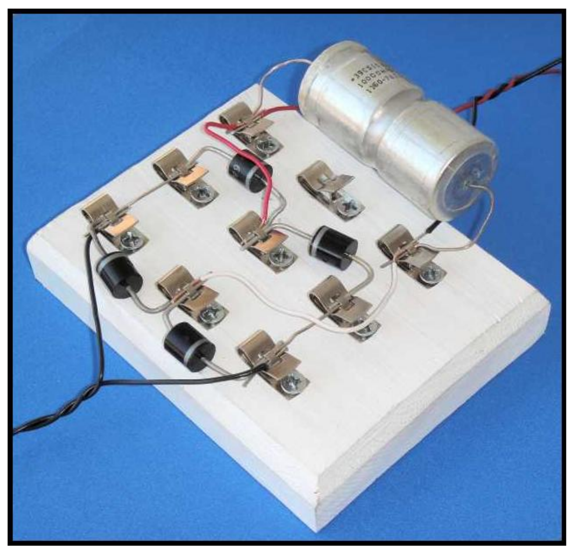


Fig. 8 - Three-amp bridge rectifier breadboard.

The CCC versions are hardly useable. I have an extensive writing project on Fahnestock clips. Fig 9 is a snippet from the article. It is an Appendix of my *Making an Electrical Connection* writing project. You may request a copy using my email address at the end.

These very handy little items will seem expensive and you need to shop, but be aware of the source and **DO NOT buy the CCC version**. They truly represent what CCCs are all about. They cut the cost using all the tricks in the book. The article provides the details. I have never seen a Chinese version that actually worked as intended. I order them by the hundred to get quantity pricing and ALL my several CCC orders are just not useable. The sellers represent the issues used by CCCs. Copy, copy, copy – photos, descriptions, and even features descriptions. Just remember **Ca′veat′ Emp′tor**.

Appendix A - Working With Fahnestock Clips(1) Page 9 of 9

Table 2 - #533 Compared to Cheap Copy

Characteristic	#533	Cheap copy
Finish	Nickel plated	Nickel plated
Weight	1.144 g	0.618 g
Thickness	20 mils	12 mils
Width	0.321 in.	0.317 in.
Height, New	0.473 in.	0.515 in.
Height, after press	0.367 in.	0.404 in.
Largest wire size	10 Ga.	12 Ga.
Smallest wire size	< 34 Ga.	34 Ga.
Magnetic	NO	YES
Clean wire hook	YES	NO
Cost	Reliable source?	13¢ ea/ hundred

Fig. 24 - # 533 left, cheap copy right, both 34 Ga. wire.

The light weight cheap copy is thin and flimsy. I didn't have a wire smaller than 34 Ga. but Fig. 24 provides an example of how two straight pieces are held by the two variations of the clip. The quickest and easiest way to distinguish between the cheap copy and the real #533 clip is using a magnet. The cheap copy will be attracted to the magnet.

Fig. 9 - Snippet from a 9-page Appendix that explores the famous Fahnestock clip youngsters don't know exists.

The CCC Puzzle

There are many different mechanical puzzle CCCs available. I wanted a particular puzzle box to modify to use my own unlocking mechanism. While shopping I noticed another cultural aspect of CCCs. The US versions did not show or explain how the puzzle worked. This is a smart business practice so that you will buy one to find out.

The CCC seller is always looking for an advantage. Why not show and explain how it works in the Ad? If the solution to a given puzzle is what you want just search Amazon for CCC ads. I didn't mind this at the time because this knowledge would create a bias that would make my unknown solution even harder. This was a decade ago and because of my situation and need, I probably noticed this CCC aspect and remembered it.

The USB meter

Every USB user should have a USB meter to provide an indication with what is happening when you are powering or charging any USB powered device, especially call phones. This is a classic example of CCC variations of the same product.

The mystery of Asian documentation

About five decades ago I worked for Sony Corporation in Los Angeles. I repaired transistor radios and TVs which gave me a good insight into the art of troubleshooting and the Sony attitude had towards their products. Sony had made the mistake of promoting the new transistor technology radios in Japan with a lifetime guarantee. They did not want to make the same mistake with their products sold in the US.

My experience working with the Japanese technicians was very educational. One lesson I learned was the difference between theory vs practice. I had little practical experience doing my job, but my circuit theory understanding was pretty good. Apparently, they searched far and wide for someone with transistor knowledge. I had taken a correspondence course while in the Army Security Agency and I was primarily self-taught.

The Japanese technicians fixed about 25% more repairs than I did, but they always gave the really unusual problems to me. They checked the radio or TV symptoms and then replaced a part. If still not fixed they repeated the process until it worked. They were experienced and quick. I used the classical trouble-shooting practice which always works. You need lots of those experienced types working for you, but it is good to have one classical type as well. Back in those Sony days test equipment, circuit diagrams, and parts were always readably available.

Everyone complains about Asian product user documentation. No matter how good the complex electronic device is, the poor understanding of it because the documentation is unreadable, is well known. There is an important reason Asian manuals do not have an Index. In their languages an index has no meaning. That realization was very meaningful to me.

The same applies to CCCs. The documentation, if it exists, is obviously written by an English-as-second-language Chinese writer. All languages make assumptions and those of a different culture are – well different. The mystery part for me is this. There are many people like me who would gladly English review a manual for just the payment of the product itself. Maybe this is a cultural pride issue, but it sure doesn't make good business sense.

Observations and conclusions

A CCC is a Cheap Chinese Copy product that is sold to be as price competitive as possible. This is accomplished by reducing material thickness, or using a lower cost material like steel for brass and copying as much as possible. The reasons for this singular attitude that drives CCC product production are characterized with three products that are described in detail.

It is imperative for the potential customer to be aware of some of the reasons that drive CCCs. The solution is simply to copy. Everything is copied to some extent – Product descriptions, internet descriptions, product photos, specifications, and applications. If you copy, you save a great deal of resources that are normally required. CCC producers are not intentionally committing fraud, and I hope I have provided some insight for their behavior and existence. Just remember **Ca′veat′ Emp′tor.**

A brief mention is made for Asian documentation and why it so often falls short to being understandable. The mystery to me is why an easy suggested solution is seldom used.

Caution notice

While this article provides parts and source details you should remember that modern sales methods (especially Chinese sourced or surplus sales) are such that parts are batched produced and there is no regular flow of products that may be the same in the (near) future. The market changes rapidly. The details are provided for you to determine if your parts available at the time will work in a similar situation. Also, there is inflation to consider when prices are given.

I write this description for my own documentation with enough detail to perhaps inspire others who may tinker in electronics to save money and Do It Yourself, DIY.

Richard J. Nelson
August 18, 2023

Comments, suggestions, ideas, questions, corrections and article copy (by title) requests are welcome at: rjnelsoncf@cox.net Richard J. Nelson is a very common name and the "cf" differentiation is for Calcfan.

V1 initial release, 8 pgs. V1a August 28, 2023. V1a added small additional text below Fig. 6 and corrected spelling/formatting errors.

Notes for CCCs

(1). *Funnels are simple, here is a more technical ignorance copy example personal experience. Several decades ago I worked for a small company that created a new tuning fork watch crystal design and manufacturing process. It was heavily US patented. A Japanese company recognized the revolutionary nature of the design and they simply copied the US patents as their own. They did not understand the technology – not surprising because it was completely new and undocumented – and when we saw their patents it was obvious.*

The tuning forks were made using thin quartz wafers and were etched into their shape. When they were finished they were simply vacuum pencil lifted off the wafer and the tine was snapped to free it. This produced a jagged shape that had nothing to do with its operation. The Japanese even patented the jagged broken tine as part of "their" design. We had a good laugh when we saw this because it was clear that they had no clue as to how the revolutionary small quartz tuning fork 32,768 Hz. quartz crystal worked, or how it was manufactured.

(2). *Ignorance of a product is always a potential issue and even CCCs play a role in one of the biggest scams perpetuated on humanity. This has been going on for over ten years and I have followed it closely. It is called the Power Saver Scam selling a simple plug-in electrical device will save you up to 90% on your electrical power bill. There are many, over a dozen, companies that sell these products. None of them work.* ***Let me be very emphatic – they do no work!!*** *They are supposed to be using your household electrical power factor and "correcting it." The tiny improvement in power factor is less than 1% and a true electrical issue. The biggest problem is that the Power Company doesn't even charge you for your load power factor anyway. The device is correcting a condition that has nothing to do with your power consumption.*

The interesting aspect of this is that these companies use CCCs and the Chinese companies that make them want in on the action, and you may actually buy them directly for a much lower price. I have seen prices reduced by more than 75%. They have no-overhead, no investment, and they make a higher profit margin than usual.

(3). *The basic IC has several features that make it useful for a wide range of instrumentation applications. It is package lead programmable and this aspect is used by the CCCers to offer their product that differentiates it from the many others. They will also consider their own resources in terms of suppliers and market exposure in what they change.*

 Appendix B - Accuracy Comparisons – V2 (10 pages)

Richard J. Nelson

Introduction

Measuring or quantifying a measurement normally includes an implied or required/specified accuracy. The closeness of the value is vital depending on what the measured quantity is. For Example:

"Attending a 7 PM party" is a specification example and at least two considerations are involved.

1. The 7 PM time is a social designation and the accuracy is intentionally vague. Arriving the next day at 7 PM is definitely too late. Arriving five minutes early is probably not a problem and within the unspecified and assumed accuracy range.

2. Because time is always changing its accuracy or preciseness is important to also include with its value. 7 PM is only 7 PM within a specified "time window." Seven PM is only a theoretical value that divides being early or being late. Cultural customs will dictate how accurate the 7 PM value is.

Determining an accuracy specification

How accurate may a practical value be specified? If we use percentage as a method of expressing a value the accuracy range will have two considerations, Theoretical and/or Technological.

If we are specifying the value of π we may use the theoretical specification as: $$\pi = \frac{C}{D}$$

Where: C is the circumference of any circle, and D is its diameter.

Because the value of π is an irrational never ending number it can only be specified as a theoretical value or a limited practical value with a specified accuracy - limited by technology. If π is given as 3.14 the value is within ±0.051 percent. Usually, however, π is "specified" or given to a specific number of digits. The usual implication is decimal digits with the 3.14 value being to two decimal digits. Even this expression of accuracy is ambiguous. Are the decimal digits rounded or truncated? Table D1 shows a few examples using the value of π.

Table 1 – Accuracy Specification Examples for π

Value	Truncated Digits	Accuracy	Rounded digits	Accuracy
3	1	± 4.6%	1	± 4.6%
3.1	2	± 1.3%	3.1	± 1.3%
3.14	3	± 0.051%	3.14	± 0.051%
3.141	4	± 0.019%	3.14<u>2</u>	± 0.01<u>3</u>%
3.1415	5	± 0.00029%	3.141<u>6</u>	± 0.0002<u>3</u>
3.14159	6	± 0.000084%	3.14159	± 0.000084%

Notes: 1. The ± value is the average of the plus percentage and the minus percentage to two significant digits.

2. The π value is rounded to 12 digits (11 decimal digits) for the percentage calculations.

*3. Unexpected digit or changed values are **orange and underlined**.*

Table 1 illustrates the usefulness of two different methods of expressing the accuracy of a measured/specified value. Was π's value first approximated by measurement thousands of years ago? How accurate can you determine π by actual measurement?

Here is a thought experiment described in my 2011 on line HP calculator newsletter article (***HP Solve #***

25 Page 64). The 12 page article has some unusual (researched) tidbits and references about **π**. A large number of **π** digits in a numerical "data base", and how to explore them (10,000 digits) are also included.

Measuring π

You may determine a desired number of digits of π in one of three ways. You may measure it, you may calculate it, or you may look it up on the internet. I really wanted to make an attempt to measure π, but the daily summer 107 degree temperatures here in the Sonoran Desert discouraged me. Instead, let's perform a thought measurement. Here are the materials I was going to use.

1. Three metal stakes (12" nails).
2. 210 feet of white polypropylene cord.
3. 110 feet of bailing wire.
4. 100 foot measuring tape.
5. Bicycle (front wheel and fork).
6. Masking tape.
7. Carpenters marking pencil and ball point pen.
8. Large flat level smooth layout area at least 220 x 110 feet. (half of a 200-foot diameter circle.)

Here is the measurement procedure. The goal is to make all measurements to a resolution of 1/8 inches.

A. Remove the front fork from the bicycle.
B. Wrap a piece of masking tape around the tire and wheel and mark a line down the outside perpendicular to the ground.
C. Attach one end of the wire to the frame near the wheel axle.
D. Move all of your materials to the layout area and pound in two stakes about 220 feet apart and stretch the white polypropylene cord to serve as the diameter of the circle.
E. Pound in the third stake in the center of the white cord to mark the center of the circle.
F. Position the wheel 100 feet from the center (an assistant is most helpful here) and make a loop to be placed over the center stake.
G. Holding the wheel with the wire tight (it should not stretch) rotate and align the mark on the rim with the white cord.
H. Keeping the wire tight walk the wire around the semicircle keeping the wheel perpendicular to the surface counting the number of times the tape comes in contact with the surface. When you are near the other end of the white diameter cord you will usually have less than one full rotation left. Finish that last rotation and place a second piece of tape on the wheel to indicate the last portion of the rotation. Write down the number of full rotations, gather your materials and head home.
I. In the car port use a long straight edge and draw a line on the concrete with a cross line at one end.
J. Use your wheel and align the first tape mark with the cross line and roll the wheel down the line one revolution and make another cross line. This is the second measurement (the first was the radius of the circle at 100 feet). Repeat the rotational measurement for the length to the second tape.
K. Calculate the value of π.

Be sure to account for the diameter of the center stake in your measurements.

Let's assume the radius (wire length) is 100 feet or 1200 inches. The diameter is 2400 inches. After doubling the thought wheel measured total length (measured circumference x revolutions + extra partial revolution) the circumference is 7,539 3/4hs (7,539.75 inches). I realize that making these measurements to a resolution of 1/8th inches takes great skill and is very difficult. Making the division we have π = 3.1415625.

The theoretical circumference with a 200.00000 feet diameter is 7,539.82236862 inches. Let's assume an error of ¼ inch too high for the circumference and ¼ inch too low for the diameter for a maximum error on the high side. The calculated theoretical value for **π** is 7,540.07236862 divided by 2,400.25 = 3.14136959426. The difference (high error) with 12 digits of **π** is 0.00022305933. This means that we can easily depend on three accurate decimal digits or 3.141 using our measurement method. If our work is really practiced, and careful, we might ***hope*** for 3.1415.

> CONCLUSION: Physically measuring a circle to determine π using normal measuring methods is not very digit productive.

One of the easiest ways to remember **π** is to think of the first three odd numbers, 1, 3 & 5. Write them down twice, 113355 and divide the last three by the first three to get 3.141592^9205 on a 12 digit calculator. You used six digits to get the answer and your result is correct to a *truncated* six decimal digits (seven digits total).

There are six common methods used to express accuracy other than specifying the number of digits. For example: A DMM, Digital Multimeter, accuracy is ±1%. Accuracy percentage is the most commonly used method.

Percentage is a ratio compared to 100. One percent is represented as one part per hundred, PPH, or 1/100 as a fraction. A fraction may also be represented as a decimal, and 1% = 0.01. The tables are HP-48 programs to convert the various accuracy methods to each other. The following is taken from another writing project.

> To convert percent to a decimal divide by 100.

Continued on the next page.

Table 2 - If Counts Are Known

Method	Conversion	RPL Program to Convert	All Results
°	Input	<< "Input" >> # B975h 10.0 Bytes	**1000.00 Input**
Percent =	$\frac{\text{Counts}}{100}$	<< 100 SWAP "Percent" →TAG >> # A2A3h 40.0 Bytes	0.10
Powers of ten =	-log(counts)	<< LOG NEG "Pwr10" →TAG >> # 498h 27.5 Bytes	-3.00
PPM =	$\frac{1,000,000}{\text{counts}}$	<< 1000000 SWAP / "PPM" →TAG >> # E46Fh 36.0 Bytes	1000.00
dB =	-20∗log(counts)	<< LOG -20 * "Db" →TAG >> # 1795h 35.0 Bytes	-60.00
BITS =	$\frac{\log(\text{counts})}{\log 2}$	<< LOG 2 LOG / "BITS" →TAG >> # CF7Dh 31.5 Bytes	9.97
ALL	ALL	<< 2 FIX DUP DUP2 DUP2 "Inpt Cunts" →TAG SWAP **Percent** 3 ROLL **Pwr10** 4 ROLL **PPM** 5 **DB** 6 ROLL **BITS** >> # 9A9Eh 101.0 Bytes	—

Table 3 - If Percent is Known

Method	Conversion	RPL Program to Convert	All Results
Counts =	$\frac{100}{\%}$	<< 100 SWAP / “Counts” →TAG >> # F2F2h 39.0 Bytes	2000.00
°	Input	<< “Input” >> # B975h 10.0 Bytes	**<u>0.05 input</u>**
Powers of ten =	$\log\left(\frac{100}{\%}\right)$	<< 100 SWAP / LOG NEG “Pwr10” →TAG >> # BC64h 43.0 Bytes	-3.00
PPM =	10,000*%	<< 10000 * “PPM” →TAG >> # 5273h 33.5 Bytes	500.00
dB =	$-20\log\left(\frac{100}{\%}\right)$	<< 100 SWAP / -20 Log * “dB” →TAG >> # B4Ah 50.5 Bytes	-66.02
BITS =	$\frac{\log\left(\frac{100}{\%}\right)}{\log 2}$	<< 100 SWAP / LOG 2 LOG / “BITS →TAG >> # 63E2h 47.0 Bytes	10.97
ALL	ALL	<< 2 FIX DUP DUP2 DUP2 “Input Percnt” →TAG SWAP **Counts** 3 ROLL **Pwr10** 4 ROLL **PPM** 5 **DB** 6 ROLL **BITS** >> # 92DAh 102.0 Bytes	—

Percentage is a linear measure. If the changes are much greater than one part per hundred or even one part per thousand, the change ratio may be better expressed non-linearly as a tenth of a bell or decibel, dB.

In addition to percentage the other five methods are: Counts, Powers of Ten, parts per million, decibels, and BITS. See Fig. 1 on page 8. Table 3 above relates percentage to the other five methods. The third column is a Reverse Polish Lisp program that will run on an HP-48/49/50 calculator. On the off chance that the reader uses one of these three machines additional related programming information is also provided on page 10.

Table 4 - If POWERS OF TEN Are Known

Method	Conversion	RPL Program to Convert	All Results
COUNTS =	$\frac{1}{10^{\text{Power of 10}}}$	<< ALOG INV “Counts” →TAG >> # 61A1h 28.5 Bytes	50118.72
PERCENT =	100*ALOG(Power of 10)	<< ALOG 100 * “Percent” →TAG >> # C14Ch 40.0 Bytes	2.00E-3
°	Input	<< “Input” >> # B975h 10.0 Bytes	**<u>-4.70</u>**
PPM =	10^6 *ALOG(Power of 10)	<< ALOG 1000000 * “PPM” →TAG >> # CE62h 36.0 Bytes	19.95
dB =	20 / Power of 10	<< 20 / “dB” →TAG >> # 2AA5h 35.5 Bytes	-94.00
BITS =	$\frac{\text{-Power of 10}}{\text{Log 2}}$	<< 2 LOG / NEG “BITS” →TAG >> # 63D0h 31.5 Bytes	15.61
ALL	ALL	<< 2 FIX DUP DUP2 DUP2 “Inpt Cunts” →TAG SWAP **Counts** 3 ROLL percent 4 ROLL **PPM** 5 **DB** 6 ROLL **BITS** >> # CC79Eh 103.0 Bytes	—

Table 5 - If PPM is Known

Method	Conversion	RPL Program to Convert	All Results

Counts =	$\frac{1{,}000{,}000}{PPM}$	<< 1000000 SWAP / "Counts" →TAG >> # C38Fh 39.0 Bytes	200000.00
Percent =	$\frac{PPM}{10{,}000}$	<< 10000 / "Percent" →TAG >> # 7866h 37.5 Bytes	5.00E-4
Powers of ten =	$\frac{PPM}{1{,}000{,}000}$	<< 1000000 SWAP / LOG NEG "Pwr10" →TAG >> # FD2E7h 43.0 Bytes	-5.30
°	Input	<< "Input" >> # B975h 10.0 Bytes	<u>**5.00**</u>
dB =	$-20 * Log(\frac{PPM}{1000000})$	<< 1000000 SWAP / LOG -20 * "DB" →TAG >> # BC4Bh 50.5 Bytes	-106.02
BITS =	$\frac{\log\left(\frac{PPM}{1{,}000{,}000}\right)}{\log 2}$	<< 1000000 SWAP / LOG 2 LOG / "BITS" →TAG >> # F551h 47.0 Bytes	17.61
ALL	ALL	<< 2 FIX DUP DUP2 DUP2 "Inpt Cunts" →TAG SWAP **Percent** 3 ROLL **Pwr10** 4 ROLL **PPM** 5 **DB** 6 ROLL **BITS** >> # 9A9Eh 101.0 Bytes	—

Counts are the maximum value the Digital Volt Meter, DVM, may resolve. An 11 bit analog to digital converter will "count" to a maximum of 2,024 counts. A DVM may be promoted by the number (maximum) of counts per range. Usually it is a method used for DVM marketing. Table 2 relates the other five methods to counts.

PPM is parts per million, and is used for very small values. Percentage is parts per hundred. Table 4 relates the other five methods to PPM. 10,000 ppm is 1% and 1 ppm is 0.00001%. The values in Table 5 relates the other five methods to PPM.

Decibels, dB, are non-linear and are used by engineers because of the way our senses respond to various stimuli, and for other (math) large ratio reasons. One of the most well-known log ratios measurements is the Richter scale used for earthquake magnitudes. Each whole increment in magnitude e.g. 6 to 7 is 31.6 times more powerful (energetic) than the value before it. Ten is essentially the upper limit.

Our hearing and visual sensitivity greatly decreases as the intensity increases. Decibels are another (fractional) method of expressing/comparing two values. The dB as used here are negative (getting smaller) values.

To calculate dB, d, of voltage, V, ratios of the same source resistances: $d = 20\text{Log}\left(\frac{V1}{V2}\right)\text{dB}$

The log in the above equation is the common or base 10 log. Table 6 relates <u>negative</u> dB to the other five methods.

Bits are the decimal representation of the number of bits used for analog to digital converters – the electronics heart of a digital volt meter. Table 7 relates the other five methods to Bits.

Powers of 10 is a simple method to represent large numbers. 10,000 is represented as 10^4. The values of the chart in Fig. 1 are negative because they represent the fractional parts of the accuracy representation, parts per 10,000 (1/10,000) is represented as 10^{-4}. Table 4 relates the other five methods to Powers of 10.

The equations and programs in tables 2 – 7 are intended to cover the practical ranges of the present state of the electronics instrumentation art in describing accuracy. Extreme or negative values (dBs and Powers of ten are always negative) have not been checked to be rigorous mathematically.

Table 6 - If dBs Are Known

Method	Conversion	RPL Program to Convert	All Results
Counts =	$ALOG(\frac{dB}{-20})$	<< -20 / ALOG "Counts" →TAG >>	262119.90

		# 1688h 34.0 Bytes	
Percent =	$\frac{ALOG\left(\frac{dB}{-20}\right)}{100}$	<< -20 / ALOG 100 SWAP / “Percent” →TAG >> # C1CAh 55.5 Bytes	3.82E-4
Powers of ten =	$\frac{dB}{-20}$	<< -20 / ALOG “Counts” →TAG >> # 2BFD 35.6 Bytes	5.42
PPM =	$10^{6-\frac{D}{-20}}$	<< -20 / 6 SWAP – ALOG “PPM” →TAG >> # 8C5Eh 43.5 Bytes	199526.23
°	Input	<< “Input” >> # B975h 10.0 Bytes	**-108.37**
BITS =	$\frac{ALOG\left(\frac{BITS}{-20}\right)+1}{Log\ 2}$	<< -20 / ALOG 1 + LOG 2 LOG / “BITS” →TAG >> # 42F3h 52.0 Bytes	18.00
ALL	ALL	<< 2 FIX DUP DUP2 DUP2 “Inpt Cunts” →TAG SWAP **Counts** 3 ROLL **Percent** 4 ROLL **Pwr10** 5 **PPM** 6 ROLL **BITS** >> # 9880 h 103.0 Bytes	—

Table 7 - If BITS Are Known

Method	Conversion	RPL Program to Convert	All Results
Counts =	2^{BITS}	<< 2 SWAP ^ “Counts” →TAG >> # A51Eh 31.0 Bytes	5007.93
Percent =	$\frac{100}{2^{BITS}}$	<< 100 SWAP 2 SWAP ^ / “Percent” →TAG >> # 89DAh 47.5 Bytes	0.02
Powers of ten =	Log 2 * BITS	<< 2 LOG * NEG “Pwr10” →TAG >> # F37Dh 32.5 Bytes	-3.70
PPM =	$E^6 * 2^{BITS}$	<<1000000 SWAP 2 SWAP ^ / “PPM →TAG >> # EAE3h 43.5 Bytes	199.68
dB =	$-20\log(2^{BITS}-1)$	<< 2 SWAP ^ 1 - LOG -20 * “dB” →TAG >> # CA11h 47.5 Bytes	-73.99
°	Input	<< “Input” >> # B975h 10.0 Bytes	**12.29**
ALL	ALL	<< 2 FIX DUP DUP2 DUP2 “Inpt Cunts” →TAG SWAP **Percent** 3 ROLL **Pwr10** 4 ROLL **PPM** 5 **DB** 6 ROLL **BITS** >> # 9A9Eh 101.0 Bytes	—

DVM (DMM) digits (digital volt meter) are a legacy means of representing the (resolution) digits in the DVM display. Normally a display digit may be 0 to 9. If the cost (historically) of each digit is very high the cost of the display may be reduced if the leading digit only needs to be 0 or 1. The most significant digit (left most digit) is called a 1/2 digit by manufacturers in this situation. The technical reason to use a half digit is the limited number of “expensive” bits (circuits) used by the electronics. This may be seen by studying Figure 1.

Why are these various methods used? Linear Technology Application Note 82 (November 1999) describes the reason this way. “To keep you from reaching a full understanding of the topic *(voltage references),*

Industry pundits use a special technique called “unit-hopping” to confuse and confound everyone from newcomer to seasoned veteran. You mention an accuracy figure and the pundit quickly hops to a new unit so that you cannot follow his line of reasoning.” While this is a good example of human nature influencing technical expression, there is also another reason. Each method has its practical implications/environment. The digital engineer may think in terms of bits. The marketing professional may best express competitive accuracy as the number of display digits. When very small values are involved the use of parts per million is simply more practical. Which value makes the most sense to you from Fig. 1? These values are calculated using the equations and programs in Table 2. Decimal Bits or decimal powers of ten may not be very meaningful in the context of specified accuracy.

262,144 counts = -106 dB = 18 BITS = 0.0004% = -5 POWER OF TEN = 4 PPM = 5-1/2 D (DVM)

The scales of Fig 1 are not exact. If you assume 262,144.00 counts, the remaining two decimal digits (Table 2) values are:

262,144.00 counts = -108.37 dB = 18.00 BITS = 0.00038%
= -5.42 POWER OF TEN = 3.81 ppm = 5-1/2 DVM

Equations note

The equations – and programs – have been derived for use with Fig. 1 only, and they have not been mathematically analyzed for general use. The sign conventions used in Fig 1 and the use of Logs impose unspecified restrictions. The use of the equations is to provide an increased accuracy to reading Fig. 1 which was originally made for approximate use only. Two or three decimal digits are probably accurate and correct.

Accuracy comparative perspectives

The reader may not be familiar with all six methods and the following selected values and the evaluations of the six ALL programs will provide a comparative perspective. I have tried to provide real world situations for the six selected values.

Counts

A tire pressure hose stretched across a street "counts" the number of vehicles each day. Table 7 shows how 4,444 counts compares to the other five methods of expressing accuracy compare.

Percentage

A very high accuracy meter may have a ± 0.01% accuracy specification. Table 8 shows how the other five methods of expressing accuracy compare.

Powers of 10

Powers of ten are usually integers. Decimal values are mathematically possible and Table 9 shows how -5.55 PPM compares to the other five methods of expressing accuracy compare.

Table 7 - Counts	Table 8 - Percent	Table 9 – Power of 10
Inpt Cunts: 4444.00	Input Percent: 0.01	Input Pwr10: -5.55
Percent: 0.44	Counts: 10000.00	Counts: 354813.39
Pwr10: -3.65	Pwr10: -4.00	Percent: 2.82E-4
PPM: 225.02	PPM: 100.00	PPM: 2.83
dB: -72.96	dB: -80.00	dB: -111.00
BITS: 12.12	BITS: 13.94	BITS: 18.44

PPM

Parts Per Million of undesirable amounts of water contaminations are commonly in the low values. Table 10 shows how 0.05 PPM compares to the other five methods of expressing accuracy.

dB

The scale values for dB are in -10 dB increments. Table 11 shows how -14 dB compares to the other five methods of expressing accuracy.

BITS

BITS are usually expressed in integers and a power of two table provides an integer BIT count. 14 BITS is a high value for most electronics circuits. Table 12 compares 14 BITS to the other five methods of expressing accuracy.

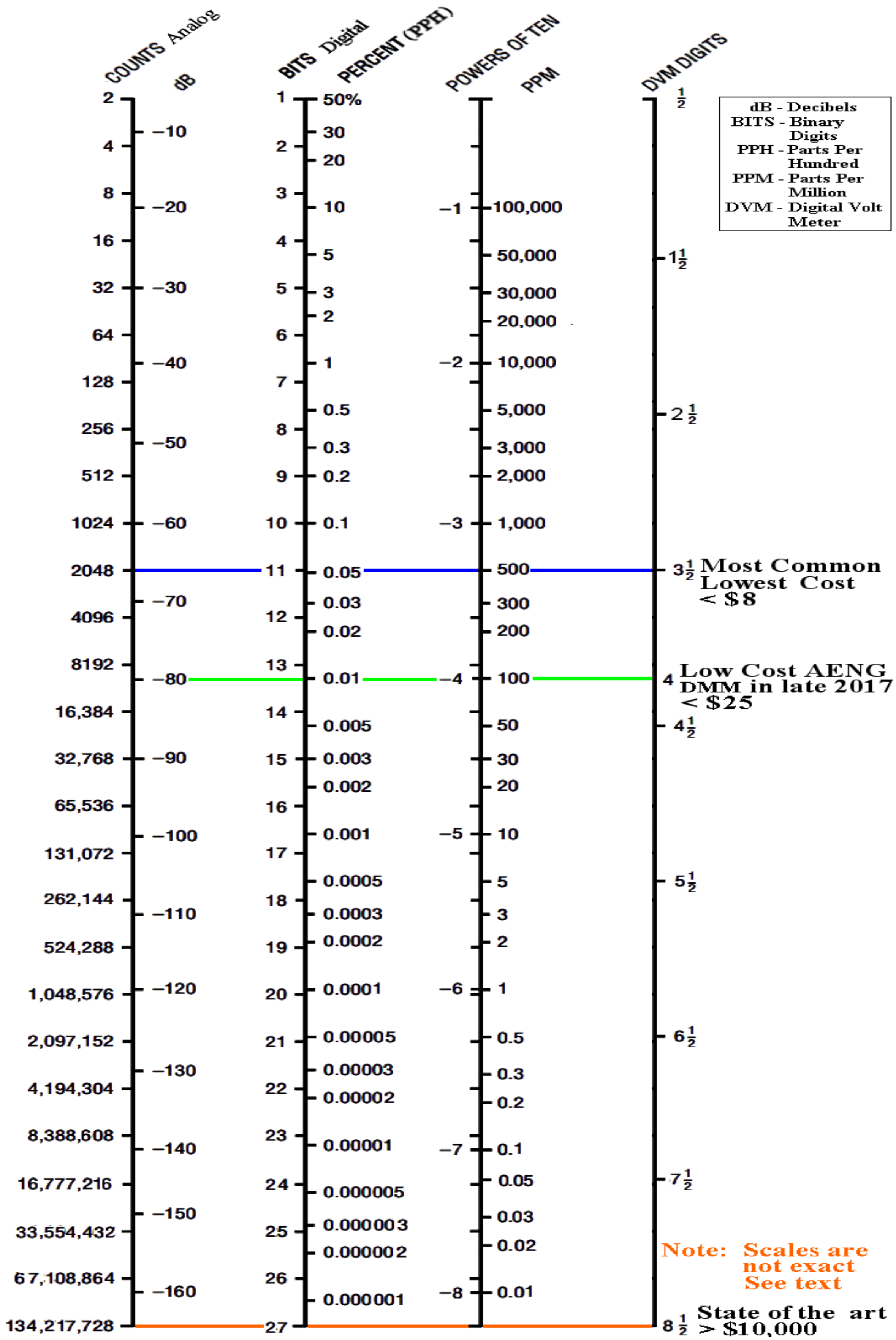


Fig. 1- Expanded scales & notations using Fig. 1 of Linear Technology Application Note 82-1.

Table 10 - PPM	**Table 11 - DB**	**Table 12 - BITS**
Input PPM: 0.05	Input dB: -14.00	Input BITS: 14.00
Counts: 20000000.00	Counts:5.01	Counts: 15384.00
Percent: 5.00E-6	Percent: 19.95	Percent: 0.01
Pwr10: -7.30	Pwr10: -0.70	Pwr10: -7.21
dB: -146.02	PPM: 199526.23	PPM: 61.04
BITS: 24.25	BITS: 2.59	dB: -84.29

Programming Notes

Thirty short RPL programs for evaluating/converting the accuracy expression methods are given in Tables 2 through 7. The following additional programming notes are provided for readers who have HP-48/49/50 calculators. These legacy RPL graphing calculators have six menus shown at a time at the bottom of the screen. Fig. 2 shows the Accuracy Display Menu with the six methods of representing accuracy. The order is that of Fig. 1. The top left horizontal bar of each menu object indicates that the variable is a directory. With six variables for each method I thought that it might be convenient to provide all six conversions by pressing one key so I added the seventh menu to each of the six directories called **ALL**. See Fig. 3. If PPM is known (the Fig. 2 PPM directory key pressed) the menu would look like Fig. 4. The added **ALL** program is placed on the second page of the menu.

The six menu programs of Fig. 2 each have a variation of the ALL program on the second page. ALL returns the input at the top of the stack with all five converted unknowns below it. A FIX 2 display uses all the available space in the display and is more than accurate for most applications. A few values will, by necessity, default display to scientific notation. See Fig. 5.

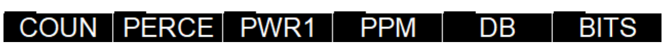


Fig. 2 – HP-48 accuracy menu of values.

Fig. 3 – ALL is added on the next page.

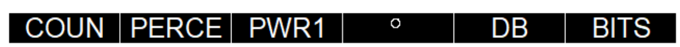


Fig. 4 – Menu for PPM showing a "blank" menu for PPM. Pressing it shows "Input" as a reminder.

The **ALL** program for counts being known (input) is shown below. Variables not native to the machine are shown in bold. Program checksum and bytes are for the program only. A missing (input) variable is shown with a degrees symbol for a name to keep all menu variables in the same position for all six methods. This program is simply the text object "Input" which will display if the menu key is pressed.

ALL << 2 FIX DUP DUP2 DUP2 "Input Cunts" →TAG SWAP **Percent** 3 ROLL **Pwr10** 4 ROLL **PPM** 5 roll **DB** 6 ROLL **BITS** >>

9A9Eh 101. Bytes

The only differences between the six **ALL** programs are the calls (**IN BOLD**) to the programs being called. The output is formatted as shown in Fig. 5. 1000 counts is input. Note that the counts and **PPM** values are the same in this situation.

Each output is tagged with its accuracy method of measure-ment. The tag disappears when a calculation or operation is performed on the tagged value.

6: Input Cunts: 1000.00
5: Percent: 0.10
4: Pwr10: -3.00
3: PPM: 1000.00
2: DB: -60.00
1: BITS: 9.97

Fig. 5 – HP-48 Stack results for Counts ALL program. Order is always the same.

Method Designations

Programming requires consistent use of variable (methods) designations. Table 13 shows how these are used with the abbreviations required to fit properly in the calculator display and to avoid conflict with variables used by the calculator operating system. A decibel is an example where the conventional designation is lower case d for the 1/10th prefix, and upper case B for the unit Bell. DB may be used if dB is the leading word in a sentence or is in the calculator menu display that only allows upper case characters. Table 13 is provided for readers less familiar with the RPL calculators and the methods being discussed.

Table 13 – Variable Designations and Where Used

Method	**Menu**	**Menu Display**	**Program**	**ALL Display**	**ALL 1st Line***
Counts	Counts	COUN	PPM	Counts	Cunts
Percent	Percent	PERCE	Percent	Percent	Percent or Percnt
Power of ten	Pwr10	PWR1	Pwr10	PwR10	Pwr10
PPM	PPM	PPM	DB	PPM	PPM
dB	DB	DB	DB	dB	dB
Bits	BITS	BITS	BITS	Bits	BITS

* Input may be abbreviated as Inpt if display space is limited.

All values

Each accuracy method has an **ALL** program that calculates/converts one method value to the other five methods value. This extends the resolution of Fig. 1. A seventh **ALL** program is added to the Accuracy directory that provides the input values of Tables 7 to 12 to execute all of the six **ALL** programs at the press of a single key. This is trivial to do and is a good example of the convenient structure of RPL programming. Here is the Accuracy directory **ALL** program.

ALL << **Counts** 4444 **ALL** UPDIR **Percent** .01 **ALL** UPDIR **Pwr10** -5.55 **ALL** UPDIR **PPM** .05
ALL UPDIR **DB** -14 **ALL** UPDIR **BITS** 14 **ALL** UPDIR >>

7F6Ch 167.5 Bytes

Programs not native to the HP-48 are **BOLD**. In this very special situation each **ALL** program (7 total) is different and unique. Not **ALL** programs are included, but the ones given will provide the structure so the rest may be easily entered.

Observations and conclusions

Specifications are often given in different metrics. Six of these are described and compared using a full page chart shown on page 8 as Fig. 1. Periodically, however, it may be necessary to calculate the chart values for greater accuracy converting one value to another. The equations to do this are provided with 30 HP-48/49/50 RPL programs for reducing the arithmetic in the process.

I write this description for my own documentation. Perhaps I will inspire others who are interested in making electrical measurements and applying them to solve practical problems.

Comments, suggestions, ideas, questions, corrections and article copy (by title) requests are welcome at:
rjnelsoncf@cox.net Richard J. Nelson is a very common name and the "cf" differentiation is for Calcfan.

Richard J. Nelson

February 23, 2021 V1 is a recovered version "lost" in the form of an Appendix (Appendix D) to another writing project and is made herein as a self-standing article discussing Accuracy Specifications.

 Appendix C - Fluke Entry DMM vs a Chinese (ANENG) DMM - V1 (21) pages) *Richard J. Nelson*

Introduction

Since I have retired (15 years ago) I have written many technical articles of the type I call writing exercises/projects. These are exploratory articles that delve into the idea, design, construction, analysis, photography, and detailed documentation of a measurement method, instrument evaluation, or electronics concept/project. I strive for ±1% accuracy in my electrical measurements, and I use various Digital Multimeters, DMMs, for taking data and documenting in-circuit parameters. My orientation for these writing projects is low cost, remembering my teenage years of electronics tinkering and buying parts with my lunch money. Now, being retired fifty years after those days, and once again being more cost sensitive, I strive for innovative ways of accomplishing a specific goal using optimum methods and resources for each project.

Electrical instruments – Two different approaches

Quantity or quality? As an electronics engineer working for companies that used expensive instruments for their labs, I am familiar with oscilloscopes, power supplies, signal generators, and DMMs from Hewlett-Packard, (Agilent and Keysight happened after I retired), Tektronix, and Fluke. These instruments cost thousands of dollars each and were stable, wide ranged, and in many cases nearly ten+ times more accurate than my ±1% accuracy goal.

From my writing perspective I desire quantity rather than quality because I am exploring measurements using instruments in a new era of low cost Cheap Chinese Copies, CCCs. These CCC products also provide designs that include a high performance and high value by being sold without robust packaging and power supplies. You buy a circuit board only, and you supply what is needed on your own. See example in Fig. 1. This instrument is amazingly accurate.

Fig. 1 – Accurate CCC example.

If you buy a low cost instrument, especially a CCC, how do you know that it is reliable and accurate? Time and experience will answer the reliable part, but the accuracy part requires an independent means of checking these DMMs. I use various standards[1] to check AC & DC voltages and currents. One standard also includes decade resistors, capacitors, and inductors as well. All of my standards are ten+ times more accurate than the DMMs they check. They are also designed for long term stability.

I end up buying many multiple low cost DMMs - over 15 models - and one set of standards for all of them. This gives me variety and the right one(s) for the current writing project. For the cost of buying just one high grade name-brand instrument I am able to afford many variations of lower cost instruments because I am able to independently verify their performance to meet my requirements of ±1% accuracy.

Not all Chinese DMMs are CCCs

A few years ago I bought a “new” *true* four-digit (9999 count) DMM that out performs just about every 3-1/2 digit DMM on the market. This meter is the ANENG AN8009 DMM shown in Fig. 2 and Fig. 3.

See Appendix A for additional specifications.

This large display, auto ranging, full function, quite accurate, “true RMS” DMM is an outstanding performer. After three plus years on the market I still don't believe that the "market" has realized the advancement and value this instrument represents.   As far as I have been able to determine there are two[4] ANENG "short comings."

1. The CAT specifications are not taken seriously by reviewers. This is maybe justifiable.
2. The response time is excessive. An excellent internet article[5] provides an easy fix for this by adding filtering capacitors. Any electronicer will find the space adequate to easily make this up-grade. The author also provides US sources for the specific capacitors.

Fig. 2 – Outstanding performance for less than $25.

Fig. 3 – Over view of AN8009 DMM functions.

The additional value of a carry case, thermal couple probe for temperature measurements, and "universal" test leads (see Fig. 6) makes this the optimum DMM for any electronicer - student or retiree.

The Fluke model 101

Fluke instruments are well known for their long working life, raggedness, technical support, and accuracy. When I received a promotional sales discount to add a Fluke DMM to my collection I ordered two. The model 101 is the lowest cost fluke DMM. Not that long ago Fluke multimeters were not made in China. That is not true today, and many experienced fluke users complain about their reduced quality and support. Their head quarters, however, is still located in Everett, WA.   See the Fluke model 101 in Fig. 4.

You will notice that the test lead jacks are not in their "normal" place on the top lower end of the case. The text at the bottom suggests that they are on the bottom side, which they are. My conclusion as to why they did this was to not emphasize that there are only two jacks, and not the more common three or four. Why? Because the current measurement function is missing. You are paying twice the market price of a normal DMM and you are missing 1/3 rd. of the basic DMM functions of voltage, current, and resistance.

Another reason fluke may have decided on this design for their entry model

Fig. 4 – Simplest fluke DMM.

is the fact that many DMMs are damaged because the meter was in a current mode, and then used in the voltage mode. Without moving the test leads. Not having a current function avoids blown fuses and the need to supply replacements. The perspective customer may not realize this situation and they will certainly need another DMM soon. This design of entry model probably makes a lot of profit for Fluke.

The model 101 and 8009 side by side

Fig. 5 shows the two compared DMMs side by side. They are essentially the same size and weight. The Fluke is just slightly heavier and wider. See Appendix B for detailed Fluke specifications.

They are shown with my low resistance (less than 10 milliohms) measurement test leads[(2)]. Both DMMs show zero ohms as they should The displays are quite different. The 8009 is obviously larger. The display also shows the difference between a 3-1/2 digit display and a full 4 digit display.

The A/mA jack is missing on the Fluke 101 as previously mentioned. The desktop parallel lead termination will also take up vital space (at least two additional inches) for the leads when several DMMs are in one circuit photo showing values. The larger 8009 display also helps for this circuit documentation application.

Note that the two function buttons below the display are the same colors. This may be confusing when different DMM brands are being used together. I

Fig. 5 – Fluke 101 compared to ANENG AN8009.

have seven of the 8009s and two of the 101s. Usage will depend on the parameter being measured and circuit illustrated.

Here are a few parameters (random order) and how they compare.

Table 1 – Model 101 Compared to Model 8009

#	Parameter	Model 101	Model 8009	Comments
1	Cost	$46 Amazon	$21 Amazon	Both china made, Fluke 2x cost
2	Test Leads	Standard, adequate	Multiple versions	8009 has greater convenience
3	Display digit size[a]	3.5D, 0.482” high	4D, 0.700” high	8009 45% larger
4	Specifications	Extensive, standards	Minimal[(2)], much missing	8009 typical Chinese attitude
5	Resolution	6,000 Counts	10,000 Counts	8009 Four full Digits
6	Support	Extensive	Non-existent	101 is a slam dunk here
7	Vital parameters	Typical, OK	Poor[(2)]	See #4.
8	DC Voltage	±0.5% +3	±0.5% +3	Identical
9	AC Voltage	±1.0% +3	±1.0% +3	Identical
10	Resistance (best)	±0.5% +2	±0.5% +3	8009 has much wider range
11	Capacitance (best)	±2.0% +5	±2.0% +5	Identical, 8009 much wider range

#	Parameter	Model 101	Model 8009	Comments
12	Accessories	None	Case, Thermo Probe	8009 is a Slam dunk here, FIG 6
13	User's Manual	Proper, well done	? Tiny size & Print, poor	101 is a slam dunk here
14	Power[b]	2 AAA cells	2 AAA cells	Identical
15	Audio Continuity	YES	YES	Same high pitch, useless
15	Back Light	NO	YES	Needed sometimes
16	Auto Turn Off	YES	YES	Saves AAA cells
17	Auto range	YES	YES	Convenient, slower response[5]
18	Viewing stand	NO	YES	Nice for lighting, position, etc.

Notes: (a) Unspecified, RJN measured using a Vernier caliper.
(b) Many low cost DMMs use an expensive inefficient 9V battery. This is one indication of cheap vs. low cost or entry level.

Each reader will relate to the various advantages and disadvantages of each machine. What you prefer will depend on how and where you use the instrument and how often.

Are you a service person and the machine is carried in your tool box, or are you an electronicer who is exploring electronics, or perhaps building various electronic projects. Do you make a lot of measure-ments, do parts sorting, or maybe you are working in the lab while taking an electronics course.

Perhaps this comparison will provide the perspective that you need for a decision as to what to buy – and why.

Each product has its advantages and the contrast is substantial. If support and a traditional printed User Manual (Table 1, lines 6 & 13) are vital, Fluke may be the logical choice. If budget and value are important, ANENG may be the logical choice.

Fig 6 – Accessories of the full version usually sold in US.

I haven't used my two new flukes for very long, but I have used seven AN8009's for three years and my choice should be obvious.

Comments on DMM specifications

How much better are 4 digits compared to 3.5 digits? Appendix D compares the seven methods used to specify digital instruments and DMMs. Also see Note **(2)**. Having a fourth full display digit is very useful for many measurements, especially for sorting component values. Appendix A, pages 3 & 4, includes a discussion of the complexity of DMM (digital) specifications and providing a better understanding of them.

Are more advanced Flukes a better value?

The next step up seems to be the fluke model 106 and adding a current function at $67. See Fig. 7. The 106 is just under three times the cost of the AN8009 and it still doesn't have all of its functions. I will leave it as an exercise for the reader to evaluate this model. Fluke offers a full range of DMMs and if the smaller shirt pocket (palm) size is not a factor then a more traditional DMM may be suitable – at still a much higher price – over $100 to $600. The latter is for a 50,000 count display, 0.025% basic DC accuracy, data recording, etc.

	Fluke 101	Fluke 106	Fluke 113	Fluke 116	Fluke 117
Voltage ac/dc	600 V	600 V	600 V	600 V	600 V
Current ac/dc		10 A		600 µA	10 A
Resistance	40 MΩ	40 MΩ	40 MΩ	40 MΩ	40 MΩ
Frequency	100.0 kHz	100 kHz		100 kHz	100 kHz
Capacitance	100.0 µF	1,000 µF		10,000 µF	10,000 µF
Temperature				(+) 400 °C	
Continuity / diode test	✓	✓	✓	✓	✓
Duty Cycle	✓	✓			

Fig. 7 – Palm sized fluke models. Note that the three rightmost models are physically larger.

Calibration check

The two meters were checked using the same functions of the Fluke 101. The measurements were tabulated in Table 2 and Table 3.

Table 2 – Fluke 101 DMMCheck Plus Measurements

#	Standard	Measured[a] 101	Accuracy[3]	Certificate	Error[b]	Pass	Comments
1	**DC Voltage**	—	—	—	—	—	
2	5 VDC	4.998 V[c]	0.5%±3 digit	5.0000 V	-0.040 %	YES	A 5.0000 setting is std.
3	**AC Voltage**	—	—	—	—	—	
4	5 V RMS$_{120\ Hz}$	5.534 V	1.0% ±3 digit	4.992 V	+10.857 %	**NO**	This is not unexpected
10	**Frequency #1**	—	—	—	—	—	
11	120 Hz	119.9 Hz	0.1 % ±3 digit	120.043364	-0.119 %	YES[d]	Close
13	**Duty Cycle, #1**	—	—	—	—	—	
14	120 Hz	49.9 %	Unspecified	50.018 %	+0.236 %	YES	
16	**Resistance**	—	—	—	—	—	

#	Standard	Measured[a] 101	Accuracy[3]	Certificate	Error[b]	Pass	Comments
17	100 Ω	100.0 Ω	0.5%±3 digit	99.938 Ω	+0.1 %	YES	
18	1 K Ω	1.001 KΩ	0.5%±2 digit	1.0006 KΩ	-0.040 %	YES	
19	10 K Ω	10.01 KΩ	0.5%±2 digit	10.047 KΩ	-0.368 %	YES	
20	100 K Ω	100.0 KΩ	0.5%±2 digit	100.051 KΩ	-0.0510 %	YES	
21	111.1 KΩ (sum)	111.1 KΩ	0.5%±2 digit	111.198KΩ	-0.088 %	YES	
22	**Capacitance**	—	—	—	—	—	
23	0.001 µF (1 nF)	1.03 nF	2% + 5	0.973 nF	+5.858 %	**NO**	This is surprising
24	0.01 µF (10 nF)	10.53 nF	2% + 5	10.48 nF	+0.477 %	YES	
25	0.1 µF (100 nF)	100.5 nF	2% + 5	100.4 nF	+0.0996 %	YES	
26	1 µF (1,000 nF)	0.989 µF	5% + 5	0.972 µF	+1.749 %	YES	
27	0.90009 nF Equiv.	0.94 nF	5% + 5	0.881711 nF	-2.04 %	**NO**	Caused by line #23

Notes: **Serial No. 54991019WS**

(a) I insured adequate time to allow the meter to settle to its final value. If the LSD, least significant digit, changes between two sequential values the lowest one is recorded.

(b) Based on the ± percentage and ignoring the ± counts. See Note (3). The Certificate value is assumed true for the ERROR calculation.

(c) An interesting observation was made that the 5 volt DC voltage was different if the "-" sign appeared in the display. With "-" polarity = 4.998 V, with no "-" sign 5.001 V. I used a DPDT polarity reversing switch (center off) to avoid any changing connection effects. A quick check of my second Fluke only showed one millivolt difference +4.999 vs -4.998 V. No such difference was noted for the AN8009.

(d) This passes if the full digital specifications are considered.

Table 3 – ANENG AN8009 DMMCheck Plus Measurements

#	Standard	Measured[a] AN8009	Accuracy[3]	Certificate	Error[b]	Pass	Comments
1	**DC Voltage**	—	—	—	—	—	
2	5 VDC	5.000 V	±(0.5%+3)	5.0000 V	None	YES	
3	**AC Voltage**	—	—	—	—	—	
4	5 V $RMS_{120\ Hz}$	4.960 V	±(1.0%+3)	4.992 V	-0.641 V	YES	
10	**Frequency #1**	—	—	—	—	—	
11	120 Hz	120 Hz	±(1.0%+2)	120.043364	-0.0361 %	YES	
13	**Duty Cycle, #1**	—	—	—	—	—	
14	120 Hz	50.0 Hz	±(1.0%+2)	50.018 %	-0.0360 %	YES	
16	**Resistance**	—	—	—	—	—	
17	100 Ω	99.9 Ω	±(0.5%+3)	99.938 Ω	-0.380 %	YES	
18	1 K Ω	0.999 KΩ	±(0.5%+3)	1.0006 KΩ	-0.160 %	YES	
19	10 K Ω	9.99 KΩ	±(0.5%+3)	10.047 KΩ	-0.567 %	YES[c]	
20	100 K Ω	99.9 KΩ	±(0.5%+3)	100.051 KΩ	-0.151 %	YES	
21	111.1 KΩ (sum)	110.9 KΩ	±(0.5%+3)	111.198 KΩ	-0.268 %	YES	
22	**Capacitance**	—	—	—	—	—	
23	0.001 µF (1 nF)	0.994 nF	±(5.0%+20)	0.973 nF	+2.158 %	YES	
24	0.01 µF (10 nF)	10.51 nF	±(2.0%+5)	10.48 nF	+0.286 %	YES	
25	0.1 µF (100 nF)	100.4 nF	±(2.0%+5)	100.4 nF	None	YES	
26	1 µF (1,000 nF)	0.9854 nF	±(2.0%+5)	0.972 µF	+1.379 %	YES	
27	0.90009 nF	0.903 nF	±(5.0%+5)	0.881711	+2.415 %	YES	Caused by line #23

#	Standard Equiv.	Measured[a] AN8009	Accuracy[3]	Certificate nF	Error[b]	Pass	Comments

Notes: ***Serial No. 74425943***

(a), I insured adequate time to allow the meter to settle to its final value. If the LSD, least significant digit, changes between two sequential values the lowest one is recorded.

(b), Based on the ± percentage and ignoring the ± counts. The Certificate value is assumed true for the ERROR calculation.

(c) This passes if the full digital specifications are considered.

Observations and conclusion

Two DMMs were compared using a newly arrived DMMCheck Plus DMM standards checker. The Fluke (bought on sale) meter arrived at the same time and the two entry models were compared for experience and perspective. This is not intended as Fluke model 101 review.

Comparing the two models provides a perspective especially for inexperienced users who may be interested in buying their first DMM. Size is more important than you might at first think. I have a full shelf of DMMS and I always seem to reach for the smaller palm or shirt pocket sizes.

Surprisingly the Fluke failed twice. The AC True RMS "failure" is a common occurrence in my testing experience for True RMS hand held models. See Note **(2)**, line # 7, for an additional perspective. The ANENG AN870 also failed. The smallest capacitance range failure, however, was unexpected, rechecked, and verified.

When researching the specifications for both meters I found disparate values on the internet. Even Fluke publications differ or are indicated, but omitted. I find this quite strange and unimpressive.

I write this description for my own documentation. Perhaps this effort will inspire others who are interested in electrical measurements and applying them to solve practical problems.

Caution notice

While this article provides parts and source details you should remember that modern sales methods (especially Chinese sourced or surplus sales) are such that parts are batched produced or bought and there is no regular flow of products that may be the same in the (near) future. The market changes rapidly. The details are provided for you to determine if your parts available at the time will work in a similar situation. Also there is inflation to consider when prices are given.

Comments, suggestions, ideas, questions, corrections and article copy (by title) requests are welcome at: rjnelsoncf@cox.net See note **(2)**. Richard J. Nelson is a very common name and the "cf" differentiation is for Calcfan.

Richard J. Nelson
V1 – November 15, 2021

Notes for: Fluke Entry DMM Vs a Chinese (ANENG) DMM

(1) Here is a snippet from a writing project titled <u>RJN Electrical Standards</u>. I have since added the latest version of the DMMCheck Plus that includes capacitance and inductance standards – See Fig. N1. This article will need updating. See Appendix C for the NIST traceable values this standard provides.

RJN standards

Fig. 1 and Fig. 2 shows two views of the nine electrical standards I use.

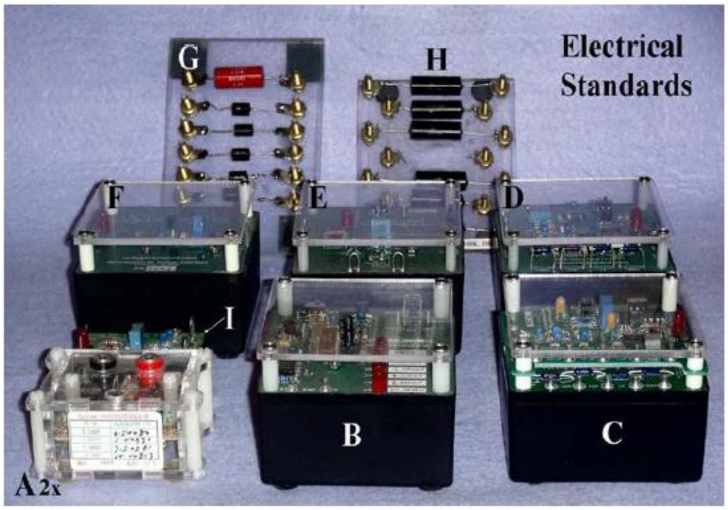


Fig. 1 - Various AC/DC voltage, current, resistance, and capacitance reference standards ±0.1% or better. See text.

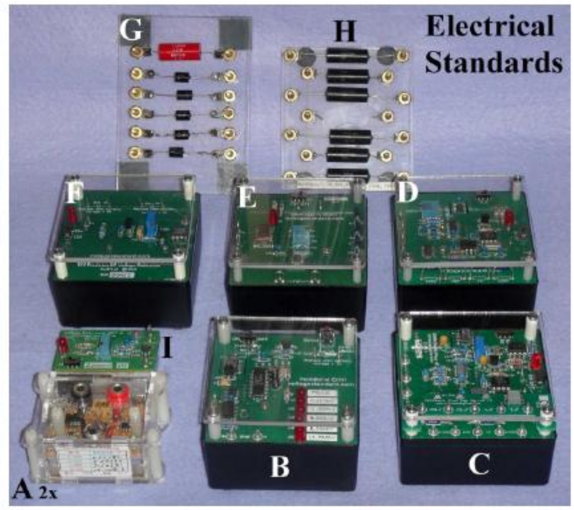


Fig. 2 – Same as Fig. 1, but at a higher angle to better see "I." I have two of "A."

A. Chinese KKmoon 2.500, 5.000, 7.500, & 10.000 VDC voltage standards ≈±0.08%. USB Rechg.
B. PentaRef **r4** 2019. 0.1500, 2.0000, 4.000, 8.0000, 10.0000 VDC **±0.02%.** Two 9V batteries.
C. DMMCheck Plus **r6**, 2020, with Dual AC frequencies and four Capacitors **±0.05%**. One 9V battery.
D. DMMCheck Plus **r2** 2013. **±0.05%** One 9V battery.
E. DMM Check **r1** 2013. **±0.05%** One 9V battery.
F. 10.0000 VDC Precision Voltage Reference **r4** 2015 **±0.0025%**. Two 9V batteries.
G. 1K, 2K, & 4K Resistors **>±0.1%.**
H. Decade 1W, low inductance, 5ppm TC, Resistors 10Ω to 1 MΩ **±0. 01%.**
I. Voltage Standard **r5** 2017, 5.0000VDC, **±0. 01%**. One 9V battery.

The DMMCheck Plus has several options. The first is the plastic case with top cover. This is important to protect this investment to have a long and useful life.

The LC Board option adds four capacitors and four inductors to use as standard decade values. Appendix C shows the traceable values found on this board. See link below for additional details.

https://dmmcheckplus.com/shop/ols/products/lc-board

A dual frequency option is available. I used frequencies that are also used by my LCR meter for additional correlation.

DMMCheck standards are designed for long term stability and calibrated to meter standards that have an accuracy to 0.0002%

Below are Agilent Owner's Manual snippets of accuracy that are used to calibrate the DMMCheck Plus.

3458A Technical Specifications

Note: 2 PPM is 0.0002%

Introduction

The Keysight 3458A accuracy is specified as a part per million (ppm) of the reading plus a ppm of range for DCV, ohms, and DCI. In ACV and ACI, the specification is percent of reading plus percent of range. Range means the name of the scale, e.g. 1 V, 10 V, etc.; range does not mean the full-scale reading, e.g. 1.2 V, 12 V, etc. These accuracies are valid for a specific time from the last calibration.

Absolute versus relative accuracy

All 3458A accuracy specifications are relative to the calibration standards. Absolute accuracy of the 3458A is determined by adding these relative accuracies to the traceability of your calibration standard. For DCV, 2 ppm is the traceability error from the factory. That means that the absolute error relative to the U.S. National Institute of Standards and Technology (NIST) is 2 ppm in addition to the DCV accuracy specifications. When you recalibrate the 3458A, your actual traceability error will depend upon the errors from your calibration standards. These errors will likely be different from the error of 2 ppm.

Agelent 3458A Accuracy

- 0.6 ppm for 24-hours in DC volts
- 2.2 ppm for 24-hours in ohms
- 100 ppm mid-band AC volts
- 8 ppm (4 ppm optional) per year voltage reference stability

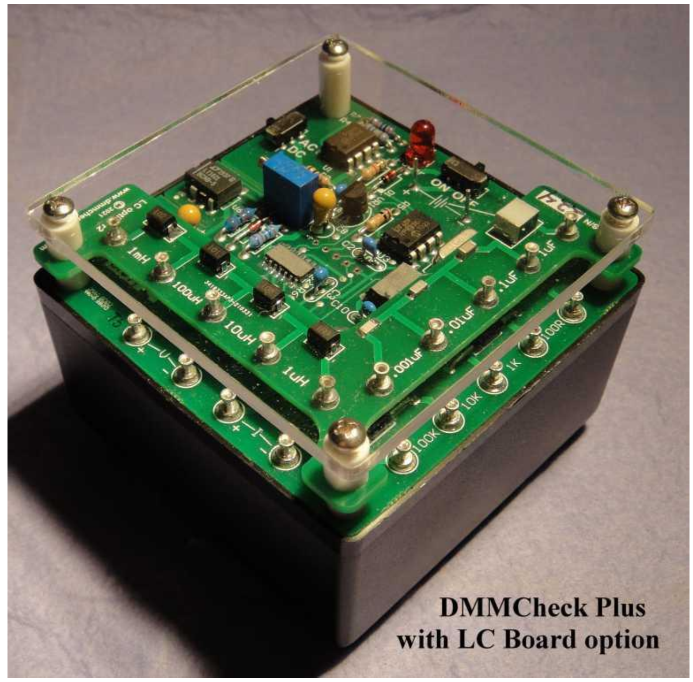


Fig. N1 - Latest DMMCheck Plus Calibration Standard

(2) Several of my writing projects address DMM related subjects. Copies may be requested by title.

DMM and Related Articles

2	Comparing the AN8008 and AN8009 DMM (Differences) - V1	171223	3	1	1	1	0	1	580 KB	4
3	4-1/2 Digit 200 mV Panel Meter- V1C	140503	10	12	1	0	2	4	990 KB	3, 5
4	CEN-TECH 7 Function Digital Multimeter- V1	130827	19	13	3	2	4	4	2.7 MB	
5	Ten Stage Voltage Divider –V3	140525	4	6	0	6	0	7	360 MB	2, 5
6	± 500 µA Panel Meters- V3a	140515	14	23	3	5	1	13	1.2 MB	4
7	Checking the ANENG AN870 DMM with the DMMCheck Plus- V1	211105	6	4	1	1	1	3	1.9 MB	4
8	Precision Variable Resistor Divider Investigation – V2	140424	8	8	5	2	1	3	500 KB	1
9	Stable Millivolt DC Supply - V1	140501	4	9	1	1	0	2	500 KB	5
10	Fluke Entry DMM Vs a Chinese (ANENG) DMM – V1	211115	21	16	5	4	4	5	3.1 MB	1, 2, 6
11	DMM Test Leads, DC – V1	210504	12	16	0	3	2	2	750 KB	2, 4, 5
12	Low Resistance & Capacitance Test Leads – V2	210306	12	19	5	3	0	4	1.9 MB	1, 2, 5
13	Seven Inch alligator Clip Leads – V2	180615	5	10	1	2	0	4	400 KB	5
14	Alligator Clip Hookup Leads V1a	151230	5	12	1	2	0	3	400 KB	4.
15	Making a High Voltage DC Probe –V1 (40 kV)	120229	16	21	0	2	5	10	1.6 MB	5.4,5
16	The Mooshimeter – A First Look – V2 (Computer specialists)	160531	23	37	3	27	2	14	2.0 MB	2, 4, 6
17	Mounting “Standard” Resistors – V1	171214	4	4	1	3	1	0	800 KB	1, 2, 4
18	RJN Electrical Standards – V1a	210225	8	5	2	6	1	1	900 KB	1, 2, 4
19	Sorting 10 Ohm 1% Resistors – V1 (176 resistors total)	160521	4	3	1	3	0	5	300 KB	
		Totals:	**211**	**243**	**47**	**84**	**27**	**95**	**23.4 MB**	1, 4

Headers: Pgs = Pages, Fgs = Figures, Tbs = Tables, Lks = Links, Apx = Appendices, Nts = Notes, PDF = Format.

Reminder: Any links (to internet pages) used may have changed (usually removed) are beyond my control. I try to only use stable links, but given enough time, all links disappear. Without links articles *would be dozens of extra pages in length.* ***Orange shaded titles are in date order as each one addresses a different issue. #11 is a general article, #12 addresses the 2-wire vs. 4-wire resistance issue, #13 documents shorter test leads for writing project photographic needs. #14 (the oldest) describes the techniques of soldering stress relieved test leads.***

Notes

1. *Original data not found on the internet.*	4. *Especially educational or historical.*
2. *Highly recommended.*	5. *Provides construction ideas.*
3. *Additional material could be added*	6. *Product Review*

(3) *It is vital to understand digital accuracy specifications. The dual value for DMM accuracy is required because the display is digital. This adds the second additional "counts" or LSD number in order to better specify the range of values the parameter may have to be considered "within specification." Let's use DC voltage as an example. The AN870 specification is ±0.05% & 3 counts. The DC voltage specification is usually the highest accuracy provided by the DMM.*

Let's assume a ***true voltage of 4.915*** *volts is measured by an AN870 DMM and the display shows 4.919 volts. Is the meter correct and within its specifications?*

The specification error is ±0.05%. This is a range of 4.913 to 4.917 volts. The display, however, reads 0.002 volts above the ±0.05% value. The meter is within its specification because the LSD counts must be added. This makes the within-specification range 4.910 to 4.920. The indicated 4.919 value is within this range and the meter passes.

From the user's perspective, however, all he is concerned about is what the display value is with respect to the true value. In this situation the displayed 4.919 is shown for a true 4.915. The percentage differences are ± 0.08%. The reason for the difference between 0.05% and 0.08% is the added counts required for the analog to digital conversion performed by the DMM. Also note that the percent values are based on the display value whereas the meter percentage applies to the whole range. In this case it is the 19.999 volt range. 0.05% of 5 volts is 0.0025 volts, but for the 19 volts it is 0.0095 volts.

This is in contrast to most analog DMMs where the specification is a simple ± percentage of full scale.

The meter specifications must cover all voltages within a specific range that the specification is given for. If we assume the DMMCheck Plus certificate values are correct and compared with the values measured, the ERROR column of table 1 shows this value. To determine if the meter is within its specifications, however, the ERROR percentage must be based on the dual specification range. If the measured value is less than just the specification percentage alone it may be assumed passed.

Fig. N2 – 0.0186 Ω shunt.

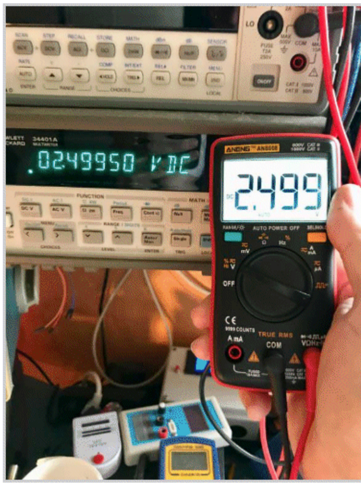
(4) *Actually I have recently noticed another ANENG AN8009 "bug." If you plug in a "zero ohms" resistor most instruments will respond with what appears to be random values as high as five ohms. Of course, the expected value would be 00.00 as shown in Fig. 5. See Fig. N2 for my gold-plated dual jack shunt. The copper wire is 8 Ga. which has 0.0006282 ohms per foot or 0.00005234 ohms per inch. This unexpected response appears to be caused by the auto ranging software. I should make this a future writing project. The auto ranging response seems to cause other related issues. I have mentioned these anomalies in other ANENG DMM related writing projects. See note (2). Also see Note (5).*

(5) *See this link for an excellent description on how to fix the response problem.*
https://www.jackenhack.com/aneng-an8008-modify-for-better-accuracy-faster-readings/

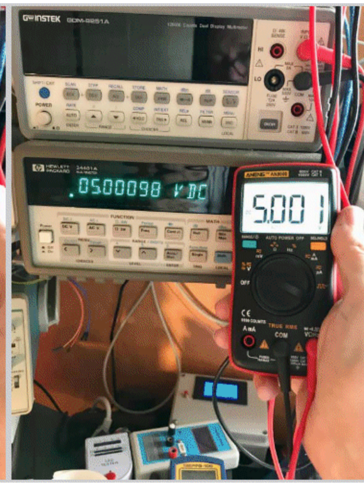
Here is a quote from that description. I smiled when I saw the photos because I also use some of the instruments seen on the reviewer's bench.

So Did It Make A Difference?

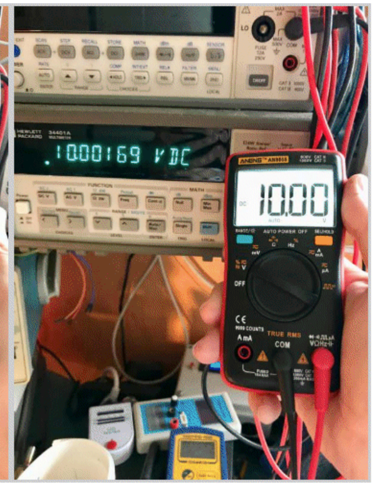
Yes! The meter settles on values immediately instead of 5 seconds of drifting back and forth. The reading is also much more stable over time because it used to wander around. It's also spot on when compared to my HP 34401A 6 ½-digit multimeter.



2.5 Volt Reference



5 Volt Reference



10 Volt Reference

So now a $25 multimeter performs even better. If you need a small portable multimeter (you can never have too many multimeters), this is a great buy! Don't believe the CAT rating on it. I wouldn't work with anything high voltage with this unit, but for low energy, it's perfect. And after this modifications, it's even better!

Appendix A – AN8009 Specifications - Page 1 of 4

Official AN8009 Specification. See Table l page 3. Where are the vital specifications?

▲ - Range values rounded up one LSD count. The red notations are mine for added clarity.

Function – switch rotation order	**Range▲ (highest value)**	**Resolution**	**Accuracy***	**MAX. Value**	**Other**
DC Voltage (V)	999.9mV **1V**	0.1mV	**DC Voltage ±(0.5%+3)**	999.9V	
	9.999V **10 V**	0.001V			
	99.99V **100 V**	0.01V			
	999.9V **1 KV**	0.1V			
DC Voltage (mV)	9.999mV **10 mV**	0.001mV		99.99mV	
	99.99mV **100 V**	0.01mV			
AC Voltage (V)	999.9mV **1 V**	0.1mV	**AC Voltage ±(1.0%+3)**	750V	40Hz-1kHz
	9.999V **10 V**	0.001V			
	99.99V **100 mV**	0.01V			
	750.0V **750V**	0.1V			
AC Voltage (mV)	9.999mV **10 mV**	0.001mV		99.99mV	
	99.99mV **100 mV**	0.01mV			
DC Current (mA&A)	999.9mA **1A**	0.1mA	**DC Current highest ±(1.0%+3)**	9.999A	
	9.999A **10 A**	0.001A			
DC Current (μA)	99.99μA **100 μA**	0.01μA	**DC Current lowest (μA)±(0.8%+3)**	999.9μA	
	999.9μA **1 mA**	0.1μA			
AC Current (mA&A)	999.9mA **1A**	0.1mA	**AC Current highest ±(1.2%+3)**	9.999A	40Hz-1kHz
	9.999A **10A**	0.001A			
AC Current (μA)	99.99μA **100 μA**	0.01μA	**AC Current lowest (μA)±(1.0%+3)**	999.9μA	
	999.9μA **1 mA**	0.1μA			
Resistance	99.99Ω **100 Ω**	0.01Ω	**Resistance lowest ±(1.0%+3)**	99.99MΩ	
	999.9Ω **1 KΩ**	0.1Ω	**Resistance ±(0.5%+3)**		
	9.999kΩ **10 KΩ**	0.001kΩ			
	99.99kΩ **100 KΩ**	0.01kΩ			
	999.9kΩ **1 MΩ**	0.1kΩ			
	9.999MΩ **10 MΩ**	0.001MΩ	**Resistance two highest ±(1.5%+3)**		
	99.99MΩ **100 MΩ**	0.01MΩ			
Function	Range	Resolution	Accuracy	MAX. Value	Other
Capacitance	9.999nF **10 nF**	0.001nF	**Capacitance lowest ±(5.0%+20)**	9.999mF	
	99.99nF **100 nF**	0.01nF	**Capacitance ±(2.0%+5)**		
	999.9nF **1 μF**	0.1nF			
	9.999μF **10 μF**	0.001μF			
	99.99μF **100 μF**	0.01μF			
	999.9μF **1 mF**	0.1μF			
	9.999mF **10 mF**	0.001mF	**Capacitance highest ±(5.0%+5)**		

Appendix A – AN8009 Specifications - Page 2 of 4

Function– switch rotation order	Range	Resolution	Accuracy*	MAX. Value	Other
Frequency	99.99Hz	0.01Hz	**Frequency** **±(0.1%+2)**	9.999MHz	
	999.9Hz	0.1Hz			
	9.999kHz	0.001kHz			
	99.99kHz	0.01kHz			
	999.9kHz	0.1kHz			
	9.999MHz	0.001MHz			
Duty Cycle	1%~99%	0.1%	**Duty Cycle** **±(0.1%+2)**		
Diode	√				
Continuity	√				
NCV	√				
Temperature	-20~1000℃	1℃	**Temperature** **±(2.5%+5)**	1000℃	
	-4~1832℉	1℉		1832℉	

General Specifications	
LCD Display	9999 Counts
Ranging	Auto/ Manual
Material	ABS
Update Rate	3 Times/Second
Ture RMS	√
Back Light	√
Data Hold	√
Low Battery Alert	√
Auto Power Off	√
Mechanical Specifications	
Dimension	130 x 65 x 32mm
Weight	114g
Battery Type	2 x 1.5V AAA Batteries (NOT included)
Warranty	One year

Environmental Specifications		
Operating	Temperature	0~40℃
	Humidity	<75%
Storage	Temperature	-20~60℃
	Humidity	<80%

***** - *The +N LSD count digits are ±N. Subtract N for the minus accuracy percent and add N for the plus accuracy percent to obtain the accuracy range the meter is specified to be reading*.

Appendix A – AN8009 Specifications - Page 3 of 4

Studying the AN8009 specifications

Numeric prefixes

Electronics specifications use parameter numeric prefixes as shown in Table A1. Note that larger than one number prefixes use upper case letters, and smaller than one numbers use lower case prefixes.

Electronicers must be able to recognize and relate to millivolts, nanofarads, femtoamps, kilohertz, gigaohms, etc. and be comfortable converting one format e.g. 1,000 µF = 1 mF, to another.

Industry customs and marketing forces act to prefer one format over another. Battery capacity is an example. Battery capacity is usually expressed as 2100 mAh rather than a simpler format of 2.1 Ah. The 2100 number seems larger from a marketing perspective. This "inconsistency" is evident on the AN8009 Specifications of the previous two pages. Which provides greater clarity for you; 0.01V or 10 mV? Sometimes greater clarity is provided by violating a "standard" format and using what the reader more easily relates to. Effective commun-ication is no easy task.

Large amounts of data are not easy to work with and generalizing the values is helpful. Table A2 provides the basic specifications in a more compact format. I printed this on a small card that I keep on the shelf with the DMMs. One could make a good case for any format. A 200 mV panel meter is really a 4-1/2 digit 999.99 mV panel meter. Are the 9s confusing?

Table A1 – Numeric Prefixes

Metric Prefix	Symbol	Multiplier (Traditional Notation)	Exponential	Description
Yotta	Y	1,000,000,000,000,000,000,000,000	10^{24}	Septillion
Zetta	Z	1,000,000,000,000,000,000,000	10^{21}	Sextillion
Exa	E	1,000,000,000,000,000,000	10^{18}	Quintillion
Peta	P	1,000,000,000,000,000	10^{15}	Quadrillion
Tera	T	1,000,000,000,000	10^{12}	Trillion
Giga	G	1,000,000,000	10^{9}	Billion
Mega	M	1,000,000	10^{6}	Million
kilo	k	1,000	10^{3}	Thousand
hecto	h	100	10^{2}	Hundred
deca	da	10	10^{1}	Ten
base	b	1	10^{0}	One
deci	d	1/10	10^{-1}	Tenth
centi	c	1/100	10^{-2}	Hundredth
milli	m	1/1,000	10^{-3}	Thousandth
micro	µ	1/1,000,000	10^{-6}	Millionth
nano	n	1/1,000,000,000	10^{-9}	Billionth
pico	p	1/1,000,000,000,000	10^{-12}	Trillionth
femto	f	1/1,000,000,000,000,000	10^{-15}	Quadrillionth
atto	a	1/1,000,000,000,000,000,000	10^{-18}	Quintillionth
zepto	z	1/1,000,000,000,000,000,000,000	10^{-21}	Sextillionth
yocto	y	1/1,000,000,000,000,000,000,000,000	10^{-24}	Septillionth

Table A2 – Condensed AN8009 Basic Function Specifications

#	Basic Function	Ranges*	Accuracy
1	DC Volts	10 mV to 1 Kv = 6	±(0.5% +3)
2	AC Volts	10 mV to 750V = 6	±(1.0% +3)
3	DC Amps	100 µa to 10 A = 4	Lowest two ±(0.8%+3) Highest two ±(1.0% +3)
4	AC Amps	Same as DC = 4	Lowest two ±(1.0% +3) Highest two ±(1.2% +3)
5	Resistance	100 Ω to 100 MΩ = 7	Lowest ±(1.0% +3) Middle four ±(0.5% +3) Highest two ±(1.5% +3)

* - *Range values rounded up one least significant count for simplicity.*

Non-uniformity of specifications

Studying DMM specifications is very educational. Note that the voltage accuracy specification is uniform over six decades of range whereas current and resistance specifications are not. Why? The reason is that some ranges degrade and are less accurate. There are only four decades of current measured. The highest

Appendix A – AN8009 Specifications - Page 4 of 4

two ranges is less accurate than the lowest two. What are the reasons for this? Component development technology plays a role. Production volume plays a role. Resistance covers seven decades. Wouldn't it be nice if all ranges had the same tolerance? Also note that the resistance tolerances tend to be less than the current tolerances. One observation is that resistance involves both voltage and current measurements and these two tolerances will be combined. Combining two equal tolerances will always result in less accurate values. Suppose both were high. Two ±1% accuracy specifications would be ±2% in this instance. If equal and one was plus and the other minus they would cancel. This gets quite complicated with statistical math.

Is a true all function ±1% DMM reasonable?

If the AN8009 accuracy specifications are examined they range from ±(0.5% +3) [voltage] to ±(5.0% +20) [lowest capacitance]. Each parameter must be considered in the real world. To measure something you must be able to isolate and define the parameter. Stray capacitance is undefinable and this will affect what the DMM actually "sees." Another factor that plays a role is the measurement method. The more factors that are involved the more difficult it is to make the measurement. Capacitors are more sensitive to their environment. The best (and very expensive) capacitor is probably glass used for the dielectric. Glass capacitors are the most reliable capacitors you can buy – if money is no object. Their range, however, is limited.

As new technology and measurement methods are developed (especially IC reference technology) the cost of a consumer true 1% DMM will come down. 1% resistors are now quite common and I can remember the days when the common tolerance was ±10%. Another issue is that when the tolerances decrease the number of manufactured values tends to increase. Much of the advancement will depend on what the market needs and technological development. The unique AN8009 is a very good step forward.

Appendix B – Model 101 Specifications - Page 1 of 3

I especially like the way the Fluke specifications provide the Range, Resolution, and Accuracy, however, their inconsistent formatting and even unspecified values are confusing. The Users Manual seems the best source. Some values, such as duty cycle, are unspecified for other 50 or 50 Hz..

Electrical Specifications		
V AC (40-500Hz)	**Range**	600.0 mV 6.000 V 60.00 V 600.0 V
	Resolution	0.1 mV 0.001 V 0.01 V 0.1 V
	Accuracy	3.0%±3 digit 1.0%±3 digit
V DC	**Range**	6.000 V 60.00 V 600.0 V
	Resolution	0.001 V 0.01 V 0.1 V
	Accuracy	0.5%±3 digit
Resistance Ohms	**Range**	400.0 Ω 4.000 kΩ 40.00 kΩ 400.0 kΩ 4.000 MΩ 40.00 MΩ
	Resolution	0.1 Ω 0.001 kΩ 0.01 kΩ 0.1 kΩ 0.001 MΩ 0.01 MΩ
	Accuracy	0.5 %±3 digit 0.5 %±2 digit 0.5 %±2 digit 0.5 %±2 digit 0.5 %±2 digit 1.5%±3 digit

Electrical Specifications Cont'd		
Capacitance	**Range**	50.00 nF 500.0 nF 5.000 µF 50.00 µF 500.0 µF 1000.0 µF
	Resolution	0.01 nF 0.1 nF 0.001 µF 0.01 µF 0.1 µF 1 µF
Frequency (10 Hz – 100 kHz)	**Range**	50.00 Hz 500.0 Hz 5.000 kHz 50.00 kHz 100.0 kHz
	Resolution	0.01 Hz 0.1 Hz 0.001 kHz 0.01 kHz 0.1 kHz
Duty Cycle	**Range**	0.1 % to 99.9 %
	Resolution	0.1 %
General Specifications		
CAT Rating	CAT III 600 V	
V AC Range	600.0 V	
V DC Range	600.0 V	
Ohms Range	40.00 MΩ	
Auto Shutoff	Y	
Continuity	Y	
Capacitor	100.0 µF	
Frequency	100.0 kHz	
Hold	No	
Duty Cycle	Yes	
Size	130 mm x 65 mm x 27mm	

Appendix B – Model 101 Specifications - Page 3 of 3

Electrical Specifications Cont’d	
Weight	160 g
Battery	Two AAA
Warranty	1 year
Environmental Specifications	
Operating Temperature	0 °C to +40 °C
Storage Temperature	-30 °C to +60 °C
Operating Humidity	Non condensing (<10 °C) <=90% RH (at 10 °C to 30 °C) <=75% RH (at 30 °C to 40 °C) (Without Condensation)
Operating Humidity, 40 MΩ	80% RH 10 °C to 30 °C, 70% RH 30 °C to 40 °C
Operating Altitude	2,000 meters
Storage Altitude	12,000 meters
IP Rating	IP 40 per IEC 60529
Vibration Requirements	MIL-PRF-28800F, Class 2
Drop Test Requirements	-10°C and 1 meter to surface, per IEC-61010-1, and Fluke SOP 39.1 for portable Hand-held equipment Shipping container drop per Fluke SOP 39.
EMI, RFI, EMC	Must meet all applicable requirements in IEC/EN 61326-1
Absorption/Corrosion	Per Fluke SOP 39.1
Temperature Coefficients	Add 0.1 x specified accuracy for each degree C above 28 °C or below 18 ºC

Note that the display digit height is not provided. I had to measure it with a Vernier caliper. Perhaps this is to allow for a larger version as display costs are reduced.

Appendix C – The Certificate for my DMMCheck Plus Standard – Page 1 of 1

Rcv'd 2/10/25

DMMCheck Plus Calibration Certificate

Measured Values

Calibration Date	10/22/2021
Serial Number	UJA1/LC224
Burn-In Duration (Hrs.)	519
Calibration Temperature	71°F
DC Voltage Reference	5.0000 Vdc
AC Voltage Reference	4.992 Vac
DCV Temp. Coefficient	+6uV/F
DC Current Source	1.0003 mA dc
AC Current Source	1.001 mA ac
Freq 1, Hz Oscillator	120.043364 Hz
Freq 2, Hz Oscillator*	1.000081 kHz
Freq 1, Hz duty cycle	50.018%
Freq 2, Hz duty cycle*	49.980%
100Ω Resistor	99.938 Ω
1KΩ Resistor	1.0006 kΩ
10KΩ Resistor	10.0047 kΩ
100KΩ Resistor	100.051 kΩ
.001 uF Capacitor*	0.000973 uF
.01 uF Capacitor*	0.01048 uF
.1 uF Capacitor*	0.1004 uF
1.0 uF Capacitor*	0.972 uF
1 uH Inductance*	1.088 uH
10 uH Inductance*	10.62 uH
100 uH Inductance*	106.0 uH
1 mH Inductance*	1.048 mH

* Indicates Optional
AC @ 100 Hz
L&C @ 10 kHz

Calibration Equipment used:

·Agilent DMM, model 3458A, S/N MY45042794, Cal due: 4/26/2022 Keysight Certificate of Calibration 1-12377620334-1

·Keysight 53220A, S/N MY59280115, Certificate of Calibration 53220AMY59280115. ref. 10 MHz Trimble GPS DSO.

·Ambient temperature and secondary measurements by Keysight 34461A, S/N MY57222226

·Capacitance measurements by BK 891, S/N 468F19199, Cal due 10/21/2021

www.dmmcheckplus.com
sales@dmmcheckplus.com
DMMCheck Plus
1129 Hidden Hills Dr.
Wake Forest, NC 27857

Measurements
SI
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International System of Units

Appendix D – Accuracy Specifications Compared – Page 1 of 1

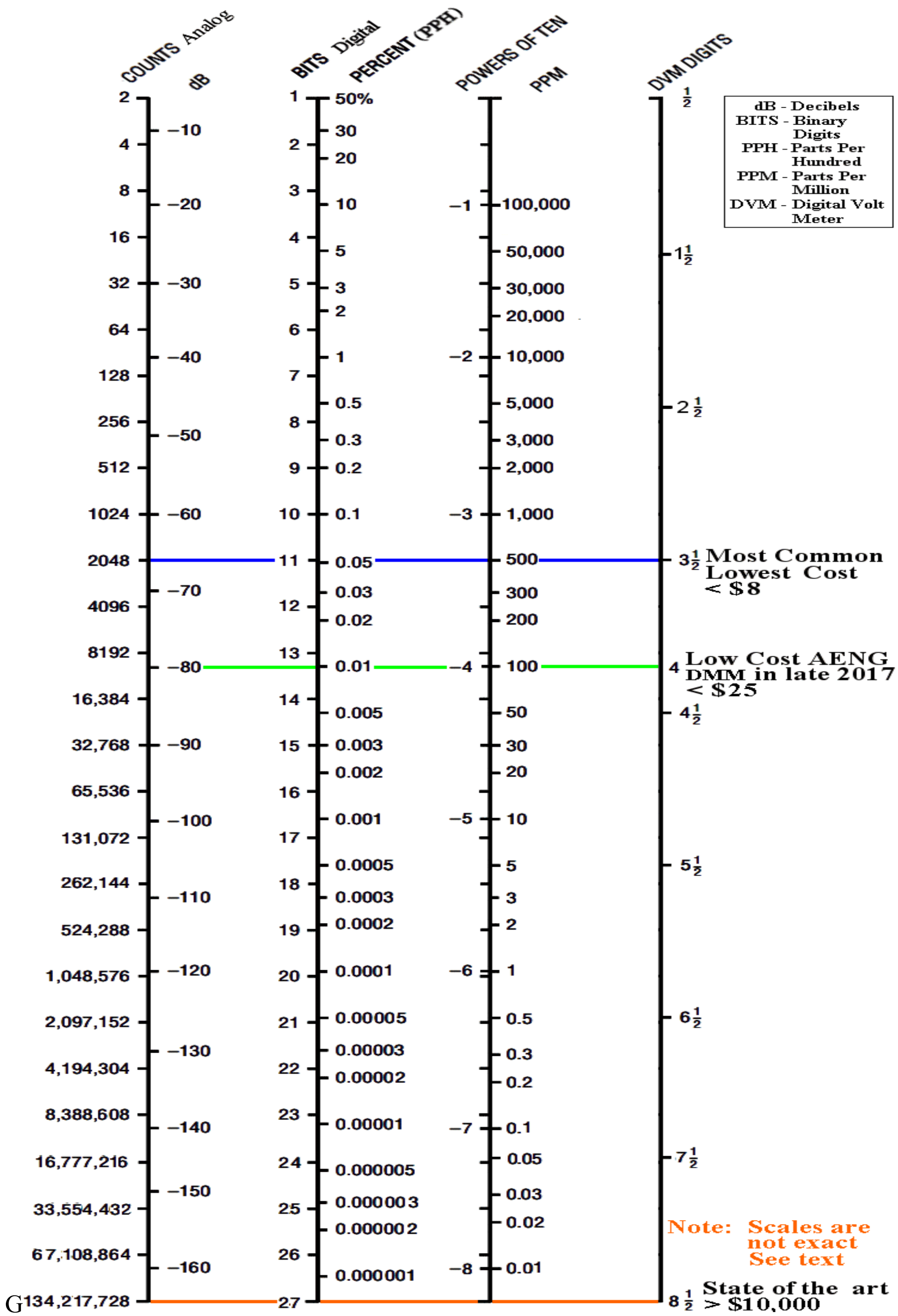


Fig. D1- Expanded scales & notations using Fig. 1 of Linear Technology Application Note 82-1.

HHC2025 Appendix D – Measuring the 2017 ANENG AN8009 DMM - V2a

Richard J. Nelson

Introduction

I enjoy making measurements of all kinds [(1)], but I especially like electrical or electronics measurements. I also enjoy, as a hobby, Do It Yourself, DIY experimental projects related to electronics, physics, mechanics, optics, and Chemistry. Because I provide electronics measurements in my articles I want them to be as accurate as practical/possible. My optimistic goal is 1% measurements. To ensure this I have a set of electrical standards that are ten times or more accurate than my meters. See Appendix B page 24. Another aspect of my measurement interests is doing them at minimum (retired) cost.

When I heard about the ANENG model AN8009 true RMS Digital Multimeter, DMM, from a friend late last year I was impressed with its specifications. It also has many very positive internet reviews. This is my third AN8009 related article. This article is concerned with its specifications (especially measuring the missing specifications) and accuracy.

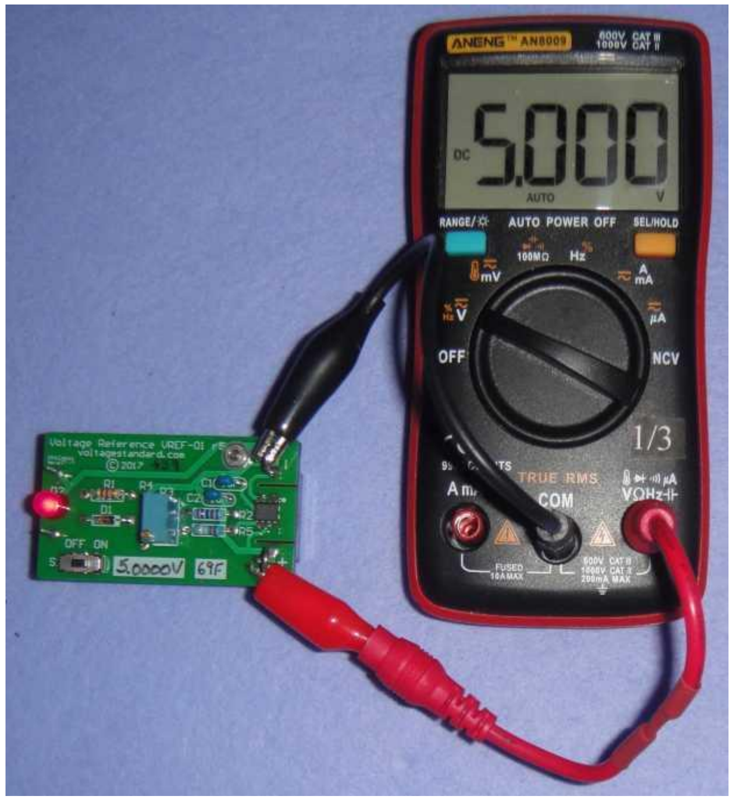


Fig. 1 - ENEG AN8009 DMM measuring a 5-volt standard.

I have three AN8009 DMMs and I am reminded of Segal's law[(2)]. Will, over time, having three DMMs of the same model prove more helpful in terms of accuracy? Standards are vital if you really want to know the correct value. Knowing the most accurate value possible helps correlate practice with theory.

What does a DMM measure?

Most DMMS measure the three basic electronics parameters of voltage, current, and resistance plus some additional parameters such as capacitance, frequency, and continuity. Often, they will also test diodes and transistors as well. Each model is a special mix of features, functions, and ranges directed at a particular market segment such as electronics, commercial maintenance, home owner, hobbyist, researcher, etc. Why not use one AN8009 to measure another?

DMM price range

DMMs are usually thought of as being handheld or portable instruments. Benchtop and laboratory grade DMMs are also common and are more expensive. The more expensive DMMs provide greater ranges, extended resolution (more digits), and better accuracy. The DMM price range is FREE (Harbor Freight[(3)]) to well over $10,000. The An8009 is about $25.

DMM display digits

The DMM senses an analog signal and converts it into a digital value which is then displayed. The process requires that the analog signal (voltage, current, resistance, etc.) be sampled and converted. The sampled value is done at a specific rate e.g. samples per second. The analog signal is continuous, but it's conversion to a digital value is done in discrete time slices. The sampling rate limits the speed at which the DMM is able to respond to changes in what it is reading.

An analog meter represents the measured value with a moving pointer over a scale of values. Visually the eye-brain ability to "read" these changes is faster (up to 10 per second) than reading rapidly changing digits in a digital display (up to 3 per second). For this reason an analog display is preferred in some applications – usually audio. Measuring power sources, selecting components, verifying connections, etc. is more appropriate for a digital display. A digital display certainly makes recording data more accurate because the reading of an analog display is less precise and of a low resolution. A sampling of three per second is adequate for a DMM being read by a person. Sending the measurements over a data link is a different use of a DMM.

To better understand the displayed digits it is useful to understand the relationship between the output of the analog to digital converter and the number of digits being displayed.

DMMs are specified and compared by the number of digits they display. Another term that is used is counts. The number of counts is the maximum display digits that the DMM will display before the next range is used. The number of counts is the upper limit of the resolution of the analog to digital conversion, ADC.

Digital resolution is measured in BITs, or binary digits. Digits are base ten and BITS are base two. ADCs are limited in the number of BITS they may resolve. In general 16 BITS is reasonable in speed and cost in today's technology. There are many methods used to convert analog to digital. A very common ADC used for DMMs is successive approximation register or SAR.

There are several specification related terms associated with DMMs and their use. These are shown in Fig. 2. The orange center horizontal line is about the average consumer DMM and others are usually compared to these values. The average consumer DMM is 3-1/2 digits with a minimum ADC of 11 or 12 BITS. The AN8009 is a true four digit DMM with a count of 9999. Note that this provides a nearly 5x greater resolution than the "average." The green line is the AN8009. From Fig. 2, a 14 BIT SAR would be required.

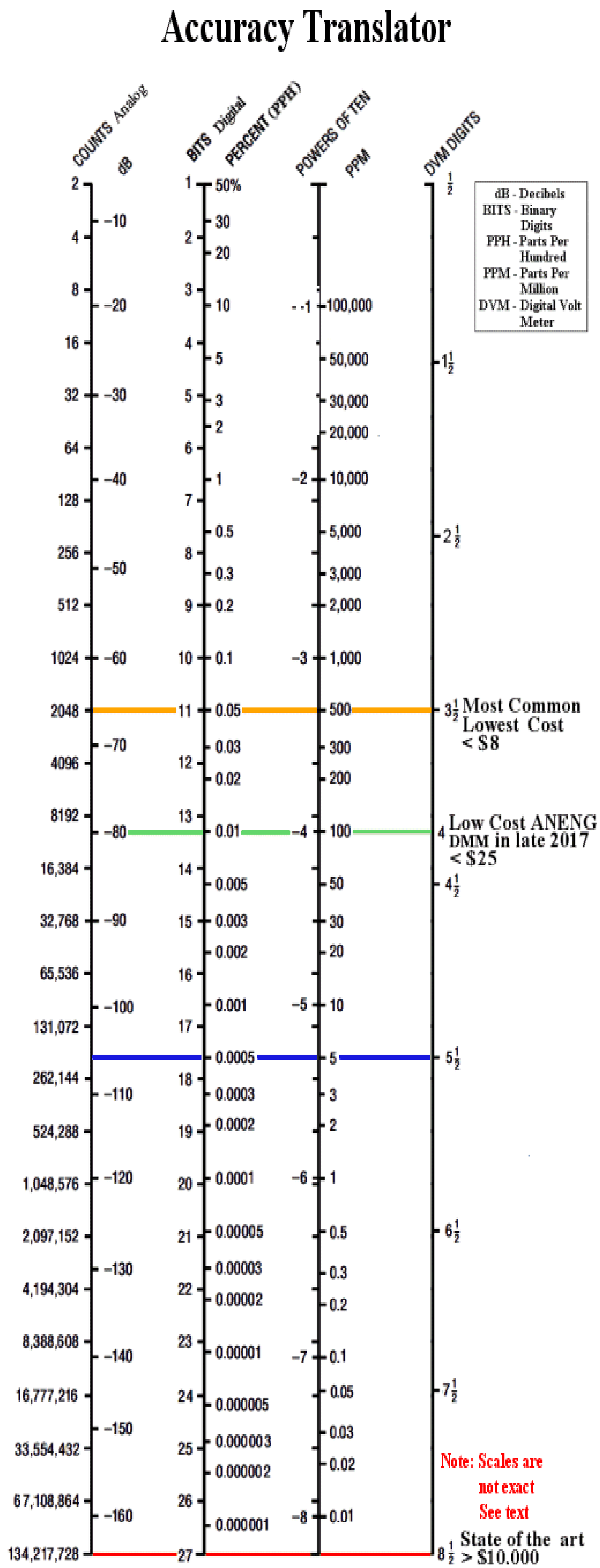


Fig. 2 – DMM display resolution specifications.

The AN8009 followed on the heels of the AN8008 in November 2017, and both DMMs are quite similar. See my article titled Comparing the AN8008 and AN8009 DMM (Differences), 3 pages, 1 figure, and **125 KB** as a pdf file, for a discussion of the three primary differences – Temperature Probe, 99.99 MΩ range, and the Non-Contact-Voltage indicating feature. The two DMMs are similar in appearance with the AN8009 NCV feature replacing the (strange and unusual) square wave signal feature of the AN8008. The AN8009 (also AN8008 and other similar models) uses an advanced integrated circuit that provides exceptional performance such as true RMS voltage and current, auto ranging, and high sensitivity with an ≈$25 cost.

Mechanically the small size (it fits nicely in a shirt pocket), large 9999 display, solid function switch and accuracy make it an exceptionally high value and high-quality instrument. The internet provides lots of details and reviews. **What is not so obvious are the vital specifications listed in the Missing specifications section below.**

Marketing research and marketing presentation is vital for all products to position one product as better than the completion. As with most products, there always seem to be product specifications and features that are seldom expressed. It almost seems that the manufacturers don't want their customers too well educated about some really important/vital features.

Missing specifications

The manufacturer's auto ranging AN8009 specifications are listed in Appendix A. Any instrument that makes a measurement will disrupt or alter (usually reduce) the parameter being measured. High quality instruments will keep the circuit loading to a minimum whereas cheap DMMs will introduce higher errors due to their higher circuit loading. Table 1 shows a list of eleven vital AN8009 specifications you must know (and understand) for any DMM. These are seldom provided in the general DMM market place including that of the AN8009. The AN8008 is similar. It should be noted that high quality instruments always provide these specifications.

Table 1 – Important Missing AN8009 DMM Specifications

1. DC mV loading resistance
2. DC voltage loading resistance
3. AC mV loading resistance
4. AC voltage loading resistance
5. DC μA resistance (burden voltage)
6. DC mA resistance (burden voltage)
7. DC Amp range resistance (burden voltage)
8. AC μA resistance (burden voltage)
9. AC mA resistance (burden voltage)
10. AC Amp range resistance (burden voltage)
11. Ohm's voltage or constant current

Voltage

Voltage is a measure of the electromotive force between two points in the circuit. When you connect the meter to the two points it will draw a small amount of current because of the finite resistance of the meter - the higher the resistance, the lower the current that is drawn. Because of the special requirements of AC measurements (frequency, wave form, and capacitance) the effective AC voltage loading resistance is frequently lower than the DC voltage loading resistance (of a typical DMM). If the meter resistance is known it may be used to correct for the error it causes when it is added to the circuit (if the circuit is also known). Simple ohms law calculations are used [4].

All voltage sources have an effective source (series) resistance. If the DMM resistance is ten or more times the effective series resistance the loading error is usually considered negligible. In reality, however, the ten to one ratio loading reduction is 9.09%. If you seek 1% measurements you must account for your DMM errors. Lower cost DMM volt meters usually have a voltage divider circuit which has various resistor values switched in depending on the voltage range.

An auto ranging meter like the AN8009 doesn't have ranges to be selected by the function switch per se. The loading resistance is a constant value which makes making measurements much easier. It may take a little more time for the DMM to search for the optimum range [5].

The normal voltage input resistance of DMMs is commonly 1, 10, 11, 100, and higher Megohms. Some meters are specified as >100 MΩ [7] or >1 GΩ. Special volt (and electric charge) meters that have an exceptionally high input resistance are called electrometers. 100 MΩ is 10^8 Ω. Electrometer input resistances are in the range of 10^{14}Ω (100 T Ω). This is very high and even dust or condensed water vapor on the electrodes will seriously affect the reading. Special precautions/techniques must be applied to get the best results. Some very sensitive electronic DMMs are described as nanovoltmeters with an input resistance in the range of 10^{10}Ω (10 GΩ).

Measuring volt meter input resistance

There are two common methods of measuring the input resistance of a voltmeter.

(1) Measure it directly with another meter. This is not always reliable.

(2) Measure it using a series variable resistor a little larger than the suspected meter value. Connect the variable resistor and meter in series to a **stable voltage source**. Measure the source voltage and adjust the resistor so that the series connected meter indicates one half of the source voltage. Connect a switch across the variable resistor to switch back and forth from power source voltage to meter voltage to adjust the variable resistor to one half of the supply voltage. Because the current is the same for both the resistor and the meter, the voltage is the same as well. Remove the resistor and measure its value. This is the input resistance value of the volt meter. See Appendix F on the last page.

Current

Current is measured by passing the unknown current through a known resistance and measuring the voltage across the resistance. The resistance is part of the DMM and is called a current sense resistor. If the DMM resistance is 0.1 ohms the voltage will indicate the current directly and only the decimal point needs placement. 1 ohm is 1 volt per ampere. 0.1 ohm is 100 millivolts per ampere, etc. Adding a resistance to the circuit will reduce the current creating an error which means that the meter reading is too low. Obviously having the lowest possible resistance for current measurements is desirable for minimizing the error. 0.001 ohms, however, will only provide 1 microvolt if one milliampere is flowing through the 0.001-ohm resistor. Making voltage measurements in the microvolt range is getting into noise territory so most current meters have higher valued current sampling resistances. Some DMMs have multi-ohm current sense resistances. Measuring microamperes may require resistances in the kilo ohm range for some DMMs. Simple ohms law calculations are used to correct for the error [6].

In addition to the errors introduced with high sampling current measuring resistances there is the issue of introducing resistance to the circuit being measured. I have often measured the current drawn by calculators [8] and the operation of the calculator is disrupted by most current meters, especially when ranges are changed. Since the calculator draws many different currents dependent on what it is doing, measuring microamperes changing into milliampere (1,000:1 changes) is problematic.

The voltage drop of the current sense (shunt) resistor is known as the burden voltage.

Measuring current meter resistance

There are two common methods of measuring the input resistance of a current meter.

(1) Measure it directly with another meter. This is not always reliable.

(2) Measure it indirectly by measuring the voltage drop (when measuring a current) with another meter. Knowing the voltage and the current allows you to calculate the resistance used by that range of the current meter.

Resistance

Resistance is measured by applying a known voltage and measuring the current that flows. The higher the resistance, the higher the applied voltage is required in order to keep the currents in a reasonable/useable (high enough) range. Resistances in the high tens of mega ohms is often measured using 100 volts. See Fig. F3 Appendix F on page 32. Special high resistance measurements involved with insulation testing often use test voltages as high as 1,000 volts and much higher. 100, 250, 500, and 1,000 volt test voltages [(9)] are commonly used. Obviously, safety becomes a significant issue. Insulation testers are specialized resistance instruments. The AN8009 with a maximum of 99.99 MΩ using a low voltage is unusual.

An alternate more modern method (as used by the auto ranging AN 8009) is to apply a constant current to the unknown resistance and measure the voltage across it. Since most modern instruments are microprocessor based the particular value of current, and resistance related voltage, may be whatever is available in terms of the reference circuit used for the constant current.

Measurement Methodology

The data described here is only intended to compare and demonstrate the uniqueness of the AN8009 DMM. It is not intended to be a formal report on its statistical accuracy or to formally reveal specifications not supported by the manufacturer. Exact standards conditions, temperatures, and measurement procedures are intentionally not completely documented. The basic accuracy differences between three identical AN8009 DMMs are documented. This serves as an indicator of the quality of the product.

Checking DC voltages

I verified that the loading of the AN8009 meters is within the output capability of my standards. This would not even be questionable except that I wanted to drive three to five meters at the same time to compare all instantly - at once with a photo. If the voltage standard will drive 1 MΩ and the AN8008 and AN8009 are 10 MΩ, five DMMs connected to the standard will only load it to 2.0 MΩ. The values do not change if one meter is disconnected. See Fig. 3.

The meter DC voltage specification (see Appendix A) is 0.5% +3. The 5-volt tolerance range is 4.975 to 5.025 volts. Add the ±3 LSD count digits and the range is 4.972 to 5.028. All the DMMs are well within specifications. Assuming that the voltage standard is 5.0000 volts the furthest any AN8008/9 meter from this value is 0.005 volts (5 mV). This is 0.10%.

Eagle eyed electronicer [(10)] readers will notice that I numbered the meters – after taking the Fig. 4 photo. Did you also notice that the Fig. 3 An 8008-meter labels are grey and the AN8009 meter labels are white? Think resister color code numbers.

As may be seen in Fig. 4 on the next page the meters are within specification. Fig. 4 also shows an interesting phenomenon related to auto ranging. Note that meter 1/3 only shows three digits and the others show four digits of resolution. Why? It seems that when meter 1/3 initially sampled the voltage it first read (the display flashed) it as 10+ volts. Apparently, this set the range and further sampling continued in that range. Meters 2/3 and 3/3, however, did not take that path and they remained in the lower range to full resolution. When I noticed this, I added labels to the meters so I would know which one was different for future measurements.

I also noted their serial numbers. 1/3 is 74321154, 2/3 is 74404483, 3/3 is 74319868. 1/3 and 3/3 are close to each other. If 1/3 was manufactured earlier I would suspect a software change as a possible explanation.

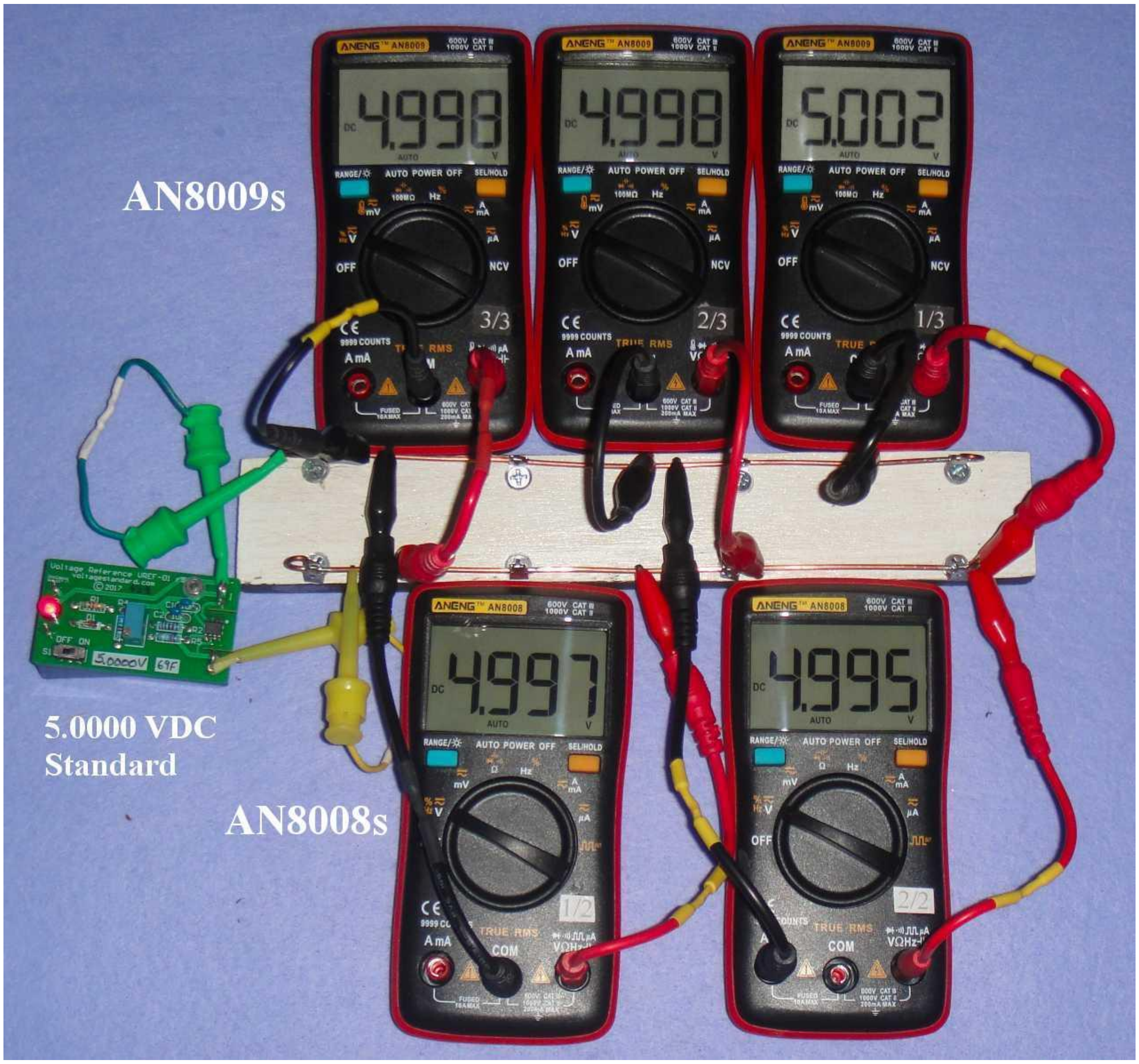


Fig. 3 – Five similar DMMs connected to a 5.0000 voltage standard (See Appendix B Fig. B1 "A").

I tabulated the voltages of the PentaRef voltage standard in Table 1. Note the voltage standard accuracy specification is not consistent.

The meters are all within specification based on the PentaRef.

Any voltage source has a value. The question is how stable is that value. Trying to record voltages that are rapidly changing is frustrating and they are more difficult to describe. The more digits of resolution your DMM provides the more likely you are to experience changing voltages [11]. The voltage standard must also be stable enough that you won't see it change. All Sources change.

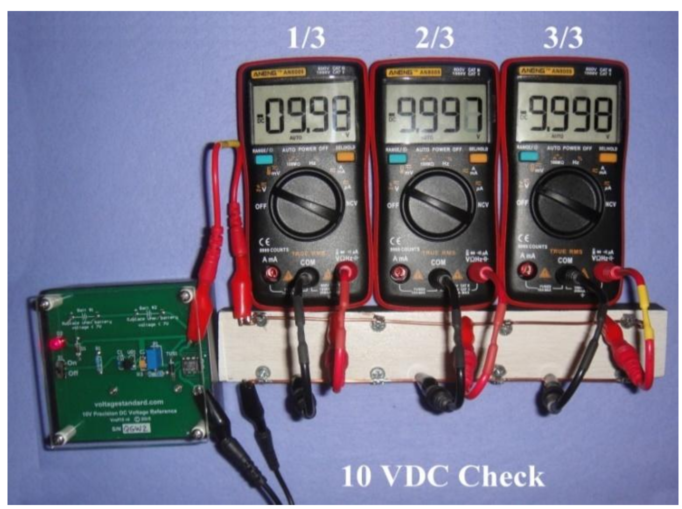


Fig. 4 – 10 VDC voltage check. See text.

I set the pot for 9.987 volts and cycled the power. The display no longer (flash) indicated 10.00 volts and showed four digits of resolution. Setting the pot to a 9.995 displayed voltage (by rising from a lower voltage) did NOT show the four digits of resolution when power was cycled. It seems that the different DMM readings is caused by the slight differences in the range selection of the three meters. The difference is about 5 to 9 counts in the least significant digit. Nine counts (mV) is 0.1% of 10 volts. What if the voltage was reduced just slightly (a few millivolts) the voltage sampling would be approached from below 10.00 volts and would not make a (resolution reducing) range change. This did not change I investigated this difference a bit further by adding a 2 MΩ pot in series with a very stable 10 VDC standard. This allowed a smooth 1 mV adjustment of the voltage as measured by the DMM. I thought

Important Note

The conclusion of this observation is that making measurements very near the decade range change may cause a loss of resolution in either auto or manual mode.

Simple Resistance Measuring Technique

Get more display digits for range changing **resistance** measurements by wetting your thumb and finger to short the meter to reduce the resistance (practice the technique) so it will integrate upwards to a higher digit count e.g. display 1/3 of Fig. 4. Full resolution is then obtained.

Table 1 – AN8009 DC Voltage Check

#	Source	Value V	Accuracy	Range V	DMM 1/3	DMM 2/3	DMM 3/3
1	Penta Ref V1	0.1500	0.2%	0.14970-0.15030	149.9/150.0[1] mV	149.8/9[1] mV	148/9[1] V
2	Penta Ref V2	2.0000	0.02%	1.9996-2.0004	2.000 V	1.999 V	1.999/2.000[1] V
3	Penta Ref V3	4.0000	0.02%	3.9992-4.0008	4.001/2[1] V	3.998/9[1] V	3.999 V
4	Penta Ref V4	8.0000	0.01%	7.9992-8.0008	8.003/4[1] V	7.997/8[1] V	7.998 V
5	Penta Ref V5	10.0000	0.01%	9.9990-10.0010	9.99 V	9.99 V	9.997/8[1] V

1. These values are border line. When a digital display consistently alternates between two digits it is indicated with a slash. For purely computation purposes consider 0.96/7 as 0.965 by splitting the difference. This value may also appear to be "out of specification." See Note (5). Installing the two described filter capacitors could possibly eliminate or greatly reduce these border line readings.

one way to verify the DMM mV range of the AN8009 is to connect two equal voltage standards in series with polarities opposing. The DMM will only "see" the difference between them. I connected the 5V standards back-to-back - the DMMCheck/DMMCheck Plus, DMMCheck/VREF-01, and DMMCheck Plus/VREF-01. I also connected the 10V standards back-to-back – PentaRef/VREF10. While this measurement doesn't check any values of the DMMs it provides a useful perspective on the standards.

The voltage difference values are shown in Table 2. In all cases the difference voltages tended to drift down a few microvolts per minute.

Table 2 – AN8009 DC "Stability" Voltage Check

#	Back to back	Value V	Accuracy %	DMM 1/3	DMM 2/3	DMM 3/3
1	Check*/Check Plus	5 V	0.007/0.007	110 µV	113 µV	113 µV
2	VREF-01*/Check	5 V	0.01/0.007	225 µV	230 µV	233 µV
3	VREF-01*/Check Plus	5 V	0.01/0.007	360 µV	361 µV	360 µV
4	PentaRef*/VREF10	10 V	0.01/0.003	105 µV	91 µV	81 µV

** Indicates the higher voltage. Note: The highest voltage is the source that indicates "+" when the DMM positive lead is connected to it.*

Checking AC voltages

My only AC voltage standard is the DMMCheck Plus[(12)]. See Appendix B "E." The 5-volt test frequency is a 100 Hz square wave of 50% duty cycle. Since the DMM AN8009 is a true RMS meter it should respond as specified. The AN8009 specification is ±1% ±3_{LSD} and the DMMCheck Plus standard is ±0.1% so it is suitable (10x better). The AN8009 frequency range is 40 Hz to 1 kHz. The 1 KHz is the upper limit of the AN8009. I only have two frequencies available. This is the weakest link in my collection of low-cost standards.

I also used the AN8009 frequency capability to check the DMMCheck Plus 100 Hz and 1 KHz frequencies. See the measurements in Table 3.

Table 3 – AN8009 AC Voltage Check

#	Source	Value V	Accuracy	Range Volts	Frequency	DMM 1/3	DMM 2/3	DMM 3/3
1	DMMCheck Plus	5 V AC_{sq}	0.1%	4.995-5.005 V	100 Hz	4.969 V	4.965/6[1] V	4.966/7[1] V
2	Plus Frequency	100 Hz	0.02%	99.98-100.02 Hz	100 Hz	99.99 Hz	99.98 Hz	99.99 Hz
3	DMMCheck Plus	5 V AC_{sq}	0.1%	4.995-5.005 V	1,000 Hz	4.664 V	4.662 V	4.661/2[1] V
4	Plus Frequency	1000 Hz	1%[2]	990.0-1,010 Hz	1,000 Hz	1,000 Hz	999.9 Hz	1,000 Hz

1. *These values are border line. When a digital display consistently alternates between two digits it is indicated with a slash. For purely computation purposes consider 0.96/7 as 0.965 by splitting the difference. This value may also appear to be "out of specification." See Note (5). Installing two capacitors could possibly eliminate or greatly reduce these border line readings.*
2. *This is a strange reduction in accuracy specification. The dual frequency option second frequency is specified as: 25 Hz-999 Hz is 0.1%, 1 KHz-9.99 KHz is 1%. 10 KHZ-20 KHz is 2%.*

Based on these measurements does the AN8009 fail the AC voltage check? At first glance it appears that it does. A closer look at the display values and the specification, however, shows that it complies. The frequency check clearly passes even without considering the least significant digit, LSD, counts.

Checking DC and AC current

The DMMCheck and DMMCheck Plus have a 1 mA DC constant current output (± 0.1%). The DMMCheck Plus also has an AC 1 mA current output. Not only is this useful for checking a DMM, but it has other measurement uses as well. One example is measuring (grading) resistors. Since you know the current through (0.001A) and you measure its voltage across, you may calculate the resistance. The current source is within specifications (±0.1%) if the load is 0 to 500 ohms.

Table 4 – AN8009 DC & AC Current Check

#	Source	Value I	Accuracy	Range Ma	Frequency	DMM 1/3	DMM 2/3	DMM 3/3
1	DMMCheck, DC	1 mA DC	0.1 %	1.001-0.9990	N/A	0.8[1] mA	0.9[1] mA	0.9[1] mA
2	DMMCheck, DC, 1Ω	1 mA DC	0.1 %	1.001-0.9990	N/A	1.000 mV	1.000 mV	1.000 mV
3	DMMCheck, DC, 10Ω	1 mA DC	0.1 %	1.001-0.9990	N/A	10.00 mV	10.00 mV	10.00 mV
4	DMMCheck, DC, 100Ω	1 mA DC	0.1 %	1.001-0.9990	N/A	99.9 mV	99.9 mV	100.0 mV
5	DMMCheck Plus, DC	1 mA DC	0.1 %	1.0002-0.9998	N/A	0.8 mA	0.8 mA	0.8 mA
6	DMMCheck Plus, AC	1 mA AC	0.02 %	4.995-5.005 V	100 Hz	0.9941 mA	No response	993.2 mA
7	DMMCheck Plus, DC, 1Ω	1 mA DC	0.1 %	1.001-0.9990	N/A	0.996 mV	1.000 mV	1.000 mV
8	DMMCheck Plus, DC, 10Ω	1 mA DC	0.1 %	1.001-0.9990	N/A	9.995 mV	9.992 mV	9.994 mV
9	DMMCheck Plus, DC, 100Ω	1 mA DC	0.1 %	1.001-0.9990	N/A	99.98 mV	99.93 mV	99.95 mV
10	DMMCheck Plus, AC, 1Ω	1 mA AC	0.02 %	4.995-5.005 V	100 Hz	0.992 mV	0.991 mV	0.991 mV
11	DMMCheck Plus, AC, 10Ω	1 mA AC	0.02 %	4.995-5.005 V	100 Hz	9.90 mV	9.922 mV	9.924 mV
12	DMMCheck Plus, AC, 100Ω	1 mA AC	0.02 %	4.995-5.005 V	100 Hz	99.30 mV	99.26 mV	99.28 mV

1 – If a lower range (µA, move probe) is used it shows O.L.

If the current value is close to 1 mA, as many as three digits of resolution maybe lost. The next lower range is the 100 µA range. Table 4 measurement #8 for 2/3 has no reading. Is the DMM defective for this range?

Checking resistance decade ranges

I have three sources of standard resistors as shown in Appendix B. I measured all standard resistance values I have with the three meters. The values are tabulated in Table 5

Table 5 – AN8009 Resistance Check Measurements

#	Source	Value Ω	Tolerance	Range Ω	DMM 1/3	DMM 2/3	DMM 3/3
1	PRC Resistors	1 Ω	0.02%	0.9998-1.0002 Ω	0.96/7[2] Ω	0.99/1.00 Ω	0.96/7[2] Ω
2	PRC Resistors	10 Ω	0.02%	9.998-10.002 Ω	10.00 Ω	10.00/1[2] Ω	9.99/10.00[2] Ω
3	PRC Resistors	100 Ω	0.01%	99.99-100.01 Ω	100.1/2[2] Ω	100.1 Ω	100.1/2[2] Ω
4	PRC Resistors	1K Ω	0.01%	999.9-1,000.1 Ω	1.000 KΩ	0.999/1.000[2] KΩ	1.000 Ω
5	PRC Resistors	10K Ω	0.01%	9,999-10,001 Ω	10.00 KΩ	9.99/10.00[2] KΩ	10.00 KΩ
6	PRC Resistors	100K Ω	0.01%	99.99-100.01 KΩ	99.9/100.0[2] KΩ	99.8/9[2] KΩ*	100.0 KΩ
7	PRC Resistors	1M Ω	0.01%	0.9999-1.0001 MΩ	1.000 MΩ	0.999 MΩ	1.001 MΩ
8	DMMCheck	1K Ω	0.1%[1]	999.0-1,001 Ω	1.000 KΩ	1.000 KΩ	1.000/1[2] KΩ
9	DMMCheck	10K Ω	0.1%[1]	9,990-10,010 Ω	9.98/9[2] KΩ	9.98/9[2] KΩ	10.00 KΩ
10	DMMCheck	100K Ω	0.1%[1]	99.90-100.1 KΩ	99.8/9[2] KΩ	99.9/100.0[2] KΩ	100.0 KΩ
11	DMMCheck Plus	100 Ω	0.1%[1]	99.90-100.1 Ω	100.1/2[2] Ω	100.0/1[2] KΩ	100.2 Ω
12	DMMCheck Plus	1K Ω	0.1%[1]	999.0-1,001 Ω	0.999/100.0[2] KΩ	1.000/[2] KΩ	1.000/1[2] KΩ
13	DMMCheck Plus	10K Ω	0.1%[1]	9,990-10,010 Ω	9.98/9[2] KΩ	9.98/9[2] KΩ	10.00 KΩ
14	DMMCheck Plus	100K Ω	0.1%[1]	99.90-100.1 KΩ	99.8 KΩ	99.8/9[2] KΩ	100.0 KΩ

1. *DMMCheck and DMMCheck Plus values are ±0.1%, but the actual measured value is to ±0.001% as provided on the data sheet. I didn't get my numbers from the file because this is not meant to be a serious statistics-based data set.*
2. *These values are border line. When a digital display consistently alternates between two digits it is indicated with a slash. For purely computation purposes consider 0.96/7 as 0.965 splitting the difference. This value may also appear to be "out of specification." See Note (5). Installing two capacitors could possibly eliminate or greatly reduce these border line readings. See the next section.*

The data shows that the meter is well within specifications – see ***2.*** above and note (13). The problem with having decade standard values is that they are on the display boundary (so to speak) e.g. the display shows 100.0 and the low value may display as 9.99. You lose one digit of resolution. Suppose you use two sequential specification decade values in series? This adds 10% to the value. Doing this will eliminate the resolution digit loss issue, but will it add complexity to the analysis of the accuracy compliance. If two 0.01% resistors are connected in series their effective tolerance will not be 0.01%. One could be high and the other low. In this situation the errors will cancel. In general the effective tolerance of two equal tolerances will be less than the tolerance of the individual tolerances. See the data in Table 6. Now all checked values have the full resolution of the meter – a true 4 digits. There is nothing to be done about the borderline readings except to use a fixed procedure of accepting the high or the low value. This also raises the issue of how long do you wait until the display settles at least 10 seconds. Make the modification in note (5) to greatly reduce this problem. See appendix D for additional comments on using multiple resistors.

Table 6 – Shifting Decade Values 10% to Eliminate Loss of Resolution

#	Source	Value Ω	Tolerance	Range Ω	DMM 1/3	DMM 2/3	DMM 3/3
1	PRC Resistors	1KΩ + 100 Ω	0.01%	1,100.11-1,100.11 Ω	1.099 KΩ	1.098/9[1] KΩ	1.100 KΩ
2	PRC Resistors	10 + 1 K Ω	0.01%	10.9989-11.0011 KΩ	10.00 KΩ	1.098/9[1] KΩ	11.00/1[1] KΩ
3	PRC Resistors	100 + 10 K Ω	0.01%	109.989-110.011 KΩ	109.8/[1] KΩ	109.8 KΩ	109.9/110.0[1] KΩ
4	PRC Resistors	1 + 0.1 M Ω	0.01%	1.09989-1.10011 MΩ	1.110 MΩ	1.098/9[1] MΩ	1.101/2[1] MΩ

1. These values are border line. When a digital display consistently alternates between two digits it is indicated with a slash. For purely computation purposes consider 0.96/7 as 0.965 splitting the difference. This value may also appear to be "out of specification." See Note (5). Installing two filter capacitors could possibly eliminate or greatly reduce these border line readings. See the next section.

The data shows that the meter is well within specifications – see ***1.*** above and note (13).

I connected four precision resistors in series and recorded the values in Table 7.

Table 7 – Multiple Series Resistor Values

#	Source	Values Ω	Sum Value	Tolerance	DMM 1/3	DMM 2/3	DMM 3/3
1	PRC Resistors	1, 10,100, 1K Ω	1.111 KΩ	0.01%	1.110/1[1] KΩ	1.109/10[1] KΩ	1.1111 KΩ
2	PRC Resistors	10, 100, 1K, 10K Ω	11.11 KΩ	0.01%	11.09/10[1] KΩ	11.08/09[1] KΩ	11.11 KΩ
3	PRC Resistors	100, 1K, 10K, 100K Ω	111.1 KΩ	0.01%	110.8/0.9[1] KΩ	110.8/0.9[1] KΩ	111.0/.1[1] KΩ
4	PRC Resistors	1K, 10K, 100K, 1 M Ω	1.111 MΩ	0.01%	1.1100 MΩ	1.109 MΩ	1.1112 MΩ

1. These values are border line. When a digital display consistently alternates between two digits it is indicated with a slash. For purely computation purposes consider 0.96/7 as 0.965 splitting the difference. This value may also appear to be "out of specification." See Note (5). Installing two capacitors could possibly eliminate or greatly reduce these border line readings. See the next section.

The data shows that the meter is well within specifications – see ***1*** above and note (13).

Measuring the missing specifications

Table 1 on page 3 lists eleven "missing" DMM specifications. I used DMM 1/3 to measure the remaining two DMMs to arrive at the values in Table 8. I measured them using every method I could think of to be sure that I had the right value. The numbers are "rounded" to even industry standard values and this is not intended to provide detailed numbers for each DMM.

Table 8 – Measured Missing AN8009 DMM Specifications

1	DC mV loading resistance . . . .>100[1] MΩ	7	DC Amp range resistance (burden voltage) . 0.0667[1] Ω
2	DC voltage loading resistance. . . . . 10 MΩ	8	AC µA resistance (burden voltage) . . . . .100 Ω
3	AC mV loading resistance. . . . . >100[1] MΩ	9	AC mA resistance (burden voltage) . . . . 0.0809[3]Ω
4	AC voltage loading resistance. . . . . 10 MΩ	10	AC Amp range resistance (burden voltage). . 0.0809[3]Ω
5	DC µA resistance (burden voltage) . . . . 100 Ω	11	Ohm's voltage or constant current. . . . . The
6	DC mA resistance (burden voltage) . 0.0667[2]Ω		constant current is 0.02 µA to 85 µA. See tables 9 & 10.

1, - The input resistance is very high and prone to noise (especially 60 Hz) pick up.
2, - This seems like an unusual value. Ten averaged measurements from 0.605A to 1.993A were made.
3, - This also seems like an unusual value. I expected/hoped it to be the same as the DC values.

The resistors measured were the standards per Appendix B "F." Except the two highest values which were 1% values. Since these are decade values additionally shifted values were also measured to verify.

Table 9 – Constant Current Vs. Resistance Range

#	1/3 Measures	1/3 Reads	Range	3/3 Current µA
1	1 Ω	101.8 Ω	100 Ω	85.31 µA
2	10 Ω	110.8 Ω	100 Ω	85.24 µA
3	100 Ω	201.0 Ω	1 KΩ	84.61 µA
4	1K Ω	1.100 KΩ	10 KΩ	9.84 µA

#	1/3 Measures	1/3 Reads	Range	3/3 Current µA
5	1K + 10Ω	1.110 KΩ	10 KΩ	9.84 µA
6	10 KΩ	10 KΩ	10 KΩ	1.02 µA
7	10 K +10Ω	10.09 KΩ	100 KΩ	1.02 µA
8	100 KΩ	100.0 KΩ	1 MΩ	0.13 µA
9	100 K + 10Ω	1.000 KΩ	1 MΩ	0.13 µA
10	1 MΩ	1.000 MΩ	10 MΩ	0.12 µA
	1 M + 100 Ω	1.000 MΩ	10 MΩ	0.12 µA
11	10 MΩ	9.95 MΩ	10 MΩ	0.08 µA
12	94.7 MΩ	94.67 MΩ	100 MΩ	0.04 µA

The last two current measurements are at the extreme limits of the DMM and are certainly questionable. Table 10 summarizes the specifications to “round” numbers. Because the instrument is microprocessor based any value may be used. The rounded values just provide perspective.

Table 10 – Resistance Measurement Simplified Constant Current

#	Resistance Range	Constant Current	Rounded Values
1	100 – 1K	85 µA	100 µA
2	10K	9.81 µA	10 µA
3	100K – 1 M	1.02 µA	1 µA
4	10 M	0.08 µA	0.1 µA?:
5	100 M	0.04 µA	?

What was not measured?

The checking of capacitance, duty cycle, and temperature were not checked/verified because I don’t have “standards” for these parameters. Temperature may be checked using ice and boiling water using established procedures and correcting for your location (barometric pressure, altitude, etc.). Accurate capacitors[14] for a set of standard values are on my wish list.

Caution notice

While this DIY article provides parts and source details you should remember that modern sales methods (especially surplus sales or Chinese sourced) are such that parts are batched produced and there is no regular flow of products that may be the same in the future. The market changes rapidly. The details are for you to determine if your parts available at the time will work in a similar situation.

Observations and conclusions

The ANENG model AN8009 (≈$25) Digital Multimeter, DMM, is an excellent value because of its quality features of 9999 counts, typical 1% accuracy, and true RMS capability. Its large display, auto ranging, and small shirt pocket size makes it a joy to use. Three identical meters were measured, compared, and found to be within specifications using my 10x better accuracy standards. Eleven vital missing specifications e.g. input resistance etc. were determined along with methods (tables and curves) of compensating for DMM circuit loading. HP-48GX RPL programs for making the calculations involved are also documented. There are extensive references, tables, and photos covering the subject of DMMs that the article is worth reading just for a better understanding of DMM measurements. Knowing the “missing specifications” is vital to obtaining the most accurate and reasonable measurements possible.

I write this description for my own documentation. Perhaps I will inspire others who are interested in electronics measurements and applying them to achieve greater accuracy.

Appendices

Comments, suggestions, ideas, questions, corrections and article copy (by title) requests are welcome at: rjnelsoncf@cox.net Richard J. Nelson is a very common name and the "cf" differentiation is for Calcfan.

Richard J. Nelson

V1 May 12, 2018. V1A May 17, 2018, minor typos on pages 7 & 8 corrected, especially Reference to Fig. 3 which is Fig. 4. V2A, May 5, 2022, minor text changes, typos corrected, Notes and Appendices links checked and updated.

Notes for: Measuring the 2017 ANENG AN8009 DMM

*(1) I was born with an excessive "C" gene (C = curiosity). I ask myself all kinds of "useless" questions such as: How thick is the copper plating on a new penny, and how could I approximate/measure it without expensive formal instrumentation? Here is a quote from my May 2016 article Penny Measurements V1a: 12 pages, 17 figures, 5 tables, 13 notes, 6 links, and **1.7 MB** as a pdf file. "You may find most of the specifications of a US penny on the Internet, but I wanted to measure them for myself. What are the dimensions of a penny? How much does it weigh? What is its density? What metals are used? The penny is zinc, but the outside is obviously plated copper, but how much and how thick?" My interest stemmed from making a demonstration battery that uses easy-to-get pennies for the electrodes.*

*(2) See Wikipedia for a description of Segal's law. https://en.wikipedia.org/wiki/Segal%27s_law "A man with a watch knows what time it is. A man with two watches is never sure."[1] The same applies to DMMs. What about three or five? As of this version V2, mid 2020, I have added two more and one sold under another name **Zotek ZT111**. Again, the solution is not to depend on the DMM, but to depend on your standard which is carefully protected, and taken care of, to check your DMMs. I have well over 40 DMMs collected over 40 years, and a dozen different models of DMMs large and small. A couple are analog and well over 30 years old.*

(3) I have well over 30 of the FREE CEN-TECH 7 Function Multi-tester DMMs acquired over the last dozen or more years using Harbor Freight's FREE coupons. These have proven to be quite accurate based on my standards testing. I use them for general measurements and I don't worry about "popping" them if they get too close to a high voltage power supply. Once you have heard an SMT resistor "explode" you will know what the pop sound is. It is amazing how these DMMs have remained very stable in its design for such a long time. The current Harbor Freight website price is $5.99 (#90899). It has one negative feature. It does NOT automatically turn off. If you leave it on you will have a dead 9V battery in a couple of days. It has 200 mV DC, 200 µA DC, and 1 KV DC ranges which are quite useful. In addition to my testing, I use multiple DMMs in a circuit to accurately photo record multiple values. Fig. 3 page 6 is an example.

Fig. N1 - Harbor Freight Freebee.

(4), *DMM circuit loading for a voltage measurement may be represented as shown in Fig. N2. If R1 is 100 KΩ, and its voltage is being measured by an AN8009 DMM, the added 10 MΩ load in parallel will reduce the effective R1 value to 99,099.90 ohms. This is a reduction of 0.99%. If R2 is 1 MΩ and the 10 MΩ DMM is connected to it the resistance is reduced to 909,090.90 ohms. This is a reduction of 8.33%. The conventional rule of thumb of having the DMM loading resistance be at least 10x that of what you are measuring doesn't work if you seek 1% measurements. As this example shows measuring a 100 KΩ source with a 10 MΩ meter will reduce the correct value by 0.90%. This is OK. Remember this when measuring a 100K source or higher.*

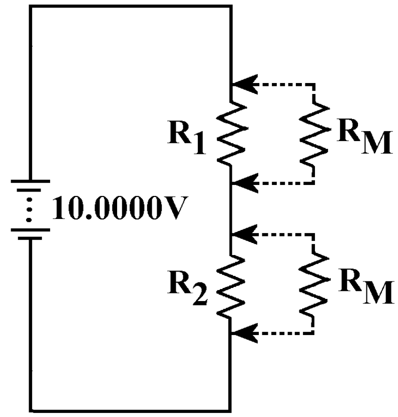


Fig. N2 – Added voltmeter resistance.

This example may also be used to visually demonstrate DMM loading error. For the readers convenience these formulas are provided in Fig. N3.

Ohm's Law & Power Formulas

R Resistance In Ohms	=	$\frac{E}{I}$	$\frac{E^2}{P}$	$\frac{P}{I^2}$
I Current In Amperes	=	$\frac{E}{R}$	$\sqrt{\frac{P}{R}}$	$\frac{P}{E}$
P Power In Watts	=	IE	$\frac{E^2}{R}$	I^2R
E Voltage (Electromotive Force) In Volts	=	$\frac{P}{I}$	IR	$\sqrt{PR}$

Fig. N3 - Ohm's Law & Power formulas.

The circuit of Fig. N2 is shown with the meters connected in Fig. N4. DMM 1/3 and 3/3 are both connected to R2. If the meters were ideal the values would be the same. They have a 5 mV difference. The difference is within the accuracy specifications. When you unplug 1/3 the value of 3/3 will increase. DMM 2/3 (R1) will also increase with the lighter load. DMM 1/3 may be added to R1 with similar results. The two DMMs (2/3 & 3/3) connected across the resistors become part of the circuit. When DMM 1/3 is added to make a measurement, you may dynamically see how it affects the circuit. You must know the "missing specifications" if you are going to make the most accurate measurements possible. Table N1 shows a few ratios, the amount of voltage reduction and a correction to apply. The ratio for the AN8009 is shown in yellow – entry #7. Note that the ratio values cover four orders of magnitude and that a logarithmic scale is used. Also note the diminishing returns (nearly vertical curve) above 10x. This is the basis for the DMM 10x rule. Achieving a true 1% accuracy (minimum loading) is a serious challenge and requires a quality instrument. You may, however, correct for the loading if you know the DMM loading resistance.

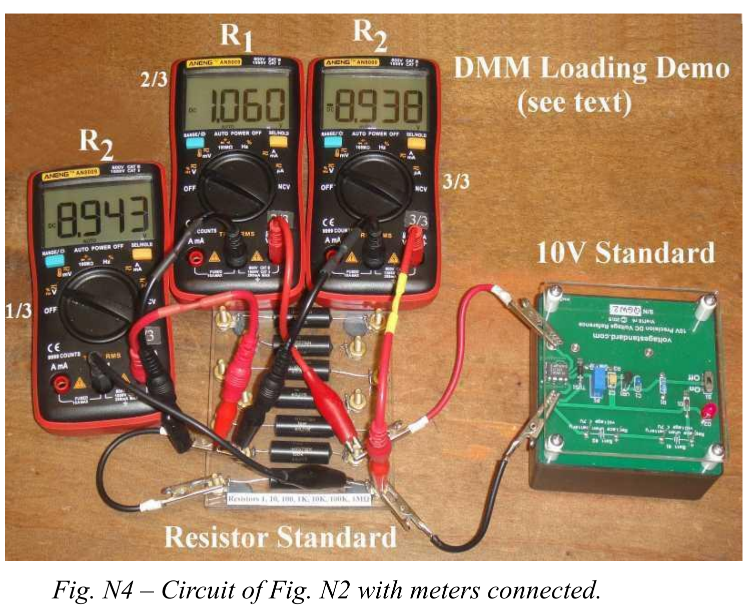


Fig. N4 – Circuit of Fig. N2 with meters connected.

Table N1 – Correction Factors for Volt Meter Loading

#	Meter-Circuit Resistance Ratio	Error (reduction)	Correction factor
1	0.1	-90.91%	11x
2	0.5	-66.67%	3x
3	1	-50%	2x
4	2	-33.34%	1.5000x
5	5	-16.67%	1.2000x
6	10 (very common)	-9.0909%	1.0999x
7	11	-8.33%	1.0909x
8	50	-1.96%	1.0200x
9	100	-0.990%	1.0100x
10	500	-0.1916%	1.0020x
11	1,000	-0.0998%	1.0010x

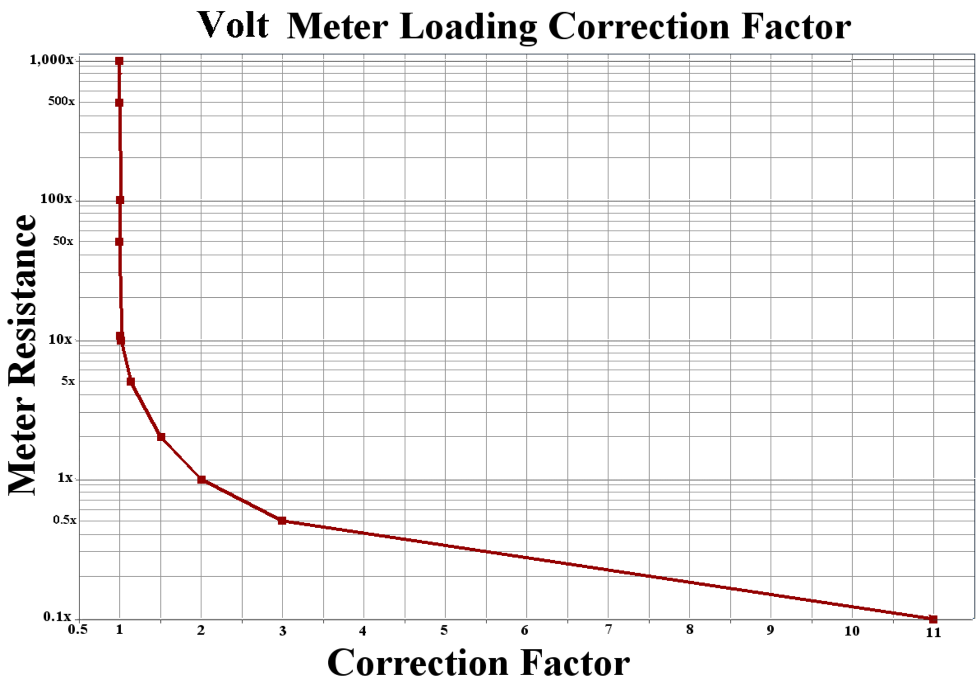


Fig. N5 – Voltmeter loading correction factor curve based on the meter resistance/circuit resistance ratio.

(5) *One AN8008 customer discovered that the electronics of the DMM causes/confuses the range search electronics resulting in a longer time to obtain a measured value. See: Improving the settling time of AN8008: https://www.jackenhack.com/aneng-an8008-modify-for-better-accuracy-faster-readings/*
Additional comments suggest that the AN8009 is similar so the fix also applies. The fix involves adding a low ESR filter capacitor to the circuit board to reduce noise on the 3 VDC rail. This is an easy fix for most electronicers [10] and is really worth the effort. One way to test/measure the response time is to connect a switch (using short "zero ohm" test leads and flipping the switch). Stopwatch measure the time for the display to change from O.L to 00.00. The auto ranging (and ADC measurement) time is just over ten seconds. Adding two capacitors as suggested at the link above will reduce the time to less than one second. This should also reduce the least significant digit flipping as well. I will make the modifications to my DMMs as soon as I get motivated.

(6) DMM circuit loading (burden) for a current measurement may be represented as shown in Fig. N6. The circuit must have power removed and broken in order to insert the meter. If the meter resistance is very small compared to the circuit, R_1, the meter loss is insignificant. The meter reading will always be too low because it reduces the current. Various decade circuit-meter resistance ratios are tabulated in Table N2. The ratio values are the same as of Table N1. Because it is a series circuit the ratios are the inverse and shown in column three.

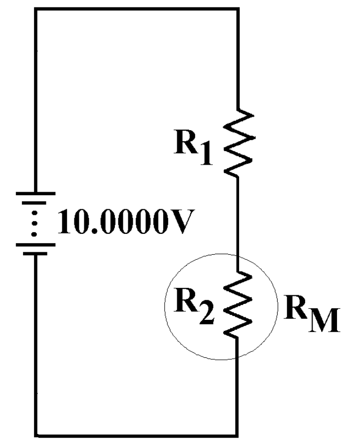


Fig. N6 - Added DMM current meter resistance.

Table N2 values are plotted as shown in Fig. N7. The curves are similar to the voltage loading errors and become small quickly above the 1/10th value. This is similar to the 10x rule for voltmeters except it is 1/10x.

Each meter resistor used has its issues. For current it is power dissipation. If the meter has 0.1 ohms as a current sense resistor it will dissipate 10 watts at ten amperes. A stable (low temperature high wattage resistor is expensive so most low cost DMMs "skimp" on their high current sense resistor and suggest in their Owner's Manual not to apply power longer than a specified time.

Table N2– Correction Factors for Current Meter Burden

#	Resistance-Meter Ratio (R1/R2)	Meter-Resistance Ratio (R2/R1)	Error (reduction)	Correction factor
1	0.1 (meter 10x ckt)	10	-99.0099%	100.9998x
2	0.5	2	-66.67%	3x
3	1	1	-50%	2x
4	2	.5	-20%	1.25x
5	5	0.2	-3.84615%	1.0400x
6	10	0.1 (meter 1/10th of ckt)	-0.99010%	1.0100x
7	50	0.02	-0.03998%	1.0004x
8	100	0.01	-0.0100%	1.0001x
9	500	0.002	-0.0004%	1.000004x
10	1,000	0.001	-0.0001%	1.0000010x

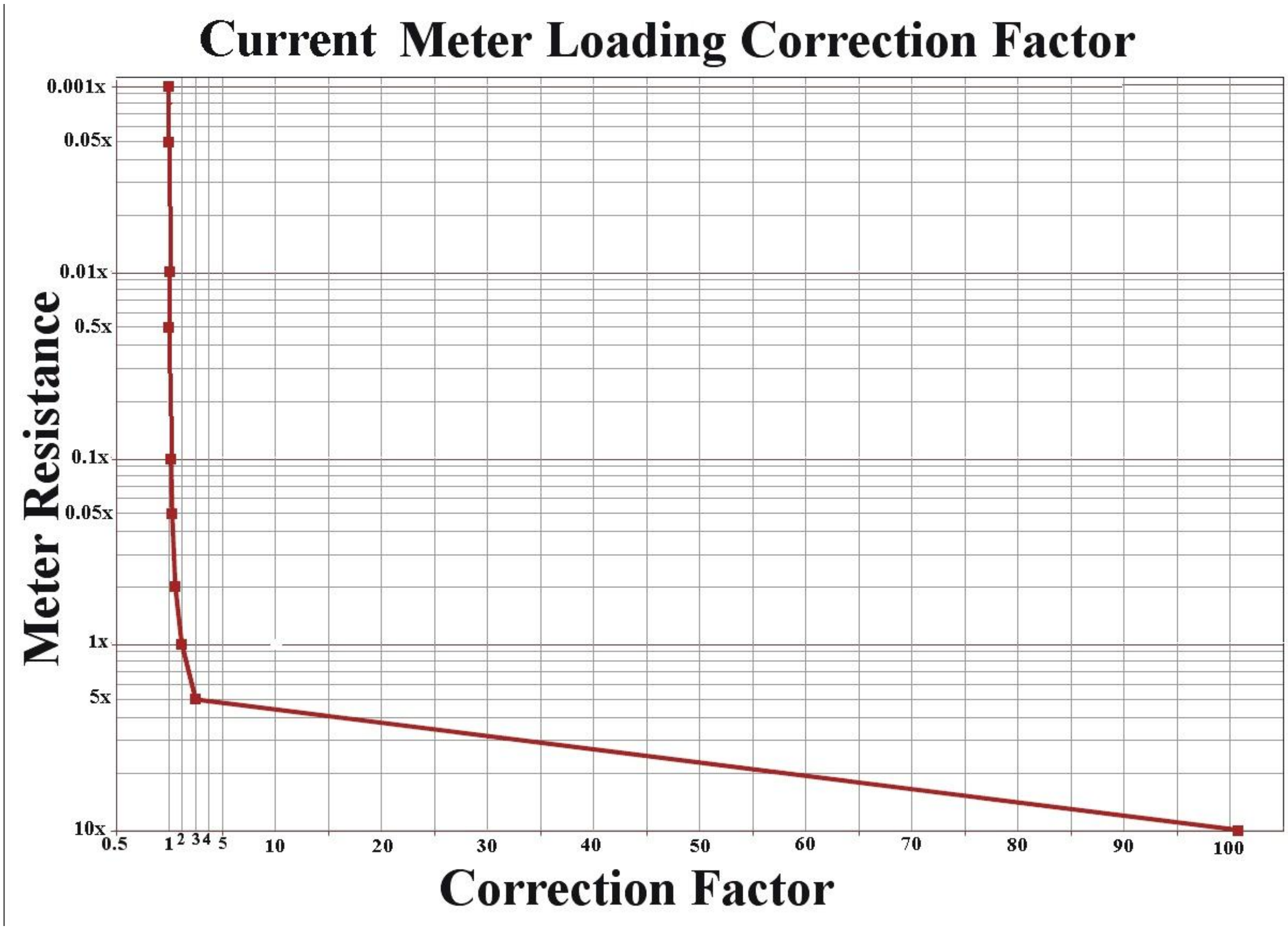


Fig. N7 – Current meter loading correction factor curve based on the meter resistance/circuit resistance ratio in Table N2.

(7) *See my December 2015 article titled* *<u>4-1/2 Digit 200 mV Panel Meter</u>, 10 pages, 11 figures, 4 notes, 1 Appendix, and* ***3 MB*** *as a pdf file. It describes how a low cost (<$20), very high input resistance (>100 MΩ) 200 millivolt meter specification is verified and used to get 5 digits (±15 PPM) of resolution. See Fig. 2. Page 2. A newer (and cheaper, $14.95) version is at: https://www.circuitspecialists.com/pm3028.html*

(8) *See my June 2011 article titled <u>Measuring Calculator Current</u>, 4 pages, 4 figures, and* ***300 KB*** *as a pdf file. It describes how switching between current ranges disrupts the operation of the calculator and the techniques used to avoid the issue. Also see my expanded article prepared for HHC 2012 titled <u>Measuring Calculator Current – Nine Measurement Examples</u>, 11 pages, 20 figures, 4 tables, 4 notes, and* ***1.7 GB*** *as a pdf file. This article describes a current measuring fixture with switches to avoid calculator disruption. It uses a very low cost (FREE) DMM. This articled references another calculator measuring article published in HPs calculator newsletter* ***HP Solve*** *#28, July 2012, titled <u>Measuring Calculator Current</u>, 6 pages, 9 figures, and* ***4.4 MB*** *as a pdf file.*

(9) *Measuring very high resistance values using higher voltages (≥100 VDC) introduces another factor in the measurement. What is the voltage coefficient of the resistance? A basic assumption that is usually made with most resistance measurements is that the resistance doesn't change with applied voltage. Of course too high a voltage may cause a breakdown of what is being tested e.g. checking the "resistance" of a 10VDC capacitor using 100 volts. You must know the "missing specifications" if you expect to get the best/correct results. If the ohmmeter causes (or is able to cause) 5 mA of current through the unknown you do not want to be testing 1 mA fuses with it. Inexperienced Technician: "I tested 20 fuses and they are all open." See a 1,000 VDC resistance meter in Appendix F, Fig. F3 and F4.*

(10) *Electronicer is a term for someone who works with electronics, hobbyist or professional. It may be an Electronics Engineer, an electronics hobbyist, or even a researcher. It is a general term not associated with experience, education, or professional achievement just interest. Experimenting with electronics seems to be*

fading as a hobby. See the link below for a perspective on this.
http://www.electronicdesign.com/archive/whatever-happened-electronics-hobbyist

(11) Having a manual range selection capability helps to reduce the number of display digits so the least significant changing digit(s) is not visible making the DMM do the "rounding" for you. This will reduce the display resolution and is undesirable. Controlling the displayed digits is also useful significant digit accuracy purposes. Also see note (5) for a fix.

(12) A stable AC voltage source is uncommon because the most common supply is the AC power line. AC power lines are very unstable. I have a digital voltmeter attached to my computer display, and I continuously monitor my AC line voltage. The lowest voltage I have seen is 118 volts, the highest 123 volts. This is a 4% change. I haven't recorded the fluctuations over 24 hours to determine the times for best stability. Checking the voltage with a standards-checked DMM isn't very practical using the power line as a source. The residential AC power line does offer the advantage of a nice sinusoidal wave form however.

(13) A digital meter has two specification values. Both must be applied to the measurement.
(1) A percentage of reading, and
(2) an additional number of counts to be added/subtracted to the least significant digit of the reading.

A four-digit display may only show one to four digits depending on the value being read, and the range of the meter. The fewer the digits the higher the error due to the counts part of the specification. Good measurement/checking techniques are to always try to provide the maximum number of digits of resolution.

Table N3 – Interpreting a DMM Accuracy Specification

#	*Specification*	*Display*	*% Range*	*Range with ± LSD counts[1]*
1	± 1 % +3	0.8	0.8 – 0.8	0.5 – 1.1
2	± 1 % +3	1.3	1.3 – 1.3	1.0 – 1.6
3	± 1 % +3	5.59	4.54 – 4.64	4.51 – 4.67
4	± 1 % +3	7.631	7.555 – 7.707	7.552 – 7.710

1, If the meter reading is within this range, it is within its specifications.

Suppose a resistor being measured is 1 ohm ±0.02%. This means that the actual value may be in the range of 0.9998 ohms to 1.0002 ohms. The DMM 8009 lowest resistance range (100 ohms) accuracy is specified as ±1% +3. The +3 is more accurately described as ±3 but is probably not shown that way to avoid confusion.

Since the displayed digits may be four digits or less depending on the range and value, the one ohm value is at the low end of the lowest range. Table 5 shows 0.96/7. The 6 and 7 slowly alternate. For accuracy and computational purposes we can consider it to be 0.96. Is this value incorrectly being read by the meter or is the resister "Out of Specification"? Let's assume that the resistor is just within specification and has an actual value of 0.9997 ohms. This is within its specified range and the meter reads this as 0.96 ohms.

The meter (Appendix A) has its specification as ±1% +3. This means that 0.96 ±1% is in the range of 0.95 ohms to 0.97 ohms (we can't use more digits just because the math provides them) MINUS the 3 least significant digits (counts). Because of the range and value, the meter is only able to show 0.96 ohms. Since this is the low side of the specification we subtract the 3 least significant digits from the low (-) percentage range for 0.92 to 0.94 ohms. Since both the resistors and the meter is "new" factory calibrated the specifications of both the meter, and the resistor being measured, the meter reading is correct and within specifications.

*(14) I explore capacitor measurement in my July 2015 V4 article titled Exploring Capacitors with the Mastech MY6013A Capacitance Meter, 24 pages, 27 figures, 9 tables, 9 notes, 12 links, 5 appendices, and **3.8 MB** as a pdf file. I mounted 11 capacitors to be used as reference capacitors. See Fig. N8.*

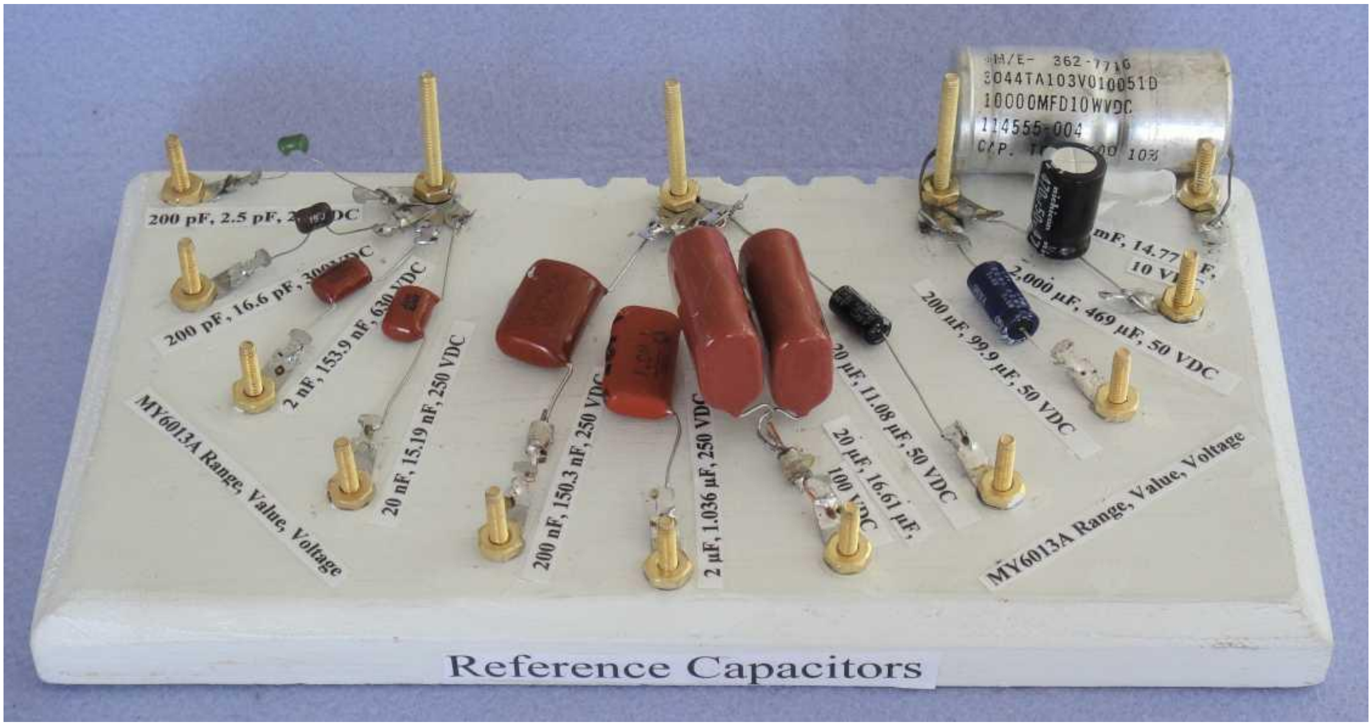


Fig. N8 – Various capacitors mounted to serve as reference capacitors for measurement and DMM checking purposes.

I also use a precision variable capacitor with graduated counting knobs – one is multi-turn. This provides 0.05 pF resolution of capacitance from 25 pF to 225 pF. See Fig. N9. This resolution is 0.20% on the low end and 0.022% on the high end.

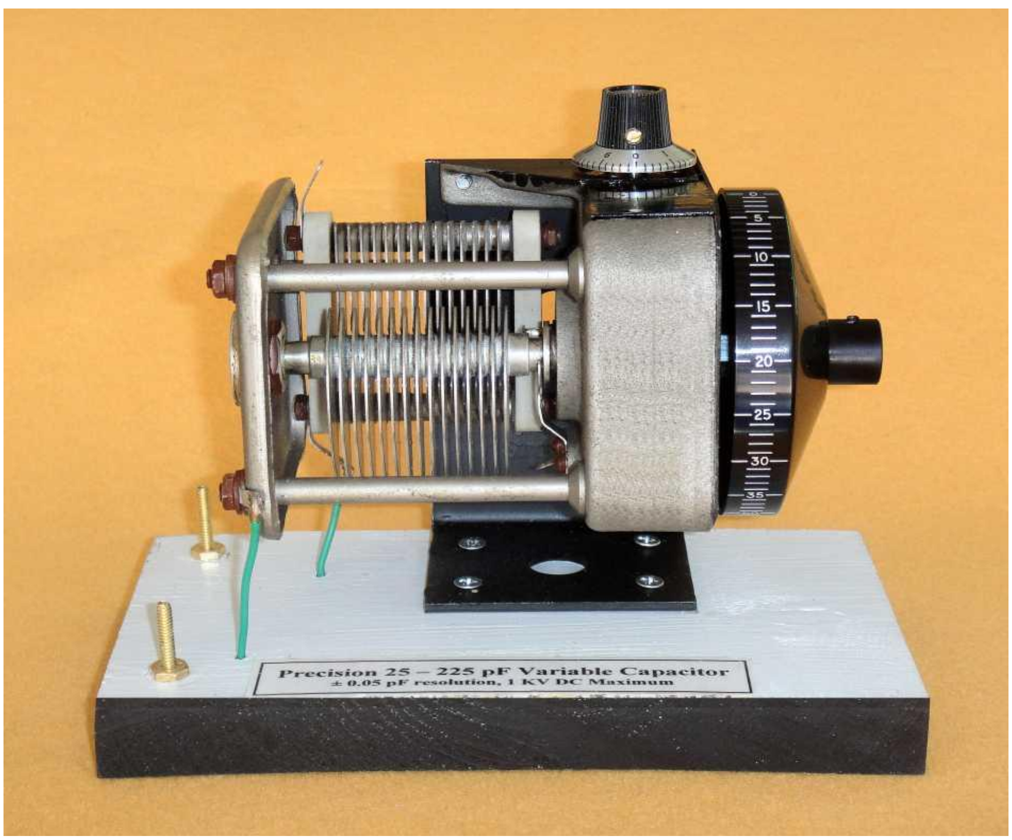


Fig. N9 - Capacitors like this were common 60 years ago. They are very hard to find and are very expensive today.

(15) If RPL program optimization is of interest to you see <u>*One-Minute Marvels*</u> *described as "One hundred simple*

programs and routines that each take only a minute to type in. Also includes tips for optimizing programs and has a programming challenge at the end. In Adobe PDF format." https://www.hpcalc.org/details/1691

*(16) See my August 2014 article titled Making an Electrical Connection V2, 28 pages, 67 figures, 6 tables, 16 notes, 4 links, and **3 MB** as a pdf file. I milliohm measure the connective resistance of 14 different common connectors (alligator clip, Fahnestock clip, No. 6 brass machine screw, etc.) to provide a perspective of the resistance added to a circuit by using them. A perspective of the milliohm and the power dissipated with higher currents (10A and higher) and what may be expected from switches, relays, MOS transistors, etc. is also provided. Fig. N10 below is an example (Fig. 8 taken from the article) of the many measurements made. Note that the difference is 88% from lowest to highest.*

Fig. 8a - Side normal. Resistance = 4.7 mΩ.

Fig. 8b - side normal deep. Resistance = 2.5 mΩ.

Fig. 8c – End normal. Resistance = 3.0 mΩ.

Fig. 8c – End deep. Resistance = 2.7 mΩ

Fig. N10 – Example of the added resistance of making an alligator clip connection - from the referenced article.

Fig. 39 in the article tabulates the results and is especially useful. There is very little technical data available on the venerable Fahnestock clip and an extensive (resistance measurement) nine page article is included as Appendix A. It documents the Fahnestock clip and provides details to identify a normal/quality version from the many cheap and nearly useless Chinese copies.

Appendix A – AN8009 Specifications - Page 1 of 4

Official AN8009 Specification. See Table l page 3. Where are the vital specifications?

▲ - Range values rounded up one LSD count. The red notations are mine for added clarity.

Function – switch rotation order	**Range▲ (highest value)**	**Resolution**	**Accuracy***	**MAX. Value**	**Other**
DC Voltage (V)	999.9mV **1V**	0.1mV	**DC Voltage ±(0.5%+3)**	999.9V	
	9.999V **10 V**	0.001V			
	99.99V **100 V**	0.01V			
	999.9V **1 KV**	0.1V			
DC Voltage (mV)	9.999mV **10 mV**	0.001mV		99.99mV	
	99.99mV **100 V**	0.01mV			
AC Voltage (V)	999.9mV **1 V**	0.1mV	**AC Voltage ±(1.0%+3)**	750V	40Hz-1kHz
	9.999V **10 V**	0.001V			
	99.99V **100 mV**	0.01V			
	750.0V **750V**	0.1V			
AC Voltage (mV)	9.999mV **10 mV**	0.001mV		99.99mV	
	99.99mV **100 mV**	0.01mV			
DC Current (mA&A)	999.9mA **1A**	0.1mA	**DC Current highest ±(1.0%+3)**	9.999A	
	9.999A **10 A**	0.001A			
DC Current (µA)	99.99µA **100 µA**	0.01µA	**DC Current lowest (µA)±(0.8%+3)**	999.9µA	
	999.9µA **1 mA**	0.1µA			
AC Current (mA&A)	999.9mA **1A**	0.1mA	**AC Current highest ±(1.2%+3)**	9.999A	40Hz-1kHz
	9.999A **10A**	0.001A			
AC Current (µA)	99.99µA **100 µA**	0.01µA	**AC Current lowest (µA)±(1.0%+3)**	999.9µA	
	999.9µA **1 mA**	0.1µA			
Resistance	99.99Ω **100 Ω**	0.01Ω	**Resistance lowest ±(1.0%+3)**	99.99MΩ	
	999.9Ω **1 KΩ**	0.1Ω	**Resistance ±(0.5%+3)**		
	9.999kΩ **10 KΩ**	0.001kΩ			
	99.99kΩ **100 KΩ**	0.01kΩ			
	999.9kΩ **1 MΩ**	0.1kΩ			
	9.999MΩ **10 MΩ**	0.001MΩ	**Resistance two highest ±(1.5%+3)**		
	99.99MΩ **100 MΩ**	0.01MΩ			
Function	Range	Resolution	Accuracy	MAX. Value	Other
Capacitance	9.999nF **10 nF**	0.001nF	**Capacitance lowest ±(5.0%+20)**	9.999mF	
	99.99nF **100 nF**	0.01nF	**Capacitance ±(2.0%+5)**		
	999.9nF **1 µF**	0.1nF			
	9.999µF **10 µF**	0.001µF			
	99.99µF **100 µF**	0.01µF			
	999.9µF **1 mF**	0.1µF			
	9.999mF **10 mF**	0.001mF	**Capacitance highest ±(5.0%+5)**		

Appendix A – AN8009 Specifications - Page 2 of 4

Function– switch rotation order	Range	Resolution	Accuracy*	MAX. Value	Other
Frequency	99.99Hz	0.01Hz	**Frequency ±(0.1%+2)**	9.999MHz	
	999.9Hz	0.1Hz			
	9.999kHz	0.001kHz			
	99.99kHz	0.01kHz			
	999.9kHz	0.1kHz			
	9.999MHz	0.001MHz			
Duty Cycle	1%~99%	0.1%	**Duty Cycle ±(0.1%+2)**		
Diode	√				
Continuity	√				
NCV	√				
Temperature	-20~1000℃	1℃	**Temperature ±(2.5%+5)**	1000℃	
	-4~1832℉	1℉		1832℉	

General Specifications	
LCD Display	9999 Counts
Ranging	Auto/ Manual
Material	ABS
Update Rate	3 Times/Second
Ture RMS	√
Back Light	√
Data Hold	√
Low Battery Alert	√
Auto Power Off	√
Mechanical Specifications	
Dimension	130 x 65 x 32mm
Weight	114g
Battery Type	2 x 1.5V AAA Batteries (NOT included)
Warranty	One year

Environmental Specifications		
Operating	Temperature	0~40℃
	Humidity	<75%
Storage	Temperature	-20~60℃
	Humidity	<80%

**** - The +N LSD count digits are ±N. Subtract N for the minus accuracy percent and add N for the plus accuracy percent to obtain the accuracy range the meter is specified to be reading*.**

Appendix A – AN8009 Specifications - Page 3 of 4

Studying the AN8009 specifications

Numeric prefixes

Electronics specifications use parameter numeric prefixes as shown in Table A1. Note that larger than one number prefixes use upper case letters, and smaller than one numbers use lower case prefixes.

Electronicers must be able to recognize and relate to millivolts, nanofarads, femtoamps, kilohertz, gigaohms, etc. and be comfortable converting one format e.g. 1,000µF = 1mF, to another.

Industry customs and marketing forces act to prefer one format over another. Battery capacity is an example. Battery capacity is usually expressed as 2100 mAh rather than a simpler format of 2.1 Ah. The 2100 number seems larger from a marketing perspective. This "inconsistency" is evident on the AN8009 Specifications of the previous two pages. Which provides greater clarity for you; 0.01V or 10 mV? Sometimes greater clarity is provided by violating a "standard" format and using what the reader more easily relates to. Effective commun-ication is no easy task.

Large amounts of data are not easy to work with and generalizing the values is helpful. Table A2 provides the basic specifications in a more compact format. I printed this on a small card that I keep on the shelf with the DMMs. One could make a good case for any format. A 200 mV panel meter is really a 4-1/2 Digit 999.99 mV panel meter. Are the 9s confusing?

Table A1 – Numeric Prefixes

Metric Prefix	Symbol	Multiplier (Traditional Notation)	Exponential	Description
Yotta	Y	1,000,000,000,000,000,000,000,000	10^{24}	Septillion
Zetta	Z	1,000,000,000,000,000,000,000	10^{21}	Sextillion
Exa	E	1,000,000,000,000,000,000	10^{18}	Quintillion
Peta	P	1,000,000,000,000,000	10^{15}	Quadrillion
Tera	T	1,000,000,000,000	10^{12}	Trillion
Giga	G	1,000,000,000	10^{9}	Billion
Mega	M	1,000,000	10^{6}	Million
kilo	k	1,000	10^{3}	Thousand
hecto	h	100	10^{2}	Hundred
deca	da	10	10^{1}	Ten
base	b	1	10^{0}	One
deci	d	1/10	10^{-1}	Tenth
centi	c	1/100	10^{-2}	Hundredth
milli	m	1/1,000	10^{-3}	Thousandth
micro	µ	1/1,000,000	10^{-6}	Millionth
nano	n	1/1,000,000,000	10^{-9}	Billionth
pico	p	1/1,000,000,000,000	10^{-12}	Trillionth
femto	f	1/1,000,000,000,000,000	10^{-15}	Quadrillionth
atto	a	1/1,000,000,000,000,000,000	10^{-18}	Quintillionth
zepto	z	1/1,000,000,000,000,000,000,000	10^{-21}	Sextillionth
yocto	y	1/1,000,000,000,000,000,000,000,000	10^{-24}	Septillionth

Table A2 – Condensed AN8009 Basic Function Specifications

#	Basic Function	Ranges*	Accuracy
1	DC Volts	10 mV to 1 Kv - 6	±(0.5% +3)
2	AC Volts	10 mV to 750V - 6	±(1.0% +3)
3	DC Amps	100 µa to 10 A - 4	Lowest two ±(0.8%+3) Highest two ±(1.0% +3)
4	AC Amps	Same as DC - 4	Lowest two ±(1.0% +3) Highest two ±(1.2% +3)
5	Resistance	100 Ω to 100 MΩ - 7	Lowest ±(1.0% +3) Middle four ±(0.5% +3) Highest two ±(1.5% +3)

** - Range values rounded up one least significant count for simplicity.*

Non-uniformity of specifications

Studying DMM specifications is very educational. Note that the voltage accuracy specification is uniform over six decades of range whereas current and resistance specifications are not. Why? The reason is that

some ranges degrade and are less accurate. There are only four decades of current measured. The highest two ranges is less accurate than the lowest two. What are the reasons for this? Component development technology plays a role. Production volume plays a role. Resistance covers seven decades. Wouldn't it be nice if all ranges had the same tolerance? Also note that the resistance tolerances tend to be less than the current tolerances. One observation is that resistance involves both voltage and current measurements and these two tolerances will be combined. Combining two equal tolerances will always result in less accurate values. Suppose both were high. Two ±1% accuracy specifications would be ±2% in this instance. If equal and one was plus and the other minus they would cancel. This gets more complicated with statistical math.

Is a 1% DMM reasonable?

If the AN8009 accuracy specifications are examined they range from ±(0.5% +3) [voltage] to ±(5.0% +20) [lowest capacitance]. Each parameter must be considered in the real world. To measure something, you must be able to isolate and define the parameter. Stray capacitance is undefinable and this will affect what the DMM actually "sees." Another factor that plays a role is the measurement method. The more factors that are involved the more difficult it is to make the measurement. Capacitors are more sensitive to their environment. The best (and very expensive) capacitor is probably glass used for the dielectric. Glass capacitors are the most reliable capacitors you can buy – if money is no object.

As new technology and measurement methods are developed (especially IC reference technology) the cost of a consumer true 1% DMM will come down. 1% resistors are now quite common and I can remember the days when the common tolerance was ±10%. Another issue is that when the tolerances decrease the number of manufactured values tends to increase. Much of the advancement will depend on what the market needs and technological development. The AN8009 is a very good step forward.

Maintaining standards is normally an expensive and time-consuming process and mostly not practical for most electronicers. Fortunately, recent developments of semiconductors provide us with some very reasonably priced options. Standards one decade more accurate than the DMM being checked are desirable. Fig. B1 shows the standards that I use.

Fig. B1 - AC & DC voltage, current & resistor standards (A – E) and DMM 1W standard resistors (F). See text.

The prices range from the lowest (A) $28 to less than $100 (B – F). Check the links below for the current pricing. The plastic cases for (B) – (E) are extra and are well worth the added (<$15) cost as they provide protection for a long life. All but (F) are from Malone Electronics. The seven decades of higher power (4x – 1/4 W vs. 1W) resistors from 1Ω to 1MΩ expand on the resistors provided by (D) and (E). These are ±0.01% accurate, low inductance, 5 ppm temperature Coefficient, TC, and they are also used for more than just standard resistors to expand the voltage and current ranges of the other standards. I mounted them on a plastic base for easy and robust series and parallel connections. See page 3 of this Appendix.

The details for each standard are listed below.

A – Malone Electronics of Battle Ground Washington, model **VREF-01**, https://voltagestandard.com/shop/ols/products/vref0-1 offers this low cost self-contained voltage standard at 5.000V ±0.01%. As of this writing, V2a, the cost is $31.00. This is a single voltage – you have an order choice of six voltages: 2.048V, 2.500V, 3.000V, 4.096V, 4.500V, and 5.000V. The specification is met if used within ± 14°F of the calibration temperature (provided with documentation, usually 21°C or 68.8°F). What is great about this website is the honest technical information it provides. Sources for his components are given and even articles that describe the history and development of the unique IC and mechanical packaging/circuit board used. You could "do it yourself" if you wanted. You will spend much more time and money even if you have a great deal of experience and skill.

B - Malone Electronics of Battle Ground Washington, model **VREF-003** Precision DC Voltage Reference, (V2A Note: this has been discontinued) offers this self-contained 10VDC ±0.003% DC voltage reference. It uses two 9V alkaline batteries. As of this writing the cost is $53.00 plus $14.50 for the optional case. It will supply 10 mA of test current. See voltage standard website for even better standards.

C – Malone Electronics of Battle Ground Washington, model **PentaRef**, https://voltagestandard.com/shop/ols/products/pentaref offers five selectable voltages of your choice – 0.10V to 10.0V. I chose 0.1500V for my millivolt panel meter, and 2.0000, 4.0000, 8.0000, & 10.0000 Volts. The maximum load current is 1 mA. (10KΩ load). Most DMMS are 1MΩ plus. As of this writing the cost is $86.00 plus $14.50 for the optional case, but is currently out of stock.

D - Malone Electronics of Battle Ground Washington, model **DMMCheck**, https://dmmcheckplus.com/is no longer available. See the link for all the technical details.

E – Spinoff business.model **DMMCheck Plus**, http://www.voltagestandard.com/DMMCheck_Plus.html **This is just what is needed for general use.** It is the best DMM standard and its cost is very reasonable. Please let me know if you find anything even close in features and value. It was discontinued and the website recently offered another batch which – of course – sold out quickly. See the link for the substantial list of features and specifications. I ordered the option of a second AC frequency of 1 KHz in addition to 100 Hz. I also ordered the more stable resistors.

F – PRC Resistor Company of Largo Florida offers a special group of Axial Ultra Precision DMM calibrator resistors, http://www.precisionresistor.com/Digital-Multimeter-Calibrator/ for $77.00 at the time of this writing. You may pay extra for a burn-in to further stabilize the resistors. I wish I had done that because I keep using them for all kinds of measurements and tests. This is not a big seller for PRC and you should call for the current pricing and availability.

I mounted them for general use and you may find a description in my December 2017 article titled Mounting "Standard" Resistors, 4 pages, 4 photos, 1 table, 1 Appendix, and **1.1 MB** as a pdf file. Fig. 4 shows an AN8008 being checked is reproduced as Fig. B2. It was, display wise, dead on.

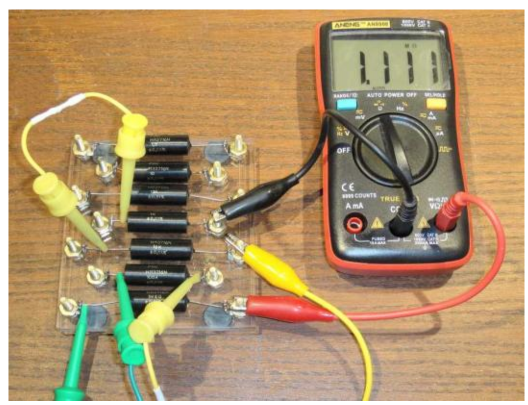


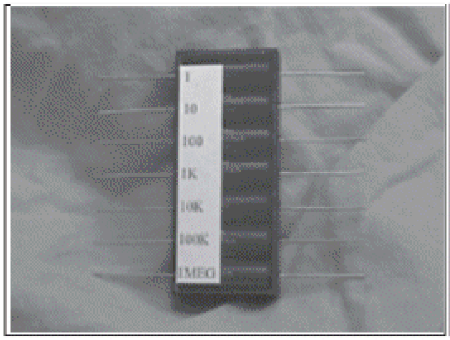
Fig. B2 – Resistor "standards" shown in use. Highest four in series. The"new" 9999 count AN8008 agrees.

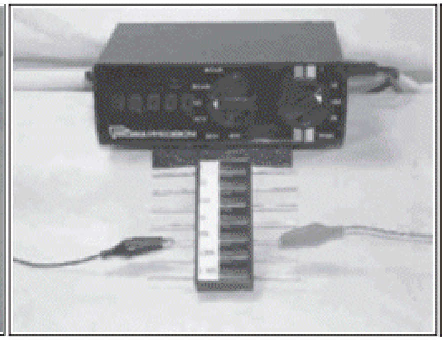
See the next page for all the resistor technical details. The low inductance, high accuracy, temperature stable, and time stable characteristics make these an excellent home brew "standard."

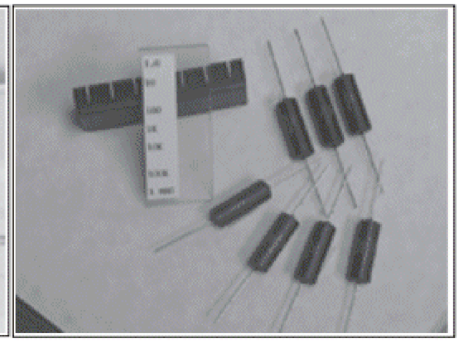
PRC

DIGITAL MULTIMETER CALIBRATOR

The MC-7 Digital Multimeter Calibrator is a packaged group of seven (7) High-Precision resistors part # HR3716N, with ohmic values ranging from 1.0Ω to 1Megohm - used in the verification and adjustment of the resistance function of 3½ and 4½ digital multimeters. To your advantage, the MC-7 is always in-stock … ready for delivery.







FOR YOUR CONVENIENCE

The seven (7) resistors are contained in a plastic case with the leads extending through the sides - ready to go to work.

ENGINEERING DATA:

STABILITY

To ±0.001% / yr. @ 25°C. (with no load).

POWER VS. AMBIENT TEMP.

All Ultra resistors are designed for full load based upon ±1% res. tol. - providing the ambient temp. - plus the temp. rise due to self-heating does not exceed +125°C. Derated to zero power at +145°C. see Fig. 1.

THERMAL EMF VS.COPPER TERMINALS

< ±3 microvolts per degree C.

PROTECTIVE SEAL

Stress free base coat and epoxy case. Solder heat and solvent resistant.

INDUCTANCE

Non-inductive balanced reverse pi windings are standard on HR and RX. Special on HVS & HVA.

MARKING (Identification)

PRC symbol, type, value and tolerance.

VALUES & TOLERANCES

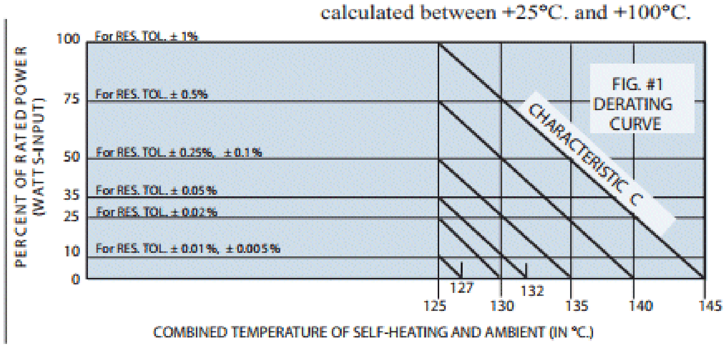
1Ω	0.02%
10Ω	0.02%
100Ω	0.01%
1KΩ	0.01%
10KΩ	0.01%
100KΩ	0.01%
1MEGΩ	0.01%

HR3716N PHYSICAL SPECS:

Length .... 25.40mm (1.00”)
Diameter .... 9.53mm (.375”)
Leads .... 0.032” dai X 1.0” long
Max Power.... 1.0 Watt @ 1% Tolerance
Max Voltage..... 600 Volts

TCR CHARACTERISTIC

Standard: 0±5ppm/°C (100Ω and above); 0±15ppm/°C. (values below 100Ω) - calculated between +25°C. and +100°C.



PRC
ISSUE NO. 42

PRECISION RESISTOR CO., INC.
10601 75TH Street North, Largo, Florida 33777-1421 U.S.A.
Tel: 727-541-5771 Fax: 727-546-9515
Email: sales@precisionresistor.com
Web Site: http://www.precisionresistor.com

When I ordered my first AN8008 mid last year I received two sets of test leads. The normal 30 inch probe-banana terminated test leads and a second unusual 36 inch "universal" test leads. See Fig. C1 at the right. The 36 inch wire has a female threaded connector on each end. The threads are metric and slightly larger than the US N0. 4 in size. Five terminations are included and may be seen in the card packaging.

Fig. C1 – Unusual extra set of test leads I call "universal."

Standard

If you wanted a second "standard" set of test leads you would screw in the long probes (Fig C2 "A") in one end and two banana plugs (Fig C2 "B") in the other end.

Banana-banana plugs

There are four banana plug (Fig C2 "B") terminations so a meter could be nicely plugged into a power supply or another meter.

Spade terminals

The spade terminals (Fig C2 "E") allow you to connect the test leads to a terminal block. If you are monitoring the voltage for an hour every few hours you simply leave the spade terminals connected and you unscrew the test lead and connect something else to be used between monitoring sessions.

Short probes

Normal long probes (Fig C2 "A") may be cumbersome in space-tight locations and a shorter probe (Fig C2 "F") is available for each of the two leads.

Alligator clips

There are four alligator clips (Fig C2 "C" & "D") provided because it is common to have them on both ends for general "clip lead" use. You may use banana plugs on one end and alligator clips on the other end to connect the meter to two points in the circuit.

Fig C2 – Shortened (6") Universal test leads. See Text.

The packaging I received with the AN8009 is slightly different as Fig C1 shows. Functionally they are the same. This is a very nice set of test leads and since I have six ANENG meters I have six of these. I also have two sets of banana-alligator test leads that were provided with capacitance meters and I use them all the time so I decided to cut the 36"

universal test leads and make six sets 6" long. These are seen in use in the photos taken for this article.

I didn't have the right size red and black heat shrink tubing so I used yellow. I keep the universal test lead parts in boxes as shown in Fig. C2 on the previous page. It is easy for such small parts to get lost or misplaced.

My only complaint is the test lead wire itself; the insulation is OK. As with most Chinese consumer wires the size is skimpy and too small. From an engineering perspective skimping on copper results in decreased reliability, excessive heat, and reduced performance. Since I cut my universal test lead wires I had lengths to measure. 12" of wire measures 16.84 mV with 1 ampere flowing. This corresponds to AWG 22 of 16.14 milliohms per foot. Normal 30" (2.5 feet times two) test leads would add 0.081 ohms just for the wire.

With a lowest resistance indication on the 100Ω range of 0.01 ohms this would show up in the low resistance measurement. Of course, friction contact of the banana plugs, and internal wiring (fuse, etc.) would add to this. Actual measurement of the shorted standard test leads is 1.74 ohms. Two six-inch leads indicate 00.00 ohms. I used the AN8009 to test my shortened universal test leads as shown in Fig. C3. Zero is good.

Making a set of short leads is justified to reduce clutter and increase measurement accuracy.

If the Universal test leads were 20 or 18 Ga. they would be first class. The real test would be to short the probe ends (I use soldered back to back Fahnestock clips or two pin jacks soldered back to back)[16] to measure the test leads. See Fig. C4 and C5. Just holding them together is not accurate and it is just silly to believe otherwise.

Fig. C3 - Testing 6" universal test leads.

Note the test lead points in Fig. C4. The small "notch" near the tip is for micrograbber connections. I did not measure the regular test lead wire (gauge) as I assume that they are of the same type wire.

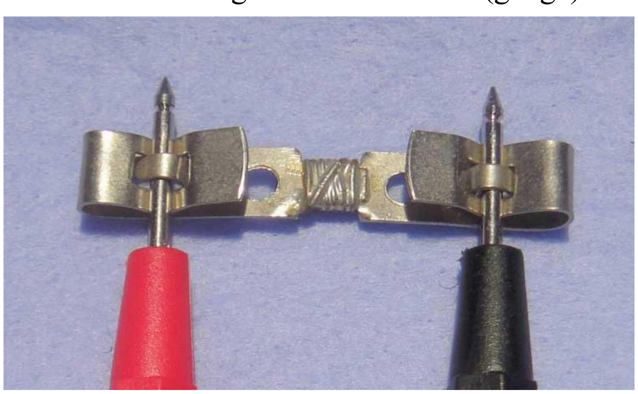


Fig. C4 – Use proper connection method to measure shorted test probes and measure lead resistance. [16]

Fig. C5 – Back-to-back pin jacks are the best for shorted test lead resistance measurement.

Appendix D – Extending the DMM Standards - Page 1 of 2

Once you have a suitable voltage standard you may use it for other voltages by dividing the standard down. For example the 10V VREF-003 may be used with **precision decade resistors** for other voltages.

The maximum load is 10 mA. This means that no lower than 1,000 ohms should be connected to the standard.

If you connect the Appendix B “F” -10K and 1K in series the 10.000 volts will cause 0.0009090909 A to flow with the 1K voltage at 0.9090901 volts and the 10K voltage at 9.090909 volts. Use the appropriate loading correction factor.

Various combinations of these seven resistors can provide many sub 10 volt voltages down to tens of microvolts.

These seven resistors may be connected in series with the five- or ten-volt standard to deliver a wide range of DC currents as well.

Table D1 – Multiple Series Connected Resistor Values with AN8009 Values

#	Source	Values Ω	Sum Value	Tolerance	DMM 1/3	DMM 2/3	DMM 3/3
1	PRC Resistors	1, 10,100, 1K Ω	1.111 KΩ	0.01%	1.110/1[1] KΩ	1.109/10[1] KΩ	1.1111 KΩ
2	PRC Resistors	10, 100, 1K, 10K Ω	11.11 KΩ	0.01%	11.09/10[1] KΩ	11.08/09[1] KΩ	11.11 KΩ
3	PRC Resistors	100, 1K, 10K, 100K Ω	111.1 KΩ	0.01%	110.8/0.9[1] KΩ	110.8/0.9[1] KΩ	111.0/.1[1] KΩ
4	PRC Resistors	1K, 10K, 100K, 1 M Ω	1.111 MΩ	0.01%	1.110 MΩ	1.109 MΩ	1.111 MΩ

1. These values are border line. When a digital display consistently alternates between two digits it is indicated with a slash.

Fig. D1 – Shows microampere and microvolt values being checked with a voltage standard and standard resistors. Resistance is 1,000,011 ohms. The current is 10/1,000,011 = 9.9998 micro-amperes. The meter shows 9.97 microamperes. The voltage across the 1 ohm resistor should be 9.99 microvolts. The meter shows 10 microvolts.

Typically you check the ranges being measured at the time and not all possible values for the DMM. You should make a table of the DMM specifications so you will have it handy when you need it. Do this for all of your test gear.

Table D1 only provides the basics for using the standard resistors with the voltage standard.

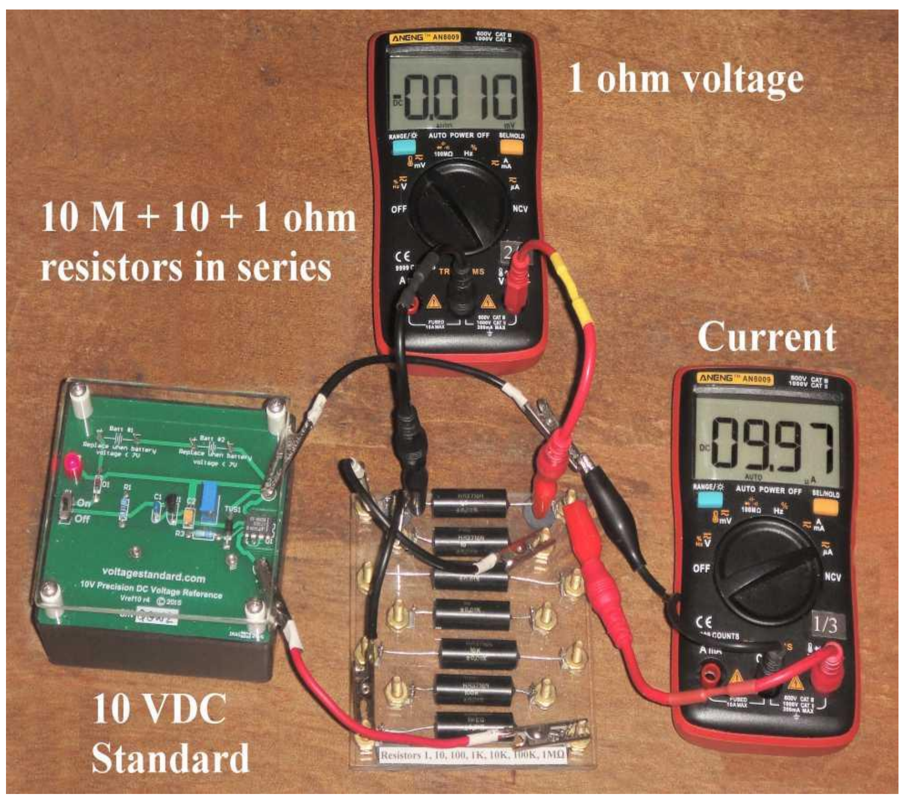


Fig. D1 – Checking low voltage and current.

Appendix D – Extending the DMM Standards - Page 2 of 2

What about higher voltages? A very useful decade divider is ten equal resistors selected to be as close to being equal as possible. I will send several articles on these precision dividers if the reader is interested. The specific value is not as important as their equality – measured within small parts per million – 15 PPM is 0.0015%. See note (7) and the last paragraph for a low cost suggestion for doing this.

Another “standards” item is a **stable DC power supply**. It should not change voltage to the nearest millivolt over a minute after warm up. Most variable bench power supplies won’t even allow a knob adjustment to the nearest millivolt (sub millivolt is better).

See my June 2014 article (V3) titled Circuit Specialists PS-28 3-12 V, 2 A Power Supply, 8 pages, 13 figures, 3 tables, 8 notes, 4 links, and **1.3 MB** as a PDF file. This is a remarkably stable low cost power supply.

How do you increase the voltage for the higher DMM ranges? Use the decade voltage divider “backwards.” Check you DMM at ten volts or slightly lower for full resolution. Adjust the stable power supply at the top of the decade voltage divider until 1/10 voltage is 10.000 volts. The power supply is now at 100 volts. You then have voltages every ten volts (or some other voltages) from 10 to 100 volts. You must allow for the divider currents that flow and temperature rise. High power voltage dividers are desirable for greater flexibility.

Alternately you may get close in voltage and use the ten volts standard “back to back” (polarity opposing) with the bottom resistor until there is zero voltage difference. Now you have the divider calibrated the best possible way. A home brew divider can be within ± 0.002%.

Using a **stable variable voltage power supply**, **standard resistors,** and a **quality decade voltage divider,** you may get to any voltage or current you need using a single 5V or 10V standard.

See my December 2015 article 4-1/2 Digit 200 mV Panel Meter, 10 pages, 13 figures, 2 tables, 1 link, 4 notes, 2 Appendices, and **1.3 MB as a PDF file.** This low cost meter (<$20) has a verified input resistance >100 MΩ. A future project is a multi-100 MΩ resistance reference to attempt to measure the value more closely. Preliminary tests indicate >200 MΩ. If used in the upper range of 100.00 mV to 199.99 mV **five digits of resolution are possible.** This is especially (low cost) suitable for grading resistors for high resolution of equality for voltage dividers.

Appendix E – Convenient DMM Math Calculations - Page 1 of 1

When you have a lot of data as is described in this article you often need to make calculations related to parallel resistors, percentage changes, correction factors, and specification tolerance ranges. While the math is not complicated or difficult, the wide range of electronics values from microvolts to mega ohms will provide many opportunities for “decimal point” location “errors.”

I use an HP-48GX calculator for most of my simple electronics calculations. Having a few short simple programs makes these calculations fun, quick, accurate, and easy. The HP-48 uses RPL programming and is a high end legacy graphing calculator. If the reader uses an RPL calculator the following five programs may be useful[(15).]

The ↑ symbol is ENTER. The ⇛ symbol is Produces/calculates. The # numbers are program check sums.

1 Parallel Resistors, R_T. Calculates effective resistance of two parallel connected resistors R_1 & R_2.

Input: R_1 ↑ R_2 ⇛ R_T

‘RT’ << * LASTARG + / >> *Example: 200 ↑ 300 ⇛ 120.* #A0$_h$, 20 Bytes

2 Parallel Resistors, R_1. Calculates parallel resistor, R_1 given Total resistance, R_T, and R_2.

Input: R_T ↑ R_2 ⇛ R_1

‘R1’ << * LASTARG - / ABS >> *Example: 120 ↑ 200 ⇛ 300* #8F95$_h$, 22.5 Bytes

3 % Change. Calculates the percent difference of two numbers. Inputs in any order. **This is VERY handy.**

Input: N1 ↑ N2 ⇛ two percentages, plus and minus (minus always on bottom of stack).

‘D%’ << %CH LASTARG SWAP MAX LASTARG MIN >> # DDBC$_h$, 27.5 Bytes

Percentage problems always have two answers. This routine provides both, no thinking required.

Example: 4 ↑ 5 or 5 ↑ 4 ⇛ 25, -20

4 ± % Range. Calculates the range of valuess given the percentage tolerance.

Input: value ↑ % ⇛ Returns three numbers on the stack. Top down: Low value, Input, High value.

‘RNG’ << 1 % OVER * OVER + LASTARG SWAP – ROT ROT >> # CECE$_h$, 37.5 Bytes

Example: 7.653 ↑ 0.8% ⇛ 7.714, 7.653, 7.592

5 Correction Factor. When a value is reduced by a percentage you may apply a correction factor to bring it back to the original value.

Input: % reduction ⇛ A number greater than one to multiply the reduced value to get the pre-reduced value.

‘COR’ << 100 OVER - / 1 + >> #316F$_h$, 33.0 Bytes

Example: 5% ⇛ 1.01375667812. If 200 is reduced 5% it becomes 190. Multiply 190 by the correction factor to get the original value. This is used to correct for the DMM resistive loading from the value it displays.

Appendix F – Quick Check DMM DC Voltage Loading - Page 1 of 1

Measuring the input resistance, **R_M**, of the AN8009 DC Voltage function may be done several ways. As mentioned in the text different methods could produce differing results. Which result do you believe? Experience and judgement are your best tools to conclude which is more accurate or correct.

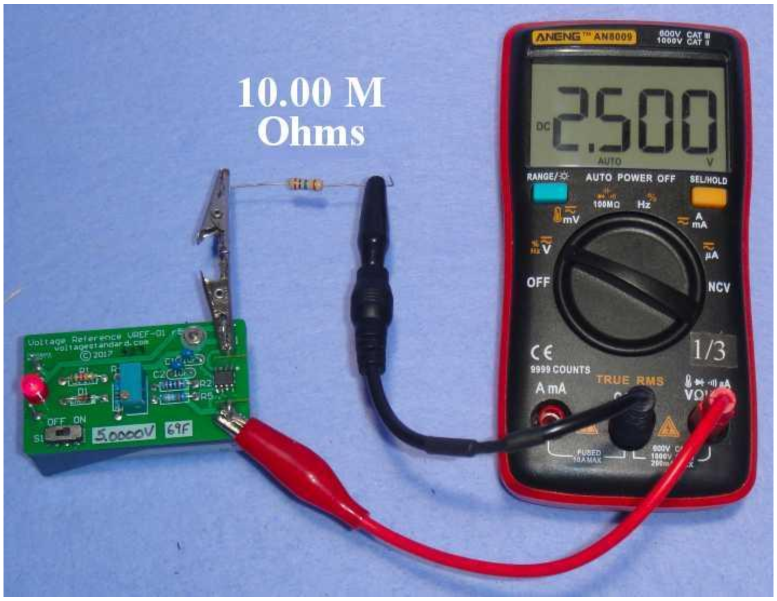


Fig. F1 - 10 MΩ resistor divides 5.000V in half. R_M is 10 MΩ.

Fig. F2 – DMM says R_M is 11 MΩ. ??

Using the half voltage method the AN8009 DC voltage **R_M** is 10 MΩ. Directly measuring with another AN8009 the input is 11 MΩ which is also a common DMM design value. See Fig. F2. Which do you believe? Examine the other two examples below. These results are correct. What is wrong with the Fig. F2 measurement? Could it be that the meters are interfering with each other? 11M Ω vs. 10 MΩ is a 10% error.

Fig. F3—This meter measures a correct (≈low) 10 MΩ R_M.

Fig. F4 -The freebee DMM is measured correctly.

In general, the results are always a bit questionable when one meter directly measures another, especially with instruments using the more sophisticated IC designs. The devil is in the details. The large green ohmmeter in Fig. F3 and F4 is a WinsPEAK model VC60B+ which uses 250. 500, and 1,000 volts DC. You learn about resistor voltage sensitivity when you use this meter. You must be careful about over stressing your device under test however.

HHC2025 Appendix E – **Checking the ANENG AN 870 DMM with the DMMCheck Plus V1a**

Richard J. Nelson

Introduction

Shortly after I received the latest version of the DMMCheck Plus[1] (including dual frequency and the L/C board) I decided to try it out by checking a 4.5-digit DMM, the ANENG AN870. The AN870 is a 19,999 count instrument with good accuracy specifications for about $30. See Fig. 2.

Keep in mind that the accuracy % value is then further adjusted ± by the counts. The best specification is for all DC voltages (± 0.05% & ± 3 counts), and the worst specification is for the 199.99 nF capacitance range (±5% & ± 20 counts).

Measuring the DMMCheck Plus

The DMMCheck Plus has function specifications that are 10x better (or more) than most DMMs[2]. See Fig. 2 for the AN870 accuracy specifications.

I checked the functions in the same order as shown on the Certificate in Appendix A. These values will be accepted as true values and used for the Error calculations in Table 1. See note 3 for additional details. On the dual specification implications

Fig. 1 –New AN870 DMM is Typical (larger) size.

Function	Range	Accuracy
DC Voltage	19.999mV/199.99mV/1.9999V/19.999V/199.99V/1000V	±(0.05%+ 3)
AC Voltage	19.999mV/199.99mV/1.9999V/19.999V/199.99V/750V	±(0.3%+ 3)
DC Current	1.9999A /19.999A / 19.999mA /199.99mA /99.99μA /1999.9μA	±(0.5%+3)
AC Current	1.9999A /19.999A / 19.999mA /199.99mA /99.99μA /1999.9μA	±(0.8%+3)
Resistance	199.99Ω	±(0.5%+3)
	1.9999kΩ/19.999kΩ/199.99kΩ	±(0.2%+3)
	1.9999MΩ/19.999MΩ	±(1.0%+3)
	199.99MΩ	±(5.0%+5)
Capacitance	9.999nF	±(5.0%+20)
	99.99nF/999.9nF/9.999uF/99.99uF/999.9uF	±(2.0%+5)
	9.999mF	±(5.0%+5)
Frequency	99.99Hz/ 999.9Hz/ 9.999kHz/ 99.99kHz/ 999.9kHz/ 9.999MHz	±(1.0%+2)
Duty Cycle	1%~99%	±(1.0%+2)

Fig. 2 – ANENG AN870 4.5 digit, 19999 count DMM basic accuracy specifications.

I had received the two instruments at the same time and I used this exercise as an opportunity to become familiar with both of them at the same time.

Normally a DMM has additional measurements to check other voltages and currents. These utilize a precision decade resistive divider and a millivolt stable variable power supply.

Table 1 – AN870 Measured Data

#	Standard	870 Measures[a]	Accuracy[3]	Certificate	Error[b]	Pass
1	**DC Voltage**	—	—	—	—	—
2	5 VDC	5.001 V	0.05% +3	5.0000 V	+0.02%	YES
3	**AC Voltage**	—	—	—	—	—
4	5 V RMS$_{120\ Hz}$	4.965 V	0.3% +3	4.992 V	-0.54%	**NO**
5	**DC Current**	—	—	—	—	—
6	1 Ma	1.0016 Ma	0.5% +3	1.0003 Ma	+0.13%	YES
7	1 Ma, 100Ω ±0.01% (extra Check)	100.09 mV = 1.0009 Ma	0.5% +3	1.0003 Ma	+0.06%	YES
8	**AC Current**	—	—	—	—	—
9	1 Ma$_{120\ Hz}$	0.9942 Ma	0.8% +3	1.001 Ma	-0.68%	YES
10	**Frequency #1,2**	—	—	—	—	—
11	120 Hz	120.03 Hz	1.0% +2	120.0433 Hz	-0.011%	YES
12	1,000 HZ	1,000.0 Hz	1.0% +2	1,000.081 Hz	-0.008%	YES
13	**Duty Cycle, #1,2**	—	—	—	—	—
14	120 Hz	50.0%	1.0% +2	50.018%	+0.036%	YES
15	1,000 HZ	50.1%	1.0% +2	49.980%	+0.240%	YES
16	**Resistance**	—	—	—	—	—
17	100 Ω	99.94 Ω	0.5% +3	99.938	-0.00200	YES
18	1 K Ω	1,000.5 Ω	0.2% +3	1,000.6	+0.01%	YES
19	10 K Ω	10.003 KΩ	0.2% +3	10.0047 KΩ	-0.0170%	YES
20	100 K Ω	100.04 KΩ	0.2% +3	100.051 KΩ	-0.011%	YES
21	111.1 KΩ (sum)	111.14 KΩ	0.2% +3	111.143.5[c]	-0.0027%	YES
22	**Capacitance**	—	—	—	—	—
23	0.001 µF (1 nF)	0.964 nF	5% +2	0.972 nF	-0.823%	YES
24	0.01 µF (10 nF)	10.44 nF	2.0% + 5	10.48 nF	-0.832%	YES
25	0.1 µF (100 nF)	100.2 nF	2.0% + 5	100.4 nF	-0.199%	YES
26	1 µF (1,000 nF)	0.981 µF	2.0% + 5	0.972 µF	+0.917%	YES

Notes:

(a), I insured adequate time to allow the meter to settle to its final value. If the LSD, least significant digit, changes between two values the lowest one is recorded.

(b), Based on the ± percentage and ignoring the ± counts. See Note (3). The Certificate value is assumed true for the ERROR calculation

(c). Based on the sum of the previous four measurements.

Observations and Conclusion

The new 4.5 digit AN870 will make a nice addition to my measurement capability. Its auto response time is slow and typical of ANENG DMMs. The AN870 arrived a day after the DMMCheck Plus. Both instruments were exercised together to prepare this document and they both performed as expected.

There was one "failure." See Table 1 line #4. I had used other DMMCheck standards and the AC True RMS voltage readings always "failed." As a check I measured the same voltage with an ANENG AN8009 and it read 4.960 volts. This agrees with the AN870 reading. I checked the wave form, see Fig. 3, and it is clean. Further investigation is needed to explain this.

Fig. 3 –DMMCheck Plus AC voltage wave form.

I write this description for my own documentation. Perhaps this effort will inspire others who are interested in electrical measurements and applying them to solve practical problems.

Richard J. Nelson
V1 November 5, 2021, V1a June 14, 2025 minor formatting changes.

Notes for Checking the ANENG AN 870 DMM with the DMMCheck Plus

(1). The DMMCheck Plus is especially useful for checking DMMS because it is reasonable in cost, is well documented, oven aged, and includes an NIST traceable Certificate. See Appendix A. Fig. N1 shows the DMMCheck Plus in its optional protective case (an important must have). The basic parameters it checks are shown in Fig. N2

Fig. N1 – DMMCheck Plus

Provided on the small 3" x 3" circuit board are the following circuits:

Resistance : Four 0.1%, 10ppm precision resistors are included: 100Ω, 1.00KΩ, 10.00KΩ, and 100.0KΩ

DC voltage : 5V, ± 0.007% voltage reference

DC current : 1mA, ±0.1% current source

AC voltage : 5V RMS, bipolar (+5V, -5V) square wave, ±0.1% voltage source

AC current : 1mA RMS, ±0.2% current source

Frequency : 100Hz, ±0.02% signal source

Duty Cycle : 100Hz, 5V RMS, signal source has 50% ± 0.05% duty cycle

***Capacitance** : .001, .01, .01 and 1uF precision capacitors measured within .05% of capacitor value. (50V)

* Capacitance is an Optional piggyback board

Fig. N2 – DMMCheck Plus functions.

(2). DMM variations are extensive and generalizing them is impossible because each model is directed to a particular market segment. A high input resistance (10 MΩ) is required for accurate voltage measurements, but a "loaded" voltmeter with lower input resistance may be desirable for testing cells and batteries. Usually, however, the resistance is higher because lower cost circuitry is used. As the market is broad so is pricing ranging from FREE to over $10,000. Harbor Freight has offered a free coupon for a seven function DMM for over a decade. I have over 30 of them obtained this way.

(3). The dual value for DMM accuracy is required because the display is digital. This adds the second additional "counts" or LSD number in order to better specify the range of values the parameter may have to be considered "within specification." Let's use DC voltage as an example. The AN870 specification is ±0.05% & 3 counts.

*Let's assume a **true voltage of 4.915** volts is measured by an AN870 DMM and the display shows 4.919 volts. Is the meter correct and within its specifications?*

The specification error is ±0.05%. This is a range of 4.913 to 4.917 volts. The display, however, reads 0.002 volts above the ±0.05% value. The meter is within its specification because the LSD counts must be added. This makes the within-specification range 4.916 to 4.920. The indicated 4.919 value is within this range and the meter passes.

From the user's perspective, however, all he is concerned about is what the display value is with respect to the true value. In this situation the displayed 4.919 is shown for a true 4.915. The percentage differences are ± 0.08%. The reason for the difference between 0.05% and 0.08% is the added counts required for the analog to digital conversion performed by the DMM. Also note that the percent values are based on the display value whereas the meter percentage applies to the whole range. In this case it is the 19.999 volt range. 0.05% of 5 volts is 0.0025 volts, but for the 19 volts it is 0.0095 volts.

The meter specifications must cover all voltages within a specific range that the specification is given for. If we assume the DMMCheck Plus values are correct, and compared with the values measured the ERROR of table 1 *shows this value. To determine if the meter is within its specifications, however, the ERROR percentage must be based on the dual (analog and digital) specification range. If the measured value is less than the analog specification percentage alone, it may be assumed passed*

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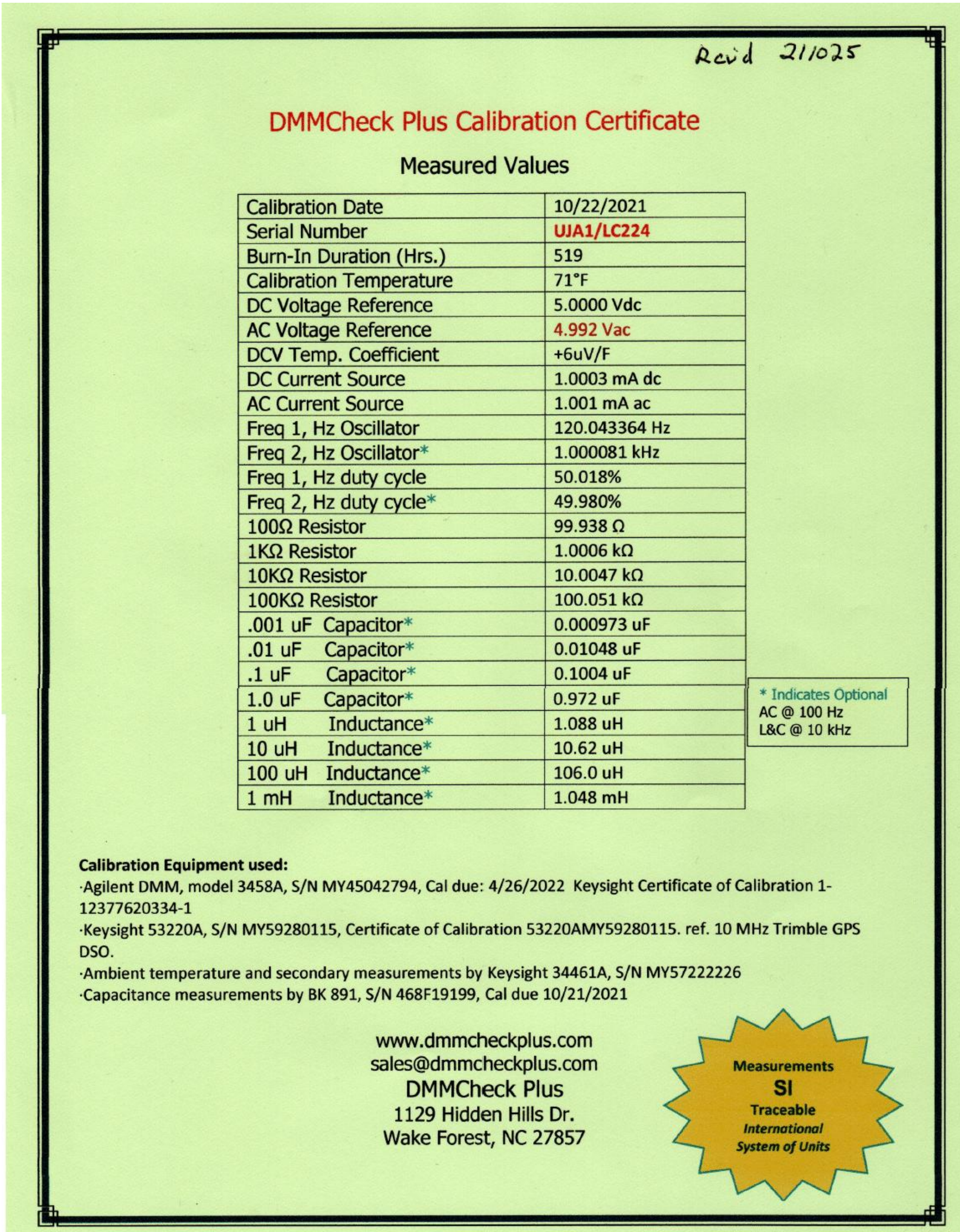
Appendix A – The Certificate for my DMMCheck Plus Standard – Page 1 of 1



Rcvd 2/10/25

DMMCheck Plus Calibration Certificate

Measured Values

Calibration Date	10/22/2021
Serial Number	UJA1/LC224
Burn-In Duration (Hrs.)	519
Calibration Temperature	71°F
DC Voltage Reference	5.0000 Vdc
AC Voltage Reference	4.992 Vac
DCV Temp. Coefficient	+6uV/F
DC Current Source	1.0003 mA dc
AC Current Source	1.001 mA ac
Freq 1, Hz Oscillator	120.043364 Hz
Freq 2, Hz Oscillator*	1.000081 kHz
Freq 1, Hz duty cycle	50.018%
Freq 2, Hz duty cycle*	49.980%
100Ω Resistor	99.938 Ω
1KΩ Resistor	1.0006 kΩ
10KΩ Resistor	10.0047 kΩ
100KΩ Resistor	100.051 kΩ
.001 uF Capacitor*	0.000973 uF
.01 uF Capacitor*	0.01048 uF
.1 uF Capacitor*	0.1004 uF
1.0 uF Capacitor*	0.972 uF
1 uH Inductance*	1.088 uH
10 uH Inductance*	10.62 uH
100 uH Inductance*	106.0 uH
1 mH Inductance*	1.048 mH

* Indicates Optional
AC @ 100 Hz
L&C @ 10 kHz

Calibration Equipment used:

·Agilent DMM, model 3458A, S/N MY45042794, Cal due: 4/26/2022 Keysight Certificate of Calibration 1-12377620334-1

·Keysight 53220A, S/N MY59280115, Certificate of Calibration 53220AMY59280115. ref. 10 MHz Trimble GPS DSO.

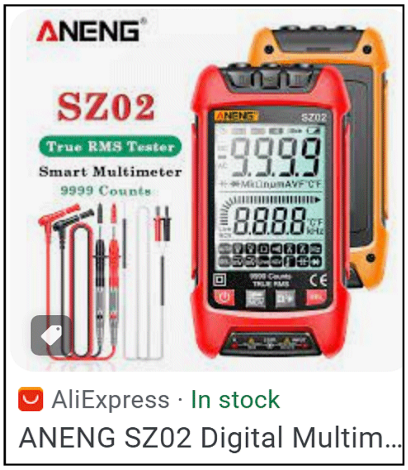
·Ambient temperature and secondary measurements by Keysight 34461A, S/N MY57222226

·Capacitance measurements by BK 891, S/N 468F19199, Cal due 10/21/2021

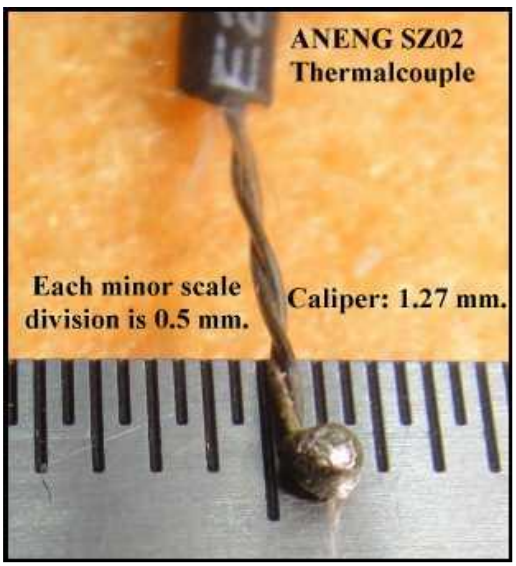
www.dmmcheckplus.com
sales@dmmcheckplus.com
DMMCheck Plus
1129 Hidden Hills Dr.
Wake Forest, NC 27857

Measurements
SI
Traceable
International
System of Units

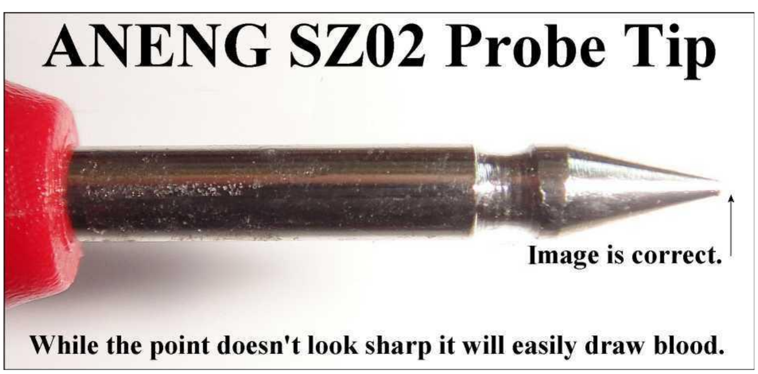
Note the large display and no expensive selector switch. It takes a little time to get to know this user interface.



The SZ02 is half the price of the AN-8009 and has a nice small thermocouple.



The probes use an excellent design.



HHC2025 Appendix G - Low Resistance & Capacitance Test Leads – V2a 11 pp.

Richard J. Nelson

Introduction

Hand held, HH, Digital Multimeters, DMMs, use a (common) set of test leads which are about 36 inches or one meter in length. They have a banana plug on one end and long pointed stiff/rigid probes on the other end. One lead is red and the other is black for keeping track of polarity. These leads are useful (more practical) for trouble shooting where the physical circuit must be "probed" to determine the electrical values all around the circuit (board). Another use of a hand held DMM is to make measurements of components. In this situation the meter is stationary and the component is usually brought to the DMM. You might call these two DMM uses investigative and measurement.

Objective

To make five sets of test leads that when shorted will show Zero Resistance on a hand held, HH, DMM 100 ohm (99.99 ohm) range i.e. have less than 10 mΩ resistance.

Investigative

In the investigative mode the meter is placed at some convenient location. The test leads are moved to the various locations within the equipment being investigated.

The test lead probes are long and sharp pointed to be pressed onto components (leads), wires, and circuit board test points. The probes are required because of the need to be used down in and between components. Some users even add heat shrink tubing, HST, around the metal ends of the probes (not the tips) to avoid touching undesirable conductive areas. See Fig. 1 for an example of a universal set of test leads supplied with some models of AENG true four-digit DMMs.

These are low-cost test leads and as such they are far from being ideal in either use or performance. Fig. 2 shows an aftermarket set of test leads. The banana plug is at right angles and better insulated for higher voltages. The tips have sharp points to ensure a better connection and they also have a recessed portion for the use of mini or micro grabber connections. See Fig. 3.

Fig. 1 – Example of Universal DMM test leads supplied with some DMMS.

Fig. 2 – Better quality test leads with several nice features, especially the points.

Making a good electrical connection is an ongoing issue for electronicers. Each situation has its own conventions/standards and test leads vary by industry, amateur vs professional and even personal taste. Fig. 4 shows a few variations of test leads, A, G, F, C & E, and adapters, B & D, that may be used with them. Investigative use of test leads is usually done with the components involved still in place with or without power applied.

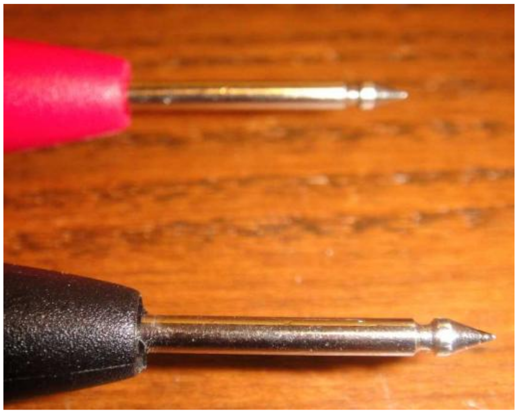


Fig 3 –Tip design for troubleshooting.

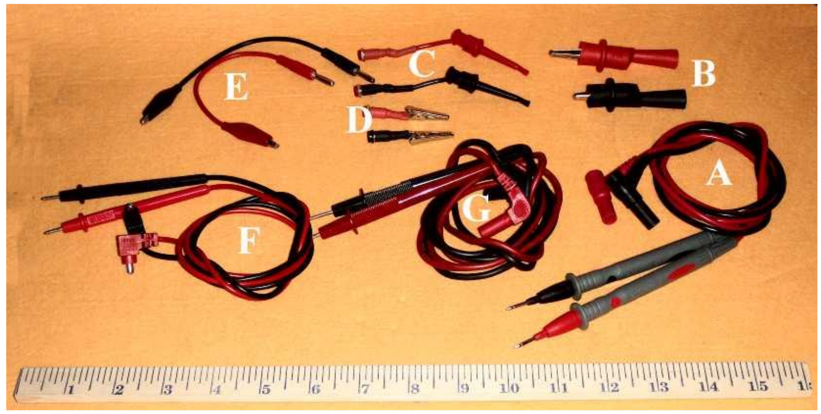


Fig. 4 - Various test leads and adapters for DMM use.

Measurement

Measurements often have more demanding test lead requirements because of the increased accuracy expected of making a component measurement. The component is brought to the instrument and often a test fixture is involved. Special connection methods such as specific sockets are provided as features to some DMMs. The basic assumption is that there are no power or other connections also being made to the component.

The demands for the best possible connections possible are much higher for measurement test situations. The test leads should not add unnecessary resistance, capacitance, or inductance to the component. The problem with low cost DMMs is that they are most often made in China. Wire is involved and because copper is expensive test lead wire will USUALLY be skimped on and be of higher then desirable resistance. If the test lead wire gage is not specified – and it seldom is - you know that it will be 20 Ga. or smaller (higher resistance). **It will NEVER be too large in size.**

Improved test leads

The use of lesser quality test lead wire is easily corrected by buying an aftermarket set of test leads. The banana jacks will be 4 mm and of two types either sheathed or not.

One of the biggest test lead issues is making a resistance measurement. If the DMM has a low resistance range the resistance of the test leads - and internal DMM switch, fuse, and wiring - must be known.

The DMM manual or instruction sheet will often tell you to "short" the test leads and note the resistance and then subtract it from what you measure. This is very important for resistances of ten ohms to about 0.1 ohms. For resistances of lower values you need to use a kelvin (four-wire) method. This is usually not found on handheld DMMs. Most electronicers just touch the test leads together to make the test lead resistance measurement. This is totally inaccurate. A more positive/ reliable method must be used such as the soldered back to back pin jacks as shown in Fig. 5. Based on my measurements[1] the pin lead shorting resistance is less than 2 milliohms. This value may be subtracted from that indicated for the most accurate results. Consult the DMM specifications for the

Fig. 5 – Proper test lead connection for "shorting"

instrument you use.

Another solution for test lead resistance is to make a set of lower resistance test leads. I decided to use 18 Ga. stranded silicon test lead wire, a simple banana jack (non-stackable, non-swivel, etc.), and medium (35 mm) alligator clips.

Short test leads

After observing the performance of my previous shorter (but not nearly as short) tests leads and those of my other instruments such as the DER EE LCR meter DE-5000, I decided that three inch (vs four inch) leads would be adequate. I cut 5 three inch lengths of red and five of black. Each end was stripped 1/2" and one end was tinned. The tinned end was inserted into the banana plug as shown in Fig. 6. Solder was applied and heat controlled so as not to overflow onto the threads. The wire was rotated and the banana jack hot enough and heat controlled to flow up the wire. After cooling, the hard plastic insulator was then threaded on.

Fig. 6 - 18 Ga.

Fig. 7 – Alligator crimped on the wire not the insulation.

Fig. 8 – Insulation is protected.

A 1 inch piece of white HST was slid on and into the just adequate space into the banana plug insulator. The other non-tinned end was inserted into the alligator clip hole and bent over and crimped as shown in Fig. 7. The untinned copper was used to flatten the wire to avoid sharp protrusions for finger pressing. The alligator clip was held in a long nose pliers with a rubber band wrapped around the handle to act as a heat sink. See Fig. 8. This protected the insulation from overheating due to the close working space. The solder was flowed toward the alligator clip nose to provide a good solder joint and a smooth surface for pinching the alligator clip. Good and correct soldering is a critical aspect of making these tests leads. The HST was slid over the back end of the alligator clip and shrunk to provide stress relief. I didn't have black and red HST of the required size. The leads were ball point pen numbered on the HST.

Fig. 9 on the next page shows the finished set. I only insulated one set. The finished test leads were plugged into my favorite DMM, clips shorted, and it showed zero resistance. Now I don't have to worry about compensating for the test lead resistance when making low end resistance measurements.

Measuring the new test leads

I cut a 13" length of the test lead wire and measured its resistance (12 inches) using the method described in Note (1). It was slightly (5%) smaller than 18 Ga. and within normal specifications so the 18 Ga. wire size was confirmed. My standard wire table provides the DC resistance values. See Table 3 on page 5. The best method of measuring stranded wire is to measure its resistance per foot. I have done this many times with known wire sizes and the method is quite accurate. I have found that counting strands, measuring the strand diameter and calculating the resistance is very inconvenient and troublesome even though I have a good Nikon Stereo Microscope.

The overall lead length is 4-1/4 inches excluding the banana plug (outside the meter). Using the values in note (1) and Table 1 the "calculated" resistance of the test leads would be:

1. Two banana plugs @ 6 mΩ each. . . . . . 12.0 mΩ.
2. Two 3-inch lengths of 18 Ga. wires are . .3.2 mΩ.
3. Two Alligator clips are . . . . 4.8 mΩ

Total test lead resistance . . . . . 20.0 mΩ

The AN8009 display is 0.02 ohms. The meter did not display any resistance. This is a theory vs reality issue. Let's do some additional (reality) measurements.

Table 2 shows the measurements of the five sets. I used my best instruments checked with my electrical standards[(2)]. The instrument accuracy is better than ±1%. The current-voltage method of Note (1) was used.

Table 2 – Measured Test Lead Resistance

Set #	Resistance (milliohms)	Current (Amperes)	Shorted Test mΩ
1	15.5	1.007	0.05
2	6.04	1.001	0.03
3	8.25	1.005	0.03
4	12.3	1.008	Zero
5	8.90	1.008	Zero
AVG	**10.2**	**1.006**	**0.02**

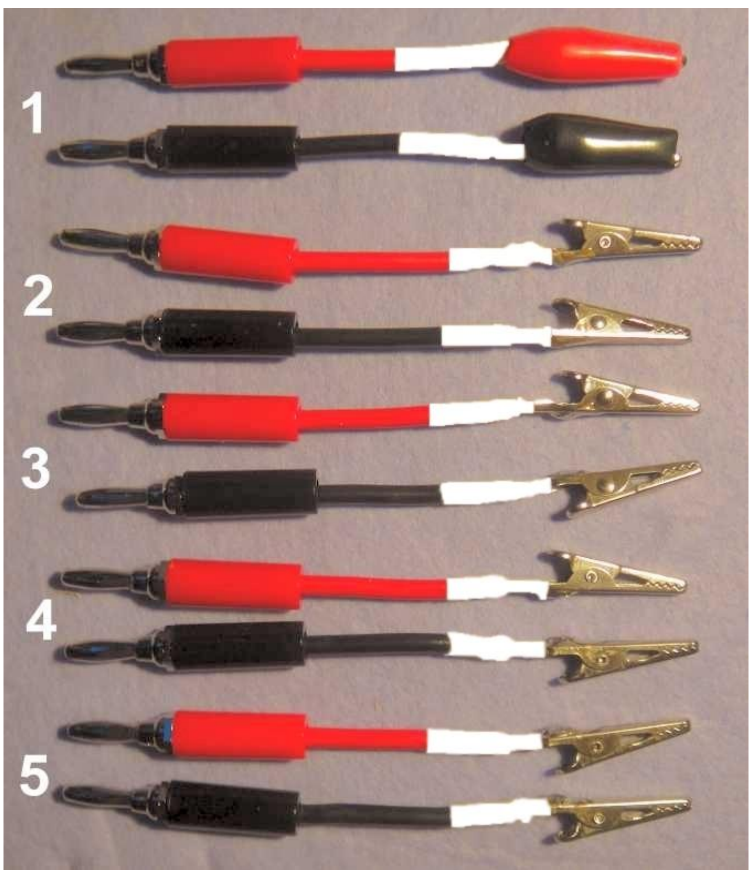


Fig. 9 – Finished sets of short test leads. One, #1, was made with insulating boots.

Fig. 10 – AN8009 DMM does not show the lead resistance with 0.01 ohm resolution, lead set #4.

The measurements were made as shown in Fig. 11. The measured values are more realistic than the "calculated" values because of such factors as the effective shorted portion of the test lead at each soldered end. Nearly half an inch is "shorted" as shown in Fig. 6 and Fig. 7.

There will still be a variable two or three milliohms based on the method of making the alligator clip connection.

The alligator clips are steel and have a much higher resistance than copper. See Fig. 13 taken from the Note (1) writing project. The example range is 2.5 to 4.7 mΩ. This is only approximate and dependent on individual alligator clip factors as material used, oxidation, spring pressure, teeth sharpness, etc.

Fig. 12 shows the normal alligator connection and the difference between this measurement and those in Table 2 (clip method) is that this adds about 3 mΩ to the values. This makes the average about 13 mΩ. This is about 1/3rd as that estimated at the top of page 4. Each test lead set was meter tested for short value and the results included in Table 2.

Fig. 11 – Kelvin 1A connection to measure test leads.

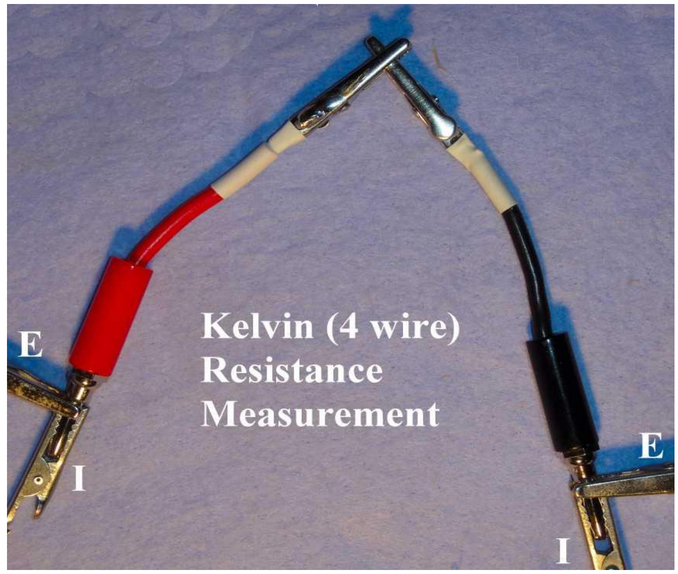
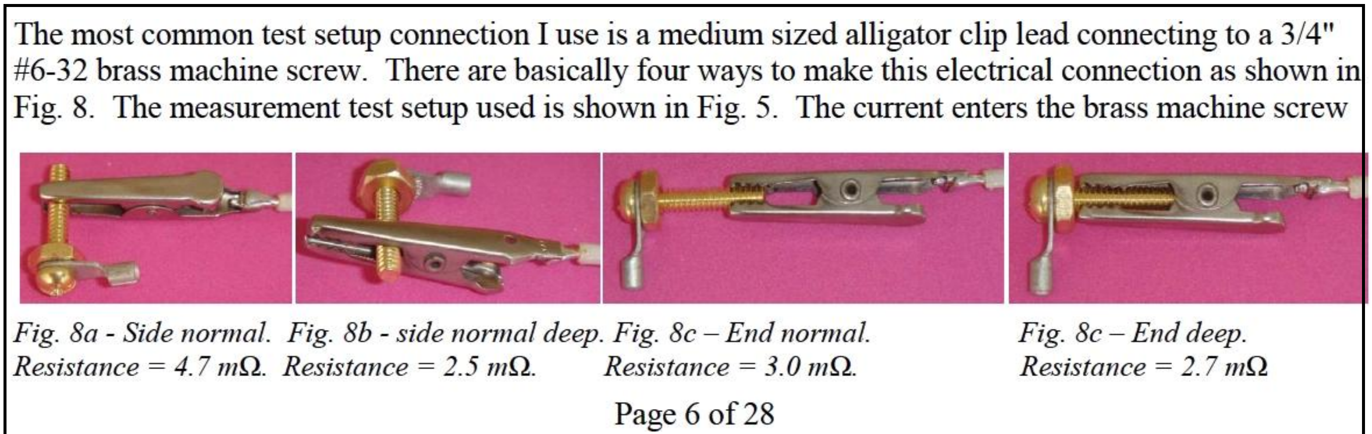


Fig. 12 – Kelvin 1A connection to measure test leads.

Table 3 – Copper Wire Table, AWG. The DC resistance values are milliohms per foot.

	Bare Copper									
	NEWT Diameters							Weight[5]		DC Resistance @ 20C Nom[5]
AWG Size	Min[2] (in)	Nominal[1] (in)	Max[2] (in)	Nominal[1] (mm)	CMA[5]	Min CMA[3]	lbs/M'	ft/lbs		
4/0	0.4554	0.4600	0.4646	11.68	211600	207368	640.5	1.561		0.0490
3/0	0.4055	0.4096	0.4137	10.40	167806	164450	507.9	1.969		0.0618
2/0	0.3611	0.3648	0.3684	9.266	133077	130415	402.8	2.482		0.0779
1/0	0.3216	0.3249	0.3281	8.251	105535	103424	319.4	3.130		0.0983
1	0.2864	0.2893	0.2922	7.348	83693	82019	253.3	3.947		0.1239
2	0.2551	0.2576	0.2602	6.544	66371	65044	200.9	4.977		0.1563
3	0.2271	0.2294	0.2317	5.827	52635	51582	159.3	6.276		0.1970
4	0.2023	0.2043	0.2063	5.189	41741	40906	126.3	7.914		0.2485
5	0.1801	0.1819	0.1838	4.621	33102	32440	100.2	9.980		0.3133
6	0.1604	0.1620	0.1636	4.115	26251	25726	79.46	12.584		0.3951
7	0.1428	0.1443	0.1457	3.665	20818	20402	63.02	15.869		0.4982
8	0.1272	0.1285	0.1298	3.264	16510	16180	49.97	20.010		0.6282
9	0.1133	0.1144	0.1156	2.906	13093	12831	39.63	25.232		0.7922
10	0.1009	0.1019	0.1029	2.588	10383	10175	31.43	31.817		0.9989
11	0.0898	0.0907	0.0916	2.305	8234	8069	24.92	40.121		1.260
12	0.0800	0.0808	0.0816	2.053	6530	6399	19.77	50.592		1.588
13	0.0712	0.0720	0.0727	1.828	5178	5074	15.68	63.795		2.003
14	0.0634	0.0641	0.0647	1.628	4107	4025	12.43	80.444		2.525
15	0.0565	0.0571	0.0576	1.450	3257	3192	9.858	101.438		3.185
16	0.0503	0.0508	0.0513	1.291	2583	2531	7.818	127.910		4.016
17	0.0448	0.0453	0.0457	1.150	2048	2007	6.200	161.292		5.064
18	0.0399	0.0403	0.0407	1.024	1624	1592	4.917	203.386		6.385
19	0.0355	0.0359	0.0362	0.9116	1288	1262	3.899	256.464		8.052
20	0.0316	0.0320	0.0323	0.8118	1022	1002	3.092	323.396		10.15
21	0.0282	0.0285	0.0287	0.7229	810.1	793.9	2.452	407.795		12.80
22	0.0251	0.0253	0.0256	0.6438	642.4	629.6	1.945	514.219		16.14
23	0.0223	0.0226	0.0228	0.5733	509.5	499.3	1.542	648.419		20.36

The Table 2 results illustrate how the moving contact variables influence milliohm measurements and why resistances at the low DMM range (non-kelvin) are always highly suspect. Measuring less than 0.1 ohms requires considerable care and should be repeated to verify the data and if the DMM specifications are being met. Besides, the DMM is usually only providing a single digit of resolution below 0.1 ohms - 100 milliohms.



The most common test setup connection I use is a medium sized alligator clip lead connecting to a 3/4" #6-32 brass machine screw. There are basically four ways to make this electrical connection as shown in Fig. 8. The measurement test setup used is shown in Fig. 5. The current enters the brass machine screw

Fig. 8a - Side normal. Resistance = 4.7 mΩ. *Fig. 8b - side normal deep. Resistance = 2.5 mΩ.* *Fig. 8c – End normal. Resistance = 3.0 mΩ.* *Fig. 8c – End deep. Resistance = 2.7 mΩ*

Page 6 of 28

Fig. 13 – Measurement example of alligator clips in my Making an Electrical Connection writing project.

Fig. 14 – 3/4" Adapter made into a low resistance "short."

Because of the surprising results (to me) of the test lead measurements I investigated the issue further. I made up the best possible "short" I could. It is shown in Fig. 14. I found this adaptor in my adapter box. I made it a few years ago using 12 Ga. wire. The wire was oxidized so I replaced it. I used the largest copper wire that would fit - 7 Ga. wire that has 0.0415 mΩ per inch – into the 3/4 inch adapter.

I used the SDM 3055 DMM to measure its resistance. The resolution is 1 milliohm. A normal resistance measurement was 70 mΩ using the normal probe test lead set. A Kelvin measurement produced a resistance of 2 mΩ. Plugged directly into the DMM (2-wire jacks) was also 2 mΩ. The only resistance a DMM would "see" is the banana plug-jack interface which is probably the 2 milliohms.

I then used this adapter to "short test" five ANENG handheld DMMs. Three tested as expected at "ZERO." Two, however, were very unstable with values ranging in the hundreds of milliohms to below 100 milliohms. It might be that this is a suitable means of indicating a minor fault in the DMMs. These same three DMMs also showed ZERO with test lead set #1. I have an additional two brand newAN8009 machines and I opened them and tested them. They both zeroed with the adapter and test lead set #1. When the alligator clips are connected as in Fig. 11 (vs Fig.12) they zeroed a bit faster.

The milliohm world

Resistance measurements less than 0.1Ω is within the realm of the milliohm world. Milliohm resistance may change due to the factors listed in Table 4. These factors play a role in making milliohm measurements challenging. Any situation that involves a moving contact such as a banana plug into a jack will be influenced by the Table 4 factors list. Making accurate (and repeatable) measurements is a challenge that requires understanding of real-world ranges and limits. It also requires proper measurement techniques and instruments.

Table 4 – Factors that Influence Milliohm Measurements

#	Resistance Influence Factor	Comments
1	Environmental; humidity, condensation	Temperature & relative humidity changes

2	Oxidation; battery outgassing	Highest influence
3	Electrochemical; liquids, bi-metals	Develops voltages that influence measurements
4	Contact pressure; battery, connectors	Sliding contacts may wipe/clean oxidation
5	Contact area; points vs larger areas	Larger areas reduce resistance, points may increase
6	Thermoelectric; specific materials	Temperature gradients may generate emf.
7	Elevated temperatures; increases reactions	Chemical activity increases with temperature

Because of the variances observed in making the Table 2 measurements using the same current-voltage method described in the Note (1) reference, I decided to repeat the test lead measurements using the SDM3055 with both the 2-wire and 4-wire methods. Resolution is 1 mΩ. See Table 5. The second column is the short test leads plugged in directly to the panel. The last two columns are normal test lead measurements. See Fig. 15.

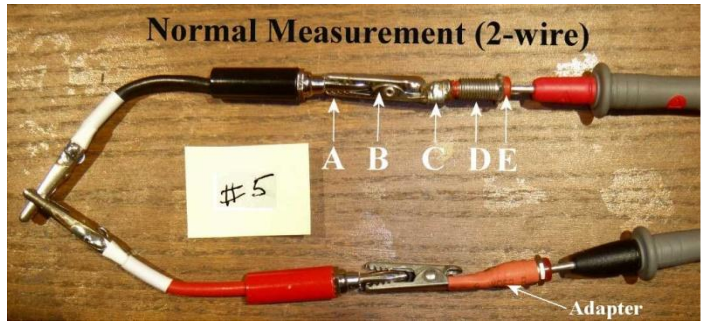


Fig. 15 – Bench DMM measurements, test set #5.

Table 5 – SDM3055 Measured Test Lead Resistance

#1 **Short Test Set #**	#2 **Resistance (milliohms) 2-wire panel**	#3 **Resistance (milliohms) 4-wire**	#4 **Resistance (milliohms) 2-wire leads**
1	13 mΩ	19 mΩ	79 mΩ
2	6 mΩ	8 mΩ	70 mΩ
3	4 mΩ	23 mΩ	75 mΩ
4	8 mΩ	17 mΩ	76 mΩ
5	4 mΩ	12 mΩ	69 mΩ
AVG	**5.8** mΩ	**15.8** mΩ	**73.8** mΩ
Adapter	**2** mΩ	**2** mΩ	**64** mΩ

The purpose in making a 4-wire (Kelvin) resistance measurement is to eliminate the test lead resistance. The addition of an alligator clip test lead adapter adds to this resistance as identified by the Fig. 15 added letters.

A – Alligator clip contact resistance which is variable, perhaps ±3 mΩ.
B – Alligator clip steel resistance. Steel resistance is 3 to 15 times higher than copper.
C – Solder joint of pin jack to alligator clip. Minimal using wrapped and soldered wire.
D – Brass pin-jack resistance. Manufacturer design controlled. Internal contacts are unknown.
E – Pin to jack moving resistance. This is minimal, and smaller than you expect. See Note (1).

Table 5 adapter values exemplify the difference between panel direct and 4-wire measurements. They should normally be the same. Why are the test lead values different than the 2-wire values? My guess is that the major difference is the alligator clip. How it is used (see Fig. 13) will make a difference. I compared the Fig. 11 and Fig. 12 measurements and the difference is about 3 mΩ. Still the differences are much higher than I would expect.

I measured the test leads using the pin shorting adapter shown in Fig. 5. They were 54 mΩ. The similar values in the fourth column might be explained by the normal test lead resistance being so much higher than that being measured. Subtract 54 mΩ from column four and you should expect to get the column two values. The values are still three times higher. Fig. 15 illustrates the added variables involved with many (alligator) "connections." The critical aspect is what the alligator clip is clipping to in addition to how it is clipping. Add the variable that each alligator clip is different (spring and joint friction) and perhaps this is not surprising. Perhaps alligator clip resistance measurements should be another writing project?

The Table 5 values explain why all of the five short test leads pass the DMM zero indication on the properly working five AN8009 instruments. Three other instruments were erratic and seemingly mal-functioning.

DMM settling time

The AN8009 DMMs are really high value and high-performance instruments, but they have one well known flaw. They take a very long time [3] settling to a final reading. AC powered instruments need to have an extensive warm-up period to ensure that the settling time is normal. I used an excessive amount of time to ensure that the values of Table 5 were final and stable.

DMM low ranges

The low-end ranges usually do not provide the number of digits of resolution as the higher ranges simply because there is no more. You can't switch to another range. Milliohm resistance measurements are pushing the limits of current HH DMMs. There is a whole new market full of instruments for making milliohm resistance measurements. Of course, sales volumes are lower and the high prices reflect this reality. Electronicers are always pushing the limits of their instruments and that is why articles like this one help to provide perspective.

A milliohm perspective [4]

How much is a milliohm in terms of various connection devices? Low milliohm connections are very desirable for switch, relay, and field effect switching transistors. A typical Home Depot 98¢ wall toggle switch has a resistance of ≈30 milliohms. See Fig. 16. This resistance includes the wiring and brass machine screw resistances.

Most of Panasonic's electromechanical relays have a specified contact resistance of 100 milliohms maximum. Solid state relays are usually ten times higher than their electromechanical counterpart. One MEMS relay design reports a contact resist-ance as low as 4 mΩ. This is for a low 1 mA current but at a life of >100 million actuations with very little change in the contact resistance. Mechanical contact resistances change (increase) over time. The better MOS transistor power switches have an on $R_{DS(on)}$ value of less than 10 milliohms.

Fig. 16 - 98¢ new wall switch.

What is the effect of 10 milliohms resistance? At a current of 10 amperes the power (I^2R) is 100 x 0.01 or 1 watt. 15 amperes is 2.25 watts. With 15 milliohms and 15 amperes the power is 3.375 watts. The milliohm contact resistance cannot be ignored. Just one watt can cause a high temperature rise if the power (heat) is not properly dissipated.

How much is 10 mΩ?

1. One foot of AWG 21 wire.
2. One inch of AWG 4 wire.
3. Contact resistance of a high-quality relay.
4. 1/10 of a normal on/off wall switch ON resistance.
5. Shunt resistance of a 10A meter.
6. One foot of AWG 12 Nichrome C resistance wire.

7. Single digit of resistance of low range of most HH DMMs.
8. A high quality MOS Power transistor on resistance.

Capacitance measurements

I used my favorite capacitance meter, the Mastech MV 6013A on its 200 pF range to measure the capacitance of the test leads being explored here. Table 6 shows the results. The meter was nulled to zero before inserting the test leads. Standard 3/4" banana jack spacing is used.

Table 6 – Lead Capacitance (3/4" Standard Jack Spacing)

#	Conditions of the leads	Capacitance (pF)
1	Straight Up.	2.3
2	Crossed.	2.6
3	Close (parallel).	3.9
4	Clip insulated (HST) & taped together.	4.8
5	One turn twist.	9.2

Additional reality check

I decided that I needed an additional reality check and I made a 6th set of short test leads using 14 Ga. stranded wire I bought at Home Depot. It was white and I used a felt pen to make them red and black like the others. It was not as flexible as the formal test lead wire but it is quite adequate. I also made a test fixture to be able to more accurately make higher resolution mΩ measurements using the current-voltage drop method. The SDM 3055 will provide six digits of current resolution. Stable currents of 1.000**nn** amperes are adjusted using a stable 4.5-volt power supply. The values used for the current limiting pots connected as a rheostat facilitated the **nn** digits to be easily adjusted, but they kept changing. Touching (holding) the slightly warm primary pot Nichrome wire showed a response to current change, i.e. cooling down caused the current to increase.

The series current limiting pots were 5Ω, 500 watts, and 0.5Ω, 50 watts series connected as a rheostat. A 100Ω, 100-Watt pot was connected in parallel with the 0.5-ohm pot for the fine adjustment. See Fig. 17 for examples. I had hoped that the large high-powered pots would be more temperature stable. The unstable currents and voltages were clearly caused by the resistance change of just a few degrees. Room: 80°F, 20% RH.

5 Ohms, 500 watts | 25 ohms, 50 watts | 50 ohms, 150 watts | 100 ohms, 100 watts

Fig. 17 – Examples of high-power pots used for test and measurements

The banana plug to banana plug resistance was 3.56 mΩ @1.000A. The alligator Clips were deep throat connected (minimum per Fig. 13) to a 6-32 brass machine screw. See Fig. 18. The system was switched over to the SDM 3055 measuring Test leads #6 by 2-wire connected to the panel at 3-4 alternating mΩ. This value correlates nicely, but is only a single digit which is not very indicative of change factors. The Fig. 18 letter notations indicate the various parts of the test lead resistor chain that influence the total resistance. A 6-32 brass machine screw is used to deep throat clip the alligator clips.

The Table 5 measurement of leads #1 (column #2.) was repeated to provide an idea of how much the value is variable. Ten measurements were made by plugging in the leads, measuring, unplugging, reversing, and plugging again. Here are the values. 14, 12, 15, 12, 14, 10, 16, 14, 13, & 12 mΩ. The average is 13.1 so the value could be specified as 13 ±3 mΩ.

A – **Variable** banana jack-plug interface.
B – Banana Jack solder joint.
C – 14 Ga. wire lead, 3 inches long.
D – Wire lead Alligator Clip solder joint.
E – **Variable** Alligator Clip jaw joint interface.
F – **Variable** Alligator Clip jaw teeth to grip test component lead.

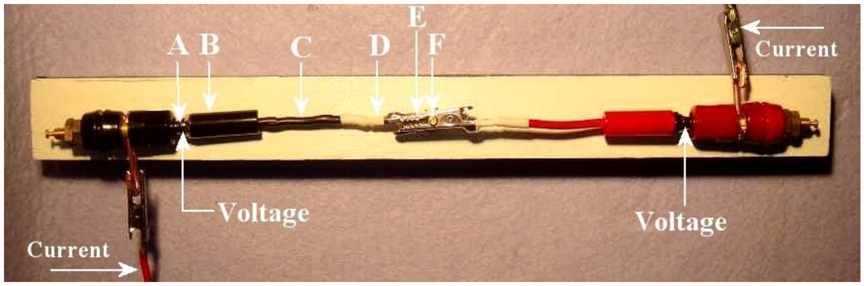


Fig. 18 - #6 Test Leads (14 Ga. AWG on test fixture to measure resistance with current and voltage drop method described in Note (1).

Observations and conclusions

I use a wide range of hand held DMMs, especially for component measurements. Even though I have some "short" 6-to-8-inch test leads with small (25 mm) alligator clips attached, I decided to make a set of five 3-inch test leads using medium (35 mm) alligator clips and 18 Ga. stranded silicon test lead wire. This should be adequate to keep the resistance below that which is detected on the lowest resistance range of 100 ohms. This would be less than 10 milliohms.

Initially the goal seemed not met with only two of the five sets (Table 2), when shorted, showing zero on the AN8009 DMM. Additional tests, however, indicated that part of the problem is the DMM design. There is a modification (see note 3) that effectively speeds up the sampling rate and I speculate that this would assist in using these test leads as well. 16 Ga. wire has 37% less resistance and using this wire would probably guarantee working with all ANENG DMMs and most others as well. As a reality check I made up one set of short test leads using 14 Ga. wire. Additional (better) measurements (Table 5) indicate that the short test lead goal was met.

I write this description for my own documentation. Perhaps I will inspire others who are interested in electrical measurements and applying them to solve practical problems.

Comments, suggestions, ideas, questions, corrections and article copy (by title) requests are welcome at: rjnelsoncf@cox.net Richard J. Nelson is a very common name and the "cf" differentiation is for Calcfan.

Richard J. Nelson

V1 – March 6, 2021. V2 March 10, 2021. I double checked the measurements to insure adequate meter settling time and added a #6 set of test leads using 14AWG wire. I also added several new sections increasing the page count by two pages. V2a June 1, 2022. Corrected Table 6 being labeled 5.

Notes for Low Resistance & Capacitance Test Leads

(1) *A writing project titled Making an Electrical Connection made milliohm measurements of 12 connection devices with the following results. Copies may be requested by title.*

Measurement Summary

I measured 12 of the 14 connection devices. Those I didn't measure are indicated with an em dash in the Fig. 39 Milliohms column. I didn't see the comparative value.

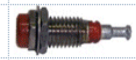
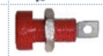
ID Device	Image	Milliohms	ID Device	Image	Milliohms
A - Alligator Clip, large		—	H - 1/4" Blade socket[4]		1.22 mΩ
B - Alligator Clip, Medium		2.42 mΩ	I - Pin Jack		0.97 mΩ
C - MiniGrabber Clip		19.9 mΩ	J - Banana Jack		4-8 mΩ
D - MicroGrabber Clip		—	K - E-Z-Hook Nailclip		0.18 mΩ
E - Pin Plug (0.080 dia.)		0.25 mΩ	L - Wire loop, 18 Ga.		0.532 mΩ Per inch
F - Banana Plug		4-8 mΩ	M - Fahnestock Clip		1.43 mΩ
G - 1/4" Blade[4]		See H.	N - #6-32 brass screw		1.79 mΩ Per inch

Fig. 39 – Various devices used to connect and terminate electrical conductors with comparative resistance.

(2) *My electrical standards are described in an eight-page writing project titled* *RJN Electrical Standards*. *The technical details and sources are provided for the interested reader. Copies may be requested by title.*

(3). *When the An8009 DMM makes an auto-ranging resistance measurement it requires a certain amount of time to settle on the final stable answer. All digital instruments have a settling time that varies from milliseconds for high-speed instruments to multiple seconds for handheld DMMs. If, for example, the AN8009 is set to ohms and showing OL in the display and the Zero-ohm adapter short is plugged in, the time to display the 0 mΩ value is on the order of seven seconds. The AN8009 DMM has a modification that greatly (10x) reduces the settling time as well as providing more reliable answers. See: https://www.jackenhack.com/aneng-an8008-modify-for-better-accuracy-faster-readings/ I have to order some capacitors to make the modifications to my machines. The SDM3055 6-1/2 D has a settling time of two to three seconds. This time is also affected by the warmup time.*

(4), This section is reproduced from the writing project of Note 1.

Appendix H– 10 V Reference Website Text – 2 pages.

VREF10-001 r9

10V, .001% Voltage Reference **(RJN note: This is 100 times more accurate than your DMM. The last paragraph is very important. You could use the AC transformer to always keep it powered and then have it recalibrated for the best usage. One year is over four times the aging already done)**

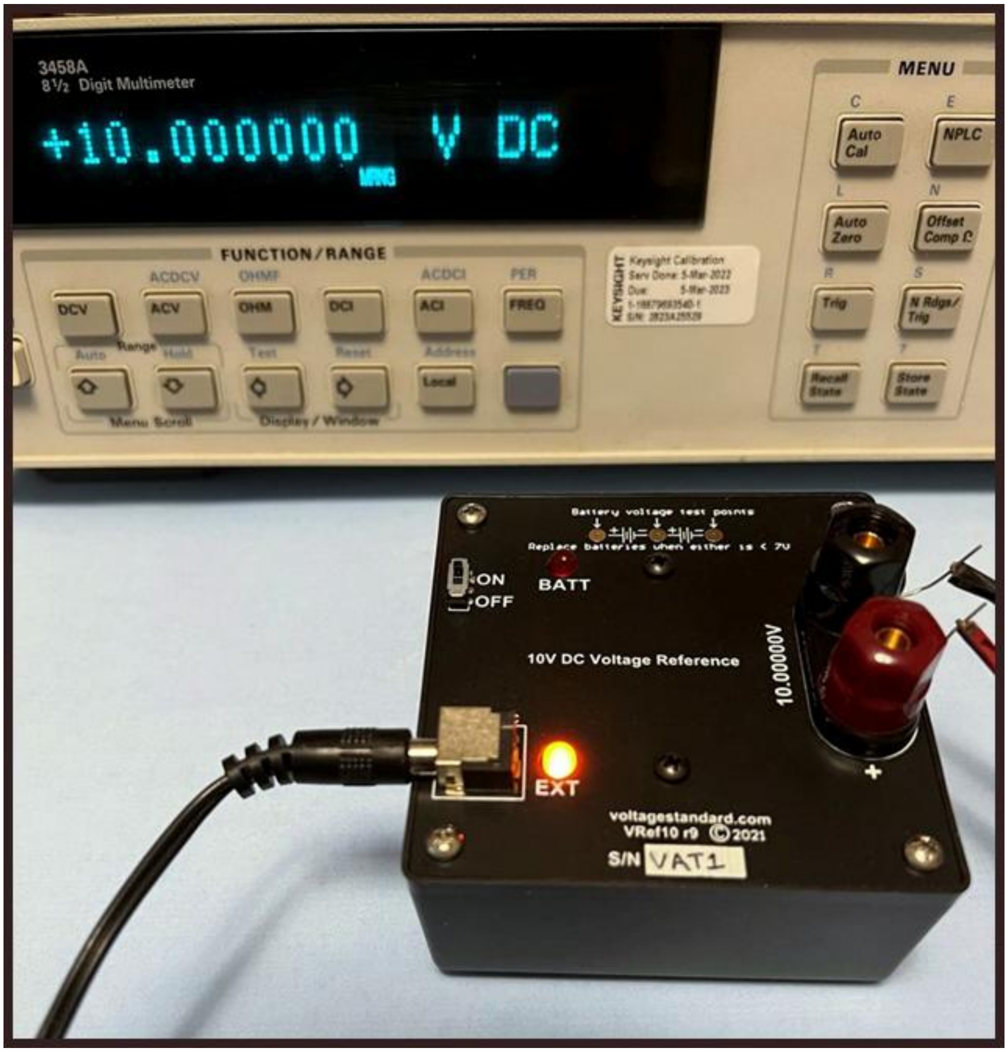


Fig. I1 – NIST 8-1/2 digit meter used to set the VREF10-001 r9.

The VREF10-001 r9 has the following updates:
***Operates from internal 9V batteries or external 24VDC power supply**
*** Output terminals are high quality gold plated 5-way binding posts**
***Gold plated circuit board**
*** Temperature compensation circuitry provides 60ºF to 90ºF (16C- 32C) TC of < +- 2uV/F (0.4ppm/C) max (Box Method)**
***Easily accessible current limited battery voltage test points**

***All Temperature sensitive components (LT1021, etc.) are located inside the enclosure to make the Vref10-001 r9 insensitive to ambient air currents**

This small (3" x 3"), portable, precision voltage reference can be used to check the calibration of your DVM or DMM. The VREF10-001 r9 features a 10.00000V output, and is conservatively rated to be accurate within 0.001% for a minimum of 8 months. The circuit is based on the Linear Technology LT1021BCN8-10 which uses buried Zener technology resulting in excellent long-term stability. Here is a link to the LT1021 datasheet on the Linear Technology website: https://www.analog.com/media/en/technical-documentation/data-sheets/1021fc.pdf

The VREF10-001 r9 can either be powered by the 2 included RayOVac Alkaline 9V batteries or an external 24VDC (24V +-1V recommended) power supply. When powered by the batteries the unit is completely self-contained and easily transported. An on-board on/off switch allows you to maximize battery life when not in use. Current drain is less than 5mA so the batteries will last many 10's of hours. Both the battery and 24V external inputs are reverse polarity protected and can withstand up to +/-40V without damage.

Buried Zener References become more stable the longer they are powered-up. Operation with an external 24VDC supply allows the VREF10-001 r9 to be continuously powered without draining the batteries. An optional low cost, UL approved, linear, regulated, 120VAC/60Hz input 24VDC output, power supply is available at our online store. Alternatively, you can use your own 24VDC supply with a 2.5mm/5.5mm plug. A lit low current red LED indicates battery operation and a lit orange LED indicates external power. The switchover from batteries to external supply (or vice -versa) is virtually instantaneous and when both are present priority is given to the external supply.

Temperature compensation keeps the VREF10-001 r9 temperature coefficient to less than +/- 0.4ppm/C over the range of 60ºF to 90ºF (16C to 32C). The temperature stability is verified by using our thermal chamber to slowly change the temperature from 60ºF to 90ºF over a period of 12 hours and measuring the Reference output every 0.1ºF

The temperature graph for your particular VREF10-001 r9 is available as an option via our online store.

After the unit is assembled, it is powered up for a minimum of 2000 hours to "age" the reference and confirm its long-term stability. During this aging process, daily measurements are made of the reference output voltage- the LT1021 is replaced on those units that have excessive long-term drift. After aging, a trim pot is carefully adjusted so that the output voltage is within 5uv of 10.000000V as measured by our calibrated, 8.5-digit Keysight 3458A DMM. (Keysight Certificate of Calibration WO-01038932, valid through March 1, 2026). The ambient temperature is recorded and unless specified otherwise will be in the range 68 to 70 degrees F. We can perform calibration at other temperatures- please inquire for feasibility and pricing.

For maximum accuracy it is recommended that the reference be powered-up 15 minutes before use and also operated as close as possible to the calibration temperature.

Recalibration is free for the first two years after purchase - just mail it back to us and pay for return shipping. For destinations within the USA please send a $11.00 PayPalpayment to doug@voltagestandard.com. After two years the calibration charge is $15.00 plus shipping.

E N D