EVALUATION OF THE PERFORMANCE OF A STATE OF THE ART DIGITAL MULTIMETER

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Abstract

The introduction of a state of the art digital multimeter presents a real challenge to the standards lab to provide external verification of its performance. The advent of internal standards and automatic internal calibration of all the DMM's functions from those standards pits the calibration expert, his methods and equipment against an effective machine capable of extreme levels of accuracy. Conventional metrology methods if used very carefully are capable of verifying the DMM's performance but there is very little room for error. The mindset of the metrologist must change because sources of error which may have been negligible in the past are now significant.

The main purpose of this paper is to describe some methods which have been found adequate to verify the performance of a very accurate automatically calibrated DMM, the HP 3458A. The verification processes have been automated as much as is practical. With well characterized processes in place it is possible to develop history on the DMM's performance. Data have been obtained on a number of HP 3458A's which indicate that the autocalibration processes work extremely well and that the instrument definitely has the capability to perform standards lab measurements at very high levels of accuracy. Also included is a description of use of a 10 volt Josephson junction array to measure linearity of the A/D converter of the 3458A, and some results of these measurements.

Verification of A/D converter linearity is imperative, since the A/D in the 3458A is used to provide all the ratios needed for the internal autocalibration processes.

Introduction

The HP 3458A DMM represents a new generation of ultra-high performance digital multimeters. It contains internal standards, circuitry and microprocessor power which enable internal self-calibration and produce performance that rivals some of the better standards lab capabilities available today. In order to establish confidence in the performance of such a "box full of automated metrology", it is necessary to assess its performance on each function and range by comparison with external standards. While many of the methods described in this paper can be applied to evaluation of any precision DMM, some of the procedures are specifically tailored for the HP 3458A DMM.

The basis of autocalibration is fairly straightforward. By comparing measurements of well known external standards to measurements of its internal standards, the DMM determines the values of its internal standards. In the case of the HP 3458A, the only internal standards are a single value each for DC voltage and resistance. These standards are relatively insensitive to ambient conditions and have excellent time stability. The instrument then uses these internal standards in a number of built-in autocalibration processes to establish its accuracy for all ranges and functions. It actually performs over a quarter million measurements in the process. Its overall accuracy and stability are then dependent upon several factors which include:

- accuracy of the external calibration standards
- stability of its internal reference standards
- its ability to compare the above standards
- its ability to transfer these standards to other ranges and functions
- overall quality of its internal calibration processes
- stability of its measurement circuitry between internal calibrations

These factors can be logically divided into two groups. They are:

1) Reference standards, which primarily affect long-term performance (>24 hours)
2) Autocalibration processes and measurement circuitry, which primarily affect short-term performance (<=24 hours)

These long and short term effects can be studied separately. This paper deals mainly with the short-term portion. Long-term assessment of the performance of reference standards is a separate topic.

Following is a very brief summary of the steps involved in calibrating the 3458A prior to evaluation of its performance. First a four-terminal short circuit is applied to the input terminals and the appropriate calibration command is executed. Next a precisely known DC voltage source (nominal 10 volts) and 10 k ohm resistor are successively connected, their values entered into the 3458A and the appropriate calibration commands are given. It is important that OCOMP be turned on prior to connecting the 10 k ohm standard if ultimate accuracy is desired and the 3458A will be used with OCOMP on when measuring resistance. The instrument performs several internal self-adjustment steps after each command. Its absolute accuracy for all parameters it measures will depend upon the accuracy of the values which are entered for the standards. Reference 6 contains detailed information about the internal self-adjustment processes.

This paper will describe some more or less conventional metrology methods which have been developed to determine the performance, in particular to verify the 24-hour specifications of this very accurate DMM. In general, the simple fundamental methods seemed to produce the best results. There are often several valid ways to achieve the same objective in metrology, and the methods chosen are somewhat dictated by available standards and equipment. The methods presented here may not be practical in every laboratory but they should at least provide ideas for alternative methods.

The verification of the various functions and ranges is divided into several areas: DC voltage, resistance, DC current, AC voltage and AC current.

A real advantage provided by an autocalibrated instrument is that when its results agree very closely with carefully derived and highly accurate external stimuli, some confidence in the results is gained by the agreement. As these procedures were being developed, the instrument was capable of pointing out that some of the external metrology tried was in need of some improvement before it would be adequate to verify 3458A performance.

METHODS USED FOR VERIFICATION OF PERFORMANCE

DC VOLTAGE

A prime requirement for evaluating DC voltage performance at the accuracy level required is that the uncertainties in the metrology process used be kept at an absolute minimum. All DC voltage standards used should be tied as closely as possible to the 10 volt calibration standard. The 24 hour DC voltage specifications for the 3458A are 0.5 ppm at 10 volts, 2 ppm at 1 volt and 3 ppm at 100 mV. Using standard resistors in a 25 degree C oil bath, several very simple dividers were set up and evaluated and found to produce adequate results. These resistors are periodically calibrated to absolute values starting from a Thomas one ohm primary standard. Ratio techniques are used to scale from one decade to the next. A closure check is also made at the 10 k ohm value against a 10 k ohm primary standard. Agreement is normally within a few tenths of a ppm. Kelvin Varley dividers were tried and even after externally evaluating their errors they were found to be not adequate for the task.

See figure 1 for the setup used to evaluate the lower three voltage ranges. First, the offset errors of the DMM are evaluated by connecting a low thermal short to its input and taking readings on each range. An accurately known voltage which is nearly full scale is then applied to the input and more readings taken (both forward and reverse). In the case of the 10 volt range, the applied voltage is the same 10 volt zener reference which was used to calibrate the DMM. The 1 volt and 100 millivolt range gain errors are checked by connecting the oil bath resistive dividers between the 10 volt zener reference output and the DMM input. The simplicity of these dividers outweighs the fact that their outputs are not exact cardinal values. Corrections must be applied for divider loading effects on the zener reference output as well as the drop through the connecting leads, even though they amount to only a few tenths of a PPM.

Any thermal emfs or other offsets in the divider network must also be dealt with. This is accomplished by first shorting the divider input leads and taking a DMM reading. In the setup used, it was found that the low voltage side of the divider achieves adequate thermal stability such that changes in thermal emfs during the measurement period are not large enough to require a time dependent model to cancel them out. The leads from the oil bath divider to the DMM are not disturbed during the measurement sequence. Connections to the resistors are made using mercury wetted connections inside the oil bath. It is imperative that careful attention be paid to these minute sources of error, because they can easily be large enough to make the 3458A appear to not meet its specifications if they are not properly handled.

Reversals for evaluating DMM negative reading performance are done with the divider input so that the effects of thermal emfs caused by the reversal process are relative to 10 volts and are minimal. The divider uncertainties are about 0.6 ppm of output for 1 volt and about 1 ppm of output for 100 millivolts. The burden for accuracy of the low voltages is placed squarely on the resistor ratios. Another possible candidate for establishing these accurate dividers is a series-parallel self calibrating ratio method, but it was not used because the simpler methods described above worked well enough.

After performing a calibration and then evaluating its performance, typical results for the gain errors of the 3458A are indicated below. These results include all variations in the instrument and the evaluation process.

DC voltage range	error
10 V	<0.25 ppm
1 V	<1 ppm
0.1 V	<1.5 ppm

Note that the absolute error of the 10 volt reference is a separate issue, and though it affects the DMM's absolute accuracy, the above process has been tailored to cancel its effect on evaluation of the DMM's scaling capabilities. With the small available margin for error and the fact that the process for comparing all the resistors involved has a very stable history it seemed preferable to use this approach to establish the necessary ratios. The same resistors will be used later to check resistance accuracy of the DMM.

Figure 2 shows how the oil bath resistors are connected to scale the 10 volt zener up to 100 V and 1000V. The 100 volt divider consists of ten 10 k ohm resistors in series, with the 10 volt tap nulled against the zener output. A series string of nine 100 k ohm resistors is added on top of this divider to provide for 1000 volt input. Using this method in the oil bath, it was not necessary to do reversals, since thermal emf's did not pose a significant problem. Resistor heating, even in an oil bath must be considered as a possible source of error, particularly if the voltage will be applied for a significant time. Dissipation is held to 100mW or less per resistor. Uncertainty requirements for these dividers are not as severe as for the lower voltages. Uncertainties of about 1 ppm at 100 volts and a few ppm at 1000 volts are adequate to verify the 24 hour specs which are 2.5 ppm at 100 V and 14.5 ppm at 1000 V

RESISTANCE

There are nine resistance ranges, and verification of the lower seven of these involves use of the same standard resistors in the oil bath. The resistors we use are calibrated with the mercury wetted connection resistance included in the assigned value, (except one ohm, which is connected as a true 4-terminal device) and they are connected the same way for all applications described here. The resistance of each mercury wetted contact is approximately 10 micro ohms and its repeatability is on the order of a micro ohm. The 3458A is used with 4-wire connections up to the heavy copper bars of the oil bath. In evaluating the resistance performance of the 3458A, the offset compensated 4-wire ohms mode (OCOMP) must be selected for all ranges 10 k ohms and below. OCOMP removes the effects of thermal emf's in the measurement circuit by taking readings both with and without the DMM's internal current source turned on and using the difference between the two readings to negate the effect of thermal emf's in the measurement leads.

A digression is in order at this point to provide some additional information regarding OCOMP which can affect the results it produces. As with many such beneficial features, there are cases where improper use of OCOMP can introduce a different kind of error. This error is related to the fact that the times between the current on and current off measurements must allow sufficient relaxation of the measurement circuit. This relaxation time can be a simple RC time constant or it can be tied to a much more insidious and slower effect called dielectric absorption (DA). DA effects can be caused by any dielectrics in the measurement circuit, including insulation on the leads. The 3458A has a programmable delay which has default values depending upon range. The 100 k ohm range is where DA problems are most likely to occur. The OCOMP feature is automatically disabled for ranges above 100 k ohms. The relative DA problem caused by various dielectric materials can be observed by connecting a 100 k ohm resistor in 4-wire mode (using twisted pairs) with OCOMP ON and experimenting with different wire insulation materials and delays. Using the default delay in the 3458A, the difference between PVC and Teflon (R) insulated leads about 24" long is very noticeable (provided that DA in other dielectrics in the measurement circuit is not swamping out the effect of the leads). Normally, programming a sufficient delay will eliminate such problems. All of the above discussion of OCOMP also applies to use of the 10 k ohm external standard which is used to calibrate the 3458A.

Relative to the 10 k ohm standard used to calibrate the DMM, achievable uncertainties for the oil bath resistors are 1 ppm or less for values from 10 ohms through 100 k ohms. These widen to about 2 ppm at 1 megohm and about 5 ppm at 10 megohms. When compared to the 24 hour specs for the DMM, these provide usable if not comfortable accuracy ratios. Fortunately the ranges where the specs are tightest, 1 k ohm, 10 k ohms and 100 k ohms, involve either direct measurement of the 10 k ohm calibration standard or a single decade ratio from it. The 24-hour spec for these three ranges is 2.2 ppm. Again, the DMM has been found to be an excellent cross-check on the metrologist and his methods.

DC CURRENT

Verification of the 100 nA, 1 uA and 10 uA current ranges could possibly be done directly with some sort of current source, but an indirect method was chosen which allows use of commonly available standards. The scheme used amounts to measuring the input resistance of the DMM being evaluated, then connecting a voltage source and series standard resistor to the DMM inputs and applying a calculated voltage to develop the desired current. See figure 3. The measurement of the DMM input resistance must be done carefully, since protection devices inside the DMM can be turned on if too large a voltage is developed across the input terminals. Since the protection devices are nonlinear, errors will result if they are activated. Also, the 3458A being measured must be locked onto the proper current range.

Recommended measurement currents for determining input resistance are shown below as well as the correct resistance range to use if another 3458A is used to make the measurements.

DUT current range	Applied Current	auxiliary 3458A resistance range
100 nA range	0.5 uA	10 megohms
1 uA range	5 uA	1 megohm
10 uA range	50 uA	100 k ohms

For the higher current ranges, the evaluation consists of connecting a current source in series with a well known standard resistor and measuring the voltage across the resistor with another carefully calibrated voltmeter. This is shown in figure 4. The oil bath resistance standards are used here also. The following table shows the resistors used and indicates the accuracies needed. The voltmeter must be accurate to within a few microvolts at 1 volt and 0. 1 volt, and must have an input resistance of at least 10 E10 ohms. A second 3458A could be used for this measurement.

range	Resistor	nominal resulting voltage	24-hr spec
100 uA	10 k ohms	1 volt	16 ppm
1 mA	1 k	1 volt	14 ppm
10 mA	100 ohms	1 volt	14 ppm
100 mA	10 ohms	1 volt	29 ppm
1 A	0.1 ohms	0.1 volt	110 ppm

Resistor uncertainties of a few ppm for 100 ohms through 10 k ohms are adequate and requirements are less severe for the 10 and 0. 1 ohm values. These methods for verification of both low and high currents have produced excellent agreement with the 3458A's internal self-adjustments.

AC VOLTAGE

Since the most accurate mode of AC voltage operation for the 3458A is the SYNC sampling mode, the following discussion is aimed at checking that mode. There are several setup parameters which must be input to the 3458A in order to set it up for maximum accuracy. These are: SETACV SYNC, RES=.001, ACBAND 10, 2E6, LFILTER ON. The 3458A manual explains these parameters. First an overview of the methods used to verify AC voltage performance will be presented. Refer to figure 5 for a block diagram of the process.

Verification of a large portion of the DMM's AC voltage performance can be accomplished by careful application of classical thermal AC/DC transfer techniques. For checking the 100 mV range, other methods employing carefully calibrated dividers driven by known input voltages are used. For frequencies above 1 MHz, a 50 ohm system is used which has been calibrated and corrected for flatness. This system is referenced by comparison with established voltages at 100 kHz.

The process chosen to perform the thermal transfer measurements starts with a set of primary standard single range thermal voltage converters (TVC's) with range resistors. This set of TVC's is periodically calibrated by NIST and is used to periodically determine the errors of a commercially available automatic thermal transfer standard (ATS) which is controlled by a computer. The primary standard TVC is connected to the ATS by a tee which is driven at its center by a programmable AC/DC voltage source using remote sensing. The AC accuracy of the source is immaterial, however, its DC voltage output is used as the reference for the primary standard TVC AC/DC transfer, and must be reasonably well calibrated.

The output of the primary standard TVC is read by a programmable DMM. The normal drift canceling DC-, AC, DC+ reversal process is used for the primary TVC. See reference 4 for a discussion of the importance of using a drift canceling algorithm. Special algorithms have been implemented in the controller software to enhance the performance of the ATS. In addition, some hardware modifications were made to the ATS to obtain lower uncertainties. The whole process is automated, and Figure 6a shows how the devices are connected.

A matrix of error data for the ATS is thus generated and stored in a file. These errors represent the error in its response vs. the actual input voltage, expressed as percent or ppm. It is necessary to generate data for each voltage and most frequencies to be used, since interpolation can lead to amplitude dependent errors. These errors arise from the fact that the turnover of the thermal converter in the ATS will, in general, be amplitude dependent and it does not employ DC reversal. The periodic evaluation of the ATS's errors has proven adequate to detect and correct for changes that may occur in its response. There are many potential causes of changes in response including internal drifts and changes in tee contact resistance. Some of these potential sources of error can be evaluated by application of a well known DC voltage to the ATS via the tee.

The ATS is then used to determine the errors of the DMM being evaluated. The DMM is connected to one leg of the tee using a 6" long twisted pair with a programmable AC source driving the center of the tee. See figure 6b. Readings are made with the ATS and the DMM. Then, using the data in the error matrix for the ATS, the DMM errors are calculated. This process is also automated. The error introduced by the 6" twisted pair is of the order of 10 ppm at 100 kHz and less at lower frequencies. Development of intelligent algorithms and software to accomplish all the steps in this scheme required a lot of time and effort, but has resulted in a system which has the capability to not only evaluate the DMM, but can also be used to determine the errors of an AC calibrator. Of course this method is subject to the usual limitations of thermal devices regarding lack of low voltage capability and speed among others. Having an automated process for verification of the AC voltage performance of the DMM is mandatory. Repetitive performance of these tedious procedures manually leads to extreme operator fatigue and measurement errors.

The process used to evaluate the performance of the 100 mV range of the DMM uses a calibrated AC voltage source at 1 volt to drive a resistive divider (using remote sensing inside the divider). The errors in the source are periodically evaluated using the ATS. The divider used is a 200 ohms per volt device which presents the same load to the source as the ATS. The output impedance of this divider is high enough to cause a significant error when connected to the 1 megohm input resistance of the 3458A in ACV SYNC mode, so a mathematical correction must be made. The divider ratio is determined by two methods, DC voltage ratio (both polarities) and by comparison with a standard inductive divider (ratio transformer). This divider ratio data is used at frequencies up to 1 kHz. The same divider is also used at frequencies up to 1 MHz, although the uncertainties required to verify the specs of the 3458A are considerably larger. A second set of ratio data for the divider is generated at 20 kHz using a six decade high frequency ratio transformer. The process of 3458A verification from the divider is also automated. See figure 6c. The tightest specs for the 3458A occur between 40 Hz and 1 kHz, at 100 ppm.

An estimate of the overall uncertainty for the AC voltage verification process described above, using 3 sigma for the random sources of error, is about 40 ppm in the audio frequency range. A detailed discussion of uncertainties of these processes for other voltages and frequencies vs. 3458A specs would be too lengthy for this paper. Data taken on 3458A DMM's are routinely well within the 24-hour specs for the instrument. The data contained in reference 5 indicate that the measurement process described above is capable of state of the art performance.

AC CURRENT VERIFICATION

Verification of AC current performance of the 3458A can be performed using a programmable AC voltage and current calibrator. The errors in the calibrator are periodically determined by measurements made with a set of primary standard current shunts and a thermal voltage converter calibrated by NIST. In order to verify the low current ranges (<10 mA) it was necessary to build a set of shunts using low reactance resistors and use ratio methods to determine the errors in the calibrator's output. Voltages across the shunts are measured with a DVM, and the loading effect of the DVM's input impedance is significant. Appropriate corrections must be made.

After the errors in the current calibrator are determined, it is then connected to the input of the DMM under test and readings are taken. This process is also automated, although checking the current errors of the calibrator is only semi-automated.

RESULTS

After a number of HP 3458A's had been evaluated using the processes described above, it seemed natural to put all 87 measurements for a number of instruments into a computer spreadsheet and do some analysis. Probably one of the better formats to see how well the instruments perform is to look at a histogram for each parameter. As a result, 87 histograms were generated, each containing the data for 41 separate HP 3458A's. Originally, the spreadsheet contained data for 57 instruments, but there were some known firmware problems in the early ones. The data set was cut down to exclude these known problems, and produce a valid sample of normal production units.

Each of the 87 histograms is plotted such that the edges of the histogram represent approximately the 24-hour specifications of the 3458A.

Figures 7 through 13 are examples of these histograms. Space precludes including all of them, but none of the results were beyond the specification limits for any of the parameters.

MEASUREMENT OF LINEARITY USING A 10 VOLT JOSEPHSON JUNCTION ARRAY

The extremely good linearity of the A/D converter of the 3458A is a key reason that it can offer such excellent performance. The only tool we have found capable of measuring that linearity is the 10 volt Josephson junction array. We have had a 10 volt array operational in the HP Loveland standards lab since November, 1988. The array chip was developed by and purchased from NIST, Boulder, Colorado. A detailed description of the Josephson junction array is beyond the scope of this paper. Reference 7 contains much of this detailed information.

Following is a very brief description of the operating characteristics of the array, how we use it, and a sample of results obtained on the 3458A A/D.

In the use of the JJ array for linearity testing, its function can be described as that of a nearly ideal frequency-to-voltage converter. A single Josephson junction follows this basic equation:

$$V= \frac{nhf}{2e} = \frac{nf}{Kj}$$

where V=voltage of a selected "step" across the junction n= an integer f= frequency of RF energy incident on the junction h= Planck's constant e= charge of the electron Kj = a defined constant representing 2e/h

To equate the volt as maintained by a Josephson junction to the SI unit, the quantity Kj must be chosen properly. As of January 1, 1990, the assigned value for Kj is 483597.9 GHz/volt.

The 10 volt JJ array contains 18,992 junctions in series for DC voltage, and can produce extremely precise selectable DC voltage steps of either polarity. Using a frequency of about 70 GHz, the 10 volt array produces a DC voltage step approximately every 150 microvolts, from negative 10 volts to positive 10 volts. The precise value of each step is calculated and compared to the reading of the 3458A under test, which is also connected across the array. We have automated the linearity measurement process, and the system can measure the errors of a 3458A between -10 volts to +10 volts in half volt steps in about 20 minutes. A block diagram of our automated JJ array system is shown in figure 14 and it is described further in references 8 and 9.

Figure 15 shows the difference between 3458A reading and JJ array setting for two different DVM'S. This plot does not reveal much about linearity. There is more than one accepted definition for linearity, but for purposes of this paper, it will be defined as the maximum deviation from a least squares straight line fit to the data represented by the above figure.

Figure 16 shows the deviations from a fitted straight line. The maximum deviation necessary for proper operation of the 3458A is 0.1 ppm of full scale (1 microvolt). These two units are seen to easily meet that requirement. Many other HP 3458A's have been tested using the array and the results have been similar. By carefully characterizing some selected "special" instruments on a periodic basis, we are able to carry linearity testing to the production floor.

SUMMARY

The arrival of a highly accurate DMM with automatic internal self-adjustment is a challenge to the metrologist, because evaluation of its performance requires him to carefully eliminate or compensate for more sources of error than ever before. The results that can be obtained with careful methods show excellent agreement with the DMM's measurements, enhancing confidence in both the methods and the DMM's performance. The methods presented in this paper have been demonstrated to be capable of verifying 24-hour specifications of the 3458A. These methods have been undergoing continuous improvement and will continue to be improved. Table 1 shows a sample set of data taken on a typical 3458A along with estimated uncertainties for each parameter. Data taken on a significant number of HP 3458A's reveal distributions that are within 24-hour specifications for 87 separate parameters. A 10 volt Josephson Junction array is successfully being routinely used as a tool to verify linearity and also to provide a state-of-the-art DC voltage standard for evaluating the performance of the 3458A.

Data thus far accumulated on the performance of the HP 3458A indicate it should earn a place as a measurement tool that can be used to greatly enhance standards lab productivity and effectiveness.

ACKNOWLEDGMENT
I would like to express my sincere appreciation to Sherman Barney, Keith Wright and Bert Hauber for the many hours they have spent developing and improving the methods outlined in this paper. Thanks also to John Giem for patiently generating 87 histograms.

Teflon (R) is a trademark of DuPont.

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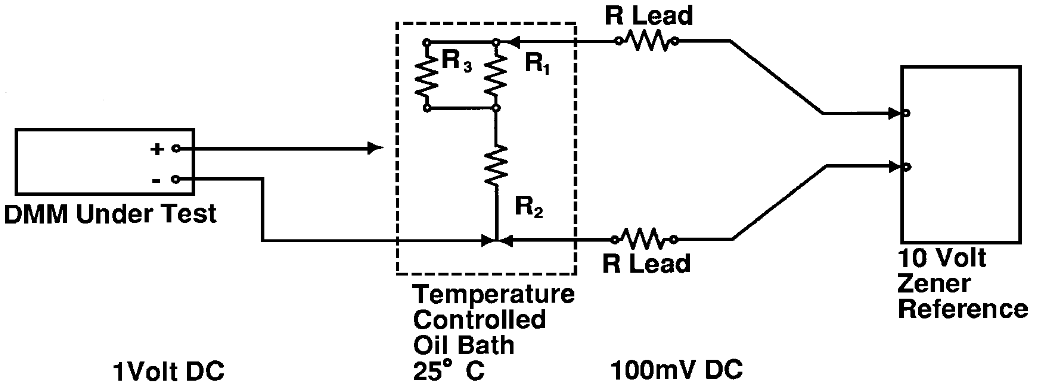
RESISTIVE DIVIDERS FOR LOW VOLTAGE PERFORMANCE CHECKS



1Volt DC
R_1 = 100K
R_2 = 10K
R_3 = 1Megohm

100mV DC
R_1 = 100K
R_2 = 1K
R_3 = Not Used

Nominal Output = .99099099...V

Nominal Output = .09900990099

(Loading Corrections Must Be Made When Using Dividers)

Figure 1

100V DC AND 1000V DC DIVIDERS

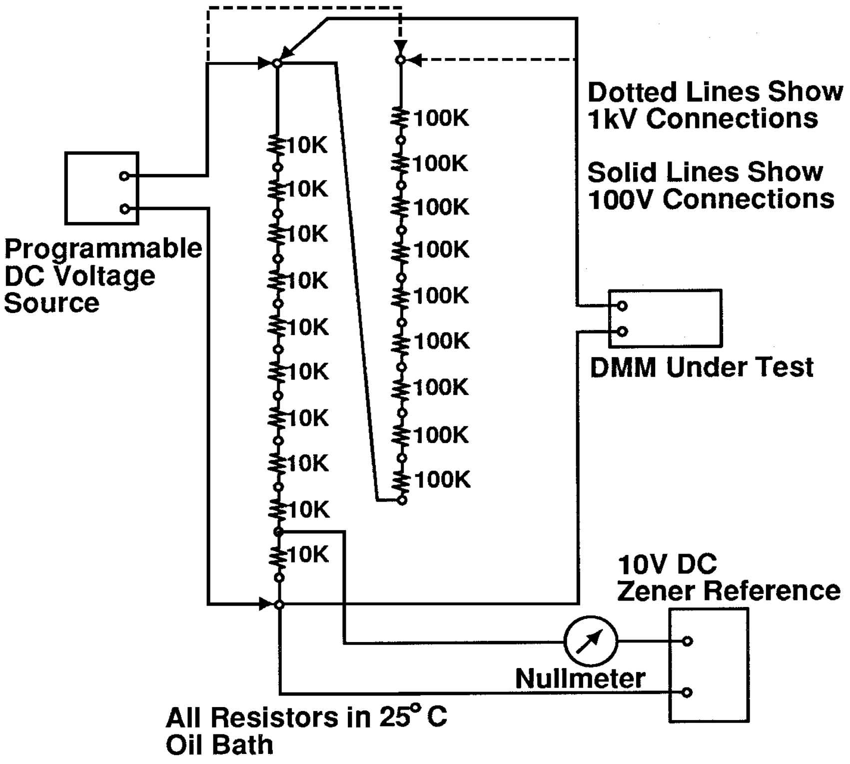


Figure 2

100 nA, 1μA and 10μA Current Verification

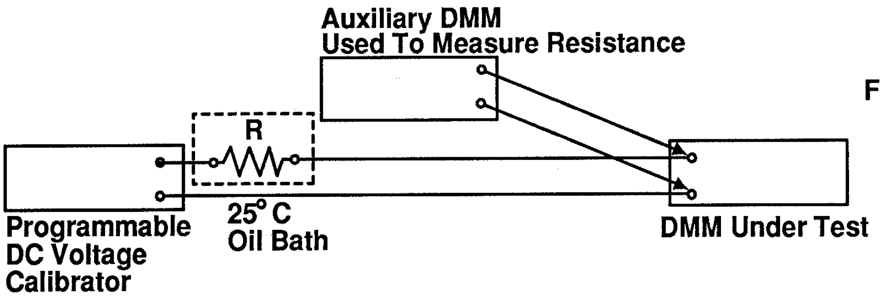


Figure 3

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100 uA thru 1A Current Verification

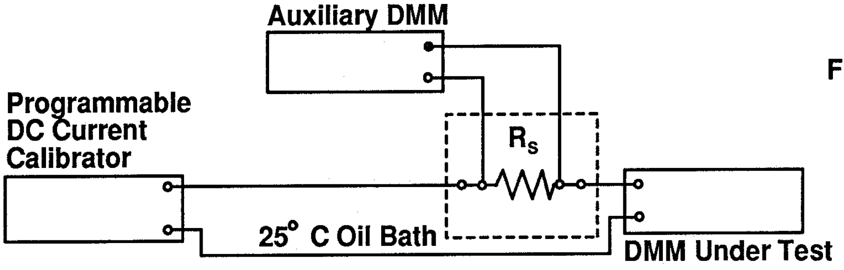

Figure 4

AC VOLTAGE

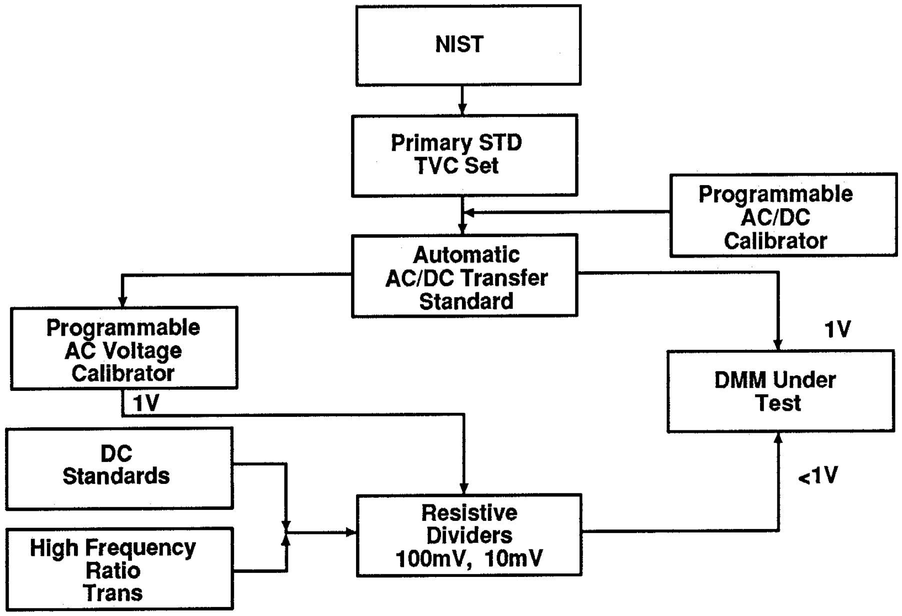

Figure 5

CALIBRATION SETUP TO DETERMINE ERRORS IN AUTOMATIC AC/DC TRANSFER STD

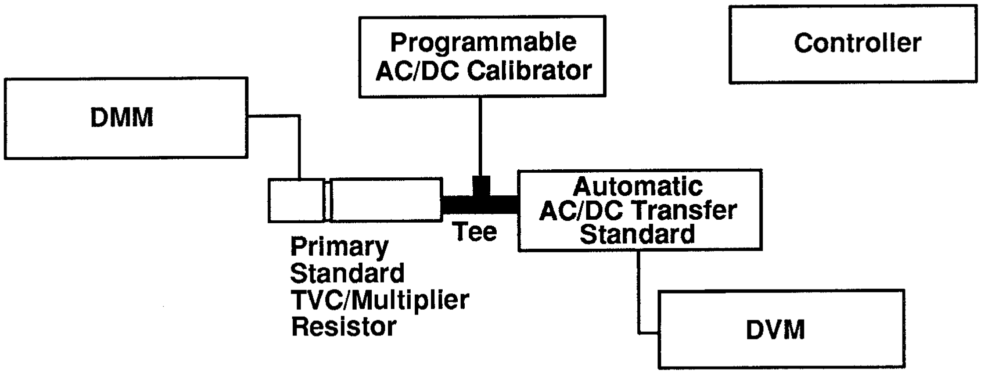

Figure 6a

SETUP FOR VERIFICATION OF ACV DMM PERFORMANCE (≥1V RMS)

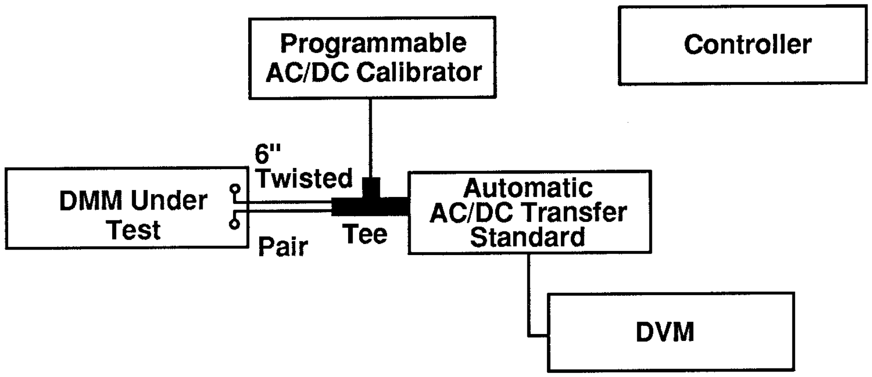

Figure 6b

SETUP FOR VERIFICATION OF ACV <1V RMS

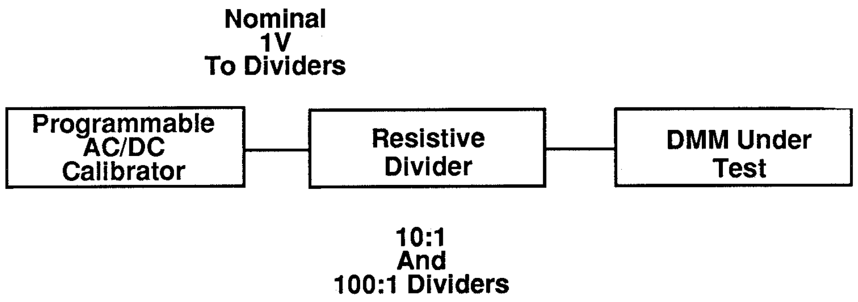

Figure 6c

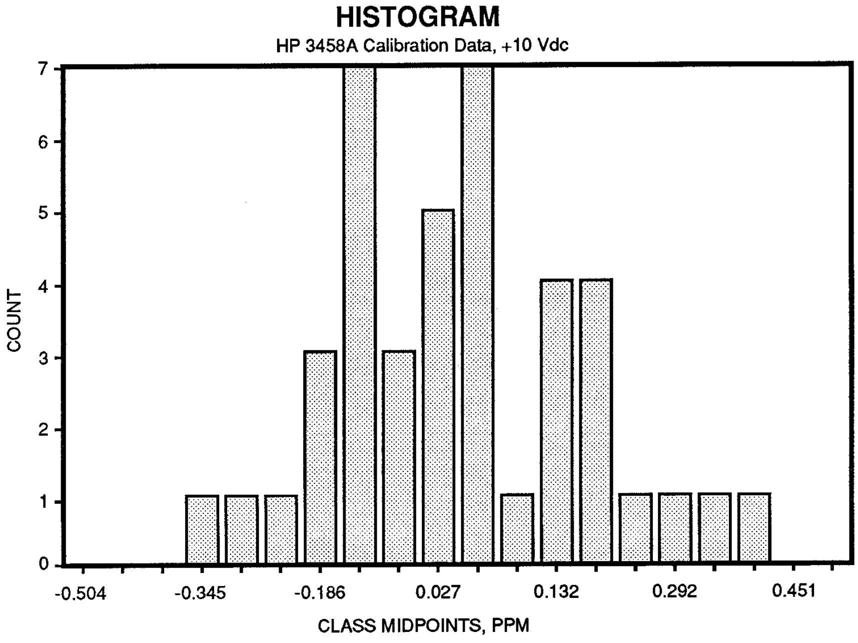

Figure 7

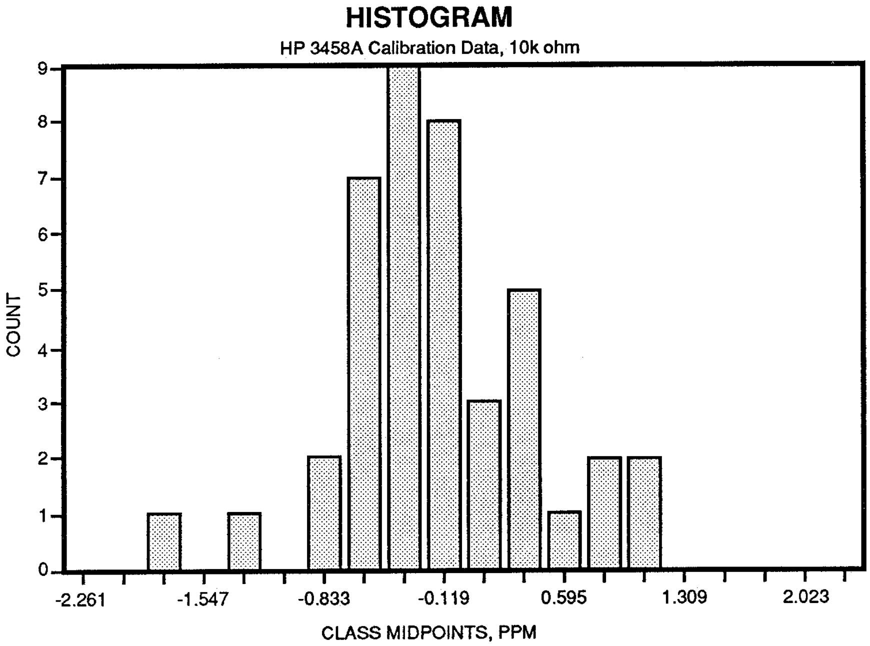

Figure 8

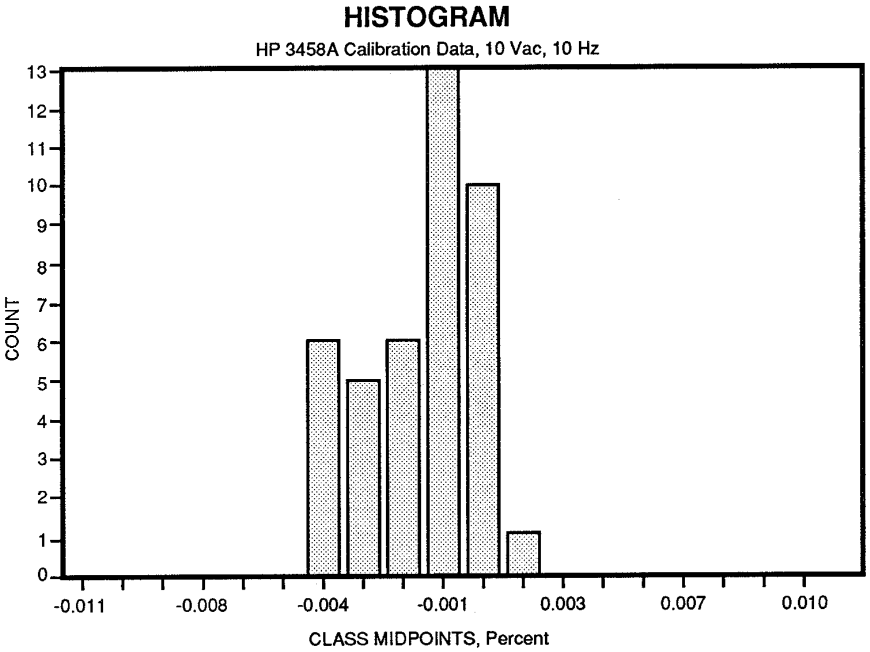

Figure 9

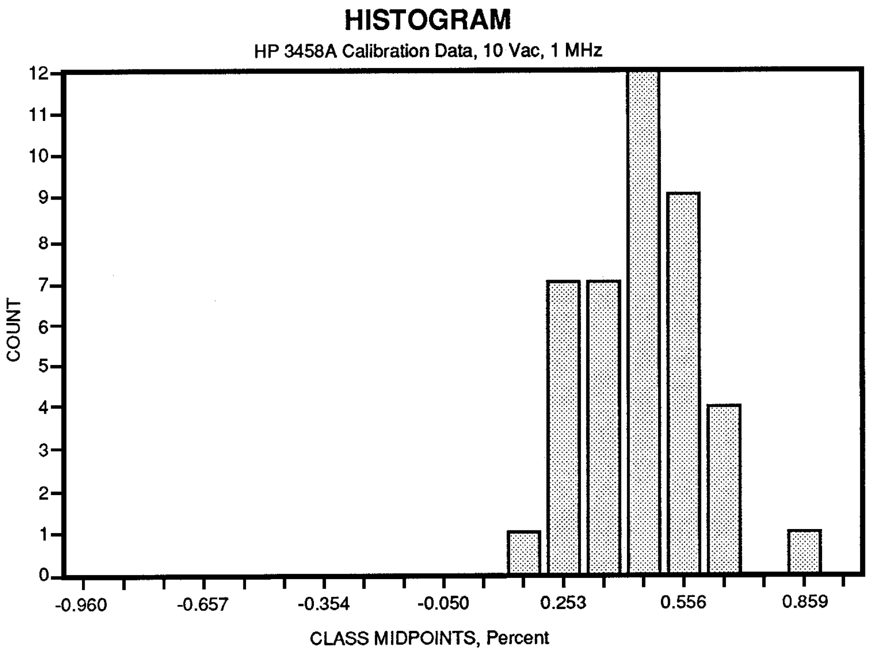

Figure 10

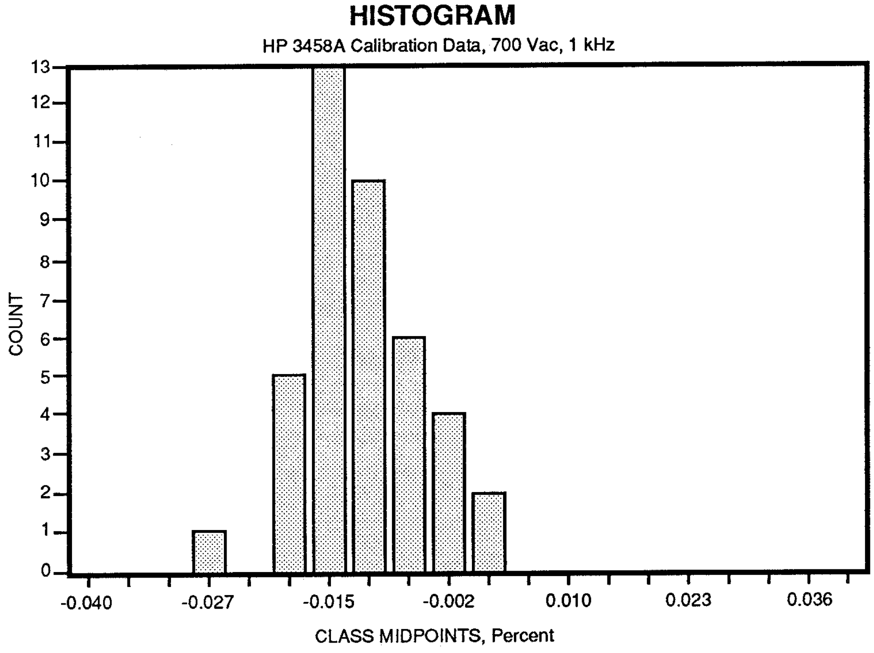

Figure 11

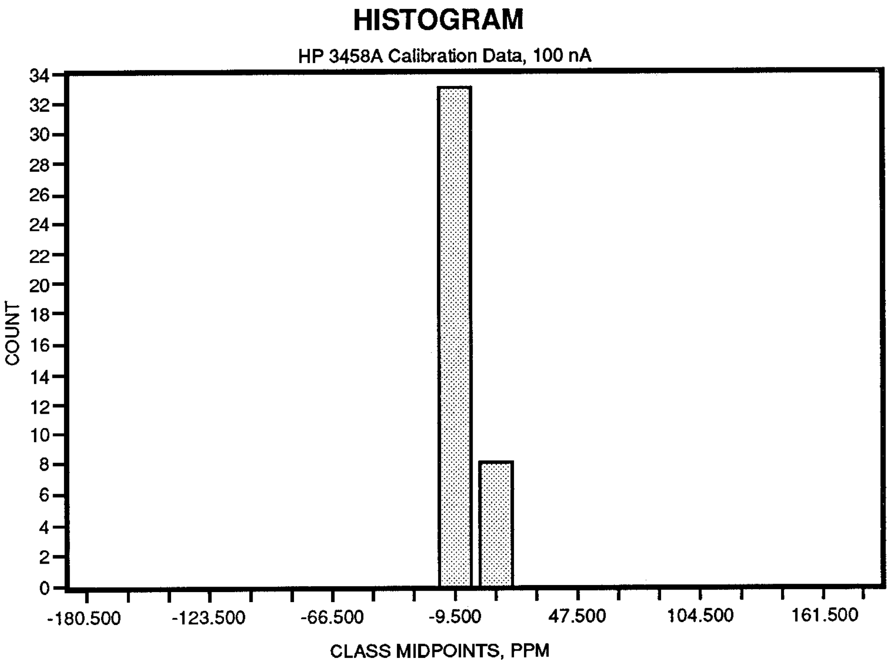

Figure 12

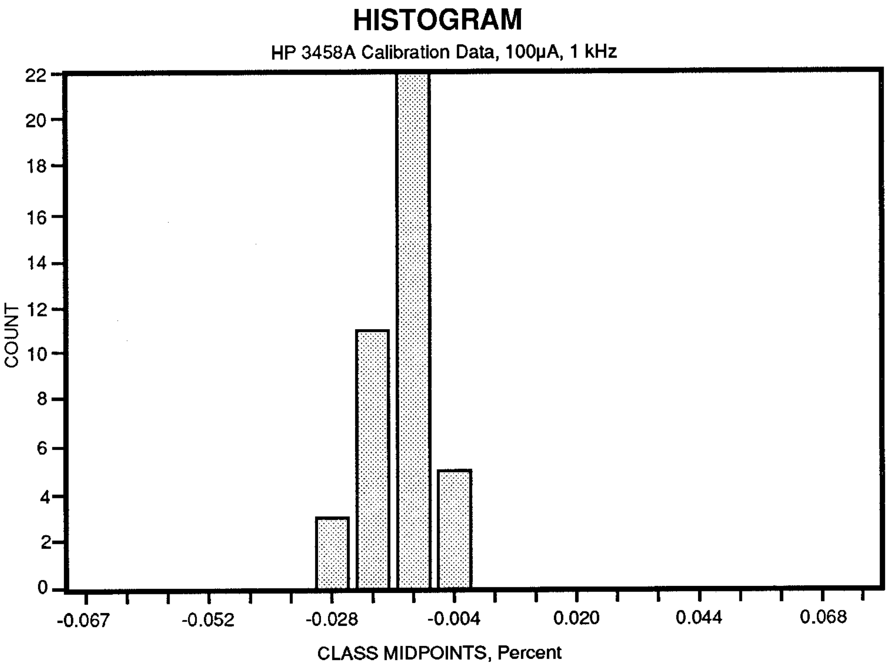

Figure 13

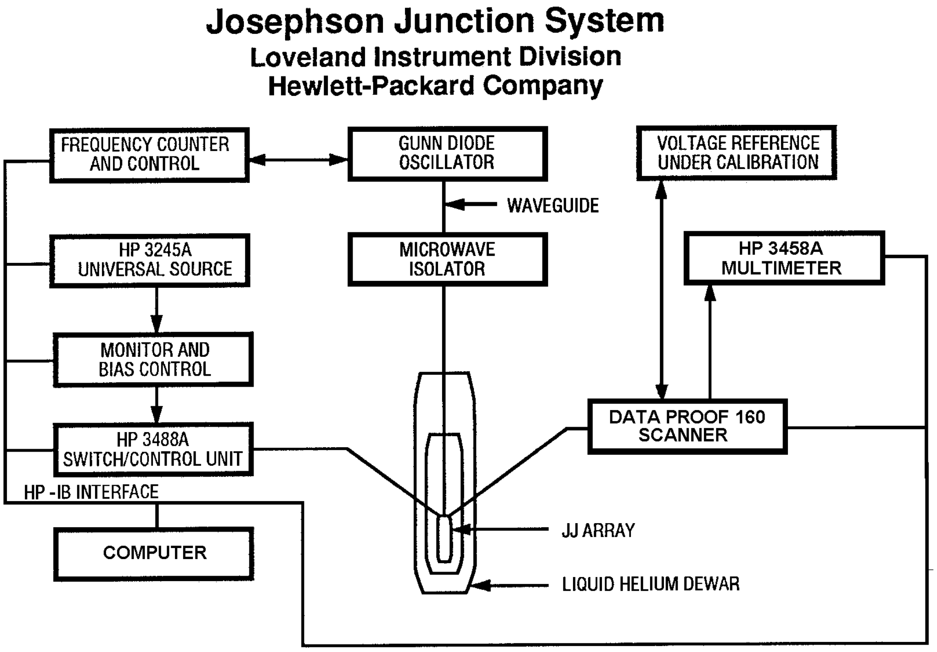

Figure 14

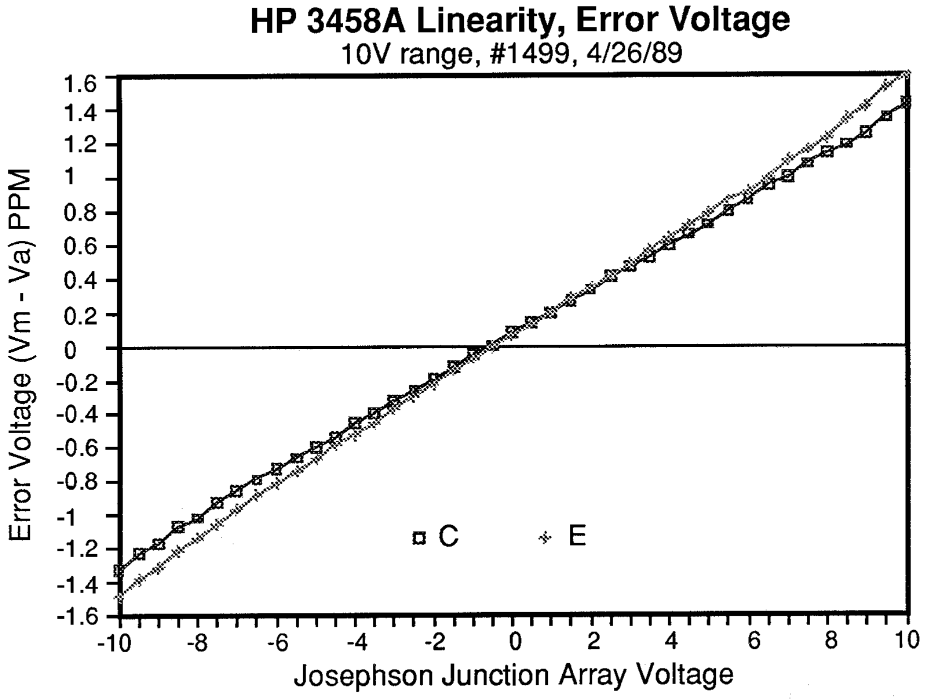

Figure 15

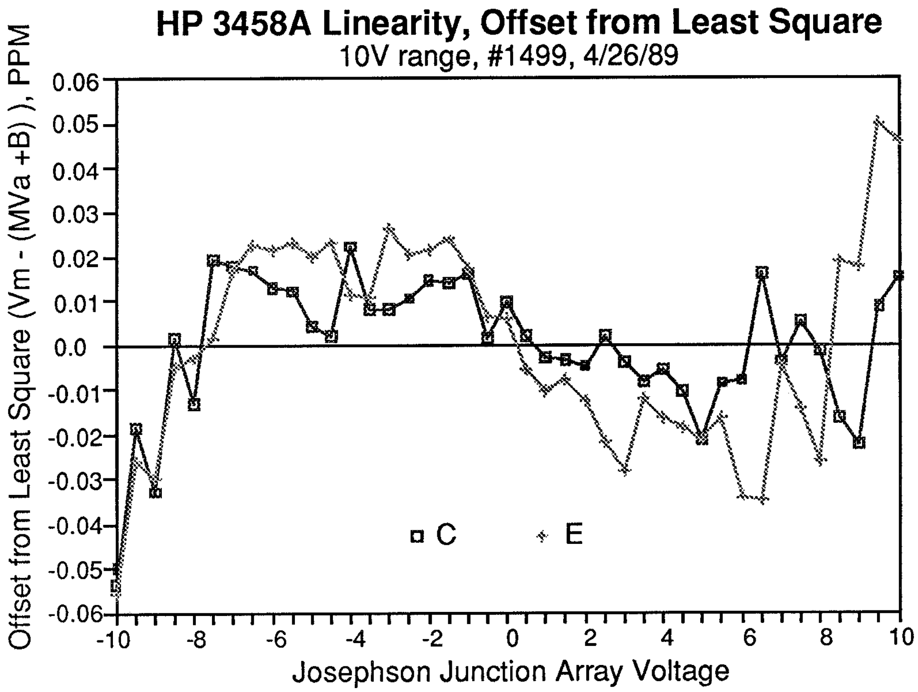
HP 3458A Linearity, Offset from Least Square
10V range, #1499, 4/26/89
Offset from Least Square (Vm - (MVa +B)), PPM
0.06
0.05
0.04
0.03
0.02
0.01
0.0
-0.01
-0.02
-0.03
-0.04
-0.05
-0.06
-10
-8
-6
-4
-2
0
2
4
6
8
10
Josephson Junction Array Voltage
C
E

Figure 16

3458A TEST DATA

DATE: 01/30/89 TEMP: 22.8°C REL HUM: 38%
TEMPERATURE of 3458A: 37.2°C SERIAL NO.: 2823A00510 C#: 16014

3458A TEST DATA (INCOMING)

NOMINAL VALUE	ERROR	UNCERTAINTY
10k ohm	0.9 PPM	.5 PPM
10V DC	1.3 PPM	1 PPM

3458A TEST DATA (OUTGOING)

NOMINAL VALUE	ERROR	UNCERTAINTY
.1V DC	0.0 PPM	2.0 PPM
-.1V DC	.1 PPM	2.0 PPM
1V DC	-.4 PPM	1.0 PPM
-1V DC	.1 PPM	1.0 PPM
10V DC	-.2 PPM	.5 PPM
-10V DC	.1 PPM	.5 PPM
100V DC	.8 PPM	1.0 PPM
-100V DC	1.4 PPM	1.0 PPM
1000V DC	-2.3 PPM	2.0 PPM
-1000V DC	-1.5 PPM	2.0 PPM
1 OHM	-28.2 PPM	1.0 PPM
10 OHM	-.7 PPM	1.0 PPM
100 OHM	-.5 PPM	1.0 PPM
1k OHM	-.2 PPM	1.0 PPM
10k OHM	-.5 PPM	1.0 PPM
100k OHM	0.0 PPM	1.0 PPM
1M OHM	-.5 PPM	2.0 PPM
10M OHM	-7.2 PPM	5.0 PPM
100M OHM	-38.5 PPM	100.0 PPM
1G OHM	378.9 PPM	2000.0 PPM
100nA DC	-1.6 PPM	35.0 PPM
-100nA DC	4.0 PPM	35.0 PPM
1uA DC	.7 PPM	22.0 PPM
-1uA DC	2.4 PPM	22.0 PPM
10uA DC	-.7 PPM	10.0 PPM
-10uA DC	1.9 PPM	10.0 PPM
100uA DC	1.9 PPM	10.0 PPM
-100uA DC	.2 PPM	10.0 PPM
1mA DC	- 1.2 PPM	5.0 PPM
-1mA DC	.8 PPM	5.0 PPM
10mA DC	-1.03 PPM	5.0 PPM
-10mA DC	2.2 PPM	5.0 PPM
100mA DC	-.4 PPM	5.0 PPM
-100mA DC	9.0 PPM	5.0 PPM
1A DC	-42.2 PPM	20.0 PPM
-1A DC	-94.3 PPM	20.0 PPM

TABLE 1

3458A TEST DATA (OUTGOING)

DATE: 01/30/89 TEMP: 22.8°C REL HUM: 38%
TEMPERATURE of 3458A: 37.2°C SERIAL NO.: 2823A00510 C#: 16014

NOMINAL VALUE	ERROR	UNCERTAINTY
.01V 1kHz	-.010%	.009%
.01V 20kHz	-.027%	.009%
.01V 100kHz	-.269%	.025%
.01V 300kHz	-2.116%	.210%
.01V 1MHz	-.116%	.450%
.1V 1kHz	-.008%	.006%
.1V 20kHz	-.010%	.006%
.1V 100kHz	-.034%	.012%
.1V 300kHz	-.168%	.030%
.1V 1MHz	-.339%	.100%
1V 1kHz	-.002%	.005%
1V 20kHz	-.005%	.005%
1V 50kHz	.005%	.005%
1V 100kHz	.021%	.008%
1V 300kHz	.133%	.015%
1V 500kHz	.254%	.050%
1V 1MHz	.530%	.100%
3V 100kHz	-.006%	.006%
10V 10Hz	.002%	.012%
10V 20Hz	.001%	.004%
10V 40Hz	-0.000%	.004%
10V 1kHz	-.001%	.004%
10V 10kHz	.001%	.004%
10V 20kHz	.001%	.004%
10V 50kHz	.008%	.004%
10V 100kHz	-.001%	.006%
10V 300kHz	-.047%	.015%
10V 500kHz	.018%	.040%
10V 1MHz	.469%	.080%
100V 1kHz	-.007%	.005%
100V 20kHz	-.006%	.005%
100V 50kHz	-.002%	.005%
100V 100kHz	-.011%	.008%
700V 1kHz	-.002%	.005%
.01V 4MHz	-1.375%	.300%
.lV 4MHz	-1.500%	.250%
.1V 8MHz	.192%	.250%
.1V 10MHz	7.745%	.250%
1V 4MHz	1.097%	.250%
1V 8MHz	.145%	.250%
1V 10MHz	1.882%	.250%
3V 2MHz	-.806%	.200%
3V 4MHz	.139%	.250%
3V 8MHz	.071%	.250%
3V 10MHz	6.052%	.250%
10uA 1kHz	.103%	.080%
100uA 1kHz	-.018%	.015%
lmA 1kHz	-.010%	.015%
l0mA 1kHz	-.008%	.015%
l00mA 1kHz	-.010%	.015%
1A 1kHz	-.017%	.015%

TABLE 1 (continued)