An Assessment of Artifact Calibration Effectiveness for a Multifunction Calibrator

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ABSTRACT

Analysis of As Found, As Left and Production data for a large sample (>250) of Multifunction Calibrators from a few months to more than six years old shows the instrument is generally very conservatively specified and that Artifact Calibration does return the instrument to essentially the same accuracy it had when manufactured.

INTRODUCTION

Several years ago, two major test equipment manufacturers effected a most significant change in performance of high accuracy measuring equipment with the introduction of Artifact Calibrated instruments. Hewlett Packard's contribution was the 3458A Digital Multimeter, and Fluke's was the introduction of the 5700A MultiFunction Calibrator. Artifact Calibration, as implemented by both manufacturers, is an interesting internal-metrology approach to maintaining an instrument's ambitious accuracy specifications.

Artifact Calibration incorporates into the instrument the metrology functions usually performed by a standards or calibration laboratory. Artifact calibrated instruments contain internal reference standards, an internal ratio device and a sensitive null detector. Under the control of internal software, the instrument performs the metrology procedures necessary to determine offsets from nominal of its many parameters, and make internal corrections to drive the offsets essentially to zero. Artifact calibration provides superior accuracy because the calibration environment and procedures are fixed by the design of the instrument, and are not affected by the conditions, attitudes and capabilities found in user facilities.

Artifact calibration is designed to return the instrument to essentially the accuracy the instrument had when it was manufactured. Hewlett Packard requires the ACAL procedure to be performed each 24 hours. Fluke requires 5700A Artifact Calibration to be performed at intervals determined by the specification maintained. For example, artifact calibration must be performed each 90 days to maintain 90 day specifications. Fluke also requires a complete accuracy verification at two year intervals to assure that the internal metrology continues to perform as designed, and to confirm the accuracy of the internal AC/DC Reference Standard.

5700A Artifact Calibration adjusts the Direct Voltage (DV), Direct Current (DC) and Resistance functions by adjusting internal references to external standards, then verifies ratio accuracy, and finally performs the measurements and makes the adjustments needed to bring the outputs to nominal. Alternating Current (AC) and Alternating Voltage (AV) outputs are also returned to nominal, referenced to an internal AC/DC Difference Standard. Artifact calibration of AV and AC differ from the other functions only in the fact that the internal reference is not measured or adjusted. Long term accuracy of these parameters depends on the long term stability of the internal AC/DC Difference standard, which is verified at 2 year intervals.

The 5700A also provides a Cal Check function, which may be used to monitor outputs relative to the internal standards. This feature provides users with a means for implementing a measurement quality program required by paragraph 9.6 of ANSI/NCSL Z540-1, which requires "in-service checks between calibrations and verifications".

Accuracy of new measuring instruments is specified by design engineers based on sensitivity analysis and knowledge of stability of components used. A conservative design will result in an instrument which has high probability of meeting its specified accuracy. For all instruments, but especially for those which implement significant innovations such as Artifact Calibration, it is instructive to determine whether the instrument actually performs as specified. Ultimately, the question is whether the instrument is found to be in tolerance As Found when returned to a supporting laboratory for calibration.

A previous paper [1] presented a preliminary analysis based upon As Found data for some 260 instruments returned to Fluke for service. The conclusions presented there were preliminary because information was not available to separate instrument performance from measuring system performance. The present paper incorporates analysis of As Left data for over 300 instruments and Factory Production data for another 300 instruments. The evidence is convincing that the 5700A was conservatively specified for all parameters and values, and has a high probability of being found In-Tolerance-As-Found.

SUMMARY OF PREVIOUS WORK

The previous paper [1] cited above focused on two issues -- does Artifact Calibration really adjust the instrument to within 24 hour specifications, and does the instrument have the stability required to support uncertainty specifications over extended periods? The results of that analysis will be briefly summarized here.

The most striking illustration of the effectiveness of Artifact Calibration is provided by scatter plots of Direct Voltage before and after calibration. Figures

1 and 2 show its effect on ± 100 mV and ± 10V, two of the most interesting values. Figure 1 shows that ± 100 mV is adjusted within 24 hour specifications, and more interestingly that zero errors, probably caused by thermal emfs, cause the measurements to be negatively correlated. Figure 2 shows that ± 10V is also adjusted to well within 24 hour specifications, and that here gain errors, probably caused by imperfect internal adjustments, cause measurements to be positively correlated.

Stability was analyzed by performing linear regressions versus time since the instruments were manufactured. The regression results were used to predict the time to "Out of Confidence" for the parameter. Out of Confidence occurs when the 99% prediction interval (the interval which will contain 99% of observations) intersects the spec limit. For this analysis, which was concerned only with stability, offsets from spec center were ignored, primarily because they could not reliably be extracted from the information available. Figures 3 and 4 present the best and worst results from this analysis.

In summary, the previous paper reported two important conclusions -- that 5700A Artifact Calibration does return the instrument to essentially the same accuracy it had when manufactured, and that it has more than adequate stability to support specified accuracies for properly calibrated instruments. A copy of the paper can be obtained from Fluke Corporation or from the author.

THE DATA

As Found Data

Fluke has established a capability for calibration and repair of the 5700A in its Northwest Technical Center, a function of its Customer Support Services (CSS) Group. (The CSS measurement system will hereafter be referred to simply as "the measurement system".) As customers require service for the 5700A, the instruments are returned to CSS for appropriate processing. As Found data is taken for operational instruments, and data for approximately 260 instruments (a small fraction of total production) was available. The number is approximate because some of the instruments were returned for repair, so not all the instruments operated properly in all functions.

As Found data was processed in EXCEL spreadsheets, using the statistical and graphing functions. As noted above, not all data is useable and in some cases outlying data points more than four standard deviations from the mean were discarded. As a result, the As Found data set analyzed consists of those points within 4 standard deviations of the mean.

As Left Data

Instruments returned to customers are calibrated, using Artifact Calibration, then are verified prior to their return, generating As Left data. As Left data is useful for demonstrating that Artifact Calibration is still operating properly at various times after manufacture, and provides one indication of 5700A stability. Analyzing the difference between As Found and As Left data not only can provide useful information about time stability of the 5700A, but clues to the operation of the measurement system as well.

Interpreting the data is complicated by the need to separate instrument performance from measurement system performance. Complete analysis of instrument performance requires complete knowledge of the contributions of the measurement system. The CSS measurement system has been modified since this data was taken, and the detailed analysis of standard deviations and offsets required for a technically rigorous investigation was not completed. Therefore, it is not possible to accurately assign offsets and variability to the measurement system or to the 5700A. In most cases, however, the combination of As Found, As Left and Production data provides enough information to separate those error parameters with good confidence.

Production Test Data

Data obtained in final test of 5700As by the Production Test Facility is routinely uploaded to a minicomputer running UNIX, and is used to generate information used by Production and Quality in controlling the production process. Production Test Stations are maintained under rigorous control through the use of check standards (for process control) and through Process Metrology (to assure processes are maintained properly centered). A key requirement of the Quality System is that $C_{pk} > 1.33$ (4 sigma process) must be maintained for each parameter. Production Test data is useful for resolving some questions about the error contributions of the CSS measurement system.

DATA ANALYSIS AND PERFORMANCE SUMMARY

As Found data is influenced by several error components, each consisting of an offset from nominal plus random error. They may be expressed as:

Internal Reference Drift ($D \pm ks_D$)
Shifts in Gains and Zeroes ($G \pm ks_G$)
Differences in Artifact Standards ($AS \pm ks_{AS}$)
Measurement System Noise and Offset ($MS \pm ks_{MS}$)
Imperfect Artifact Cal Adjustments ($ADJ \pm ks_{adj}$)
Noise in 5700A ($\pm ks_n$)

$$F = D + G + AS + MS + ADJ$$
$$s_1 = \sqrt{s_D^2 + s_G^2 + s_{AS}^2 + s_{MS}^2 + s_{adj}^2 + s_n^2}$$

In the equations, k is a coverage factor used to compute an expanded uncertainty. As Left data is influenced by a subset of the above error components:

Measurement System Noise and Offset (MS $\pm$ ks$_{MS}$)
Imperfect Artifact Cal Adjustments (ADJ $\pm$ ks$_{adj}$)
Noise in 5700A ($\pm$ ks$_n$)

$$L = MS + ADJ$$
$$s_2 = \sqrt{s_{MS}^2 + s_{adj}^2 + s_n^2}$$

Since Artifact Calibration does not adjust the internal AC/DC Difference Standard, As Left data for Alternating Current and Voltage also are influenced by

Internal Reference Drift (D $\pm$ ks$_D$)

$$L' = D + MS + ADJ$$
$$s_2' = \sqrt{s_D^2 + s_{MS}^2 + s_{adj}^2 + s_n^2}$$

Production data is influenced by a slightly different set of error components:

Production Test Noise and Offset (P $\pm$ ks$_P$)
Imperfect Artifact Cal Adjustments (ADJ $\pm$ ks$_{adj}$)
Noise in 5700A ($\pm$ ks$_n$)

$$PT = P + ADJ$$
$$s_3 = \sqrt{s_P^2 + s_{adj}^2 + s_n^2}$$

For Direct Current, Direct Voltage and Resistance, we can place an upper bound on offsets and random effects contributed by the 5700A as shown below. This procedure cannot be applied to Alternating Current and Voltage, because the internal AC/DC Reference Standard is not adjusted by Artifact Calibration. There we generally just take the As Found mean and standard deviation as being those of the instrument. How exceptions are handled is discussed in the appropriate place below.

$$Max_{5700A} = F - L + PT$$
$$Max_{5700A} = D + G + AS + ADJ + P$$
$$s_{Max} = \sqrt{s_1^2 - s_2^2 + s_3^2} = \sqrt{s_D^2 + s_G^2 + s_{AS}^2 + s_{adj}^2 + s_n^2 + s_P^2}$$

As can be seen from these equations, calculations of maximum 5700A offset and standard deviation treat imperfect adjustments and errors in the Production Test system as originating in the instrument.

Tables 1 and 2 present the results of the analysis. Tabled there, by parameter, are 24 hour and 1 year accuracy specifications, mean and standard deviation for As Found, As Left and Factory data sets, Trend, 5700A Offset (except for AC and AV) and 5700A standard deviation, sigma multiple, and minimum percentage within 1 year specification As Found. "Sigma multiple" is the number of 5700A standard deviations contained in the interval [Spec - |Offset|], related to C_{pk}, a concept which will not be discussed here.

Tabled 5700A standard deviations are combined with one standard deviation estimates of uncertainty in calibration standards. This value is then used in the EXCEL NORMDIST function to calculate the (normally two-tailed) probability that instruments will be found within the spec limits. One-tailed probabilities are computed when |Offset|> 1/2 standard deviation. These probabilities are tabled as "% within 1 year specification". The analysis of each parameter is discussed briefly below.

Direct Current

Computed sigma multiples for this parameter are very large, the smallest being 7.6. The 5700A is very conservatively specified for Direct Current, and 100% of properly maintained instruments should be found within 1 year specifications on recall.

Resistance

Sigma multiples for this parameter are considerably larger than the 2.6σ required to provide 99% probability an instrument will be found in tolerance on recall, the smallest multiple being 3.4. The instrument is conservatively specified for resistance.

Direct Voltage

This parameter requires a more detailed analysis than the previous two. Tabled values of Mean As Found for the different voltages are strongly correlated. This correlation cannot result from drifts in zeroes or gains, since those would vary randomly. And the measuring system cannot be the source of the errors, because the same system is used for both As Found and As Left measurements. Clearly we have here a classical standards problem. The standard used in the initial Artifact Calibration or the one used in calibrating the measuring system, or the instrument's internal standard must be varying over time.

Whether the correlated offsets might result from faulty Artifact Calibrations was tested by examining some 80 calibration records for Fluke-owned 5700As. We know that the artifacts used both in Production and in CSS have very small offsets from nominal, because all are calibrated monthly by the Standards Lab. The offsets and standard deviations for the 80 instrument subset are almost identical to those for the larger data set. We conclude that the observed mean offset and variability are not caused by differing Artifact Calibration standards, so must be due to drift in the internal DV references.

Here for the first time we see a non-trivial probability of instruments being out of tolerance upon recall after one year. The approximately 1.6% of instruments expected to be out of tolerance at - 1V is by far the largest uncovered in the analysis. Why this number should be three times as large as the number for + 1V is not clear, especially as all values are strikingly similar except for Production Test's offset. A data entry or similar error seems likely. With this one exception, we may be confident that the instrument is conservatively specified for Direct Voltage.

Alternating Current

As was discussed above, it is not possible to remove the measurement system error contributions from AC and AV data. However, raw As Found information is sufficient to show that the 5700A has no problems meeting AC specifications. No significant trends exist in the data, the largest being less than 5% of 1 year spec per year. The instrument is very conservatively specified for Alternating Current.

Alternating Voltage

As Found results presented in Table 2 indicate the time trend for 20 mV, 300 kHz and 1 Mhz and 20V, 1 Mhz can be characterized as "dispersion". This term indicates that variability increases with time. Analysis of one of these (20 mV, 1 Mhz) indicates that 3.1% of instruments may be outside 1 year specification on recall. Figures 5 to 7 are time stability plots for these parameters. Annual drift rate in the three plots is small relative to specifications. Other Alternating Voltages show no such problem.

Information in the Figures and in Table 2 can be used to show the measuring system has significant offsets relative to the Production Test System, which is considered to be accurate because it is supported by Process Metrology. We can calculate and correct for the offsets by taking CSS - Production differences a short time after manufacture as the error in the measuring system. We then use regression analysis to obtain the average offset at other times, and calculate standard deviation of points about the regression line for a subset of data at the longest times after manufacture.

Using these averages and standard deviations (for 5.7 years from manufacture) yields a sigma multiple of 3.2 at 20 mV, 300 kHz and 4.3 at 20 mV, 1 Mhz, which means nearly 100% of instruments will meet 1 year spec 5 years after manufacture. A similar analysis for 20V, 1 Mhz yields a modified sigma multiple of 2.7, providing 99.3% probability of in tolerance on recall.

We conclude that the 5700A is conservatively specified for Alternating Voltage.

CONCLUSIONS

An analysis of As Found, As Left, and Production Test data for over 250 5700As, obtained over a period of about five years, provides important information about the instruments' performance to specifications. The analysis shows the instrument to have been conservatively specified, in accordance with long standing Fluke tradition, and to have high probability of being in tolerance on recall.

REFERENCES

1. "A Preliminary Assessment of the Effectiveness of 5700A Artifact Calibration", Les Huntley, ***Proceedings of the 1995 NCSL Workshop and Symposium***, July, 1995.

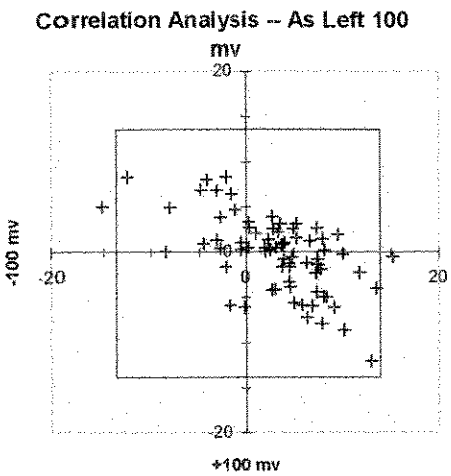

Figure 1.

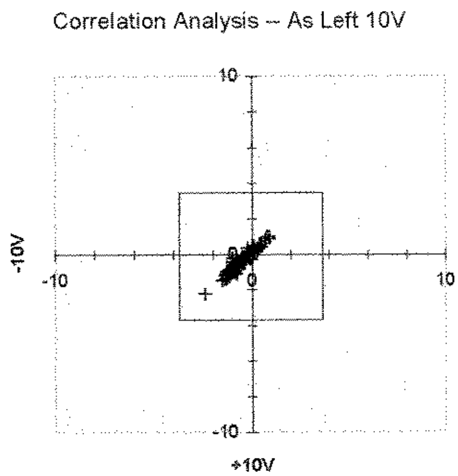

Figure 2.

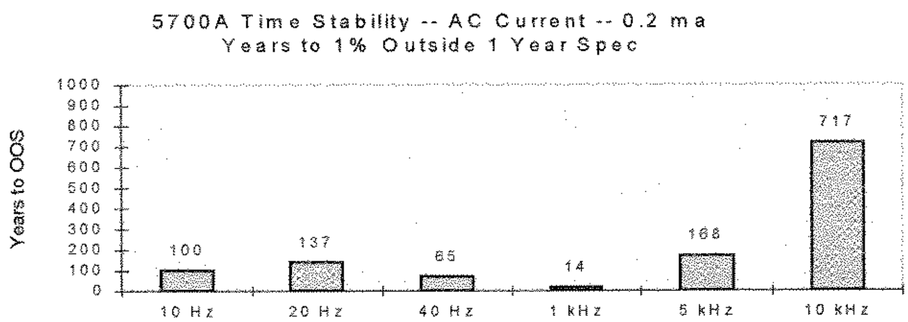

Figure 3.

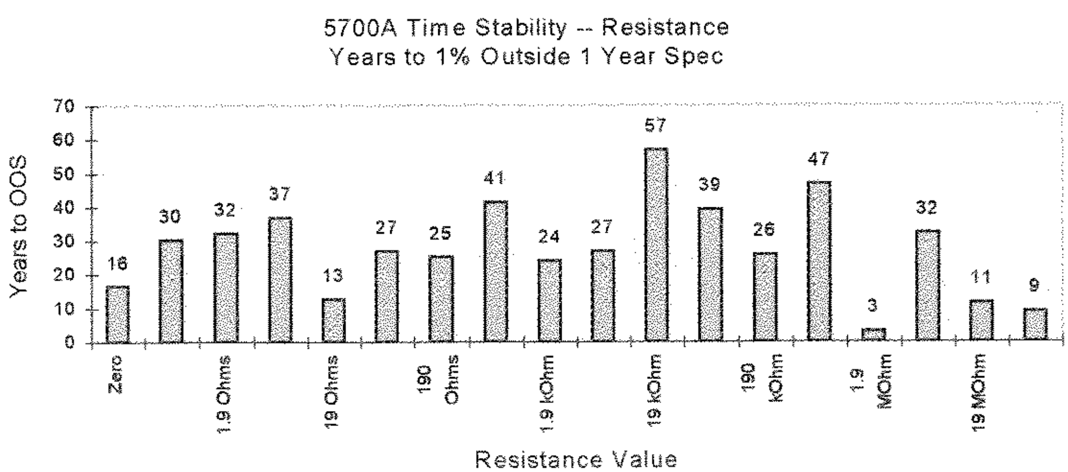

Figure 4.

Direct Current Summary

Current	1 Year Spec	24 Hour Spec	As Found Mean	As Found Std Dev	As Left Mean	As Left Std Dev	Time Trend?	Production Mean	Production Std Dev	5700A Offset	5700A Std Dev	Sigma Multiple	Minimum % Found In Spec
200 uA	110	95	7.7	9.3	8.4	8.7	No	4.6	3.6	-5.4	4.9	20.1	100.0%
-200 uA	110	95	1.5	8.0	0.8	7.9	No	7.8	2.6	-7.1	3.0	30.4	100.0%
2 mA	65	50	4.0	6.9	4.2	6.4	No	10.0	1.9	-10.2	3.4	14.7	100.0%
-2 mA	65	50	-3.0	5.6	-3.4	6.4	No	13.9	2.0	-13.5	2.0	20.2	100.0%
20 mA	65	50	-0.3	6.4	-1.1	6.8	No	10.7	2.3	-9.9	0.6	32.5	100.0%
-20 mA	65	50	1.7	6.8	1.7	6.8	No	15.2	2.1	-15.1	1.9	19.9	100.0%
200 mA	75	60	-8.6	6.6	-8.5	6.3	No	10.3	5.0	-10.4	5.5	11.4	100.0%
-200 mA	75	60	-7.9	6.8	-7.8	6.5	No	18.2	4.9	-18.4	5.4	10.1	100.0%
2A	110	90	-20.1	19.2	-24.9	20.1	-2 ppm/yr	-6.2	14.2	11.0	12.9	7.6	100.0%
-2A	110	90	-28.1	17.2	-32.6	19.9	-2 ppm/yr	-0.4	14.4	4.9	10.3	10.1	100.0%

Resistance Summary

Resistance	1 Year Spec	24 Hour Spec	As Found Mean	As Found Std Dev	As Left Mean	As Left Std Dev	Time Trend?	Production Mean	Production Std Dev	5700A Offset	5700A Std Dev	Sigma Multiple	Minimum % Found In Spec
1	110	85	-24.1	21.9	-19.7	19.5	No	-7.6	3.7	3.2	10.6	8.8	100.0%
1.9	110	85	-24.8	17.2	-21.8	13.8	No	-2.5	6.1	-0.5	11.9	8.5	100.0%
10	33	26	-2.2	6.3	-3.7	5.1	No	-2.0	2.5	3.4	4.4	5.9	100.0%
19	31	24	2.3	10.6	0.9	10.2	No	-4.5	2.3	5.8	3.8	6.0	100.0%
100	20	15	-1.4	3.7	-1.7	3.2	No	-3.9	1.3	4.3	2.3	6.3	100.0%
190	20	15	-3.0	4.1	-3.8	2.9	No	-2.5	1.3	3.4	3.1	5.1	100.0%
1k	15	11	-2.0	1.8	-2.3	1.2	No	0.3	0.7	0.0	1.4	8.8	100.0%
1.9k	15	11	-1.4	2.5	-1.6	1.6	No	-2.5	0.6	2.8	2.0	5.6	100.0%
10k	14	9	-3.3	2.3	-3.7	1.3	No	0.7	0.5	-0.3	1.9	7.2	100.0%
19k	14	9	-1.5	2.2	-2.1	1.6	No	-0.1	0.5	0.8	1.6	7.2	100.0%
100k	16	11	-1.1	2.4	-2.3	1.9	No	0.3	0.7	0.9	1.6	7.8	100.0%
190k	16	11	-0.4	2.8	-1.4	2.4	No	-3.7	0.8	4.7	1.6	5.6	100.0%
1M	23	16	-0.6	3.4	-1.9	2.8	No	-2.2	2.2	3.5	2.9	6.1	100.0%
1.9M	24	17	-2.5	7.9	-4.9	6.8	1.5 ppm/yr	-4.3	2.4	6.8	4.6	3.4	100.0%
10M	46	33	-0.1	8.6	-1.0	6.0	No	-0.4	2.4	1.3	6.6	6.3	100.0%
19M	55	43	23.0	13.5	22.2	9.4	1.6 ppm/yr	-4.2	3.3	5.1	10.1	4.7	100.0%
100M	130	110	-15.1	30.8	-25.8	26.1	-6 ppm/yr	-20.6	10.3	31.3	19.4	4.7	100.0%

Direct Voltage Summary

Voltage	1 Year Spec	24 Hour Spec	As Found Mean	As Found Std Dev	As Left Mean	As Left Std Dev	Time Trend?	Production Mean	Production Std Dev	5700A Offset	5700A Std Dev	Sigma Multiple	Minimum % Found In Spec
0.1	17	14.5	1.8	7.2	3.0	5.4	No	-0.6	2.1	-0.7	5.1	3.2	99.8%
-0.1	17	14.5	-2.1	6.8	0.4	4.6	No	-1.2	2.9	-1.3	5.7	2.8	99.4%
1	9.2	7.2	-2.1	3.6	-0.6	1.2	No	-1.4	0.6	-0.2	3.5	2.6	99.1%
-1	9.2	7.2	-2.3	3.5	-0.5	1.1	No	0.0	0.9	-1.8	3.5	2.1	98.4%
10	8.4	5.4	-1.2	2.1	-0.3	0.6	No	-0.9	0.5	0.0	2.0	4.1	100.0%
-10	8.4	5.4	-1.5	2.5	-0.2	0.6	No	-0.6	0.4	-0.6	2.4	3.2	99.9%
100	10	7	-2.1	2.8	-0.9	1.3	No	1.0	0.6	-2.2	2.6	3.0	99.9%
-100	10	7	-1.9	2.8	-0.6	1.2	No	-0.6	0.6	-0.7	2.5	3.6	100.0%
1000	11.6	8.6	-1.7	2.8	-0.3	1.6	No	-2.1	1.0	0.8	2.5	3.9	100.0%
-1000	11.6	8.6	-1.9	2.8	-0.5	1.6	No	-3.1	1.0	1.7	2.5	3.8	100.0%

NOTE: CSS Results have opposite sign from Production's

Table 1. Summary of the Analysis of Zero-Frequency Parameters.

Alternating Current Summary

		1 Year	24 Hour	As Found		As Left		Time	Production		5700A	Sigma	Minimum
Current	Frequency	Spec	Spec	Mean	Std Dev	Mean	Std Dev	Trend?	Mean	Std Dev	Std Dev	Multiple	% Found In Spec
200 uA	40 Hz	260	220	-17.16	18.90	-13.8	17.9	No	21.8	6.3	18.9	5.4	100.0%
	1 kHz	260	220	8.03	31.20	11.2	28.3	-12 ppm/yr	11.4	41.8	31.2	4.9	100.0%
	10 kHz	21800	21500	876.27	198.66	867.3	192.4	No	-239.5	147.0	198.7	106.5	100.0%
2 mA	1 kHz	180	140	3.33	16.91	3.2	14.6	No	-13.2	8.0	16.9	3.9	100.0%
	10 kHz	3800	3500	-11.27	47.31	-13.8	46.0	No	-487.8	71.6	47.3	54.0	100.0%
20 mA	1 kHz	180	140	23.28	21.48	23.4	18.5	No	0.1	7.3	21.5	4.0	100.0%
	10 kHz	2800	2500	-194.49	36.15	-199.6	37.3	No	217.9	32.3	36.2	48.7	100.0%
200 mA	40 Hz	200	140	-8.23	18.79	-7.5	20.5	No	37.7	7.1	18.8	3.7	100.0%
	1 khz	200	140	16.21	17.99	17.8	20.6	No	16.2	10.3	18.0	4.3	100.0%
	10 kHz	2300	2000	-404.36	73.88	-378.3	115.8	No	371.7	35.8	73.9	22.8	100.0%
2A	40 Hz	770	620	-48.81	26.69	-52.9	26.4	No	21.0	15.2	26.7	16.0	100.0%
	1 khz	770	620	-48.04	27.04	-54.3	27.0	No	-22.4	19.0	27.0	15.6	100.0%
	10 kHz	10100	8100	7.69	374.75	10.4	391.4	No	-386.9	194.3	374.7	25.8	100.0%

Alternating Voltage Summary

		1 Year	24 Hour	As Found		As Left		Time	Production		5700A	Sigma	Minimum	Modified
Voltage	Frequency	Spec	Spec	Mean	Std Dev	Mean	Std Dev	Trend?	Mean	Std Dev	Std Dev	Multiple	% Found In Spec	% Found In Spec
2 mV	1 kHz	2620	2600.0	-4.1	131.3	-30.6	147.4	No	1077.7	113.3	131.3	5.6	100.0%	100.0%
	20 kHz	2620	2600.0	-666.1	163.1	-665.6	150.3	No	1450.0	111.5	163.1	4.3	100.0%	100.0%
20 mV	40 Hz	420	400.0	-24.6	29.3	-22.1	27.7	No	-88.8	30.8	29.3	4.8	100.0%	100.0%
	1 kHz	420	400.0	-25.8	21.1	-25.9	21.6	No	-96.4	29.9	21.1	5.7	100.0%	100.0%
	20 kHz	420	400.0	-174.4	29.1	-173.1	26.8	No	55.0	30.4	29.1	3.4	99.9%	99.9%
	100 kHz	1350	1200.0	-562.8	228.6	-514.4	221.8	No	218.1	65.1	228.6	3.0	99.7%	99.7%
	300 khz	2050	1850.0	122.1	500.4	-71.8	442.1	Dispersion	849.9	199.2	500.4	3.5	**100.0%**	**99.8%**
	1 MHz	5100	4500.0	1842.1	1457.0	1500.2	1339.7	Dispersion	-3046.1	40.6	1457.0	2.2	**96.9%**	**100.0%**
200 mV	40 Hz	160	145.0	-17.8	11.8	-15.2	10.5	No	-38.0	10.5	11.8	4.3	100.0%	100.0%
	1 kHz	160	145.0	-2.4	7.7	0.0	6.2	No	-50.7	12.1	7.7	6.4	100.0%	100.0%
	20 kHz	160	145.0	5.9	6.8	7.7	6.6	No	-45.4	16.5	6.8	6.3	100.0%	100.0%
	100 kHz	1050	900.0	94.5	20.5	92.9	20.2	No	-37.1	19.0	20.5	20.1	100.0%	100.0%
	300 kHz	1250	1090.0	255.1	84.3	248.1	79.8	No	98.1	49.2	84.3	9.1	100.0%	100.0%
	1 MHz	4100	3500.0	767.5	652.4	810.8	661.0	No	290.5	323.5	652.4	4.9	100.0%	100.0%
2V	1 kHz	88.5	73.5	-2.3	6.5	-1.3	5.0	No	3.8	17.9	6.5	5.1	100.0%	100.0%
	20 kHz	88.5	73.5	-0.4	8.5	0.8	7.7	No	12.4	16.7	8.5	6.1	100.0%	100.0%
	1 MHz	2900	2500.0	755.0	475.3	913.1	454.3	No	4.1	295.9	475.3	4.3	100.0%	100.0%
20V	1 kHz	88.5	73.5	-10.6	9.1	-9.3	8.0	No	-10.8	2.6	9.1	5.3	100.0%	100.0%
	20 kHz	88.5	73.5	-11.8	7.1	-10.7	5.6	No	1.8	14.4	7.1	5.6	100.0%	100.0%
	1 MHz	3450	3050.0	815.9	993.8	838.0	867.6	Dispersion	-589.7	591.4	993.8	2.6	**99.1%**	**99.3%**
200V	40 Hz	95	80.0	-43.2	10.5	-40.7	10.2	No	4.7	8.3	10.5	2.8	99.4%	99.4%
	1 kHz	95	80.0	-26.8	9.7	-24.6	8.6	No	-17.3	4.4	9.7	4.5	100.0%	100.0%
	100 kHz	650	550.0	-42.9	95.2	-33.1	89.9	No	87.8	29.4	95.2	6.1	100.0%	100.0%
1000V	50 Hz	94	79.0	-1.3	8.8	0.6	7.5	No	-16.0	4.7	8.8	6.3	100.0%	100.0%
	1 kHz	94	79.0	-15.7	14.4	-13.7	13.2	No	-6.6	5.6	14.4	4.2	100.0%	100.0%

NOTE: CSS Results have opposite sign from Production's

Table 2. Summary of the Analysis of Alternating Current Parameters.

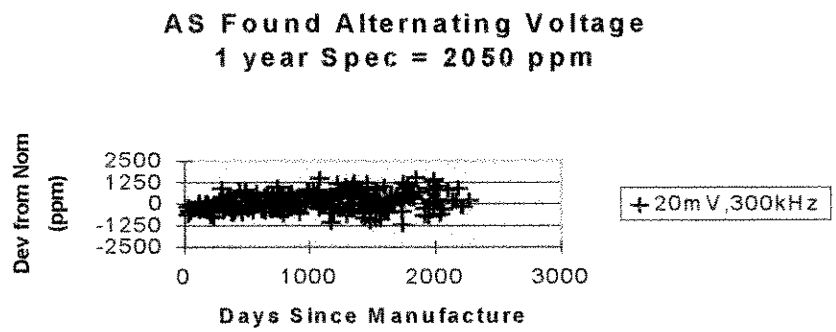

Figure 5. Time stability of 20 mV, 300 kHz.

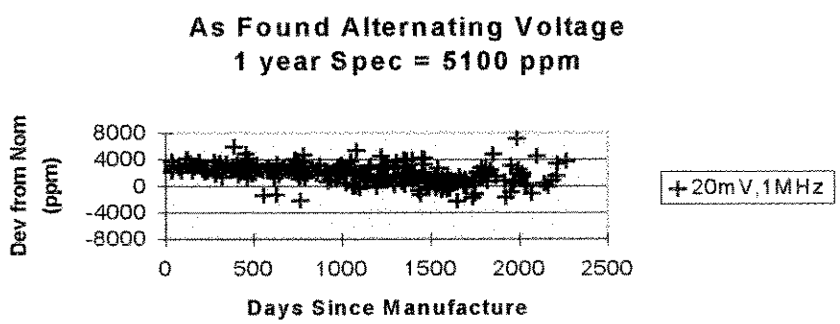

Figure 6. Time stability of 20 mV, 1 MHz.

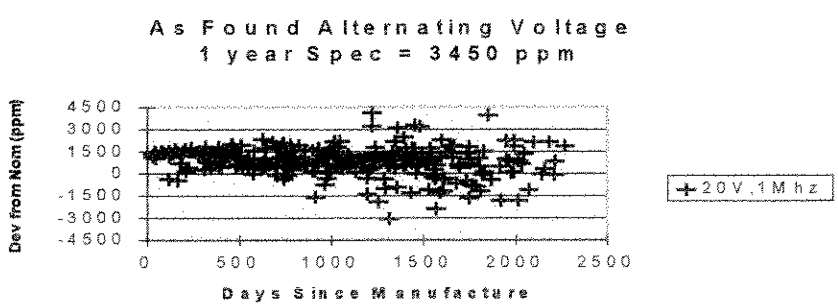

Figure 7. Time Stability of 20V, 1 MHz.