Knowledge Base: How to Use the Keysight 3458A for Precision Measurements and What is Important to Know about It

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Abstract

The 3458A is one of the workhorses in metrology labs and for precision measurement applications. Using this meter requires to observe certain critical factors to achieve the results desired, some of which are not well known. In addition, there are certain methods to optimize the use of the meter. Despite e.g. its excellent specification parameters, often its specified absolute accuracy allone is still not sufficient to do certain metrology work.

Based on our long-term experience in using, calibrating and maintaining/repairing the 3458A, this document explains some of the workarounds to achieve higher accuracies, e.g. with the help of other lab standards and its outstanding linearity. Error propagation calculations are given to demonstrate the achievable accuracy. Also, some general hints are given in conjunction with the use and maintenance of the 3458A, helping new owners, including also those of used meters, to quickly get up to speed and avoid mistakes.

1. General Aspects Using the 3458A

In order to achive the accuracy one expects from using the 3458A, it is key to select the correct setting for the meter. Keysight is giving recommendations for this, although they are somewhat hidden in a pretty unknown document, and therefore summarized here below.

DCV:
- RESET
- NPLC200
- NDIG 8

(Note: Firmware revision 6 and below have a bug such that LFREQ is set to 60 also in 50Hz mains environments during RESET. Therefore use LFREQ 50 in addition for rev. 6 and below in 50Hz mains environments to avoid a mains-related decrease of accuracy).

ACV:
- RESET
- ACV
- SETACV SYNC
- RES .002
- LFILTER ON

(Note: LFILTER ON is only recommended up to 50kHz measurement frequency)

OHMS:
- RESET
- OHMF
- OCOMP ON
- DELAY 1
- NPLC 200

Most of the above may be obvious, but some is probably not so much, but is important to observe. E.g. DELAY is seldom considered, but it has a big impact on the ohms measurement accuracy (it may be more than 10ppm) and circumvents impacts caused by dielectric absorption of the test cable.

Besides that, generaly:
- avoid any airflow accross the binding posts when doing measurements. You may even protect them with some foam or so, but usually just normal care re. airflow is sufficient.
- use bare copper spades (remove any copper-oxid as it bears very high thermal EMF voltages!) or gold plated copper spades as cable terminals. The impact of the gold plating on EMF can be neglected, as we have verified many times. It is just too thin to generate any relevant thermal drop and thus any relevant EMF.
- use quality teflon-insulated cable (at least) for ohms measurements, in order to avoid measurement errors at high resistances through parasitic currents in the test cable.
- use twisted cable (shielded) as it avoids pick-up of noise from the environment. If you you use (tellurium-copper) banana cables (e.g. available from Pomona), you should also twist them. The shield alone is less efficient than the twisting, so shielded, non-twisted cable is not recommended.

2. Precision Voltage Measurements

Generally, one of the major assets of the 3458A is its excellent linearity. It is specified to 0.05ppm of the measured value plus 0.05ppm of range. It in fact is so precise, that the only way to validate it (and was during the design of the unit) is an adjustable Josephson voltage standard. That said, it must be stressed, that this linearity is also applicable to units that may not have been calibrated for a while. So the method described here below is not even dependent on a 3458A operated within its calibration period. (However, of course, other precise standards are needed as the reference for the voltage, in specific a precise voltage standard such as e.g. a Fluke® 732A or B.)

So lets assume one wants to calibrate the 1.018V output of a Fluke® 732B which has its 10V calibrated only (because e.g. you ordered the calibration of the 10V only from your cal lab, to save money). The 10V output has a reasonably low specified drift rate (2ppm/a, K=3; so on a side note, 1% of the units considered may actually not meet this specification, or in other words you have no absolute guarantee that your unit is within these 2ppm; although obvious, keep this in mind). The 1.018V output has no drift specification for 90 days or one year, only for 30 days. So frequent (once a month) recalibration of this output is needed anyway.

One way to calibrate the 1V output is to use a calibrated 3458A in its 1V range. Lets assume it was calibrated by the manufacturer, then your absolute accuracy within 90 days of calibration is 6.9ppm worst case (low drift version of the 3458A, called Opt 002, is 5.4ppm). This value consists of the 90 day specs of the 3458A of 4.6ppm related to the reading plus 0.3ppm of the range plus 2ppm related to the standard used when calibrating it at the manufacturer (information as given in manufacturer Calibration manual 90017, edition 5). You can do better, by using e.g. a 0.5ppm accurate standard for the calibration of the 3458A, that brings you down to 5.4 respectively 3.9ppm absolute. Still not very precise, and you can do better that that.

The more precise and cheaper (because you do not need to have your 3458A calibrated every 90 days) solution, repeatable as needed, at any time, is to use a (potentially even uncalibrated) 3458A in the 10V range and do a comparision measurement of the 1.018V ouput, relative to the known 10V. Use the 3458A DCV transfer accuracy specs for this. The error budget here is (assuming the 732B was calibrated with the same 2ppm uncertainty as is used for the 3458A factory calibration):

2ppm (732B uncertaínty) plus 0,05ppm (reading) plus 0.05ppm (of range, results in 0.5ppm absolute) of 3458A, or about 2.6ppm worst case total absolute (0.6ppm worse than the 10V used as the reference for this calibration). This is is considerably more accurate and does not even require a meter within calibration period, nor an option 002.

This method should e.g. also be used when precision measurement are needed, by using the

3458A in relative mode, relative to known precise voltage standard, and use its drift rate plus correction factor of the 3458A, rather than doing direct measurements with the 3458A. As can be seen, a voltage standard pays off quickly, as it may save some calibrations.

3. Precision Ohms Measurements

Now the same scheme can be applied for doing precision ohms measurements. Here again, the voltage mode is used. It must be kept in mind, that other than with the DC voltage range, the Ohms range of the 3458A has no specification for transfer accuracy, so relative measurements are not specified, and the absolute accuracy of the 3458A in ohms mode is arround 11.5ppm (90 days, 10k range, also considering the 3ppm calibration standard accuracy; and opt. 002 does not make it better). Another caveot, again, that is often overlooked, is the fact that when doing ohms measurements, the dielectric absorption of the cables used may introduce errors. This can be avoided adding sufficient DELAY, but is often not done adequately (see above). So make sure, for OHMF measurements, you apply that.

So lets assume the lab has a calibrated 10k ohms standard (assumed calibrated to 3ppm uncertainty, similar to the value used in the 3458A budget as per calibration manual from the manufacturer), and you wish to calibrate a 1k standard. This can be done by measuring the voltage drops of the 10k and 1k standards connected in series in 4-wire mode. The series connection (force binding posts) is hooked up to a short-term stable voltage, such as the 732B 10V output or a precision voltage calibrator. The voltage drops of the sense binding posts of the two standard resistors are then measured after thermal stabilization. The voltages should be measured also in reverse mode (polarities reversed, e.g. supply voltage reversed) to compensate for any potential thermal EMF voltages, and the average is used as the input for the calculations. The voltage drops across the resistors are directly proportional to the resistances, and since the drops are measured at the resistances themselves (4-wire standards), any losses in the cables are cancelled out. The front/rear binding posts could be used to switch between the two resistors (provided both front and rear have been null-calibrated).

When doing the error budget (GUM error propagation calculation), based on a stable voltage of say 10 to 12V, depending on the stability of the source used, and ensuring low EMF voltages (typically <50nV), one can show that an additional error of only arround 1ppm above the 10k-Standard uncertainty can be achieved, so in the example above, arround 4ppm absolute.

Compare this to the 11.5ppm abolute accuracy of a measurement of a 1k resistor with a calibrated 3458A within 90 days of cal. This method in principle can actually be used to do a ladder calibration of reference resistors (up and down), based on a single calibrated 10k resistor standard. At high resistance values, the input impedance of the 3458A in voltage mode sets a natural limit, and with low resistances, a constant current rather than a constant voltage may be the better approach. The author has used this method for a set of standard resistors from 1 Ohm to 1 MOhm with excellent accuracy. Make sure you do not exceed the allowable voltages/currents for the standards used.

So in our opinion, the true values of this meter really is its outstanding DCV linearity, which can help in many aspects.

4. Some Background Information

The meter has been built since 1988, and many have been used since then, more or less continuously. Throughout the years we have repaired, calibrated and maintained quite a bunch of them, and some experience has since accumulated, some of which is summarized below in no specific order.

- Often users are very keen on getting an opt. 002 version. This includes the better (more stable; 4ppm/a) reference. This essentially is the same reference board (assembly), except the reference has shown in aging test after manufacturing to be low-drift, qualifying it for a new PCB-tag related to the low-drift version. It must be noted, that most of the used 3458As, because of its age, and especially if they have been in regular use, have anyway reached the same level of drift. Of course you cannot apply the 002 drift specs without any analysis, but you could establish your own drift history, and apply it for your specific instrument. Or you could do precision relative (i.e. transfer) measurements with reference to a low-drift Voltage Standard, (732...), even achieving better-than-002 uncertainties (see above). The 002 option does anyway only have an impact on the DCV range, all others are unaffected.

- Opt. 001 is extended memory, it can be added easily in sockets in the earlier two versions of the CPU board; in the newer it is not possible just just like that; opt 001 is detected by OPT?.

- The 3458A is pretty good in measurimg low frequency ACVs (with SETACV SYNC). It is not good in higher frequency ranges, say above 1MHz or so. Any old URE AC voltmeter e.g. is better. But you can get even better low frequency AC results, up to about 1kHz, using the so called Swerlein algorithm. You can reach about the same accuracy as with a thermal voltage converter, but at a much higher input impedance. Do some web search if you are interested in this software.

- the 3458A can very well be used as a null-meter. Analog null-meters are essentially obsolete these days (few exeptions, plus on the used market of course; here, the K155 is hard to beat), but some application such as e.g. calibrations using the Fluke® 752 precision voltage divider do require a nullmeter. The 3458A is very precise here. Use the setting for DCV precision measurements as described above. It has relatively low input current noise, making it usable also together with higher source impedances (such as e.g. the ® 752A). We have found it to be supperior in our applications to our state-of-the-art digital Nanovoltmeters.

- Many of these meters have now been in operation for about 20 years, and time has left its traces there. A regularly, but not continuously used, old meter may actually be a very good choice. Its voltage reference has cerainly settled and has become very stable. The problem is, you do not realy know what you get, until you have it. And it may also have hidden issues. See also further below regarding comments and recommendations for buying used 3458As.

- In any case, if you posess an older one, it should be submitted to preventive maintenance. This includes new NVSRAMs (the content of the old CAL NVSRAM should be read, if still working, and progammed to the new one). The fan filter should be cleaned (the old mesh one; this should be done on a regular basis anyhow, as otherwise dust collected in the mesh may increase the meter's inside temperature. Or you may even wish to replace that mesh filter against a newer version filter). In the newer CPU board, Snaphat batteries (2 pieces, yellow) are plugged into the SRAMs as backup batteries, these batteries should also be replaced. Although a date code is printed on, since the year data is single digit only, this info may be misleading. We do this replacement very carefully, while the meter is on, and thus the RAM data will be maintained. Avoiding to short any traces is key here, when the Snaphat batteries are removed and inserted, requiring more force than one would assume (and of course working on an open item under power requires the standard industry precautions such as an insulation transformer... work on open gear under power only if you have been properly trained to do so and know what you are doing!). The power inlet filters tend to blow up (we have seen many of these failing, and it can be ugly), and should be replaced before that happens. And when the meter is open, new bulk capacitors and new Y2 caps and a new fan are not a luxury. Also, if your firmware is old, you could consider upgrading the EPROMs. Service Note 12C gives details about the firmware revision history. Revision 8 is fine, essentially no relevant changes made in rev. 9, as can be read there. Also check your rev. numbers on the A/D, AC and CPU boards for fixes as per Service Notes 01, 06, 13. These require some simple modification, depending on the revision numbers of these boards. Make yourself familiar with all service notes, and check if they are relevant to you.

- The 3458A achieves its high accuracy by digital calibration, which needs to be done on a regular basis. The instruction is ACAL. You need to do this at least every 24 hours, or if the temperature (inside the unit!; TEMP?) has changed by more than 1K. If you only want to measure DCV, ACAL DCV is sufficient. Other subgroups are available. ACAL ALL is pretty time consuming (about 12 minutes). People often forget to use this routine on a regular basis, and thus loose accurcy. Note that under certain conditions, initiating ACAL AC from 4-wire ohms mesurements (OHMF) may result in errors, see Service Note 17 for details. Delete all errors, switch to ACV, and rerun ACAL AC if this occurs.

- In Service Note 18A, issues with drift are mentioned. This covers two causes of drift, in two components, the voltage reference board, and the A/D converter board. While the described drift rate of the voltage reference board can be healed by operating (aging) the reference (i.e. the meter), the A/D drift cannot be healed. The meter should be switched on anyway on a regular basis (even if not needed), to ensure the reference is not reverting back to its original voltage (the references are aged by the manufacturer before installation). Long periods of leaving the meter off may adversly affect the reference drift rate, and you would need some time (no more than 6 weeks according to the manufacturer) to get it back to where it was. Part of the issue is that the heated reference inside is operated at a high temperature, about 95°C, normal would be arround 60°C. This is due to the overall environmental spec of the 3458A, which was probably also driven by military requirements. The operating temperature can be decreased to a lower level by adding a resistor on the reference board assembly, but this changes the maximum operating temperature of the meter and a new calibration is needed as well. On a side note, the specification does not say anything about how much / how long the meter needs to be on to maintain its specified voltage reference drift.

- But as far as drift is concerned, the real problem is the A/D board drift. If you have that (use the procedure in SN 18A to find out, leaving the meter on for a week; follow exactly the instructions; do not use a shorter period), you need a new A/D board (a 4-digit number in costs, plus calibration costs). The failing part responsible for that drift is not available. We have seen meters that drifted some 10 ppm per day, 0.43ppm is acceptable!

- A word of caution here when buying used 3458As: if you intend to buy a used meter, the fact that it passes selftest, and measures 10V accurately after ACAL means nothing. You may still have a unit with a drifty A/D board. Or you can have other problems. Spare boards are expensive, turning a cheap buy quickly into a nightmare. Many parts are selected and not available for purchase, or are obsolete. Now if the said drift rate is e.g. below 1ppm/day, you can still use the meter, you just need to perform ACAL more often, which corrects for drifts (or add 0.57ppm of uncertainty to the meter results for this example). But beyond a certain point, you get outside of a practical usabilty, or you even get outside ACAL to fix the problem. So if you buy such a meter used, ask for that drift. Ask for proper operation in all ranges. Preferably, ask for a cal certificate. If the seller does not know, or cannot tell you, our recommendation would be: hands off.

- Throughout the years, the firmware revision has increased, to now current version 9. Version 8 is good too (minor differences to V9), and some even older ones are ok as well for practical use (Service Note 12C summarizes details, so check for your purposes). Replacement EPROMs (both the single as well as the 'six-pack' EPROMs) are available from the manufacturer.

- Executing CAL? 2941 shows the number of so-called 'destructive' events. It is a hidden feature, and there is nowhere a mentioning what it actually covers or means. We have seen well working meters, well in cal, which had 3-digit numbers of such events. We also believe that the manufacturer will not exclude such meters from warranty-extension, so we doubt anything meaningfull can be derived from it. We have not seen any used meter which had zero events.

- When you have your meter adjusted, (10V, 10k, through its internal artifacts calibration mechanism), a performance verification needs to follow, checking everything is within spec. The US military has analyzed artifacts calibration, and there is e.g. guidance out there that verification is needed only every second time. It's up to you to decide. Verification, as per Calibration Manual, does anyway not cover verification of ACI and ACV in SYNC mode, most likely because verifying this is pretty hard, and because by design, if everyhting else works to spec, these two work as well. It is not easy to verify a 3458A after adjustment, and there are cal labs out there that use unsuitable means (calibrators...) to do that. How could you e.g. use a Fluke® 5520 for this? Even a Fluke® 5730 has its challanges, Fluke® has published a document about the related details. Therefore, we do not just use a calibrator, but other standards (voltage, resistance) to do the verification. This involves much manual work, and is not as convenient as just connecting a calibrator and run a software, but it pays off. And keep in mind, a calibration, when done in a cal lab, ususally is to K=2, i.e. 95% probability, so the likeliness of a meter being out of spec, but still passed verification, is still 5% (or vice versa)!

- Setting NPLC to multiples of 10 (NPLC 100 or 200 is usual for precision measurements), the meter is actually doing 10 / 20 measurements with NPLC10 internally and creating the average. This may insofar be of relevance, as some standards (e.g. the 1605A Thermal Transfer Standard) require multiple measurements averaged over a certain time, so just set the NPLCs to the appropriate value and do one measurement, thats it, the 3458A does it properly.

- Some meters may not show a good 0 when doing OHMs (not OHMSF) measurements (or a zero CAL failure). In such cases, the problem may be related to bad crimping in the cabling between binding posts and input posts on the input board. The front/rear switch also has its issues sometimes.

- And there is also plenty of information on the web, so do some search if you are interested.