APPLICATION NOTE

Improved verification of a 55XX Series Multi-Product Calibrator with an 8588A Reference Multimeter

Simplifying calibrator verification and calibration

The 8588A Reference Multimeter has greatly simplified and improved the verification and calibration adjustment processes used in 55XXA Series Multi-Product Calibrators. Compared to the previous model—the 8508A Reference Multimeter—the 8588A features more measurement functions and better uncertainties, which help to improve and simplify the metrology required to support multi-product calibrators and similar instrumentation.

This application note describes how the 8588A has been improved and offers guidance to metrologists to help them integrate these new capabilities into their organizations' metrology practices.

The role of the reference multimeter in calibrator verification

Multi-product calibrators are the workhorses of most electrical calibration labs, which must support today's wide range of digital multimeters and other measurement instrumentation. Beyond their basic voltage, resistance, and current sourcing functions, multi-product calibrators often have additional sourcing capabilities such as capacitance; power and phase; voltages linearized for thermocouple instrumentation; resistance linearized for RTDs and PRT measurement instrumentation; and oscilloscope calibration functions. As a result, the process to verify and calibrate multi-product calibrators has changed to cover these additional functions.

Multi-product calibrators offer varying levels of precision and accuracy, enabling users to match measurement ranges with their intended workloads and budgets. Because different calibrators' sourcing uncertainties can vary widely, verification methods that work well on one model might fall short on another.

Over time the process to verify multi-product calibrators has evolved to where it increasingly relies on precision multimeters to do the job. Precision multimeters—also called reference or long-scale multimeters—have functionality and measurement accuracies increasing in similar ways. Yet other measurement instrumentation is often still required for verifying functions such as capacitance, phase, and so on.

That requirement is now changing. The latest generation of precision digital multimeters, and specifically the 8588A Reference Multimeter, offers unprecedented functionality (now including capacitance and frequency) and improved accuracy. This promises to make the verification of multi-product calibrators better and simpler.

It is the metrologist's job to ensure that the instruments they use for verification/calibration procedures meet their organization's testing and quality requirements. So it is part of this job to evaluate how new and improved metrology instrumentation, and new calibration and verification techniques are best used and applied.

Improvement summary

At the heart of the 8588A Reference Multimeter's improvements are better measurement uncertainties over the previously recommended 8508A Reference Multimeter. The 8588A provides better test specification ratios (TSR) across all functions used to verify the calibrator, substantially improving the confidence of the verification. Additionally, new measurement functions such as capacitance and frequency improve and simplify the verification process.

Verification overview

Calibration verification of a multi-product calibrator means testing its performance over eleven or more different functions with multiple ranges on each function. As indicated in table 1, the calibration standards commonly used for making such a broad range of measurements include reference multimeters, current shunts, ac measurement standards, temperature instrumentation, LCR meters, frequency counters, and so on. Of these, the reference multimeter is the most used instrument. Initially the reference multimeter was used for verifying direct voltage, direct current, resistance, and thermocouple simulation functions. AC voltage and current functions were verified with an ac measurement standard, because the reference multimeter's ac function was often not accurate enough to handle these calibrator functions. LCR meters and frequency counters were used for verifying capacitance and frequency.

As the reference multimeter evolved from the 8508A to the 8588A, its performance and functions improved. These improvements helped to simplify and improve the quality of the verification process from a metrology perspective. Table 2 shows the reduced complexity of required instruments per function of the 8588A Reference Multimeter, as it replaces both the LCR meter and frequency counter previously needed for verification.

Detailed improvement considerations

Different calibrator models'—performance and functionality: The multi-product calibrator models used in industry span a wide performance range across eleven or more functions. The performance, as specified, is designed to verify measurement instruments which range across three orders of magnitude. (In a digital multimeter area, these are commonly termed 3.5, 4.5 and 5.5 digits of measurement resolution.) The required

Function	Required Instrumentation for Calibration Verification Per 5522A Service Manual								
	Reference DMM	Reference divider	AC measurement standard	Standard resistors	Current shunts	Voltage calibrator	Phase meter	LCR meter	Frequency counter
DCV < 30V	●								
DCV > 30V	●	●							
DC volts aux	●								
DC current	●			●	●				
Resistance	●								
AC volts normal			●						
AC volts aux			●						
AC current			●	●	●				
Capacitance	●					●		●	
TC source	●								
TC measure	●					●			
Phase							●		
Frequency									●

Table 1. Required instrumentation for calibration verification per 5522A service manual

Function	Instrumentation for Calibration Verification When Using the 8588A DMM								
	8588A reference DMM	Reference divider	AC measurement standard	Standard resistors	Current shunts	Voltage calibrator	Phase meter	LCR meter	Frequency counter
DCV < 30V	●								
DCV > 30V	●	●							
DC volts aux	●								
DC current	●			●	●				
Resistance	●								
AC volts normal			●						
AC volts aux			●						
AC current			●	●	●				
Capacitance	●								
TC source	●								
TC measure	●					●			
Phase							●		
Frequency	●								

Table 2. Instrumentation for calibration verification when using the 8588A DMM

calibrator specifications significantly increase as the digits of measurement resolution increase.

In this application note we consider direct voltage as the key indicator. For direct voltage, the range of specified uncertainties range from what might be considered “Good” performance of approximately 100 µV/V, to “Better” at 50 µV/V and ultimately “Best” at 11 µV/V.

For purposes of comparison, we focus on the verification challenges of both the “Best” and “Better” categories of performance. The example for “Best” is the Fluke Calibration 5522A Multi-Product Calibrator and the example for “Better” is the Fluke Calibration 5502A Multi-Product Calibrator. This comparison illustrates the key differences that need to be considered.

Calibration interval: The time interval between successive verifications dictates the specific performance specifications checked in the verification/calibration process. While calibrators are specified with differing uncertainties applied to the verification intervals of 90 days and 1 year, the most common interval used is a 1-year interval, so we will focus on this class of performance specifications.

The 5522A Multi-Product Calibrator (top) and the 5502A Multi-Product Calibrator (bottom)

Regarding the DMM, it needs to be at a better grade of performance for tasks such as this. So, we recommend a more frequent interval than once per year. Consequentially we will apply a 90-day absolute uncertainty, tcal ± 1 °C specification on the reference multimeter used in the verification process.

However, the only published 90-day, tcal ± 1 °C specification is the relative specification (meter only, not including the additional traceability uncertainty). The additional traceability uncertainty will need to be added to the relative spec. This will provide the absolute uncertainty specification needed for the DMM. This is a straight forward process where the traceability uncertainty is extracted for the published absolute specification and then added to the relative uncertainty specification. As the traceability uncertainty is combined to the instrument uncertainty with an RSS (square **r**oot of the **s**um of the **s**quares) calculation, we will use this method to calculate the absolute spec.

For example, in the 10 volt dc range of the dmm, the 99 % confidence, 90-day, tcal ± 1 °C, relative accuracy specification is: ± (+1.8 µV/V of reading +0.06 µV/V of range). The calculated traceability uncertainty for this range is ± 0.8 µV/V of reading. Doing an RSS combination of the two components (1.8 µV/V and 0.8 µV/V) gives a result of 2.0 µV/V. The result is for the 10 volt range the measurement specifications for this confidence level, calibration interval and temperature range is: ± (+2.0 µV/V of reading + 0.06 µV/V of range). For further details, see the accompanying example shown on the right.

Test ratio analysis: Finally, there will be a figure of merit used in evaluating the suitability of the measurement standards used to verify the calibrator. We will use as a figure of merit the TSR (commonly called the **t**est **s**pecification **r**atio)– the ratio of the specification being tested on the calibrator and the specification of the standard doing the test, in this case the reference multimeter. A TSR of 3:1 will be the threshold of acceptability for evaluating the performance. While it is true that a 4:1 TSR is commonly used as the threshold for requiring a more detailed analysis of the particular test uncertainties, a 3:1 level is more practical to use as a suitability indicator when doing test quality analysis for verifying a calibration standard.

It is up to the user/metrologist to do a final evaluation of the overall test uncertainty ratio (TUR), a ratio that compares the calibrator's verification specification to the overall measurement uncertainty of the test. This total measurement uncertainty includes all other significant uncertainty contributions in the verification setup, including the measurement device's specification uncertainty used in the TSR analysis. The individual metrologist can then evaluate how the specifics in the testing impacts their quality processes and their acceptable level of decision risk.

Calculating traceability uncertainty and applying it to a relative specification

As a further illustration of the details in this process, the calculation of traceability uncertainty from the published specifications is as follows. The two specifications used in this calculation are the 365 day relative and 365 day absolute specifications because the only difference is the effect of the traceability uncertainty. The published specifications provide specs for equal time, temperature and confidence conditions to support this calculation. Also, only the reading portion of the specification is needed to be considered as the range portion is equal in both the absolute and relative specifications.

To illustrate, these specs for the 10 volt DC measurement range are:

- Absolute: ± (+3.6 µV/V of reading +0.06 µV/V of range)
- Relative: ± (+3.5 µV/V of reading +0.06 µV/V of range)

Calculations to extract the traceability in an RSS manner are:

- Traceability uncertainty = sqrt(3.6^2-3.5^2) which equals 0.84 µV/V

The absolute 90 day specification is calculated by an RSS addition of the 90 day relative spec to the traceability uncertainty just calculated. This equals: sqrt(1.8^2+0.84^2) or 2.0 µV/V

This gives a 90 day absolute specification of ± (+2.0 µV/V of reading +0.06 µV/V of range)

Using this process, one can calculate a complete 99 % confidence specification for a 90 day calibration interval in a tcal ± 1 °C environment.

TSR analysis

A TSR analysis was done for the recommended verification points for a 5522A Multi-Product Calibrator. As mentioned earlier for the purposes of explaining the analysis, we focus on a detailed analysis of the direct voltage (dc voltage) function. The other functions will be summarized, but the details of the analysis will be left for the metrologist to consider. The reference for the tested verification points is identified in the 5522A calibrator's service manual.

Table 3 shows all 23 verification points for normal dc voltage operation.

Calibrator specification limits used: 1-year, tcal ± 5 °C, absolute accuracy, 99% confidence level

Reference multimeter specifications: 90-day, tcal ± 1 °C, absolute accuracy, 99% confidence level

As this verification would usually be done in a calibration lab with a controlled temperature, it is appropriate and advantageous to use the reference multimeter's tighter temperature range specification for this analysis.

Table 3 shows the different dc voltage verification points. These points were analyzed three ways. First, considered the "Best" method, shows TSRs for the verification done by the 8588A and using a reference divider for measurements greater than 10 V. The second analysis shows the TSRs for the 8588A measuring these higher voltages directly, without using a reference divider. In the third analysis the verification is done using the originally recommended 8508A Reference Multimeter as well as the divider. This can be considered a "Good" method, but it supports the improvement in TSRs when using the newer 8588A Reference Multimeter.

8588A + divider verification: This is a highly recommended "Best" method for 5522A verification. All 23 points verified are at a 3:1 TSR or better, when using the divider for voltages greater than 12 V.

8588A verification (no divider): For comparison, the second group of TSR information shows the ratios when the calibrator verification does not use the 752A Reference Divider but does a direct measurement with the 8588A's higher voltage ranges. As expected, all lower voltages have the same TSR as initially shown in the first

Verification tests for dc voltage (normal) on 5522A

5522A range	5522A output setting	5522A spec µV	8588A + divider			8588A and no divider for high voltage			Original 8508A verification methodology		
			Comment	spec µV	TSR	Comment	spec µV	TSR	Comment	spec µV	TSR
329.9999 mV	0 V	1.0		0.26	3.8 : 1					0.12	8.3 : 1
329.9999 mV	0.329 V	7.6		1.57	4.8 : 1					1.82	4.2 : 1
329.9999 mV	-0.329 V	7.6		1.57	4.8 : 1					1.82	4.2 : 1
3.299999 V	0 V	2.0		0.60	3.3 : 1					0.26	7.7 : 1
3.299999 V	1 V	13.0		4.20	3.1 : 1					9.00	1.4 : 1
3.299999 V	-1 V	13.0		4.20	3.1 : 1					9.00	1.4 : 1
3.299999 V	3.29 V	38.2		12.4	3.1 : 1					18.16	2.1 : 1
3.299999 V	-3.29 V	38.2		12.4	3.1 : 1					18.16	2.1 : 1
32.99999 V	0 V	20.0		0.60	33 : 1					5.00	4.0 : 1
32.99999 V	10 V	140		36.6	3.8 : 1					45.00	3.1 : 1
32.99999 V	-10 V	140		36.6	3.8 : 1					45.00	3.1 : 1
32.99999 V	32.9 V	415	752A divider	13.1	3.2 : 1	no divider	213	1.9 : 1	752A divider	18.82	2.2 : 1
32.99999 V	-32.9 V	415	752A divider	13.1	3.2 : 1	no divider	213	1.9 : 1	752A divider	18.82	2.2 : 1
329.9999 V	50 V	1050	752A divider	19.6	5.4 : 1	no divider	925	1.1 : 1	752A divider	26.00	4.0 : 1
329.9999 V	329 V	6072	752A divider	14.1	4.3 : 1	no divider	2460	2.5 : 1	752A divider	19.81	3.1 : 1
329.9999 V	-50 V	1050	752A divider	19.6	5.4 : 1	no divider	925	1.1 : 1	752A divider	26.00	4.0 : 1
329.9999 V	-329 V	6072	752A divider	14.1	4.3 : 1	no divider	2460	2.5 : 1	752A divider	19.81	3.1 : 1
1000.000 V	334 V	7512	752A divider	14.3	5.3 : 1	no divider	2487	3.0 : 1	752A divider	20.03	3.8 : 1
1000.000 V	900 V	17700	752A divider	37.5	4.7 : 1	no divider	5600	3.2 : 1	752A divider	45.50	3.9 : 1
1000.000 V	1020 V	19860	752A divider	42.4	4.7 : 1	no divider	6260	3.2 : 1	752A divider	50.90	3.9 : 1
1000.000 V	-334 V	7512	752A divider	14.3	5.3 : 1	no divider	2487	3.0 : 1	752A divider	20.03	3.8 : 1
1000.000 V	-900 V	17700	752A divider	37.5	4.7 : 1	no divider	5600	3.2 : 1	752A divider	45.50	3.9 : 1
1000.000 V	-1020 V	19860	752A divider	42.4	4.7 : 1	no divider	6260	3.2 : 1	752A divider	50.90	3.9 : 1

Table 3. Verification tests for dc voltage (normal) on 5522A

evaluation data set. While this can be considered a somewhat “Better” scenario, the main consideration here is how the lower TSR affects the required metrology quality for the 33 V and higher ranges of the calibrator. While better than a similar test with the 8508A, it is still strongly recommended to use a divider for higher voltages to get TSRs greater than 3:1.

8508A + divider verification: This illustrates the verification method originally recommended for the 5522A and can be considered “Good” but there is room for improvement. Most points are better than a 3:1 TSR, but 6 out of 23 (over 25 %) are lower and should be evaluated further in critical situations.

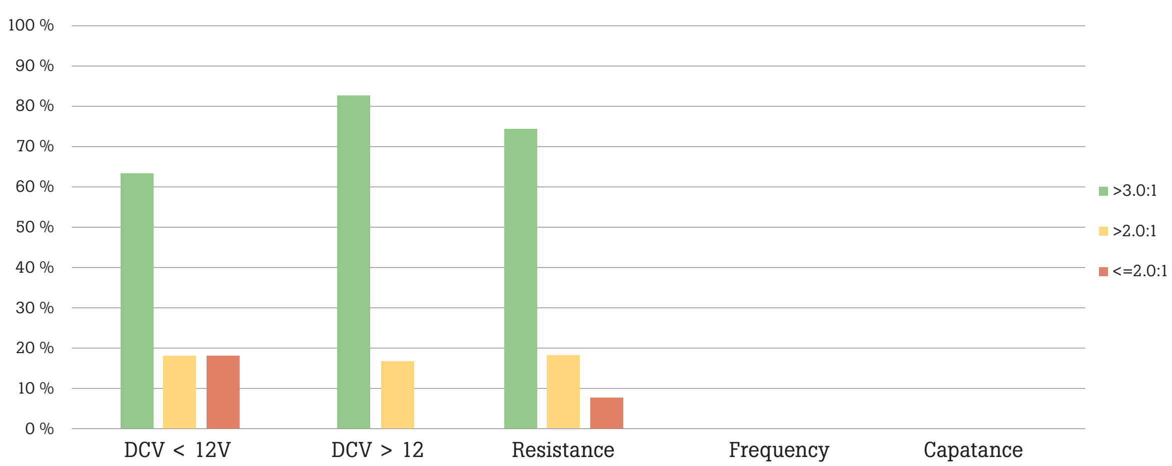
Conclusion: Supported by these three data sets, the improvements offered by the 8588A in general accuracy improvement over the 8508A are easy to see. TSRs where the 8508A falls below a 3:1 threshold have been substantially improved. The “Best” practice is when the 8588A is used with the 752A Reference Divider; there are no test points verifying the dc voltage function of the 5522A where the TSR is less than a 3:1 ratio.

Beyond dc voltage verification

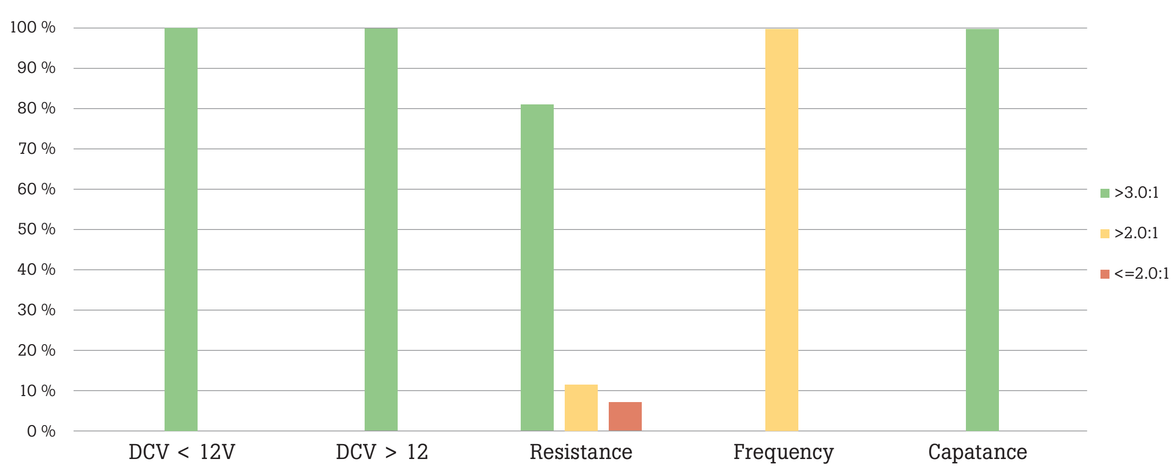
Continuing beyond the 8588A and 8508A comparison for dc voltage verification, it is good to compare how these reference multimeters support the calibration of other 5522A functions. As seen in the following two graphs, the 8588A covers dc voltage, resistance, frequency and capacitance with acceptable TSRs. However, the 8508A can only cover dc voltage and resistance, with weaker TSRs as compared to the 8588A.

For best practices across all functions, including the ac voltage and current, phase and thermocouple and thermocouple measure functions, use additional instrumentation as detailed earlier.

TSR coverage of 5522A verification tests with 8508A grouped by function



TSR coverage of 5522A verification tests with 8588A grouped by function



Further improvement considerations

Beyond using a divider for higher dc voltages and an ac measurement standard for ac voltages, there are other improvements one can consider for improving the TSR of the multi-product calibrator tested with a direct measurement by the 8588A. Some suggested alternatives are listed below for each calibrator function.

Resistance: On specific ranges with lower TSR's, rather than measuring resistance directly with the 8588A Reference Multimeter, other techniques such as using a standard resistor for characterizing the reference multimeter measurements at these required points, or doing ratio measurements between the calibrator and the standard resistor at these points, can be used to improve these low TSR's to acceptable levels.

Current: A precision metrology shunt, such as the Fluke Calibration A40B series, can be used with the 8588A to easily verify the calibrator's ac and dc currents with an acceptable TSR.

Frequency: Simple frequency counters can measure frequency with better uncertainties if necessary.

8588A verifying other calibrators

Up to this point our analysis has centered on verifying the 5522A, the best available Fluke Calibration multi-product calibrator. Let's now examine how the TSRs change when moving to a 5502A, a mid-range calibrator considered to be in the "Better" class of performance.

Initially, we will analyze the TSRs for the 8588A verifying direct voltage for the 5502A. Table 4 shows verifying the 5502A with the 8588A both with and without the use of the 752A to improve TSRs for voltages higher than 12 V. Also, because of the 5502A's specification are significantly different than the 5522A's specifications, we used the 8588A's 1 year specification for this analysis. The results show the 8588A can be used with or without the divider and in either configuration all test points maintain TSRs better than 3:1.

Verification tests for dc voltage (normal) on 5502A

5502A Range	5502A Output Setting	5502A spec µV	8588A + Divider			8588A and No Divider for High Voltage		
			Comment	spec µV	TSR	Comment	spec µV	TSR
329.9999 mV	0 V	3.0		0.26	12 : 1		0.26	12 : 1
329.9999 mV	0.329 V	22.7		1.57	14 : 1		1.57	14 : 1
329.9999 mV	-0.329 V	22.7		1.57	14 : 1		1.57	14 : 1
3.299999 V	0 V	5.0		0.60	8.3 : 1		0.60	8.3 : 1
3.299999 V	1 V	55.0		4.20	3.1 : 1		4.20	13 : 1
3.299999 V	-1 V	55.0		4.20	13 : 1		4.20	13 : 1
3.299999 V	3.29 V	170		12.4	14 : 1		12.4	14 : 1
3.299999 V	-3.29 V	170		12.4	14 : 1		12.4	14 : 1
32.99999 V	0 V	50.0		0.60	83 : 1		0.60	83 : 1
32.99999 V	10 V	550		36.6	15 : 1		36.6	15 : 1
32.99999 V	-10 V	550		36.6	15 : 1		36.6	15 : 1
32.99999 V	32.9 V	1695	752A divider	13.1	13 : 1	no divider	213	7.9 : 1
32.99999 V	-32.9 V	1695	752A divider	13.1	13 : 1	no divider	213	7.9 : 1
329.9999 V	50 V	3250	752A divider	19.6	17 : 1	no divider	925	3.5 : 1
329.9999 V	329 V	18595	752A divider	14.1	13 : 1	no divider	2460	7.6 : 1
329.9999 V	-50 V	3250	752A divider	19.6	17 : 1	no divider	925	3.5 : 1
329.9999 V	-329 V	18595	752A divider	14.1	13 : 1	no divider	2460	7.6 : 1
1000.000 V	334 V	19870	752A divider	2,487	14 : 1	no divider	2487	8.0 : 1
1000.000 V	900 V	51000	752A divider	5,600	14 : 1	no divider	5600	9.1 : 1
1000.000 V	1020 V	57600	752A divider	6,260	14 : 1	no divider	6260	9.2 : 1
1000.000 V	-334 V	19870	752A divider	2,487	14 : 1	no divider	2487	8.0 : 1
1000.000 V	-900 V	51000	752A divider	5,600	14 : 1	no divider	5600	9.1 : 1
1000.000 V	-1020 V	57600	752A divider	6,260	14 : 1	no divider	6260	9.2 : 1

Table 4. Verification tests for dc voltage (normal) on 5502A

For all functions of the 5502A where the 8588A can verify its operation, the graph below illustrates in all functions and ranges, except resistance are fully covered. Of all the required resistance tests, 95% of these points meet a 3:1 TSR. The test meets and exceeds a 2:1 TSR in only two of 43 resistance test points. This confirms that the 8588A can be satisfactorily used to verify all performance levels of multi-product calibrators.

What about capacitance?

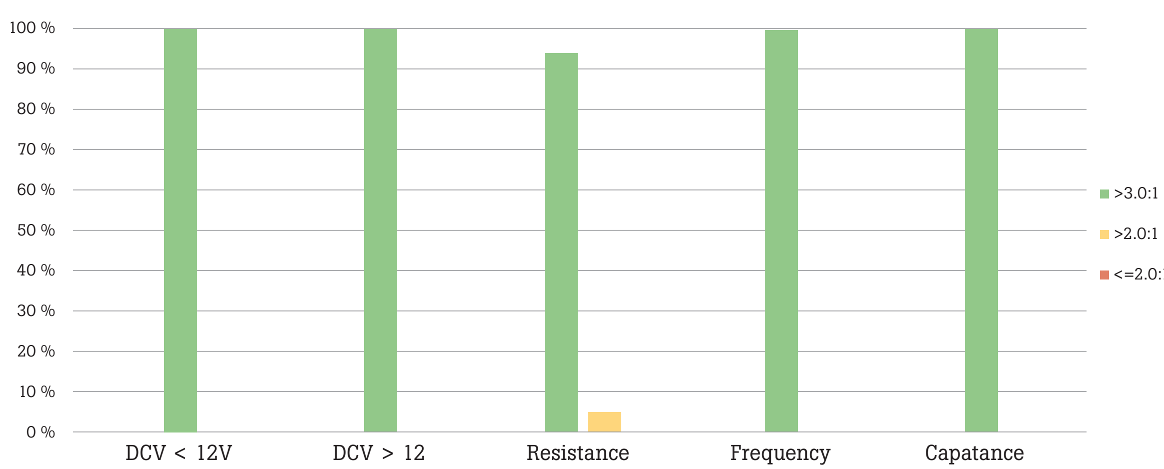
It is important to point out that a verification with 8508A in addition to an LCR meter requires a second reference multimeter that can digitize for the capacitance areas outside of the LCR meter's capability. An obvious improvement with the 8588A shows it has measurement capability across the full capacitance ranges of the calibrators and can be used directly and simply to do this verification.

Conclusions and recommendations

The 8588A Reference Multimeter simplifies and improves the verification of multi-product calibrators. The new generation 8588A greatly outperforms the 8508A in this task. By examining the TSR between the calibrator and the meter, the 8588A can fully verify most of the functions in the calibrator. And when a 752A Reference Divider assists with the points of dc voltage that exceed 12 volts, all voltage verification points will meet and exceed the 3:1 test specification ratio.

Metrologists who verify multi-product calibrators such as the 5522A and 5502A will benefit by using the 8588A Reference Multimeter, perhaps even reducing the cost of in-house calibrations in the process. The overall quality of the calibration and verification is better, with fewer points resulting in marginal or indeterminate tests. The test process will be simplified as there are fewer instruments used to verify these calibrators. Whether done manually or via automation, these calibrations and verifications will be more reliable and efficient than what previous calibration standards and instrumentation could offer.

TSR coverage of 5502A verification tests with 8588A grouped by function



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