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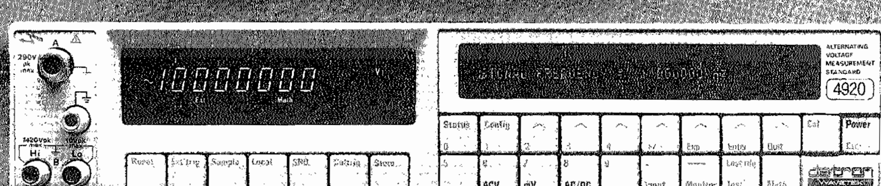
MODEL 4920

ALTERNATING VOLTAGE MEASUREMENT STANDARD

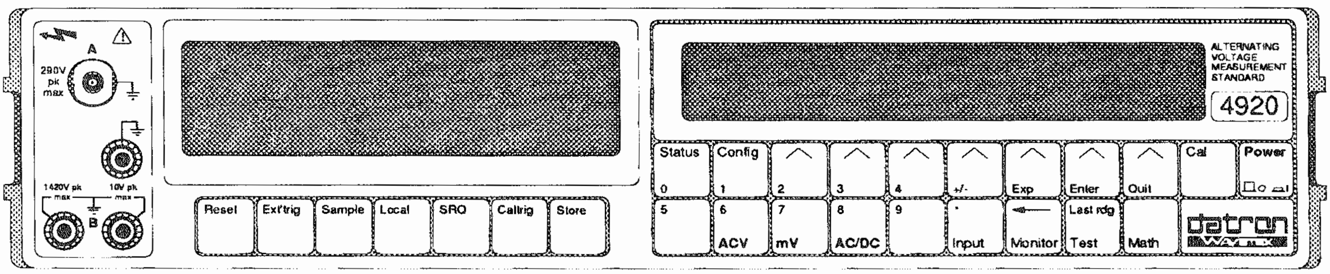
CALIBRATION AND TRACEABILITY



4920 Calibration and Traceability

Introduction

The Datron model 4920 is an alternating voltage measurement standard with performance normally associated with thermal transfer standards. It provides the direct display of measured alternating voltage in the range of 1mV to 1kV at frequencies between 1Hz and 1.25MHz with measurement times of a few seconds. Operation is fully automatic, ranges may be selected from the front panel or via GPIB, with simultaneous display of input signal frequency. The techniques used to support its calibration are presented in the following paragraphs, together with a discussion of traceability issues.



Datron's 4920 Alternating Voltage Measurement Standard

Alternating Voltage Traceability Overview

The established path for Alternating Voltage traceability in the range of interest is invariably via AC/DC difference standards. These devices are thermal converters utilizing various techniques, but they all realize the definition of Root Mean Square Alternating Current producing an equivalent heating effect to a Direct Current. To make an absolute Alternating Voltage measurement, a Direct Voltage reference is needed in addition to an AC/DC Difference standard.

Thermal Transfer instruments incorporate the additional circuitry to provide the means of comparison for the Alternating and Direct inputs, usually requiring manual operation, to provide a means of absolute measurement when provided with a DC reference. Most calibration laboratories use a Thermal Transfer or individual Thermal Voltage Converters (TVCs) to obtain Alternating Voltage traceability.

At levels below approximately 250mV thermal converters become difficult to use and better performances are obtained with Ratio Transformers (Inductive Voltage Dividers - IVDs) or Selby Micropotentiometers.

These dissimilar techniques are supported to differing levels of uncertainty over differing voltage and frequency ranges by the various National Standards laboratories around the world.

IVDs can provide extremely accurate ratios to allow division to below millivolt levels, but are restricted in frequency of operation and voltage/frequency range over which calibration is available. Micropots, a thermal technique relating AC/DC difference to a milivolt level Direct Voltage reference, operate over a wider frequency range, though calibration uncertainties are generally much larger.

Calibration System Philosophy

Development of the 4920 required the development of two calibration systems; one to transfer National Standards traceability from a thermal converter set calibrated to NIST's best capability to a Working Standard, or 'Master' 4920, which is then used in the second system to calibrate production instruments. This approach provides the highest level of traceability to production 4920s while maintaining the practicality, useability and robustness required for manufacturing and service centre use.

This approach was chosen to avoid the use of fragile thermal converter standards on a routine basis, to reduce the risk of loss of performance history, the investment it represents and the delay of replacement in the event of damage occurring. The product calibration system was designed to be totally automatic, to speed and simplify the process and make it as economic as possible. Automation of the Working Standard calibration system was required to achieve the measurement uncertainties required and reduce operator intervention to a minimum.

Product Calibration System

In the fully automated product calibration system, a characterized 4920 is used as Working Standard, in effect providing a transfer between prime standards and the product.

The system consists of an alternating voltage source and the 'Master' 4920, as in Fig. 1 opposite, under the control of a personal computer system via GPIB.

The working standard 4920 is accompanied by an error table in the form of a file on the computer system. The error file can be considered as the equivalent of the calibration certificate used to record a standard's performance at the time of calibration, which is subsequently referred to during its use.

The product calibration system is configured to ensure both the Unit Under Calibration (UUC) and the Working Standard have the same input voltage applied. This is achieved with the use of precision flexible coaxial cable forming an extended 'T' piece between the N Series input connectors of the two 4920s and the input from the voltage source - a Datron 4708 calibrator. The calibrator output is also connected via a high quality coaxial cable in remote sense configuration to develop its output voltage accurately at the point electrically closest to the 4920 input 'T'. The input impedance of the 4920 is a minimum of 125 kilohms, which ensures the matching of input levels at each 4920 input connector without placing stringent requirements on the connector and cabling.

This parallel measurement approach was chosen to minimize the effect of some characteristics of voltage sources which the 4708 shares in common with all calibrators, which are significant in relation to the 4920 performance levels:

Firstly, load regulation, which is the ability of a calibrator to maintain the correct output when driving a load. This is particulary significant at high frequencies, due to reactive effects in the cabling and load. Second is the increased settling times associated with high voltage operation. This parallel approach ensures that both 4920s have the same voltage applied, even if it differs by a small error from the nominal value due to load regulation and settling time errors.

During operation, for each individual voltage/frequency point, the system establishes the input level by measurement by the Master 4920 prior to making an adjustment to the UUC utilizing its electronic Autocal facility. Immediately following the Autocal adjustment a verification phase is performed which simultaneously triggers measurements from the Master and UUC. Any change in input is seen by both 4920s, ensuring the highest integrity of transfer from the Master to the UUC. In both adjustment and verification phases the error file is accessed for the Master calibration error factor for that particular range, voltage and frequency point.

In any transfer measurement, steps must be taken to ensure that in event of failure of the Working Standard, the UUC is not miscalibrated by exactly matching its performance to the erroneous Master. The system software checks the input value as measured by the 'Master' against a set of limits dependent on input voltage and frequency, to prevent calibration errors in the event of voltage source or Master failure.

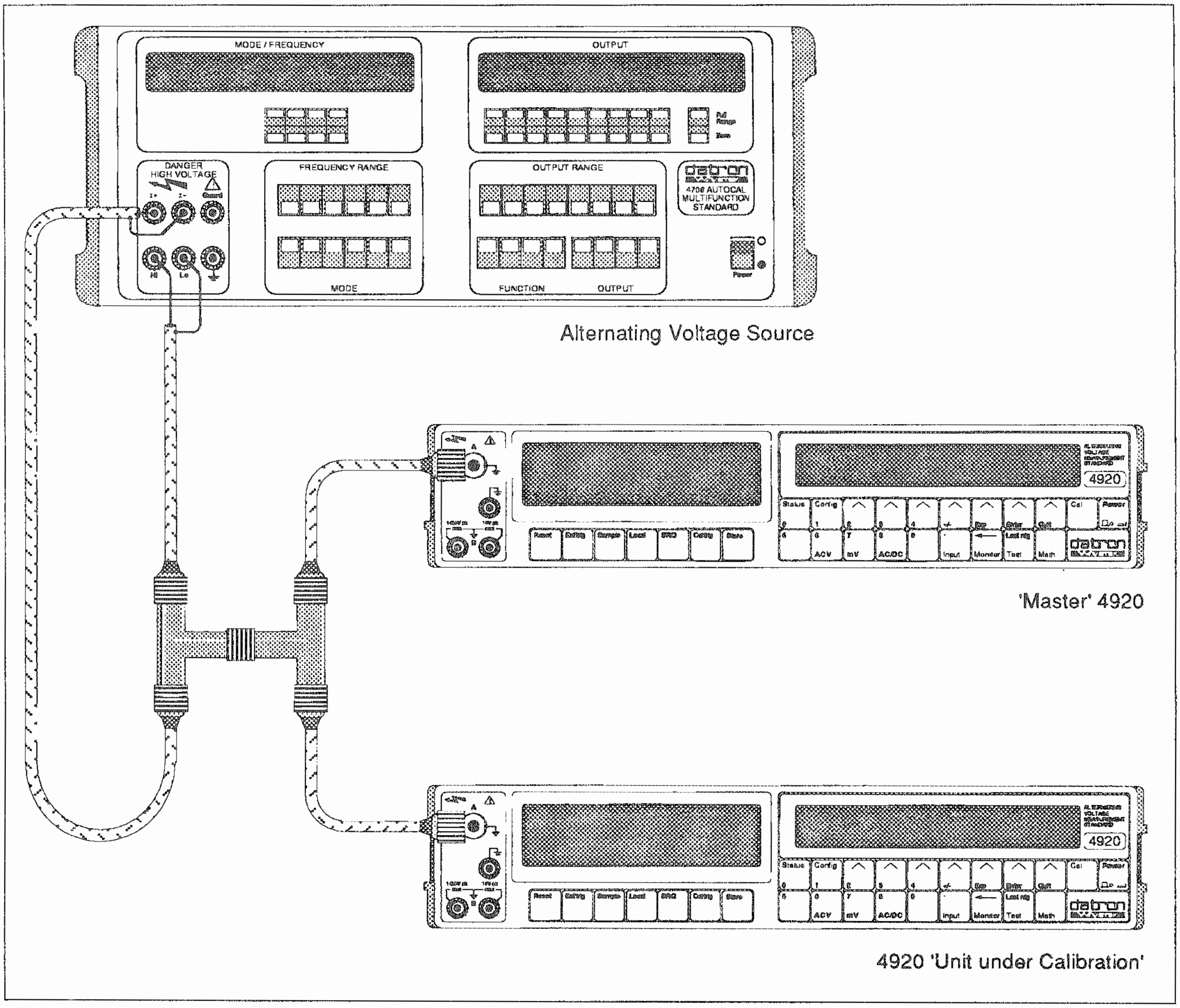


Figure 1 Datron 4920 - Automated Calibration System

Working Standard Calibration System

The 4920 which forms the Working Standard in the product calibration system for Manufacturing and Service Centre use is characterized in the Standards Laboratory directly against prime thermal converter standards using an automated system.

On a periodic basis, the working standard is characterized - adjustments are not made - it is simply measured, to enable a history to be maintained. The calibration intervals of the working reference 4920 is adjusted when history indicates that its performance justifies extending the cycle.

The majority of measurements are made against a Holt Model 11 thermal converter set over the range 1V to 1kV in an automated system shown in *Figure 2*, opposite. For measurements at the lower levels a low voltage thermal converter is substituted, and at the 100mV level a micropotentiometer is used. Refer to *Figure 3* overleaf for the micropot system.

Measurement sequences are run under control of a Personal Computer via GPIB, requiring manual intervention only to change thermal converters. This system is an evolution of a system developed to make automated TVC measurements of calibrators and intercomparison of TVCs within Datron's prime standards laboratory.

A 4-wire transfer switch, employing vacuum relays, is used to switch the output of the Direct or Alternating voltage sources to the input of a 'T' piece connecting the 4920 and TVC inputs in parallel. The 4-wire switch avoids channel difference errors between the AC and DC paths, and rapidly changes over the TVC input preventing cooling of the TVC element when switching between AC and DC.

The TVC output voltage, nominally 7mV, is measured in a differential setup with a DC nanovoltmeter and Backoff Source in a manner similar to the traditional thermal transfer Lindeck/Null Detector arrangement. In this case the analog nanovoltmeter functions as a low noise preamplifier prior to digitizing the TVC / Backoff Source difference voltage with a digital voltmeter. In use, the single range TVCs are changed for each voltage level. The Backoff Source is manually adjusted to balance the TVC output with the appropriate TVC and voltage combination prior to initiating the automated sequence.

Each TVC is characterized for output change with input (sensitivity) at the operating points of interest. This information is stored on the computer in a database together with AC/DC difference data from calibrations performed at the National Standards laboratory (NIST, NPL etc) for the various TVC, voltage and frequency combinations required.

During operation, the system makes drift compensated AC/DC difference measurements relative to the Direct Voltage source to establish the absolute value of the Alternating Voltage presented to the 4920 input. A typical measurement sequence for a single point is shown in *Figure 4* overleaf.

For the 100mV level a micropotentiometer is used in an automated system performing AC/DC difference measurements relative to the Direct Voltage measured at the micropot output. An absolute Alternating Voltage level is therefore established at the 4920 input.

System operation is broadly similar to the TVC system, except that during the DC phase of the cycle the micropot output is measured on the precision DMM (a Datron 1281) via the Sampling switch. The Sampling switch operates together with the 4-wire transfer switch, connecting the precision DMM only during the DC phase thus avoiding loading the micropot output with additional capacitance of the DMM input during the AC measurement phase. Sample switch capacitance is dominated by the connectors, giving around 6 picofarads in total. A typical measurement sequence for a single point is shown in *Figure 5* overleaf.

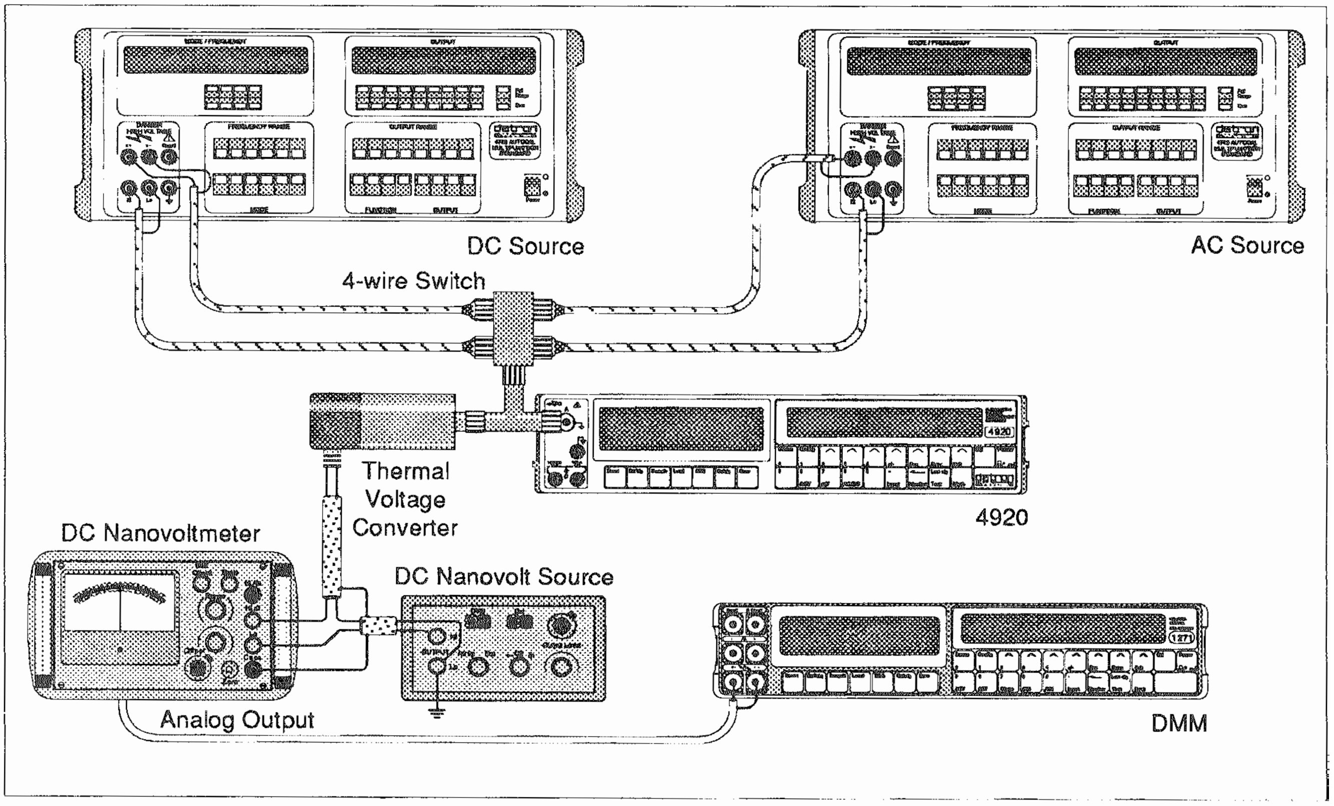


Figure 2 Datron 4920 - Automated TVC Measurement System

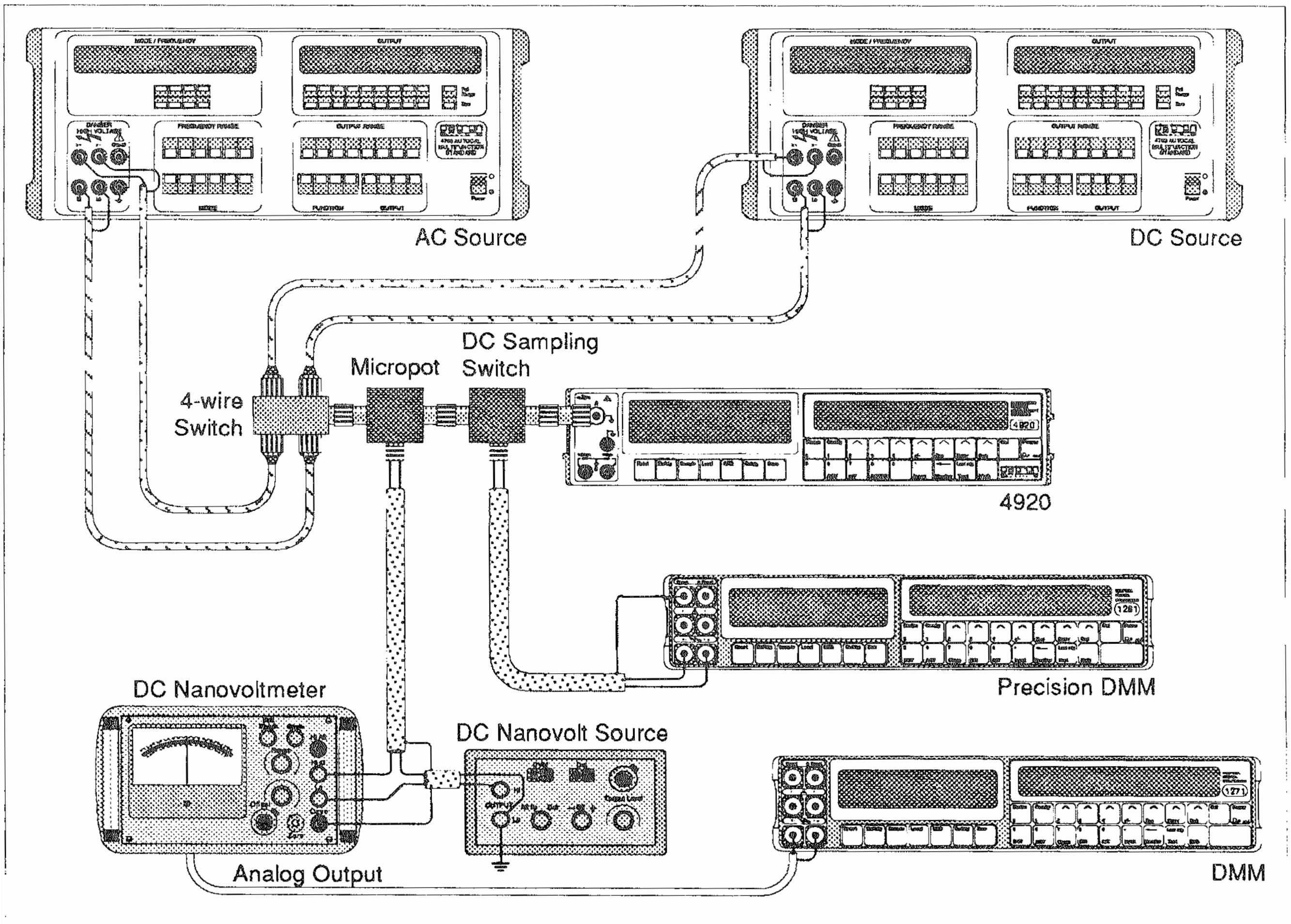
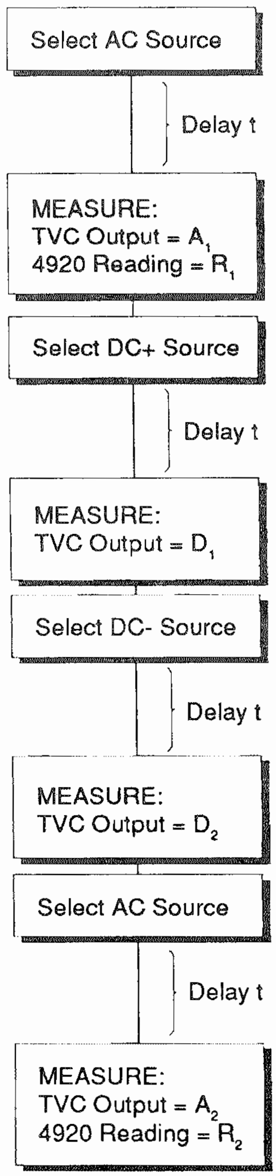


Figure 3 Datron 4920 - Automated Micropot Measurement System



$$\text{4920 Reading} = \frac{R_1 + R_2}{2} \quad \text{(Volts)}$$

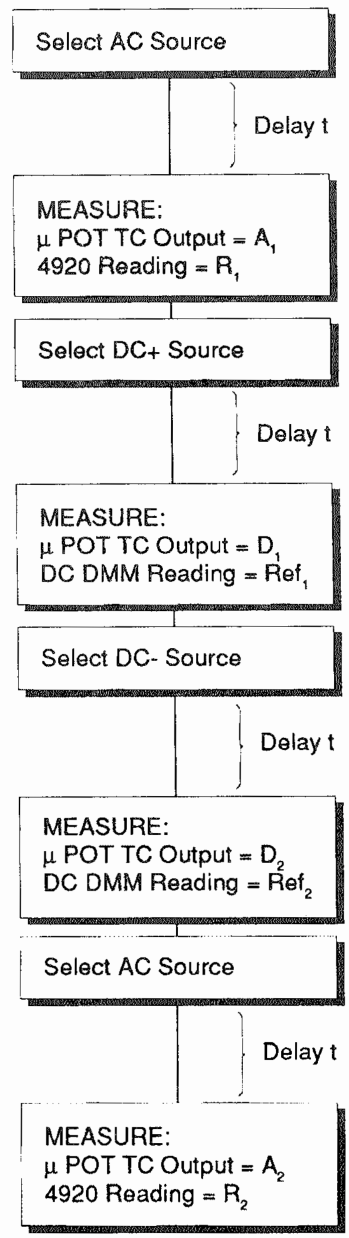
$$\text{4920 Input Level} = \left\{ \frac{A_1 + A_2}{2} - \frac{D_1 - D_2}{2} \right\} \frac{1}{S}$$

(ppm from nominal)

Where S = TVC Sensitivity

From which the 4920 absolute AV error may be computed.

Figure 4 Datron 4920 - TVC Measurement Sequence



$$\text{4920 Reading} = \frac{R_1 + R_2}{2} \quad \text{(Volts)}$$

$$\text{DV Ref Level} = \frac{Ref_1 + Ref_2}{2} \quad \text{(Volts)}$$

$$\text{AC/DC Difference at 4920 Input} = \left\{ \frac{A_1 + A_2}{2} - \frac{D_1 - D_2}{2} \right\} \frac{1}{S}$$

(ppm from nominal)

Where S = μ POT Sensitivity

From which the 4920 absolute AV error may be computed.

Figure 5 Datron 4920 - µPOT Measurement Sequence

Measurement Considerations

When the 4920 is calibrated against a thermal converter, a standard of AC/DC difference (the TVC) is compared with a measurement of absolute alternating voltage (the 4920). The AC/DC difference calibration of the TVC is made absolute by the DC reference within the system.

In the 4920 TVC measurement system, the absolute voltage is established at the 4-wire sense point within the transfer switch. Loading effects within the 'T' piece and transfer switch due to the low input resistance of the TVC cause the alternating voltage seen by the 4920 to be less than the voltage at the 'sense point' by a small amount. If skin effect changes of resistance at high frequencies are ignored (a valid assumption at the frequencies and impedances of interest), it can be assumed that both alternating and direct voltages are attenuated by the same amount.

For the Holt Model 11 set, the lowest load resistance is 400 Ohms, giving a 5ppm error for the actual equipment used. 4920 input resistance is several orders higher so its contribution may be ignored. The effect will diminish with the higher input resistance TVC combinations used at higher voltage levels. Low voltage TVCs often have a 50 Ohm input resistance which yields an error of 45ppm for this particular setup. Characterization of these loading errors is relatively simple to perform and is incorporated into the system as an additional set of correction data.

Repeatable measurements to the uncertainty levels required to support the 4920 to its full capability utilizing TVC techniques are only possible with the use of drift compensations during the transfer cycle. A linear drift compensation algorithm is adequate for the purposes of the system. This is best achieved in a fully automated system which accurately times the transfer cycle stages and incorporates the drift compensations in the computations performed within the system software.

Cycle timings are a compromise between allowing the TVC heater sufficient time to settle to its final value without allowing ambient temperature changes to show through. In addition to changes in TVC output due to warmup and ambient changes, any change in source value is also compensated. This becomes more significant at higher voltage levels.

Repeated measurement or multiple AC/DC transfer cycles improve random uncertainties with averaging.

Emphasis has been placed on the sources of error arising from the TVC and AC aspects of the measurement systems, which dominate measurement uncertainties for an alternating voltage standard. However, the Direct Voltage source is also important, providing the link from the relative AC/DC difference measurement to absolute voltage, and is chosen and calibrated to minimize any additional uncertainty.

Traceability and Uncertainty

Introduction

To verify the performance of the 4920, it was necessary to obtain the best traceability possible for the standards used. At the time of writing, the lowest uncertainty in AC/DC difference certification is available from the U.S. National Institute of Standards and Technology (NIST). Therefore, each 4920 shipped from the factory is calibrated using standards traceable to NIST.

It is anticipated that some users will require traceability to other National Standards Laboratories, which will yield different measurement uncertainties. Furthermore, unless the Datron calibration system and process is exactly duplicated, the additional uncertainty due to transfer from National Standards to the unit under calibration will be different.

For this reason, the performance of the 4920 is specified separately to the uncertainty with to which the factory calibration system is capable of measuring it. This allows the substitution of different calibration uncertainties and calculation of subsequent measurement uncertainties.

Statistics and Uncertainties

The basis of Datron's Alternating Voltage uncertainty build up is the AC/DC difference measurement of prime thermal converter standards calibrated at NIST. Sources of additional uncertainty contributions have already been described.

The international metrology community has never agreed on how individual uncertainty contributions should be combined when calculating the total uncertainty of a measurement. In the case of the factory calibration uncertainties published for the 4920, summation of estimated uncertainties is performed using standard statistical methods.

Each uncertainty contribution must first be classified as either random or systematic, according to the following definitions:

A random contribution is the spread observed in measurement results due to the presence of small independent variables, causing differences in results when the same measurement is repeated under substantially the same conditions. The most common sources of random error are effects such as temperature fluctuations, noise etc.

A systematic contribution is a residual constant uncertainty for which corrections cannot be made, such as the uncertainty placed on the value of a standard reported on its calibration certificate.

Combined Systematic Uncertainty Usc, based on individual systematic uncertainty contributions of rectangular distribution Us_1, Us_2, etc to Us_n is given by:

$$Usc = K\sqrt{\frac{[Us_1^2 + Us_2^2 + \ldots Us_n^2]}{3}}$$

Where K is a factor dependent on the required confidence level, sometimes known as Student's t Factor

In the case of one component of systematic uncertainty Ud being dominant, the above summations may yield a value of Usc greater than the arithmetic sum of the individual systematic uncertainty contributions. The formula should then be modified as follows:

$$Usc = Ud + K\sqrt{\frac{[Us_1^2 + Us_2^2 + \ldots Us_n^2]}{3}}$$

The Total Uncertainty Ut, based on the Combined Systematic Uncertainty Usc above and Random Uncertainty contributions of Gaussian distribution Ur_1, Ur_2, etc to Ur_n is given by:

$$Ut = \sqrt{Usc^2 + Ur_1^2 + Ur_2^2 + \cdots Ur_n^2}$$

Uncertainty Contributions in the 4920 Factory Calibration System

Random Contributions

Repeatability of measurement for the initial characterization of the master 4920 is typically better than 1ppm, dependent on voltage level and frequency, thermal converter current etc. Repeatability achieved by the product calibration system is similar. These two contributions are easily identified and are considered to include all random effects within the measurements. System performance was initially evaluated by performing repeated measurements on sample 4920s, including verification of product level measurements by comparison of sample 4920s calibrated on the product calibration system directly with thermal converter standards, thus closing the loop as shown in Fig 6. This loop closing technique is valuable as an overall confidence check and is used regularly as a statistical control on product calibration.

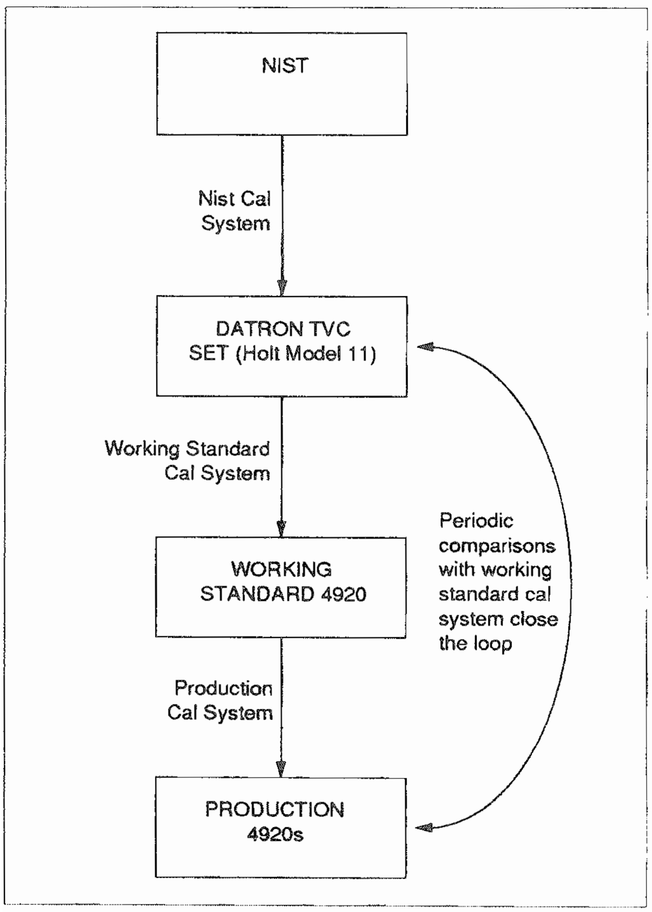


Figure 6: Closing the loop

Systematic Contributions

The major contribution of systematic uncertainty is in the AC/DC difference attributed to the TVC set at NIST. The drift of this AC/DC difference with time has been established through NIST calibration history and intercomparisons within the set and with other sets. Results of these intercomparisons show that at moderate frequencies, uncertainties due to converter stability effects and set-to-set variations are much less than the AC/DC difference uncertainty. In addition, compensations for the TVC drift substantially reduce the systematic character of this drift. As a result, the remaining uncertainty in the drift rate prediction may then be considered to be random in nature.

DC Voltage Contributions

The calibration by NIST of the TVC set defines the AC/DC difference of each converter at frequencies of interest. To convert this difference uncertainty to alternating voltage uncertainty, it is necessary to include the uncertainty of the direct voltage reference. Therefore, an uncertainty is included for the direct voltage source used in the Working Standard calibration system of 1ppm as an additional systematic and 1ppm as random.

Conclusions

At moderate levels of voltage and frequency, the use of these techniques yields a combined uncertainty of 8ppm for the absolute alternating voltage calibration of product 4920s from a 5ppm NIST AC/DC difference uncertainty.

References

DEF STAN 00-26 - Guide to the Evaluation and Expression of the Uncertainties associated with the Results of Electrical Measurements.

BCS 3003 - The Expression of Uncertainty in Electrical Measurements.

Notes

Notes

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