Artifact Calibration and Its Use in Calibrating 8.5 Digit DMMs

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Abstract

Verifying that an 8.5 digit digital multimeter's (DMM's) measurement performance is within its specification is not a trivial task. In dc and low frequency ac electrical metrology, the specifications are similar for both the DMM (measurement device) and the calibrator (source) used to verify it. Specified maximum measurement errors are typically on the order of 5 to 50 parts per million over various functions and ranges. When using an electrical calibrator as a source to calibrate/verify a precision DMM, the calibrator's performance must be at its best level with minimum uncertainties.

This paper examines how the Artifact Calibration capabilities of the Fluke Calibration 5700 Series of Precision Multifunction Calibrators can optimize the uncertainties for calibrating 8.5 digit DMMs. Topics include:

a. Review of the Artifact Calibration concept
b. Evaluation of Artifact Calibration's history as an effective method of maximizing a calibrator's performance
c. Performance improvements that Artifact Calibration offers over traditional periodic calibration with higher level primary standards
d. An approach using Artifact Calibration to make the calibration of 8.5 digit DMMs more efficient with improved confidence

The problem

High-performance electrical calibration sources of precision dc/ac voltage and current plus resistance (called calibrators in this paper) have very good specifications. These reflect small errors in their precision electrical outputs. Such calibrators supply the parameters necessary to verify and optimally adjust the functions and operating ranges of electrical measurement instruments (referred as digital multimeters or DMMs in this paper). DMMs, in turn, have varying levels of measurement performance, each with different amounts of inherent measurement errors. One key differentiator is categorized by the number of measurement value digits they supply. These digits are stated numerically as 3.5 digits, 6.5 digits or even 8.5 digits of resolution. A 3.5-digit DMM can measure with a measured value resolution of one part in several thousand. A 6.5-digit DMM can measure with a resolution of one part in several million. An 8.5-digit DMM can measure with a resolution of one part in several hundred million. The higher the resolution or precision of the measurement device, the higher the required performance level is of the calibrator used for its testing and calibration.

The challenge associated with this natural progression is that a calibration standard used to check a DMM needs to have specified performance of four to ten times better than the DMM being checked. This minimizes the effect of compounded errors shared between the calibrating standard and the unit under test (UUT). Confidence in the performance of the UUT is more reliable when the standard used to test it is at least four times better.

The numerical ratio of a calibration's performance specification versus the test specification of the UUT is commonly known as the Test Accuracy Ratio (TAR). The value of a test's TAR is considered a reliable measure of the test's quality. If the TAR is larger than four, then the various test's decisions on a UUT's fitness for use are deemed to be reliable. Tests with a TAR value lower than four to one typically require added analysis and extra care to ensure the correctness of the decisions regarding these tests.

Techniques do exist where the calibration of the best high resolution DMMs (8.5 digit classification of measurement capability) can readily be done by the best (similar performance) calibration sources--those also with 8.5 digits of sourcing capability.

The problem to be solved when using these techniques is that an 8.5-digit calibrator can reliably calibrate DMMs only up to a 6.5-digit performance level before the TAR ratios become marginal. Comparing the measurement specifications of both 6.5-digit and 8.5-digit DMMs to the sourcing specifications of the high performance calibrator, it is evident that the 8.5-digit DMMs require different or additional techniques. Table 1 illustrates several specifications of common 6.5-to-8.5-digit DMMs as compared to the calibrator's commonly used one-year specification. Some of the DMMs' specifications actually have smaller errors than those of the calibrator.

Example Cal. Points	Manufacturer's Specifications (parts in 10^6)					
	Popular 6½ & 8½ Digit DMMs					Calibrator
	Agilent 34401A (1 year)	Fluke 8846A (1 year)	Agilent 3458A (1 year)	Fluke 8508A (1 year)		Fluke 5730A (95% conf. 1 year)
1.0 V dc	47	32	10.3	**5.0**		5.7
10.0 V dc	40	29	10.05	5.0		3.75
10.0V 1 kHz ac	900	900	92.0	102.0		47.0
100 Ω	110	140	20.0	**10.6**		10.0
10 kΩ	110	110	13.5	10.6		6.5
10 mA dc	550	700	**30.0**	**22.0**		39.0
10 mA 1 kHz ac	0.14%	0.21%	505	610		138

Table 1: Comparison of key DMM specifications to a 5730A calibrator's specifications

Metrologists have several options to choose from to address this problem, including:

- Verify the dmm manually, using primary lab-class standards

- Improve the calibrator's specifications by calibrating it more frequently
- Improve the specifications by calibrating more frequently, plus applying a guardband to the test limits
- Customize the calibrator's specifications through control charting and characterizing the calibrator

These techniques have been discussed in other material. There is another equally worthy technique that is less frequently used, and it is discussed in the remaining parts of this paper.

This technique involves optimizing the calibrator's performance so a user can apply better specifications than the standard one-year specifications. The 90-day specifications, or even the 24-hour specifications, offer the user guaranteed improvements of 25 to 30 percent over the one-year specifications. Table 2 illustrates the possible specification improvements. These improvements are readily realizable by using a process called Artifact Calibration.

DC Voltage Specifications

Selected as the most practical specs to use

Up to 2 X better, often preferred, but not usually used

5730A DC Voltage Specifications

Range	Resolution	Absolute Accuracy ±5 °C from calibration temperature				Relative Accuracy ±1 °C	
		24 Hours	90 Days	180 Days	1 Year	24 Hours	90 Days
		±(ppm output + µV)					
99 % Confidence Level							
220 mV	10 nV	5 + 0.5	7 + 0.5	8 + 0.5	9 + 0.5	2 + 0.4	2.5 + 0.4
2.2 V	100 nV	3.5 + 0.8	4 + 0.8	4.5 + 0.8	6 + 0.8	2 + 0.8	2.5 + 0.8
		2.5 + 3	3 + 3	3.5 + 3	4 + 3	1 + 3	1.5 + 3
		2.5 + 5	3 + 5	3.5 + 5	4 + 5	1 + 5	1.5 + 5
		3.5 + 50	4 + 50	5 + 50	6 + 50	2 + 50	2.5 + 50
1100 V	100 µV	5 + 500	6 + 500	7 + 500	8 + 500	2.5 + 400	3 + 400
95 % Confidence Level							
220 mV	10 nV	4 + 0.4	6 + 0.4	6.5 + 0.4	7.5 + 0.4	1.6 + 0.4	2 + 0.4
2.2 V	100 nV	3 + 0.7	3.5 + 0.7	4 + 0.7	5 + 0.7	1.6 + 0.7	2 + 0.7
11 V	1 µV	2 + 2.5	2.5 + 2.5	3 + 2.5	3.5 + 2.5	0.8 + 2.5	1.2 + 2.5
22 V	1 µV	2 + 4	2.5 + 4	3 + 4	3.5 + 4	0.8 + 4	1.2 + 4
220 V	10 µV	3 + 40	3.5 + 40	4 + 40	5 + 40	1.6 + 40	2 + 40
1100 V	100 µV	4 + 400	4.5 + 400	6 + 400	6.5 + 400	2 + 400	2.4 + 400

Notes:
DC Zeros calibration required every 30 days.

Table 2: Specification table for DC volts of a calibrator

<u>What is Artifact Calibration?</u>

Artifact Calibration refers to the adjustment process for optimizing a calibrator's performance using primary-level electrical standards. In this user-controlled self-adjustment process, all functions and all ranges of the calibrator are tested and optimally adjusted to their best level of performance – quantified through the 24-hour specifications of the calibrator. It is a traceable, documented process that eliminates the calibrator's drift errors.

Artifact Calibration is a specifically-designed capability found in the Fluke Calibration 5700 Series of electrical calibrators. Every 5700 Series calibrator uses this self-adjustment technique when it is routinely calibrated, whether on an annual basis or at whatever frequency the owner performs a routine calibration. Artifact Calibration has been the only systematic adjustment process possible. It has been used in every 5700 Series calibrator since its initial introduction in 1988, and continued through its various generations of models since then. It continues to be used in today's latest model, the 5730A High Performance Multifunction Calibrator.

Agilent has a similar self-adjustment process in its 3458A Digital Multimeter. Coincidently, it was introduced at a similar time (~1988) as the first 5700A calibrator introduction, and it also is designed to simplify the routine adjustment and calibration process.

There are differences in the self-adjustment implementations on these two instruments. Self - adjustment in the 3458A is a regularly done process. To keep the 3458A's standard specifications, the ACAL function corrects the measurement errors caused by the day-to-day electronics drift. Any measurement process changes due to ambient temperature changes of more than one degree Celsius are also mitigated by ACAL. Additionally, during routine calibration, the 3458A uses two primary electrical standards to correct for errors in all functions and ranges. This returns the instrument's performance to its best, traceable specifications.

The Fluke Calibration approach uses Artifact Calibration at a user's discretion to optimize the calibrator and return it to the best performance specifications (a measure-then-adjust/optimize process). An additional measure-only function called Cal Check tests and documents all output changes (for every function and range) since its most recent Artifact Calibration.

In either case (3458A or 5700A Series), the respective auto-adjustment processes are intended to simplify the routine calibration adjustment process for these instruments and return them to their best operating specifications in an easy-to-use, and relatively fast user-initiated process.

Compared to traditional methods of calibrating an electrical calibrator, the Artifact Calibration self-adjustment process has many advantages. Traditionally, primary standards laboratories used top-level standards and manual metrology techniques to measure and adjust the calibrator. On a 5700 Series calibrator, this task is comprised of approximately 235 individual tests that can take many man-hours of time to complete. It is not a convenient process when the best performance of the calibrator is needed.

Artifact Calibration, on the other hand, offers several innovations to make the process simpler and easier. The first innovation is an electrical primary lab-level measurement system built into all 5700 Series calibrators. This measuring system is independent from the calibrator's sourcing systems, so the calibrator can use it to internally and independently verify its performance. It quantifies all the measured errors it finds in each operating configuration of the calibrator. This measurement system has internal voltage and resistance standards, a voltmeter for measurements, an ultra-linear 26-bit digital-to-analog converter which compares different values ratiometrically, and two multi-range thermal voltage standards to measure ac voltages and ac currents. These are for measurement comparisons and traceability of ac parameters to the internal dc standards. This process duplicates measurements done in a primary lab.

The second innovation is that traceability to the SI is maintained, tested, and guaranteed as a key part of Artifact Calibration. It is used to certify the internal voltage and resistance standards, using traceable voltage and resistance artifacts that are external and independent from the 5700 Series calibrator.

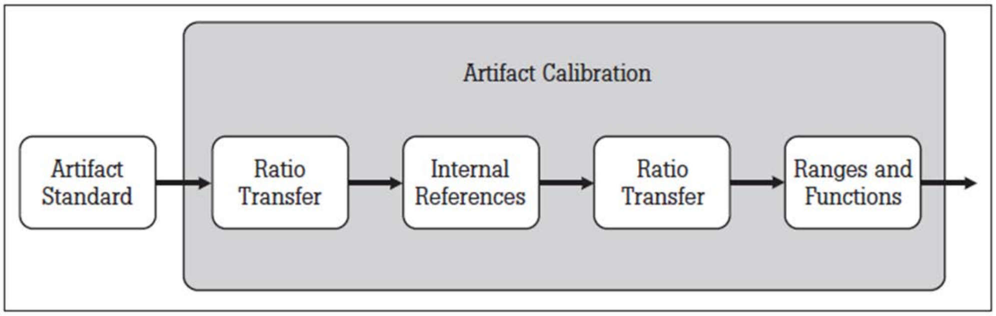

Figure 1: Electrical Traceability to the SI of Artifact Calibration

The physical measurements and comparison from external standards to internal standards, and then onto all the functions and ranges of a 5700 Series calibrator, is illustrated in Figure 1. In addition, the documentation of this process is provided by the Artifact Calibration process. Just as a traditional calibration report documents the measurements and errors for all required function and ranges, so does the internal measurement system of the 5700 Series calibrator. As seen in the Cal Check report shown in Figure 2, the detailed measurements and associated errors provide a formal record of the measurements done. These can be performed as an independently-taken measurement set, or as part of a formal Artifact Calibration. It provides formal documentation of the traceability of Artifact Cal. Compared to a traditional report of calibration for a 5700 Series calibrator, both reports provide a equally thorough report of the measured performance of the calibrator.

DC VOLTAGE	Range	Zero Shift	Magnitude	Abs Shift		Rel Shift	Spec		Pct of Spec
DC	220 mV	1.16E-07	2.20E-01	-3.60E-07	V	-1.637	9.2727	ppm	-17.654
DC	220 mV	1.16E-07	-2.20E-01	5.93E-07	V	2.6932	9.2727	ppm	29.0446
DC	2.2V	4.07E-09	2.20E+00	-3.01E-06	V	-1.3684	4.3636	ppm	-31.3585
DC	2.2V	5.81E-12	-2.20E+00	3.01E-06	V	1.3702	4.3636	ppm	31.4009
DC	11V	2.03E-08	1.10E+01	-7.85E-06	V	-0.714	3.2727	ppm	-21.8166
DC	11V	0.00E+00	-1.10E+01	7.87E-06	V	0.7158	3.2727	ppm	21.873
DC	22V	-2.85E-07	2.20E+01	-9.79E-06	V	-0.4452	3.2273	ppm	-13.7948
DC	22V	5.29E-07	-2.20E+01	1.00E-05	V	0.4563	3.2273	ppm	14.1385
DC	220V	-2.66E-05	2.20E+02	7.24E-06	V	0.0329	4.2273	ppm	0.7781
DC	220V	-2.70E-05	-2.20E+02	-6.09E-05	V	-0.2766	4.2273	ppm	-6.5433
DC	1100V	-4.81E-11	1.10E+03	7.78E-04	V	0.7071	6.4545	ppm	10.9546
DC	1100V	-2.03E-06	-1.10E+03	-7.80E-04	V	-0.7089	6.4545	ppm	-10.9833
AC VOLTAGE	Range	Magnitude	Frequency	Abs Shift		Rel Shift	Spec		Pct of Spec
AC	2.2 mV	2.20E-03	All Freqs.	-5.39E-09	V	-0.0002	0.2363	%	-0.1036
AC	2.2 mV	2.20E-03	2.00E+04	5.59E-09	V	0.0003	0.2363	%	0.1075
AC	2.2 mV	2.20E-03	5.00E+04	-1.20E-08	V	-0.0005	0.2503	%	-0.2174
AC	2.2 mV	2.20E-03	1.00E+05	-1.10E-08	V	-0.0005	0.3267	%	-0.1531
AC	2.2 mV	2.20E-03	1.20E+05	-6.27E-09	V	-0.0003	0.6655	%	-0.0428
AC	2.2 mV	2.20E-03	1.20E+05	-1.07E-08	V	-0.0005	0.6655	%	-0.0728
AC	2.2 mV	2.20E-03	2.00E+05	1.33E-08	V	0.0006	0.6655	%	0.0906
AC	2.2 mV	2.20E-03	3.00E+05	-2.41E-08	V	-0.0011	0.6655	%	-0.165
AC	2.2 mV	2.20E-03	4.00E+05	1.48E-08	V	0.0007	1.2864	%	0.0521
AC	2.2 mV	2.20E-03	5.00E+05	3.59E-08	V	0.0016	1.2864	%	0.1268
AC	2.2 mV	2.20E-03	6.00E+05	-1.73E-08	V	-0.0008	1.4464	%	-0.0543
AC	2.2 mV	2.20E-03	7.00E+05	-1.65E-08	V	-0.0007	1.4464	%	-0.0518
AC	2.2 mV	2.20E-03	8.00E+05	-2.70E-08	V	-0.0012	1.4464	%	-0.0847
AC	2.2 mV	2.20E-03	9.00E+05	-1.30E-08	V	-0.0006	1.4464	%	-0.0408
AC	2.2 mV	2.20E-03	1.00E+06	-1.91E-08	V	-0.0009	1.4464	%	-0.0599
DC CURRENT	Range	Zero Shift	Magnitude	Abs Shift		Rel Shift	Spec		Pct of Spec
DC	220 uA	5.83E-11	2.20E-04	-1.63E-10	A	-0.7415	73.8182	ppm	-1.0044
DC	220 uA	6.64E-11	-2.20E-04	2.88E-10	A	1.3081	73.8182	ppm	1.772
DC	2.2 mA	9.81E-10	2.20E-03	-1.23E-09	A	-0.5608	38.6364	ppm	-1.4515
DC	2.2 mA	1.06E-09	-2.20E-03	3.28E-09	A	1.4896	38.6364	ppm	3.8553
DC	22 mA	2.27E-09	2.20E-02	1.11E-08	A	0.5026	37.2727	ppm	1.3485
DC	22 mA	3.08E-09	-2.20E-02	-5.71E-09	A	-0.2595	37.2727	ppm	-0.6963
DC	220 mA	4.52E-08	2.20E-01	1.11E-07	A	0.5025	58.3164	ppm	0.8617
DC	220 mA	5.33E-08	-2.20E-01	-1.21E-08	A	-0.0548	58.3164	ppm	-0.094
DC	2.2A	-1.12E-07	2.20E+00	1.16E-06	A	0.5264	125.2182	ppm	0.4204
DC	2.2A	-3.04E-08	-2.20E+00	-1.30E-06	A	-0.5911	125.2182	ppm	-0.472
AC CURRENT	Range	Magnitude	Frequency	Abs Shift		Rel Shift	Spec		Pct of Spec
AC	220 uA	2.20E-04	All Freqs.	-2.68E-10	A	-1.2192	162.4545	ppm	-0.7505
AC	220 uA	2.20E-04	5.00E+02	-3.61E-08	A	-164.091	162.4545	ppm	-101.0073
AC	220 uA	2.20E-04	1.00E+03	-7.77E-10	A	-3.5299	162.4545	ppm	-2.1729
AC	220 uA	2.20E-04	2.00E+03	-6.01E-10	A	-2.7309	388.1818	ppm	-0.7035
AC	220 uA	2.20E-04	5.00E+03	3.35E-10	A	1.5229	388.1818	ppm	0.3923
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Figure 2: Documented Artifact Calibration Data

To summarize, Artifact Calibration traceably adjusts the assigned value(s) of a large array of multidimensional parameters with documentation. It uses three physical artifact standards, measures more than 390 operational points of the calibrator output systems, and formally calibrates 182 specifications. The performance is optimally adjusted to be within the 24-hour performance specifications to give the user the best standard guaranteed performance available. The measure-only Cal Check function measures and quantifies all drifts on each specified operating function and range with respect to the calibrator's specified performance.

This process takes approximately one hour, and once the three external standards are used to certify the internal standards (in about the initial ten minutes or less of the Artifact Calibration process), it requires no further operator intervention.

In Artifact Calibration, the measurement system takes external references and calibrates the similar internal standards via ratiometric processes. Similarly, the measurement system compares all the output functions and ranges to the freshly certified internal standards. Full measurement and drift/shift analysis is done. The detailed information is recorded for every function, range, and specification point. The information is viewable and storable, and it is used to adjust the 5700 Series calibrator to its optimal performance level.

Once the Artifact Calibration is completed, the user can use the 24-hour specifications, or continue on to use the 90-day or 180-day specifications as required. Of course, for longer periods of time, the one-year specifications can also apply.

Artifact Calibration also presents an economical alternative to the calibrator owner. Since traceability is maintained by three standards, it is a viable alternative to be self-supporting on this calibrator using just these three standards--rather than requiring a fully-equipped primary electrical calibration laboratory for support.

Does Artifact Calibration work?

It is a fair question to ask if this innovative process works. The answer is yes and it is substantiated by several key points.

- **Yes by design.** The design of the 5700 Series was intended to be supported by this method.
- **Yes by testing**. Fluke Calibration tests every unit's ability to perform properly as designed. Every instrument is tested to meet and exceed this level of performance. Plus, for the life of the instrument, it is recommended that the owner test the Artifact Calibration process every two years to ensure it continues to be measuring and adjusting properly. This is done by duplicating the measurements made by Artifact Calibration with external primary lab standards to confirm the instrument is within its specified operating limits.
- **Yes by independent parties.** This has been independently proven by third parties and by special evaluations by Fluke.
- **Yes by historical fact.** The process works through proven performance. For over twenty years, thousands of 5700 Series calibrators provided to industry proved that this technology and metrology approach meets and exceeds its intended performance. Whether Artifact Calibration has been done annually by the user, or by a calibration service provider, or if it has been used at a daily, or monthly, or quarterly frequency, the basis for a 5700 Series calibrator working to meet its specification operates with Artifact Calibration at its core.

The earliest evaluation of Artifact Calibration by a formal independent party was published in 1999 by a group of European National Measurement Institutes, in a report titled "Artifact Calibration, An Evaluation of the Fluke 5700A Series II Calibrator."[1] It is available on the Fluke Calibration website, www.flukecal.com.

More recently, the German PTB published a study of the performance of their Quantum AC JV System measuring the errors of a calibrator. They studied several 5700A Series calibrators, which included the new 5730A model. They found excellent agreement between the calibrator and their system. As seen in the following plots in Figure 3, the errors of voltage at various amplitudes, each at three different frequencies from 125 Hz to 1 kHz, were seen to be between 10 to 15 µV/V – where the specified maximum error of the calibrator following an Artifact Calibration was between 53 µV/V to 78 µV/V for these same points. A similar test of performance across a wider bandwidth at one test voltage found that the main testing band (within the best performing frequencies of the ac JV system) had errors less than 10 µV/V, while the specification was on the order of 58 µV/V. This substantiates the ability of Artifact Calibration to provide excellent ac voltage performance, even though there are no external ac voltage artifacts used in the Artifact Calibration process.[2]

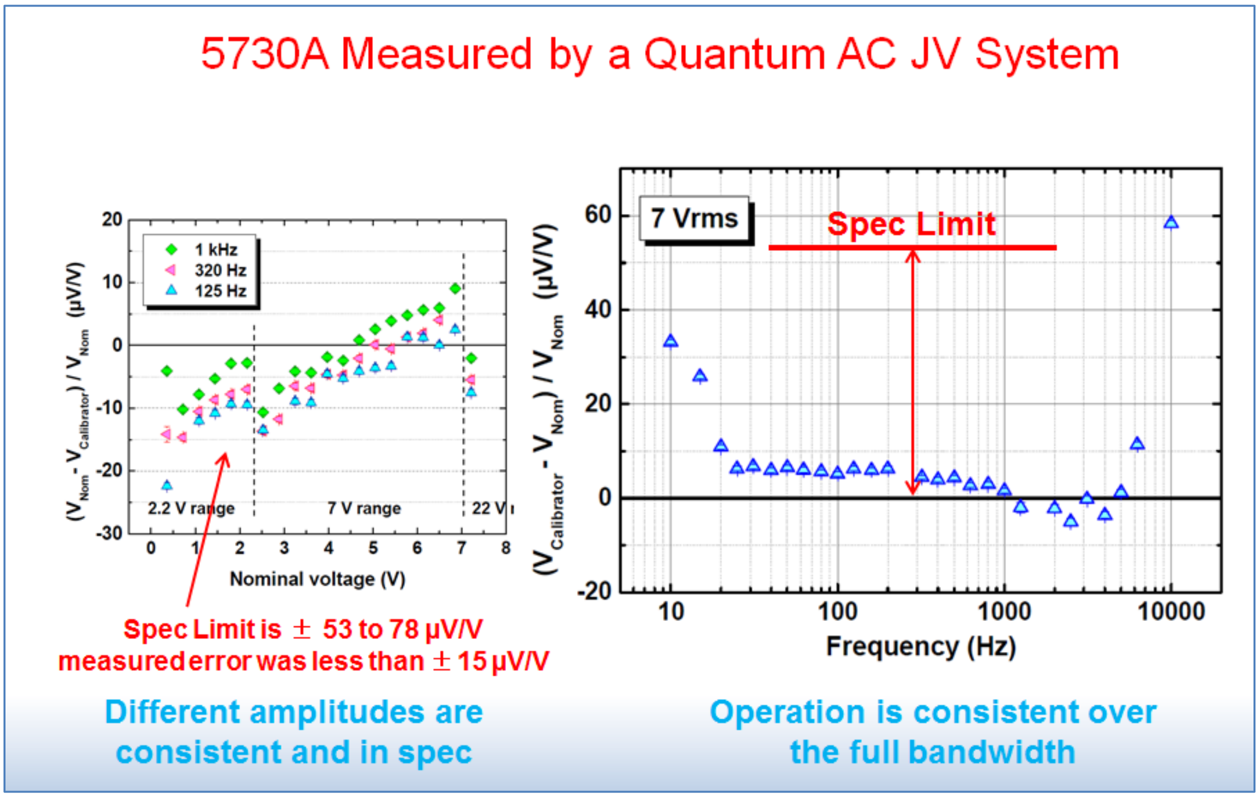

Figure 3: 5730A calibrator ac performance as measured by an AC JV system at the PTB

Fluke testing of the calibrators also confirms excellent performance. For example, the performance acceptance limits for evaluating Artifact Calibration in the Fluke manufacturing factory tests for performance are well within the guaranteed commercial specifications. To amplify this fact, Fluke guarantees a specification of a maximum error over one year of 43 µV at 10 volts. At the other extreme, the maximum error over 24 hours from Artifact Calibration at 10 volts is 28 µV. Yet the acceptance level of performance for passing Fluke's production is 80% of this 24-hour specification – or a maximum error of 22 uV. In Figure 4, a histogram of the errors at 10 volts for a population of 59 calibrators shows a consistent error much less than this 80% threshold. Additional histograms in Figure 5 show similar performance in other test points – including ac voltage, resistance and dc current. Fluke monitors approximately 280 points on a 5700 Series calibrator, and all must meet such a passing grade before they are found to be acceptable for delivery to customers.

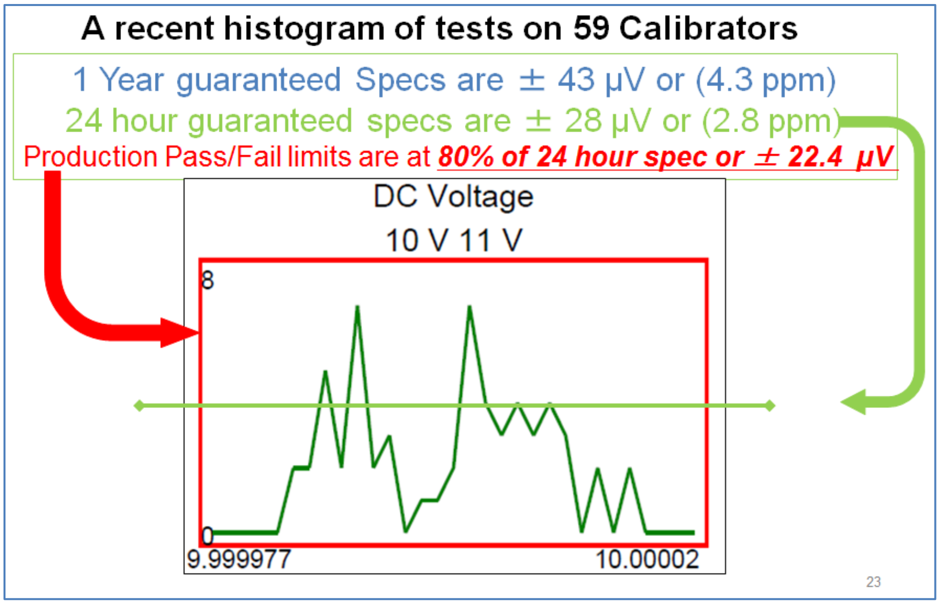

Figure 4: Histogram of measuring Artifact Calibration capability of calibration 10 volts on a group of 59 calibrators

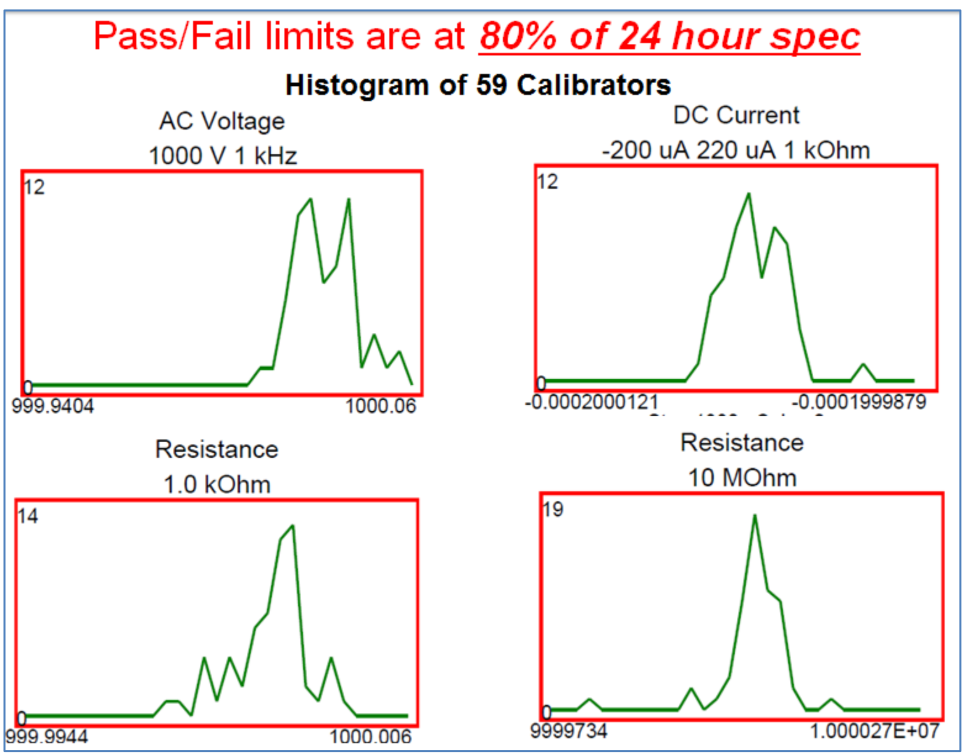

Figure 5: Histogram of measuring Artifact Calibration capability of calibration other parameters on a group of 59 calibrators

Additionally, Fluke uses repeated Cal Check measurements to evaluate short-term drift and stability. Over a typical two-week period, a Cal Check measurement set is taken at intervals of about every three hours. The Cal Check measurement is sensitive and reliable enough to evaluate drift at better than one percent of specification. The drift of the newly made 5700 Series instruments is measured while they initially burn in and become stable. A control chart is made from the repeated measurement data of these Cal Check measurement points. The drift is evaluated, and the most recent drift over the past several days is a key indicator of the calibrator's stability. Once it is seen to be less than a particular percentage of specification, it is able to be approved for customer shipment once a final Artifact Calibration is done. Figure 6 shows examples of the control charts with calibrator stability indicators.

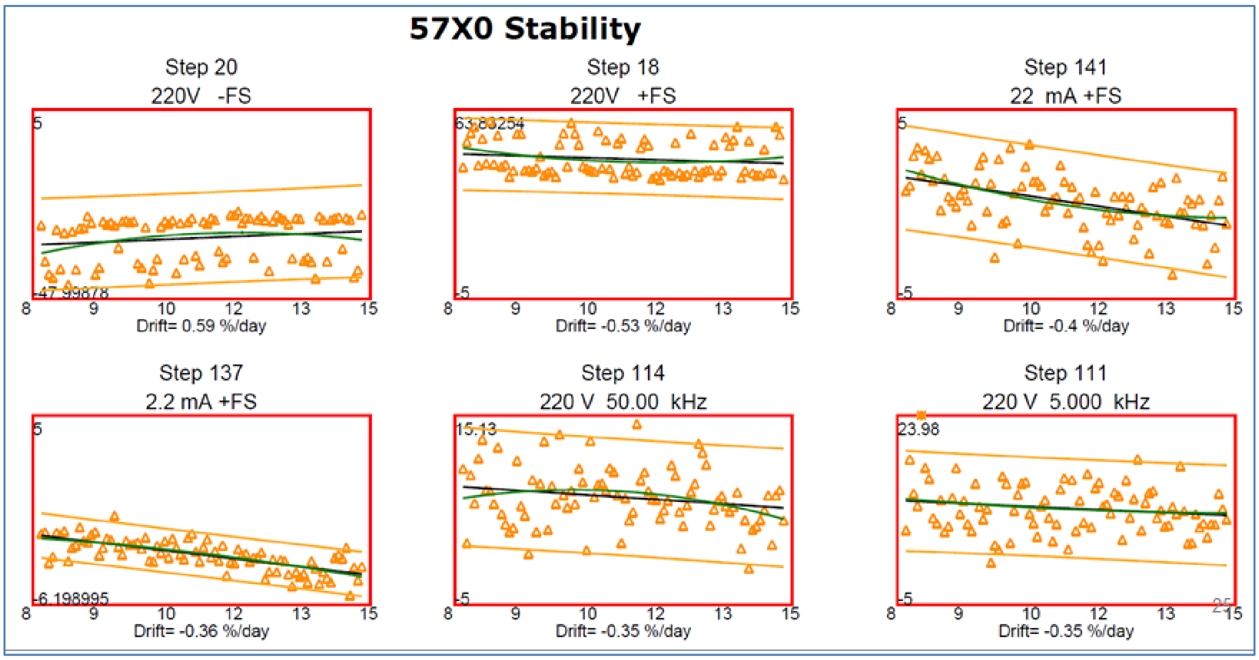

Figure 6: Control charts of stability data taken from Cal Check measurement data

Such use of the Cal Check system enables users to develop control charts of their individual calibrators so they can develop history and get maximum performance from their instrument.

The challenge to calibrate 8.5 digit DMMs

Artifact Calibration works; it has been demonstrated to work and to work well. So how can it be used to improve the task of calibrating 8.5-digit DMMs?

Some years ago, Fluke and Agilent created an application note that describes a reliable way to calibrate a 3458A Digital Multimeter. It was based on using a 90-day calibration interval plus guardbanding to insure confident test decisions. This application note is available on the Fluke Calibration website.[3]

This paper recommends that users support the 90-day calibration interval by using their own Artifact Standards as an alternative to relying on outside calibration services. By self-supporting the calibrator's Artifact Calibration process, a user can get a 20-to-30-percent specification improvement of the calibrator as shown in Table 2. The improvement of the calibrator uncertainty specification over its one-year specification is substantial if a 90-day Artifact Calibration interval is used, or even if a process of Artifact Calibration on the day of use is done. Table 3 illustrates the TAR of a 3458A as the UUT against the specification of a 5730A calibrator. The TARs are calculated at the 3458A's calibration points for both dc voltage and resistance. The one-year spec of the calibrator versus the 3458A's one-year spec has a TAR which ranges from 1.22 to 3.47: this is clearly less than the desired TAR levels. Improvements ranging from 10% to 41% are achieved with quarterly Artifact Calibrations. Should a user do an Artifact Calibration on the day of calibrating the 3458A, there are improvements of 15% to 67% in the TARS of the various tests.

	TAR 5730A vs. 3458A						
Setting	1 year		90 day	improvement		24 hour	improvement
100 mV	1.84		2.12	15%		2.65	44%
1.0 V	1.75		2.38	36%		2.70	54%
10 V	2.38		3.24	36%		3.96	67%
100 V	2.06		2.86	38%		3.28	59%
1000 V	3.47		4.89	41%		5.45	57%
10 ohms	1.22		1.33	10%		1.40	15%
100 ohms	2.31		2.57	11%		2.89	25%
1k ohms	2.18		2.49	14%		2.58	18%
10k ohms	2.18		2.58	18%		2.84	30%
100k ohms	1.67		1.89	13%		2.58	55%
1M ohms	1.61		1.90	18%		2.09	30%
100M ohms	1.76		2.27	29%		2.60	48%
			improvement 10% to 41%			improvement 15% to 67%	

Table 3: A comparison of TARs between the 3458A and the 5730A calibrator for various calibration intervals of the 5730A

<u>Results of frequent Artifact Calibrations</u>

With such improvements in the TAR of the 3458A, this has a direct improvement in the quality of decisions made of passing and/or failing the 3458A's performance versus their calibration measurements. The chances of making a mistake on marginal 3458As are reduced. Also, the sizes of the testing guardbands of the 3458A are optimized. And finally, the need for manually testing a 3458A with primary lab standards is greatly reduced.

<u>Conclusion: the benefits of Artifact Calibration</u>

To summarize the benefits of Artifact Calibration to a user of a 3548A or other 8.5 digit DMM:

- Improve and simplify the measurement assurance process around using a 5700 Series calibrator by frequent use of the Cal Check portion of Artifact Calibration. As Cal Check evaluates each function and range across the appropriate bandwidths, use it to quantify the drift of each capability area of the calibrator. If this is done regularly (daily, or weekly or monthly as appropriate) the assurance of the calibrator's proper performance will be regularly substantiated. Any problematic or inferior performance will be found before it causes a serious problem to a lab's quality.
- Use Artifact Calibration to self-support your calibrator. The three artifact standards of 10 V, 1 ohm and 10 k ohm are an economical set of items that fully support the ongoing traceability of the 5700 Series calibrators. This maximizes your calibrator's up-time availability, so it only needs to leave your lab for a bi-yearly check to confirm that its measurement system is working as designed.
- Use Artifact Calibration more frequently than yearly to improve the specification basis of the calibrator. Take advantage of an ongoing 90-day basis of improved specification performance. To have the best performance when it is needed, do an Artifact Calibration on the day of such uses.
- Use Cal Check to build control charts of your calibrator's performance. This is a convenient way to track changes over time of all the calibrator's functions and ranges. You can determine the natural drift characteristics of your calibrator which lets you develop your own specifications rather than the generic manufacturer specs.

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