A Case Study In Characterizing & Disciplining Electrical Calibrator Instrumentation to Improve Test Accuracies & Measurement Uncertainties

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ABSTRACT

This paper examines a solution to the problem of insufficient accuracy of calibration sources used for dc & low frequency ac electrical voltage, resistance, and current calibration when the instruments being tested have an accuracy which approaches that of the calibrator. The solution lies in techniques of using higher accuracy precision measurement devices to characterize the calibrator and thereby improve the measurement uncertainties obtained in these tests.

Problem Statement: Quite often the accuracy of the most commonly used electrical calibrators is insufficient to adequately verify performance of the better performance test instrumentation. For example the higher precision 6½ digital multimeters that are commonly used in industry must be tested with signal accuracies that are better than the capabilities of the most commonly used calibrators. Laboratories equipped with these “better but not best” calibrators find they must
1) use a different and more accurate calibrator, or
2) develop the metrology techniques which provide the proper measurement uncertainties (or test specification ratios) to satisfy these better units to be tested, or
3) be forced to provide a limited calibration with less than desired quality.

Proposed Solution: Using the precision 8½ digit multimeters commonly found in metrology labs to characterize or discipline lesser accuracy calibrators is a method to source signals with improved accuracies and provide appropriate measurement uncertainties.

Benefit: A solution using improved metrology techniques with existing instrumentation is very attractive when compared to investing to replace a lab’s lesser performing calibrators. However, such accuracy enhancement techniques haven’t necessarily been rigorously studied. So many laboratories haven’t implemented these techniques due to a lack of understanding or technical support. This paper evaluates several techniques and methods used to obtain test accuracies that are more than sufficient to make proper tests of higher performance dmms.

Summary: This paper is a case study of metrology methods that offer improved accuracies and measurement uncertainties for the calibration of a precision 6½ dmm using a calibrator with some initial test ratios less than 2:1, and ending up with metrology where these tests have been improved to ratios of more than 4:1.

1.0 Introduction – the problem, a solution method, and its benefits

The continual improvements in test instrumentation can outpace the specified capabilities of existing calibrators. This causes a problem to confidently verify and certify this better grade of measurement instrumentation. The solutions for this problem are for laboratories to improve their calibration capabilities. This means to either acquire new calibrators with appropriate capabilities, or develop test methods that can properly do the required testing.

This paper examines different approaches that can be used to effectively improve accuracies/uncertainties of the existing calibration instruments found within the lab. This improvement is based on characterizing the actual performance of a calibration instrument rather than relying on its generic performance specifications.

Aiding in this task is the performance provided by high precision multimeters, those in the category often called 8½ digit dmms. These instruments assist in and simplify the process of improving accuracies/uncertainties for these calibrations. Such measuring instruments are readily available and can often be found in calibration and standards labs.

The benefits of using such methods are that calibration tests can be reliably done with existing instruments through using advanced metrology methods rather than replacing existing calibration instruments with those having a better specified performance. Such techniques provide for getting the maximum performance from present instrumentation with very reasonable investments of time and effort – and not resorting to general upgrading to a higher level of metrology instrumentation.

2. What is basis for performance characterization of a calibrator?

Calibrating/verifying a measurement instrument requires a stable, predictable, and accurate signal source. Hence a calibrator is used to provide such signals. Generally speaking, the calibrator's performance specifications describe those overall basic characteristics for signal accuracy (signal stability, predictability). However, because this generic specification of a calibrator applies to a huge population of instruments (it is not unusual to have a specification apply to multiple thousands of individual calibrators), the actual performance of an individual calibrator is much better than what is reflected in the generic specification. Usually the actual instrument uncertainty or error is one half to one third or even less of the total error allowed by the generic specification. (This is the philosophy and experience of Fluke as a provider of such calibration instruments.)

This buffer between actual performance of a particular instrument and its generic specifications is an important characteristic that becomes a potential advantage for the user of such calibration instruments. It is a fact such an improved specification applied to the calibrating standard can be used during routine calibration testing without degrading the confidence in the results of the testing.

With such an improvement in specifications, this problematic test instrument population that cannot be verified or calibrated using the calibrator's generic specification can easily be done using special and unique performance specifications based on the calibrator's characterized performance.

3. How can a calibrator be characterized to improve the working specification?

There are several methods that can be used to determine the working specifications of a calibration instrument. Each involves measurements of the calibrator so its actual performance can be characterized. These are:

1. **Real Time Characterization:** Use of additional instruments (with a better accuracy/uncertainty specification) to augment or assist the central calibrating instrument. In such a technique the accuracy/uncertainty of the test setting is know in a manner better than the generic performance calibrator specifications. This can be termed as disciplining a calibrator with a precision measurement instrument. In this way, the improved performance specifications of the added instruments, with additional considerations, form the basis of the better specification with lower overall instrumentation errors. In our study, using a high performance dmm (with a better specification than the calibrator) to measure and quantify the actual output from calibrator does this needed characterization.
2. **Long Term Drift Characterization:** Repeatedly evaluate the calibrator at frequent intervals to measure its actual error as well as the rate this error changes. Doing this for an appropriately long period of time at key operating settings will establish the actual long term drift of the calibrator at the critical test points. This known drift characteristic then replaces the standard accuracy specification for these points. For example, repeated testing of an instrument develops a characterized unit or "golden calibrator". This is a calibrator which has very well known performance characteristics. This known history is used to predict future trends which in turn function as a better set of specifications to apply to the calibrator.

This paper will examine approaches used in both of these areas.

4. Establishing a basis for studying the effectiveness of characterization.

The study is based on the real need to use a medium to high performance calibrator to verify a new high performance digital multimeter. However this concept can be applied to other existing calibration standards and to the test and measurement instruments which require certification.

To illustrate this concept in a practical scenario, we used the 90 day specifications of a Fluke 8846A Precision Digital Multimeter as the unit being calibrated. This is the latest instrument in the area of 6½ dmms whose performance specifications are best in class and represent the more difficult specifications to verify. In turn we will use the 1 year absolute specifications of the Fluke 5520A Multiproduct Calibrator for considering performance characterization. It is the calibration instrument most widely used in industry in the medium/high accuracy performance class. It is capable of verifying some, but not all of the 8846A's parameters with calibrator's 1 year specifications and achieving an acceptable level of accuracy/uncertainty.

The analysis we have done in this case study is of the 8845A verification specification. (This includes many points, approximately 130 points for this particular UUT for all ranges and functions.) But, we have limited the study to the functions of voltage and resistance. These are the most commonly used functions in dmms and it covers well the intent of this topic for this paper.

Table 1 shows a comparison of the Fluke 5520A 1-year specification to the Fluke 8846A 90-day specification. The table represents a subset of the actual verification test points used to verify the 8846A – the 27 points in the voltage and ohm functions where the specification ratios between the calibrator and UUT are less than desired. As can be seen, these test specification ratios are below the 4:1 expected for precise verification. (Only the 1 G ohm range is particularly poor even with the assistance of the 8508A). It is clear that without characterization by another standard, the 5520A, at least for these test points, is not adequate.

Table 1: 8846A versus 5520A Specifications.

Function		Nominal	Frequency	5520A 1-year specification	8846A 90-day specification	8846/5520A Ratio	Comments
4WR	Ohms	10		0.0014	0.0038	2.71	Assume zero 5520A at beginning of each day.
4WR	Ohms	100		0.0042	0.012	2.86	
2WR	Ohms	1.0E+6		34.00	90.00	2.65	5520A 4-W connection at 8846A terminals
2WR	Ohms	10.0E+6		1350.00	2100.00	1.56	
2WR	Ohms	1.0E+9		15.5E+6	1.6E+6	0.10	
DC	V	0.1		0.000003	0.000006	2.00	
DC	V	-0.1		-0.000003	-0.000006	2.00	
DC	V	1		0.000013	0.000025	1.92	
DC	V	-1		-0.000013	-0.000025	1.92	
DC	V	5		0.00008	0.000115	1.44	
DC	V	-5		-0.00008	-0.000115	1.44	
DC	V	10		0.00014	0.00023	1.64	
DC	V	-10		-0.00014	-0.00023	1.64	
DC	V	100		0.00195	0.0033	1.69	
DC	V	-100		-0.00195	-0.0033	1.69	
DC	V	1000		0.0195	0.041	2.10	
DC	V	-1000		-0.0195	-0.041	2.10	
AC	V	0.1	10	0.000038	0.00009	2.37	
AC	V	1	10	0.00035	0.0008	2.29	
AC	V	10	10	0.00365	0.008	2.19	
AC	V	100	100000	0.25	0.68	2.72	
AC	V	750	45	0.235	0.6	2.55	
AC	V	750	1000	0.1975	0.6	3.04	
AC	V	750	1200	0.1975	0.6	3.04	
AC	V	750	10000	0.235	0.6	2.55	
AC	V	1000	45	0.31	0.8	2.58	
AC	V	1000	10000	0.31	0.8	2.58	

5. What improvements can be expected with Characterization?

5.1 Improvements using real time characterization?

In our study, the real time characterization process uses a high accuracy dmm to measure the output of the calibrator. The dominant influencing factor of any accuracy/uncertainty improvement is the measurement capability of the high accuracy dmm. Secondly, as the goal is to improve the calibrator to be adequate versus the unit being tested (UUT), the best indicator of improvements is to compare the specification of the precision dmm to the specification of the UUT. This analysis is done for the required test points identified earlier.

Table 2 shows a comparison of the Fluke 8508A 1-year specification to the 8846A 90-day specification at the 27 points where the 5520A test specification ratios with the 8846A do not meet a 4:1 ratio. It is clear from the table that using the 8508A to correct for the 5520A calibrator output in real time would be a viable solution for all but the 1 G ohm range. For that case, we will need another standard such as Fluke 1 G ohm resistor.

Table 2: 8846A specs versus 8508A specifications at the low test ratio test points.

Function		**Nominal**	**Frequency**	**8508A 1-year specification**	**8846A 90-day specification**	**8846/8508 Ratio**	**Comment**
4WR	Ohms	10		0.0000825	0.0038	46.06	8508A 4W Normal I
4WR	Ohms	100		0.00102	0.012	11.76	8508A 4W Normal I
2WR	Ohms	1.0E+6		9.50	90.00	9.47	
2WR	Ohms	10.0E+6		250.00	2100.00	8.40	
2WR	*Ohms*	*1.0E+9*		*2.01E+6*	*1.6E+6*	*0.80*	
DC	V	0.1		0.00000055	0.000006	10.91	
DC	V	-0.1		-0.00000055	-0.000006	10.91	
DC	V	1		0.0000037	0.000025	6.76	
DC	V	-1		-0.0000037	-0.000025	6.76	
DC	V	5		0.0000185	0.000115	6.22	
DC	V	-5		-0.0000185	-0.000115	6.22	
DC	V	10		0.000037	0.00023	6.22	
DC	V	-10		-0.000037	-0.00023	6.22	
DC	V	100		0.00057	0.0033	5.79	
DC	V	-100		-0.00057	-0.0033	5.79	
DC	V	1000		0.006	0.041	6.83	
DC	V	-1000		-0.006	-0.041	6.83	
AC	V	0.1	10	0.000016	0.00009	5.63	
AC	V	1	10	0.000125	0.0008	6.40	
AC	V	10	10	0.00125	0.008	6.40	
AC	V	100	100000	0.067	0.68	10.15	
AC	V	750	45	0.10125	0.6	5.93	
AC	V	750	1000	0.10125	0.6	5.93	
AC	V	750	1200	0.10125	0.6	5.93	
AC	V	750	10000	0.10125	0.6	5.93	
AC	V	1000	45	0.135	0.8	5.93	
AC	V	1000	10000	0.135	0.8	5.93	

Assume +/- 5C max temperature variation

5.2 What improvements can be expected through long term characterization?

As stated earlier, an individual calibrator performs well within its overall specification. With a specification based on the philosophy used by Fluke calibrators, a calibrator is commonly performing within one half to one third of its allowable specification accuracy/uncertainty.

This will vary instrument to instrument, so it is not possible to have a general method to quantify the improvements without making repeated measurements on the individual calibrator in question. So we evaluated three different instruments to obtain a general indication of what improvements could be achieved.

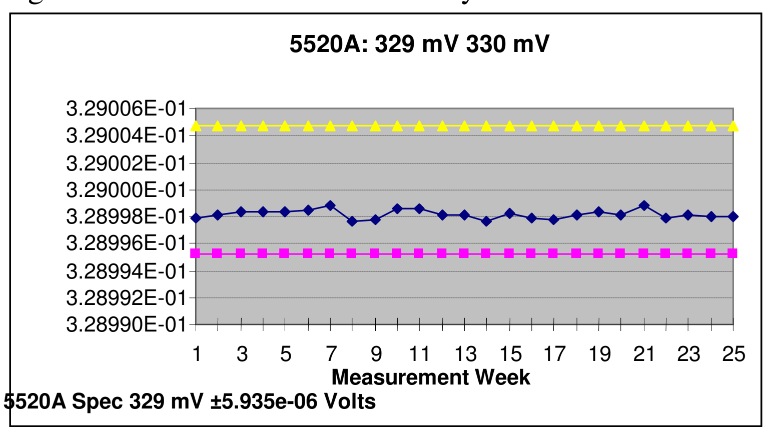
Also, the time interval of the effective characterization is important. It will determine how often it will be needed to verify and re-characterize the calibrator. For comparison purposes we used three periods of time where we routinely tested the calibrator's key operating points. These periods were:

1. Testing daily for approximately one month
2. Long term weekly testing for approximately 14 to 25 weeks

Such testing provided data for a calibrator's actual drift/stability characteristics for time periods including daily, weekly, and monthly intervals.

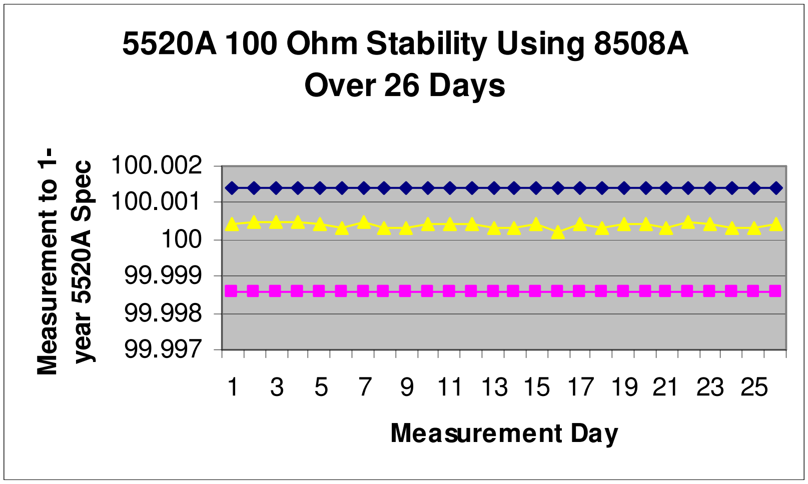
To illustrate the characterized weekly stability of the 5520A Calibrator, Figure 1 shows the stability at 329 millivolts dc as measured in the Fluke Standards Lab. As a graphical example of the data collected, it shows the data for the 25-week test results at 329 millivolts dc. The upper and lower bars in the graph represent the limits of the specifications for the 5520A.

Figure 1: . 5520A Collected Stability Data Over 25 Weeks.



In a separate test, another 5520A was measured daily by an 8508A to determine variation in output values. Figure 2 shows the results for 100 ohm measurements made over 26 working days.

Figure 2: 5520A Data Collected over 26 Days.



Both graphs illustrate the characteristic of actual long term stability for an individual instrument is much better than the generic specification. The take aways from these experiments are:

1. Individual calibrators show excellent stability, well within their specification
2. It is possible to routinely measure and characterize the actual stability of the calibrator
3. The day to day, week to week, and month to month stability are very consistent, so a calibrator can be evaluated for its unique predictability to a characterized performance much better than its actual specification.
4. It is definitely possible to develop and specify the performance of a "golden calibrator" – that is one whose individual performance at key points known and useable for metrology where the standard specification is not adequate.

6.0 An Overview Of Both Methods Used To Characterize Calibrators

Both methods of characterization will serve to provide a basis for improved accuracies/uncertainties to address the subject workload. Details for each process follow.

6.1 Method 1 – Real Time Calibrator Characterization (or disciplining a calibrator)

This method uses a high precision digital multimeter (specifically in our experiments, the 8508A Reference Multimeter) to be connected to the calibrator in parallel with the 884X UUT. It measures the actual signals applied to the UUT. Effectively the dmm's measurement defines the basic uncertainty of the measurement and the dmm is the calibrating standard. The calibrator in effect is a stable, precision source, but is not used for determining the accuracy of the test signal.

This measurement technique can be used with all UUT tests that can be measured with the reference dmm. With active stimulus test signals, such as calibrator sourced voltage measurements, it is an actual dual & simultaneous measurement process where both the UUT and reference dmm are simultaneously connected to the sourced test signal and make nearly simultaneous measurements. This means the precision dmm's measurement of the test setting can be considered to be the actual value as applied to the UUT (to within the specification of the reference multimeter). It measures the calibrator's output more accurately than the spec of the calibrator and the measurement itself is the traceable value used for the UUT verification.

However when a passive parameter, such as resistance, is tested, it is usually more complex and requires other considerations. In measuring a passive parameter, the measurement device (in this case, either UUT or reference dmm) stimulates the calibrator's resistance with a very defined and known signal then measures the response. (For example a precision current is applied to the resistance and the voltage drop across the resistance is measured to calculate resistance.) Because of this methodology, simultaneous measurements by two instruments on the resistor are impossible. The stimulus signal of each measurement device would interfere with the other devices stimulus signals. So each measurement must be done separately without simultaneous connections. Therefore additional considerations for the short term stability of the calibrator at a given output setting must be made. At one point of time the first measurement device measures the resistance and then some time later (a varying amount of seconds or minutes) the second measurement device makes a similar but different measurement of the same resistance.

For the real time characterized measurement process this means the overall instrumentation related uncertainty of the measured resistance is a combination of the precision dmm measurement value and the short term stability calibrator supplying the resistance. (It is important to note that the resistance value generated by the calibrator is not totally passive, it is also partially electronic in nature – so the effects of short term stability are more of a consideration.)

Evaluating the Short Term Stability of the Calibrator – For resistance calibrations, the short term stability of resistance value was evaluated. Simply speaking, the process was to evaluate resistance stability over a several minute interval. The interval selected (in our case it was three minutes) represents a period that practically covered the time needed for individual calibration tests. We made repeated measurements over the period to determine the variation seen during this time, then we repeated this test ten times, in order to include any possible variation between different 3 minute intervals. Between each three minute interval we switched the calibrator's output in and out of standby, so any operate/standby/operate influenced variations would also be captured. This gave us a measurement set in excess of 100 measurements. We then statistically analyzed the data for the standard deviation, and expanded it to an appropriate coverage factor.

The measurements were done with an 8508A reference multimeter. The short term stability of the meter is also in this same order of magnitude, and it works well to measure the stability. In fact using the measurements as taken would conservatively over estimate the short term instability of the calibrator as the dmm instability is also included in this measurement.

For reference, our experiments showed that the measured short term stability on a 5520A at various resistances is substantially less than the specification. Experimentally it has been demonstrated at 100 ohms that the short term stability over three minutes was less then ±0.3 μΩ/Ω, with a 99% confidence level. The following table compares the demonstrated stability to the specifications of the other instrumentation related in this paper.

Table 3: Comparison of instrumentation uncertainties considered in real time characterization.

Calibration Test Value	UUT: 8846A (90 day Specification)	Calibrator: 5520A (1 year Specification)	Calibrator's Tested 3 Minute Stability	Ref DMM: 8508A (1 year Specification)
10 volts	±23.0 µV/V	±14.0 µV/V	not required	±3.7 µV/V
100 ohms	±120.0 µΩ/Ω	±42.0 µΩ/Ω	±0.3 µΩ/Ω	±10.2 µΩ/Ω
10 volts 10 Hz	±800.0 µV/V	±365.0 µV/V	not required	±125.0 µV/V

This short term stability is dependent upon the individual calibrator, and it is very consistent over time. This stability could be periodically checked on a regular basis – say the normal calibration interval of the calibrator.

Determining the Uncertainty of the Real Time Characterized Measurement – From the preceding table it can be seen that for UUT testing at 10 volts, the UUT spec of ±23.0 µV/V cannot be reasonably verified by the ±14.0 µV/V specified performance of the 5520A calibrator. But with the applied calibrating voltage value being measured by the 8508A with an uncertainty is specified at ±3.7 µV/V. So with the applied test voltage being measured to approximately ±3.7 µV/V, it is more than adequate to verify the ±23.0 µV/V performance of the UUT. In this case there was an improvement in accuracy/uncertainty by a factor of more than three (3.7 µV/V, as compared to 14.0 µV/V).

Similarly it can be seen that for testing at 100 ohms, the UUT spec of ±120.0 µΩ/Ω cannot be reasonably verified by the ±42.0 µΩ/Ω specified performance of the 5520A calibrator. But with a test resistance value measured by the 8508A to an accuracy/uncertainty of ±10.2 µΩ/Ω, combined with the stability of the resistance value at ±0.3 µΩ/Ω the overall uncertainty is more than adequate to verify the ±120.0 µΩ/Ω performance of the UUT. (However, it is interesting to note that at this particular test point the uncertainty due to the calibrator stability is so small as not contributing a significant added uncertainty compared to the reference dmm.) This characterization method improved the accuracy/uncertainty by a factor of more than four (10.2 µV/V compared to 42.0 µΩ/Ω).

Summary of Real Time Characterization

Real time characterization is a method where using calibrator as a stable source, in conjunction with a higher accuracy reference multimeter, to verify/calibrate precision multimeters. It requires augmenting the use of additional instrumentation during the test to provide a better uncertainty for the required test points. It does not require much additional evaluation on the calibrator other than examining the unspecified parameters such as short term stability – when testing passive parameters such as resistance. It does improve the uncertainties up to the extent of the performance of the reference multimeter.

One of the drawbacks of this technique is that the 8 ½ digit dmm cannot be used for other lab work while it characterizes the 5520A in real time. The next method solves that draw back.

6.2 Method 2 – Long Term Drift Characterization

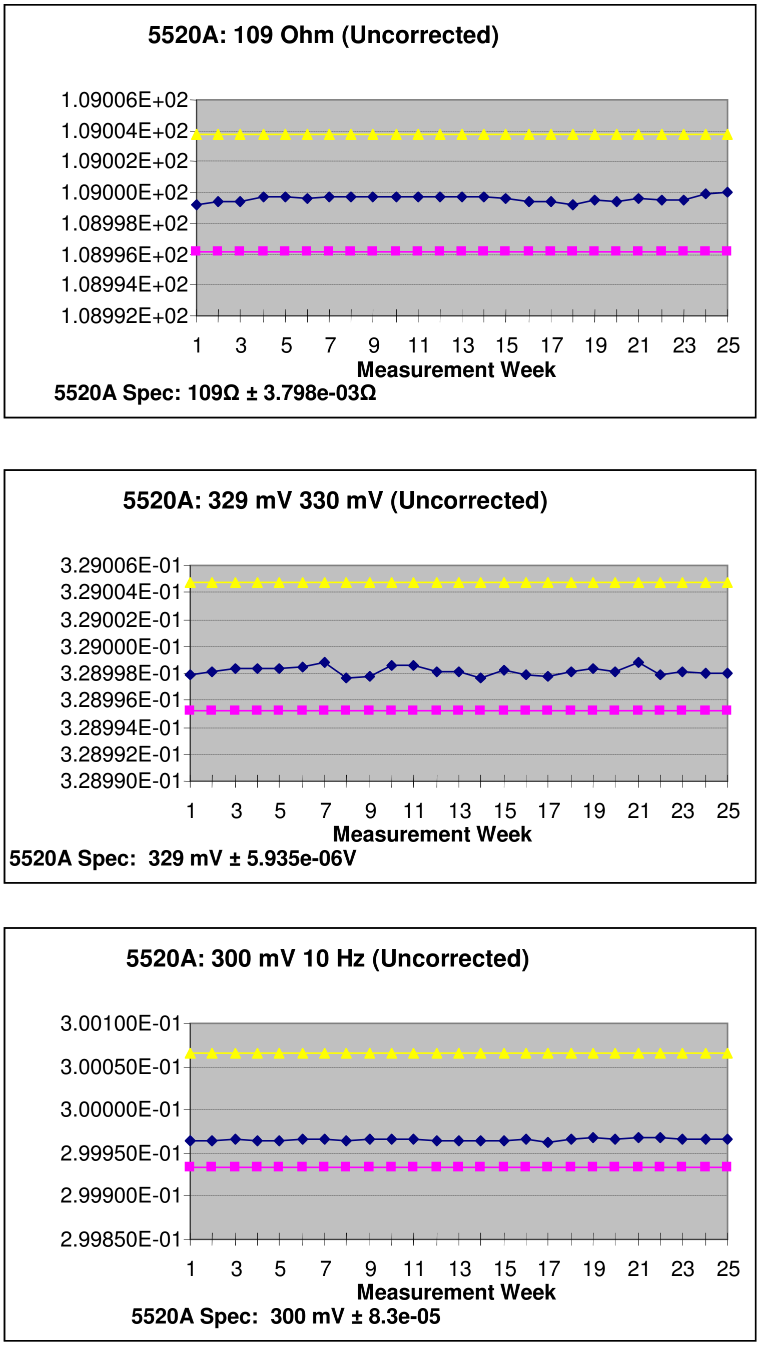
This technique takes advantage of a "golden calibrator", one that has been extensively measured and whose performance is well known. It is known to the extent that its unique drift characteristics have been identified and demonstrate a better drift than those reflected by the calibrator's standard, generic specifications. It should be noted that a "golden calibrator" is not necessary a better calibrator, but merely a characterized one. As shown earlier, it is highly likely that any single calibrator will be significantly better (with less errors), than what is detailed in the generic specification. The method to determine this is one where the calibrator is regularly measured and the history of its changes over time are available. Its particular outputs are calibrated, and periodic recalibration establishes its long term drift and stability.

The measuring process is simple enough – use instrumentation with sufficient accuracy to prove performance that is two to four times better than the calibrator's standard specification. In this case a multimeter with 8½ digits of resolution and an appropriate accuracy is convenient. It can make the measurements quickly, easily, and can be automated. Of course more exacting and precise measurements can be done (such as manual measurements with standards, dividers, bridges, etc.), but the uncertainty/accuracy improvement is not worth the effort

This process requires the characterization of the calibrator stability over time. The operator must save the stability as an uncertainty factor. Secondly, the operator must characterize the absolute output of the calibrator using a precision dmm and save that value. The total uncertainty of the calibrator's characterized output value becomes the measured stability of the calibrator plus the specified error of the dmm. As shown in Table 2, most of the measurements done by the 8508A are about 5 to 10 times better than the test requirement of the UUT.

Evaluating the Long Term Stability of the Calibrator – To determine the stability of the 5520A Calibrator, we ran several experiments. The Fluke Standards Lab checked two 5520As once a week and deltas from nominal were recorded. One 5520A was checked for 25-weeks and a second was checked for 14-weeks. As a graphical example of the data collected, Figure 3 shows the data for the 25-week test results at 100.9 ohm, 329mVdc, and 300mV 10 Hz. Uncorrected means that the results were measured against internal Fluke Standard Lab instruments with no modification made to the measured data. A summary of the results collected for the measurement data is shown in Appendix A. The upper and lower bars in the graph represent the limits of the specifications for the 5520A.

Figure 4: 5520A Stability Data Over 25 Weeks.



Calculations – While the averages were different among the 5520As due to the values used, the calculated standard deviations were 210 μΩ for the daily measurement versus 523 μΩ for the 26 week unit and 281 μΩ for the 14 week, respectively. These values are considerably less than the 5520A 1-year specification of 4 mΩ. See Appendices A and B for a summary of the data collected on the 5520As.

The above charts indicate the stability of the output of the calibrator. This long term stability is well within the overall specification limits. The next question to consider is how can a lab efficiently create their own history on their calibrator in order to characterize the stability?

Using a DMM for Characterizing a Calibrator – While the long term testing was done in the Fluke Primary Standard's Lab using a variety of instruments, it is not a necessity to use such an elaborate system. In a separate test, a third 5520A was characterized by an 8508A daily to determine variation in output values, positioned earlier in this paper. Figure 2 shows the results for 100 ohm measurements made after 26 working days. A summary of the results collected for the entire measurement data is shown in Appendix B. Note that for all data collected, temperature varied no more than 23 +/- 5 ^{o}C max and measurements were made using leads with low thermal emf connectors and Teflon insulating material.

Using good measurement techniques, it is simple for a precision dmm to measure a calibrator. It is a process that is straight forward and repeatable, so it lends itself to automation. So a large variety of output settings can be measured in a simple setup, and it can be repeated on a regular basis over time. In our case it took less than 15 minutes to do a daily test of approximately 30 different calibrator settings. Our results were more than sufficient for developing the drift history of these critical UUT calibration points.

With the demonstrated week to week stability, as well as the day to day stability, characterizing a calibrator could be done with daily tests over a period of as little as one month, and then routinely checked thereafter at a longer intervals of several weeks to a month. The specifics would be dependent upon the tested stability of the calibrator and the requirements of the UUT.

Determining The Overall Uncertainty – Using a dmm to measure a calibrator to determine the long term stability requires considering both the calibrator's measured stability and the accuracy/uncertainty of the dmm.

Table 4 shows a summary of the data collected from the 5520A with the 8508A and 8846A specifications. We have two choices for how to combine the 5520A and 8508A information. Firstly, if we add the 5520A stability uncertainty directly to the 8508A specification, we will generate a conservative set of uncertainties. If we RSS the uncertainties, we will have a different and slightly less conservative set of uncertainties. Your choice may depend on the risk your lab is willing to take with regard to a unit escaping with a bad adjustment point.

Table 4: 5520A Measurements Compared with 8508A and 8846A Specifications.

Function		Nominal	Frequency	Measured 5520A Stability (2.58-Sigma)	8508A 1-year specification	8846A 90-day specification
4WR	Ohms	10		4.00E-05	0.0000825	0.0038000
4WR	Ohms	100		2.10E-04	0.0010200	0.0480000
2WR	Ohms	1.0E+6		5.99E+00	9.50	90.00
2WR	Ohms	10.0E+6		3.47E+02	250.00	2100.00
DC	V	0.1		1.92E-07	550.0E-9	6.0E-6
DC	V	-0.1		3.20E-07	-550.0E-9	-6.0E-6
DC	V	1		1.33E-06	3.7E-6	25.0E-6
DC	V	-1		1.30E-06	-3.7E-6	-25.0E-6
DC	V	5		4.60E-07	18.5E-6	115.0E-6
DC	V	-5		9.50E-06	-18.5E-6	-115.0E-6
DC	V	10		1.22E-05	37.0E-6	230.0E-6
DC	V	-10		1.21E-05	-37.0E-6	-230.0E-6
DC	V	100		1.21E-04	570.0E-6	3.3E-3
DC	V	-100		1.33E-04	-570.0E-6	-3.3E-3
DC	V	1000		1.64E-03	6.0E-3	41.0E-3
DC	V	-1000		8.44E-04	-6.0E-3	-41.0E-3
AC	V	0.1	10	4.86E-06	16.0E-6	0.00009
AC	V	1	10	6.42E-05	125.0E-6	0.0008
AC	V	10	10	7.00E-04	1.25E-3	0.008
AC	V	100	100000	4.03E-03	67.0E-3	0.680
AC	V	750	45	1.48E-02	101.25E-3	0.600
AC	V	750	1000	9.641E-3	101.25E-3	0.600
AC	V	750	1200	8.846E-3	101.25E-3	0.600
AC	V	750	10000	8.394E-3	101.25E-3	0.600
AC	V	1000	45	26.486E-3	135.0E-3	0.800
AC	V	1000	10000	12.696E-3	135.0E-3	0.800

Table 5 shows the results of both of those methods. Adding the 8508A specification directly to the 5520A stability measurements is shown in the Sum column. Root sum squaring the 8508A specification with the 5520A stability measurements is shown in the RSS column. A ratio of those values to the 8846A specification is then calculated. In either case, we still maintain a test specification ratio of better than 4:1 for the values shown.

Table 5: Ratio of Sum and RSS methods to 8846A Specification.

Function		Nominal	Frequency	Sum of 8508A+5520A Stability	RSS(8508A with 5520A Stability)	Sum Ratio to 8846A Spec	RSS Ratio to 8846A Spec
4WR	Ohms	10		1.23E-04	9.17E-05	31.02	41.44
4WR	Ohms	100		1.23E-03	1.04E-03	39.01	46.09
2WR	Ohms	1.0E+6		1.55E+01	1.12E+01	5.81	8.01
2WR	Ohms	10.0E+6		5.97E+02	4.28E+02	3.52	4.91
DC	V	0.1		7.42E-07	5.83E-07	8.09	10.30
DC	V	-0.1		8.70E-07	6.36E-07	6.90	9.43
DC	V	1		5.03E-06	3.93E-06	4.97	6.36
DC	V	-1		5.00E-06	3.92E-06	5.00	6.38
DC	V	5		1.90E-05	1.85E-05	6.07	6.21
DC	V	-5		2.80E-05	2.08E-05	4.11	5.53
DC	V	10		4.92E-05	3.89E-05	4.68	5.91
DC	V	-10		4.91E-05	3.89E-05	4.68	5.91
DC	V	100		6.91E-04	5.83E-04	4.77	5.66
DC	V	-100		7.03E-04	5.85E-04	4.70	5.64
DC	V	1000		7.64E-03	6.22E-03	5.37	6.59
DC	V	-1000		6.84E-03	6.06E-03	5.99	6.77
AC	V	0.1	10	2.09E-05	1.67E-05	4.32	5.38
AC	V	1	10	1.89E-04	1.41E-04	4.23	5.69
AC	V	10	10	1.95E-03	1.43E-03	4.10	5.58
AC	V	100	100000	7.10E-02	6.71E-02	9.57	10.13
AC	V	750	45	1.16E-01	1.02E-01	5.17	5.86
AC	V	750	1000	1.11E-01	1.02E-01	5.41	5.90
AC	V	750	1200	1.10E-01	1.02E-01	5.45	5.90
AC	V	750	10000	1.10E-01	1.02E-01	5.47	5.91
AC	V	1000	45	1.61E-01	1.38E-01	4.95	5.82
AC	V	1000	10000	1.48E-01	1.36E-01	5.42	5.90

When comparing the data from the different 5520As, the data is stable. It does not require a leap of faith to allow us to accept that in a 24-hour period, the unit changes by a measurable but low value compared to the specifications of the 8846A. Depending on your labs level of acceptable risk, you may decide to extend the stability to a longer interval than 1 day. Using either a direct sum of the 8508A specification to the measured 5520A stability or root sum squaring the values together indicates that the test specification ratios are greater than 4:1.

Summary of Long Term Stability Characterization:

We have shown that long term stability characterization of a source by a precision DMM can compensate for low test specification ratios between the unit under test and the source. This characterization can be limited to once a day or even longer if sufficient data is collected to show stability of the source and if the longer period also factors in the risk of a bad standard being caught before use. One advantage of this method is that the 8 ½ digit dmm is available for other tasks after the daily characterization is complete.

7.0 Conclusion

In conclusion, we have seen that characterization of the actual errors of a calibrator will work to improve the uncertainty/accuracy of a calibrator. This permits the calibrator to be used for calibrating/verifying better and more accurate test instruments. If a lab relies on the general specifications of the calibrator alone, such calibrations are not possible.

Two methods of characterization are studied. One measures the true output of the calibrator during use and uses this real time data as a correction basis for improved accuracy/uncertainty. , The other measures the true out of the calibrator over time and with this history develops correction factors with improved specifications. These improved specifications allow for use with better specifications. The following table compares example specifications using both techniques, and compares them to the test specification, and the generic calibrator specification. The Test Specification Ratios (TSRs) are also shown.

Table 6: Example Improvements In Calibrator Specifications Using Characterization.

Calibration Test Value	UUT Test Specification	non characterized calibrator spec	Calibrator's TSR	Example spec with long term characterization with dmm	Example spec using real time characterization by dmm	Best TSR
10 volts	±23.0 μV/V	±14.0 μV/V	1.6:1	±4.9 μV/V	±3.7 μV/V	> 6:1
100 ohms	±120.0 μΩ/Ω	±42.0 μΩ/Ω	2.86:1	±12.3 μΩ/Ω	±10.2 μΩ/Ω	> 11:1
10 volts 10 Hz	±800.0 μV/V	±365.0 μV/V	2.2:1	±195.0 μV/V	±125.0 μV/V	> 6:1

Both methods rely on the use of a precision dmm to measure the calibrator and develop the correction factors with improved accuracies/uncertainties. Because this is a commonly available and used instrument in calibration labs, these methods can be used on a broad basis throughout the metrology industry to extend the workload of electrical calibrator instruments. In considering using either method, different considerations need to be understood and taken into account.

Table 7 compares different usage and support considerations for both of the two methods.

Table 7: Usage And Support Considerations For Calibrator Characterization.

	Real Time Characterization	Long Term Characterization
Usage Requirements For The Precision Dmm	The DMM is used with the calibrator during all calibrations needing improved accuracies. This is additional instrumentation for this workload class.	The DMM is only used during the initial characterization process and for routine recalibration. Otherwise the calibrator alone addresses the workload
Basis For Improved Uncertainty/Accuracy Of The Working Calibration Instrumentation	The working instrumentation uncertainty is dominated by the dmm specification in most functions. Calibrator short term stability factors are a consideration in only some passive parameters such as resistance	The working instrumentation uncertainty is a combination of both the characterized long term uncertainty of the calibrator, plus the overall uncertainty of the dmm. This is somewhat less accurate than the real time method
Calibration Procedure Complexity Considerations	The calibration test procedure is more complex as it requires an additional real time measurement of the calibrator applied with corrections for every test.	The calibration test procedure is as simple as using a traditional calibrator. There needs only to apply the improved uncertainty to the test value..
Impact On Calibration Testing Time	Because of measuring each output setting with the dmm the test routine is slower than the traditional method, possibly twice as long.	The test routine is as fast as traditional methods as the calibrator has the appropriate accuracy/uncertainty to test the UUT efficiently.
Metrology Work Required To Support Characterization	The routine calibration procedures need to be written to support this real time characterization. The calibrator and dmm do not need any special metrology support beyond what is considered normal	Metrology needs to initially characterize the calibrator and routinely recertify the improved characteristics. The calibrator becomes a special standard and is uniquely supported as such
Managing The Special Uncertainty And Corrections	Accuracy/uncertainty is based on the measurement ability of the dmm. Additional stability corrections are only needed on a few specific test points	Requires the use of a correction table with specific points and specific improved uncertainties.

Appendix A: Summary of Stability Data for 5520As

Table 8: The test results for the 25 week and 14 week tested 5520A instruments.

Function		Nominal	Frequency	5520A 25 Week Average (SN7175203)	5520A 2.58-sigma (SN7175203)	5520A 14 Week Average (SN7175203)	5520A 2.58-sigma (SN7175203)
4WR	Ohms	10.9		10.90014	100.7533E-6	10.89997	104.7656E-6
4WR	Ohms	109		108.9995	522.9663E-6	109.0001	281.2102E-6
2WR	Ohms	1.09E+6		1.089986E+6	5.30422	1.090006E+6	2.62210
2WR	Ohms	10.9E+6		10.89974E+6	71.0477	10.900031E+6	51.4584
2WR	Ohms	1.09E+9		1.09058E+9	1,970,070.0	1.090326E+9	815,312.5
DC	V	0.329		0.328998	868.99E-9	0.328999	713.766E-9
DC	V	-0.329		-0.328998	1.395E-6	-0.328999	1.379E-6
DC	V	1		0.999992	2.665581E-6	0.999999	4.600072E-6
DC	V	-1		-0.999997	3.73478E-6	-0.999997	3.69183E-6
DC	V	3.29		3.28998	7.79792E-6	0.32900	713.7656E-9
DC	V	-3.29		-3.28998	9.74938E-6	-3.28999	11.2171E-6
DC	V	10		9.99996	26.99295E-6	9.99999	41.05135E-6
DC	V	-10		-10.00000	30.65742E-6	-9.99999	33.2375E-6
DC	V	329		328.9995	784.313E-6	329.0002	875.399E-6
DC	V	-329		-328.9995	832.947E-6	-328.9995	932.313E-6
DC	V	1020		1019.999	2.294E-3	1020.005	2.712E-3
DC	V	-1020		-1019.998	2.5144E-3	-1020.006	3.0118E-3
AC	V	0.3	10	0.299953	4.32248E-6	0.299987	3.09834E-6
AC	V	3	10	2.99948	56.5077E-6	2.99958	23.1398E-6
AC	V	30	10	29.9955	411.956E-6	29.9972	383.673E-6
AC	V	200	100000	200.133	26.65382E-3	199.874	14.52324E-3
AC	V	1000	45	999.985	12.7276E-3	1000.116	6.93758E-3
AC	V	1000	1000	1000.022	13.0283E-3	1000.002	9.78124E-3
AC	V	1000	5000	1000.373	23.07232E-3	1000.003	11.92922E-3
AC	V	1000	8000	1000.981	49.154E-3	999.988	21.2465E-3

+/- 5C max temperature variation from calibration temperature

Appendix B: Summary of Daily Measurements of the 5520A by an 8508A

Table 9: The test results from testing a 5520A daily, using an 8508A.

Function	Nominal Output	Frequency	Units	Ave	Std Dev	2.58 Std Dev (99%)	Units
4WR	10		Ohms	10.00009615	15.5E-6	40.0E-6	Ohms
4WR	100		Ohms	100.0003769	81.5E-6	210.4E-6	Ohms
2WR	1.0E+6		Ohms	999998.0385	2.3	6.0	Ohms
2WR	10.0E+6		Ohms	10000251.15	134.5	347.0	Ohms
DCV	0.1		V	0.099999192	74.4E-9	192.1E-9	V
DCV	-0.1		V	-0.10000025	124.1E-9	320.2E-9	V
DCV	1		V	0.999996115	516.5E-9	1.3E-6	V
DCV	-1		V	-1.000000577	503.7E-9	1.3E-6	V
DCV	5		V	4.99998	178.4E-9	460.3E-9	V
DCV	-5		V	-5.000031538	3.7E-6	9.5E-6	V
DCV	10		V	9.999986923	4.7E-6	12.2E-6	V
DCV	-10		V	-10.00003692	4.7E-6	12.1E-6	V
DCV	100		V	99.99993077	47.0E-6	121.3E-6	V
DCV	-100		V	-100.0002231	51.4E-6	132.7E-6	V
DCV	1000		V	999.9941923	634.3E-6	1.6E-3	V
DCV	-1000		V	-999.9958846	327.3E-6	844.5E-6	V
ACV	0.1	10	V	0.09997925	1.9E-6	4.9E-6	V
ACV	1	10	V	0.9998765	24.9E-6	64.2E-6	V
ACV	10	10	V	9.998748077	271.2E-6	699.7E-6	V
ACV	100	100000	V	100.0317077	1.6E-3	4.0E-3	V
ACV	750	45	V	749.9616923	5.7E-3	14.8E-3	V
ACV	750	1000	V	750.0482692	3.7E-3	9.6E-3	V
ACV	750	1200	V	750.0523462	3.4E-3	8.8E-3	V
ACV	750	10000	V	750.0461154	3.3E-3	8.4E-3	V
ACV	1000	45	V	999.9607692	10.3E-3	26.5E-3	V
ACV	1000	10000	V	999.9761538	4.9E-3	12.7E-3	V

Max temperature variation +/- 5 C.