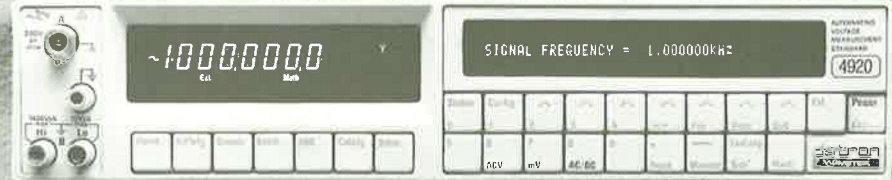
datron
WAVETEK

MODEL 4920

ALTERNATING VOLTAGE
MEASUREMENT STANDARD

DESIGN, APPLICATION AND PERFORMANCE



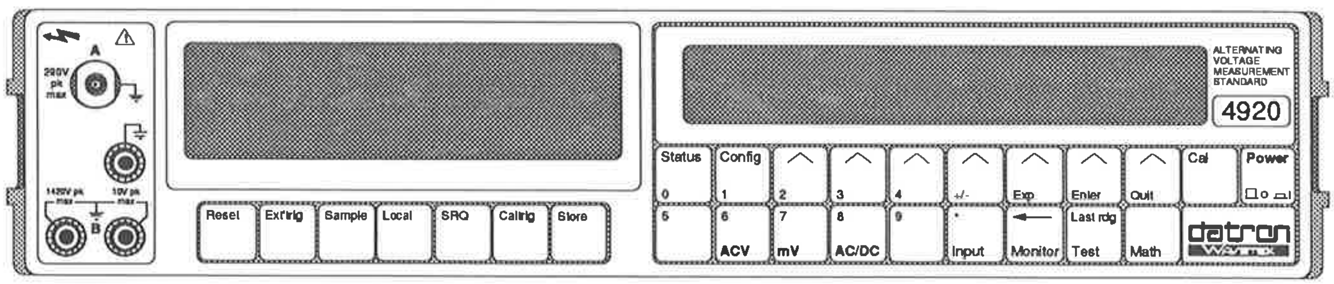
4920 Design, Application and Performance

Introduction

As a manufacturer of high accuracy multifunction calibrators and DMMs, we at Datron have long been familiar with the applications and use of AC/DC Thermal Transfer Standards (TTSs). We have invested significant amounts of time and money in the automation and simplification of Alternating Voltage calibration using TTSs in our factory in an attempt to reduce costs and improve measurement uncertainties. This investment has been worthwhile because of the lack of viable alternatives, but the maintenance, support and operating costs of these systems are still a very significant overhead.

Regular dialogue with our customers has revealed that we are not alone. In the last ten years, the metrology community has seen the measurement capabilities of the best programmable DMMs and calibrators improve dramatically, catching up with National Standards Laboratories' abilities to disseminate the standards required to support them.

As a technological leader in the design and manufacture of precision, programmable DC-LF instrumentation, Datron is now able to apply these design techniques to applications that previously required use of a TTS. This opportunity has led to the development of the model 4920 Alternating Voltage Measurement Standard (AVMS).



Datron's 4920 Alternating Voltage Measurement Standard

Design Requirements

For the AVMS to be an effective replacement for a traditional TTS, there are several design requirements that had to be met.

Ease Of Use

One of the biggest drawbacks in the use of a TTS is the skill level required of the personnel that operate it. By providing the AVMS with microprocessor - based intelligence, the operator skill level required may be reduced, freeing skilled and expensive metrology experts for other, more productive work.

Programmability

This in-built intelligence should be combined with a remote interface that can control all operating modes and functions. As calibration of modern DC-LF calibrators may also be controlled over a remote interface, calibration of their alternating voltage function is easy to automate in a simple system. Furthermore, the total automation of the calibration process means that it is easy to implement computerized statistical process control (SPC) techniques.

Settling Time

Another significant problem faced by users of the traditional TTS is the time required for thermal stabilization after initial application of a signal, especially at high voltages. To achieve the best uncertainties, a TTs usually requires 30 minutes or more to settle to a steady state. For ultimate accuracy the remaining drift needs to be compensated for, resulting in curve fitting and timing constraints. As a result, calibration of the alternating voltage function of today's high performance calibrators can take several hours. One of the design requirements of the 4920 was the ability to make a measurement to full accuracy specifications in just a few seconds, reducing the calibrator measurement process to minutes rather than hours.

Input Overvoltage Protection

Some designs of traditional TTS have no overload protection, which presents a significant risk of permanent damage to the thermal element. As there is often a long and expensive calibration history attached to the thermal element, the costs of overload are far more than just the cost of a new element. Other designs have incorporated a 'protection override' switch for removal of the protection when a measurement is made, which still makes it possible for an operator to apply an inadvertent overload and burn out the thermal elements. Modern electronic instrument design techniques, however, allow full overload protection with minimal performance degradation, and are incorporated into the AVMS design.

Calibration Support

The traditional TTS is generally used in conjunction with a calibration certificate that states its AC/DC difference at specific input voltage ranges and frequencies. The operator balances the unknown alternating voltage against the known direct voltage input and then manually applies a correction, based on the calibrated AC/DC difference at that voltage and frequency. Each and every voltage range/frequency combination requires its own correction for AC/DC difference which must be calibrated at those points. Therefore, the cost of calibration of a TTS is proportional to the number of voltage/frequency points required in use, and can often exceed the price of a new unit.
One of the design requirements of the 4920 is to hold the characterization of a unit in non-volatile memory and employ intelligent algorithms to extrapolate between a limited number of traceable calibration points and any other point in the entire performance envelope of the instrument. These limited number of calibration points will significantly reduce the cost of ownership of the standard.

Millivolt Level Calibration

Another significant problem faced in the calibration of today's programmable calibrators is the traceable measurement of the 1mV to 100mV ranges that they offer, since the majority of TTSs do not work at these levels. One approach is to use IVDs (Inductive Voltage Dividers) for lower frequencies and micropotentiometers at higher frequencies. A major design requirement of the Datron AVMS was to simplify this process and enable its automation.

Ruggedness

The traditional multi-range TTS is not well suited to transport. It contains a number of mechanical elements that effect its measurement characteristics. For example, the frequency flatness is often trimmed using mechanical trimmers that can suffer physical disturbance (and therefore electrical disturbance) if subjected to vibration or mechanical shock.
Since the AVMS is designed to be used as a transfer standard, typically between standards laboratories and remotely deployed calibrators, is must be able to withstand the mechanical shock encountered during transport by commercial carriers. All calibration corrections for the AVMS are stored in non-volatile memory - even those that correct for frequency response, and there are no trim-pots that require 'tweaking' during calibration. A variant of the AVMS designed specifically for the US Navy, the 4920M, has successfully undergone rigorous environmental testing to MIL-T-28800D, type III, Class 5 Style E, proving its suitability to transfer applications.

System Design

The measurement uncertainties required to replace a traditional TTS was the biggest technical challenge posed by the project. However, several years of history of the operation and performance of the RMS detector used in the Model 4708 Multifunction Calibrator proved that, with some slight design modifications, it could easily meet the required accuracy levels.

The RMS detector is essentially a circuit element that converts an alternating voltage input into a direct voltage output, that may be measured by a precision A-D converter. The circuit in Fig. 1 is similar to the 4708 but with some additional modification to improve open loop linearity, which is not a critical parameter in the calibrator since it utilises a null searching control loop.

The op amps and FETs operate as precision differential current steering stages which provide the currents to drive the differential log/antilog stages. Q3, Q4 is an emitter follower used to buffer the log stage from the capacitance of the antilog. The transfer function is:

$$I_{out} = \frac{V_{sig}^{\ 2}}{R^2 I_b}$$

Note that the overall gain is inversely proportional to Ib and, therefore, if Ib is set to be proportional to the RMS output value using feedback techniques, then the transfer function has constant gain! Therefore the settling time is independent of input signal level, it has excellent linearity and the relative noise in the converter is lower than designs using other conversion techniques, especially at low percentages of range.

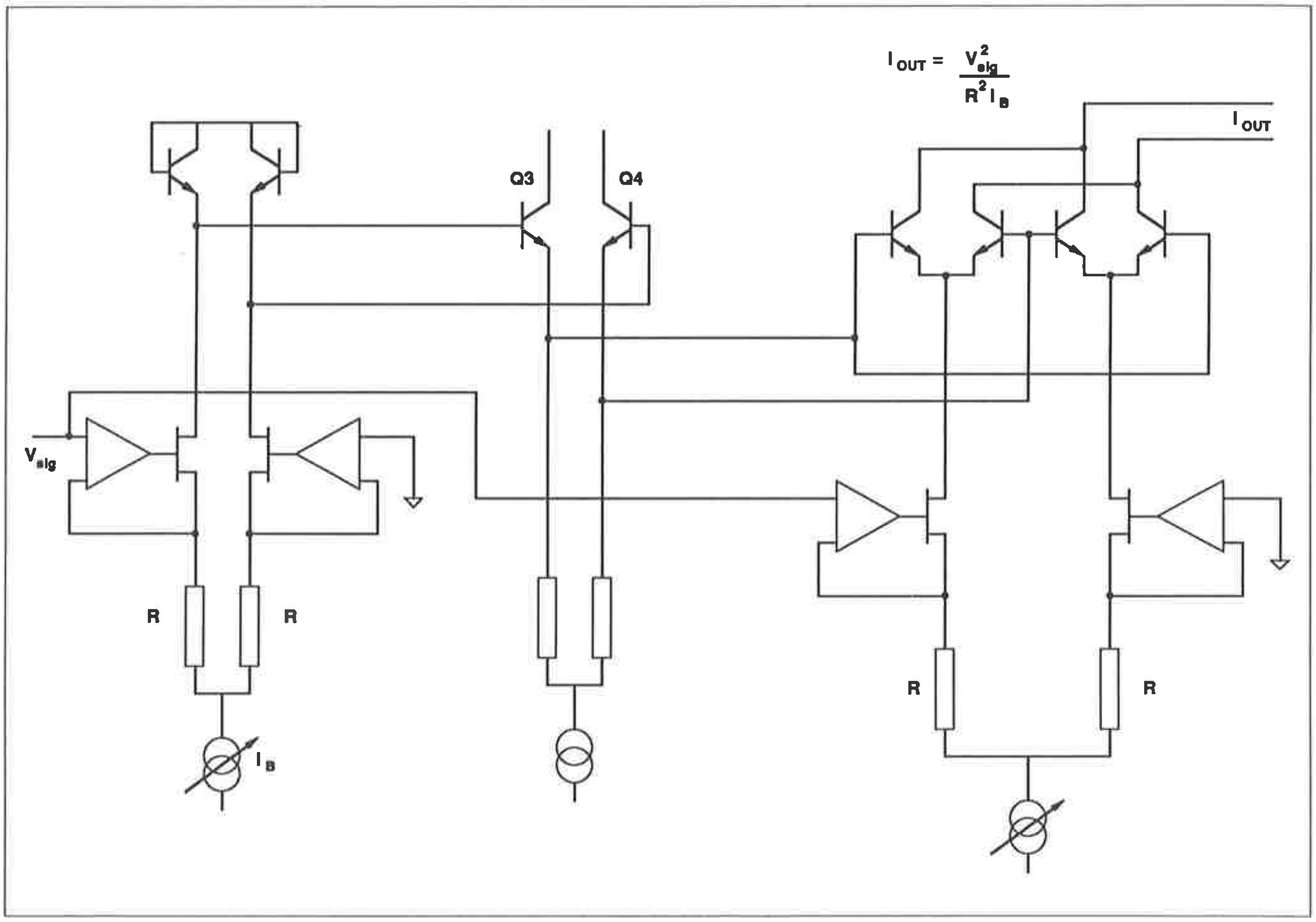


Figure 1 Datron 4920 - RMS Converter Design

The biggest drawback in using log-feedback RMS conversion is that the gain of the detector changes with time and temperature. So, for ultimate stability, the 4920 measures its detector's gain every measurement cycle. The first stage of the measurement cycle is an open loop measurement that results in a DC value output from the RMS detector that is approximately equal to the RMS input, with a basic accuracy of ±1%. This DC estimate is converted to AC using precision chopping techniques, as shown in Fig. 2. This chopped waveform is then fed back through the detector so that it performs an AC/AC transfer which eliminates additional errors from DC offsets. Appropriate selection of the resistor values allows the circuit to function as a simple calculable AC reference source.

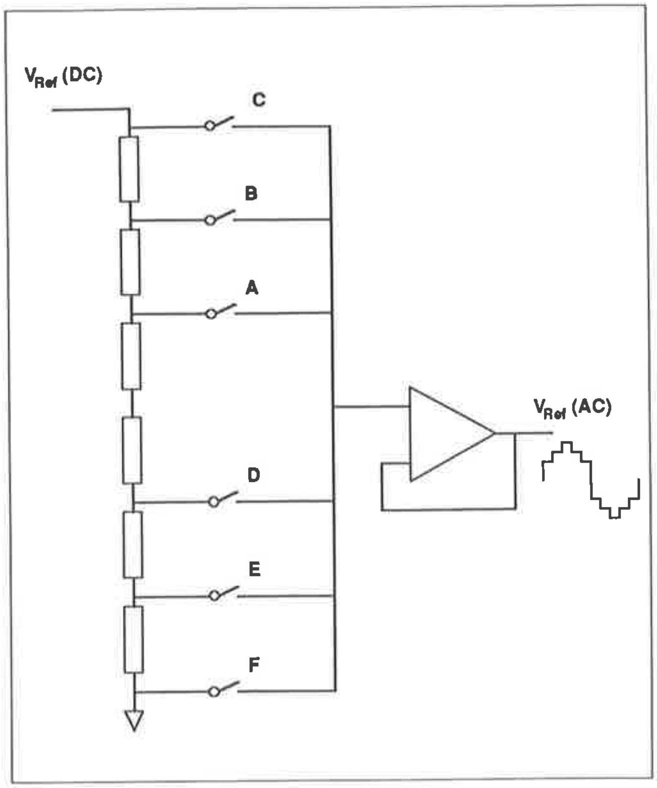


Figure 2 Datron 4920 - Quasi-Sine Generator

A complete AC cycle is defined by 10 equal periods with the following sequence:

A, B, C, B, A, D, E, F, E, D

which produces the waveform shown in Fig. 3, which is known as a 'Quasi-sine'.

The step levels defined by the resistors in Fig. 2 provide the calculable RMS value and are chosen to minimize any imperfections in the RMS detector's power law (i.e. any higher order multiplication). The levels are easily chosen such that

$$Sin^2 = Quasi\text{-}Sine^2$$
$$Sin^3 = Quasi\text{-}Sine^3$$
$$Sin^4 = Quasi\text{-}Sine^4$$

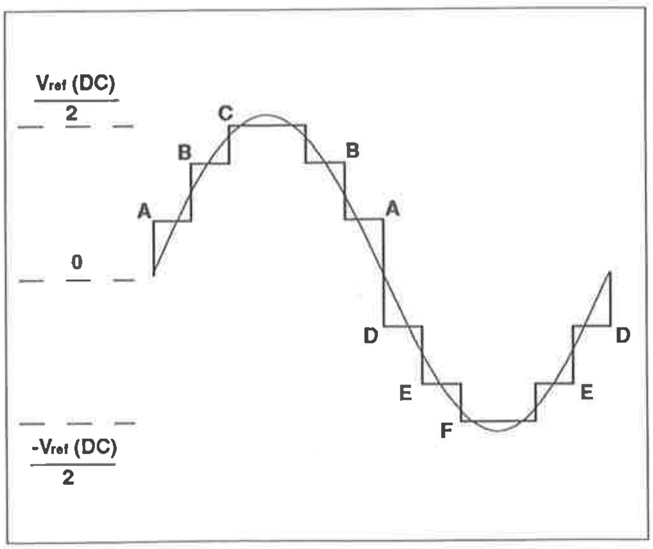


Figure 3 Datron 4920 - Quasi-Sinewave

Three measurements are made to precisely determine the RMS value of the signal. The first of these is the DC estimate discussed earlier, which is a function of the gain of the detector. The subsequent two measurements precisely determine that gain and are used to correct the first measurement. Fig. 4 highlights the three measurement conditions with the switches set appropriately. Let these precise measurements via the A-D be M_1, M_2 and M_3.

First Measurement:	**S_1, S_3 and S_5 Closed** RMS (estimate) = M_1
Second Measurement:	**S_1, S_3 and S_5 Open, S_2 and S_4 Closed** DC Reference = M_2
Third Measurement:	**S_4 Open, S2 and S_3 Closed** RMS measurement of DC reference = M_3

If the gain of the RMS detector is G (not precisely known), then:

$$M_1 = G.V_{sig}(RMS)$$

However, from the subsequent two measurements, G is determined very precisely:

$$G = \frac{M_3}{M_2}$$

and this is used to eliminate G so:

$$V_{sig}\ (RMS) = \frac{M_1.M_2}{M_3}$$

Since the switches are all CMOS types switching into high impedances, virtually all errors are eliminated relative to the calculable AC source and the only other significant source of errors is in the pre-amp and attenuators.

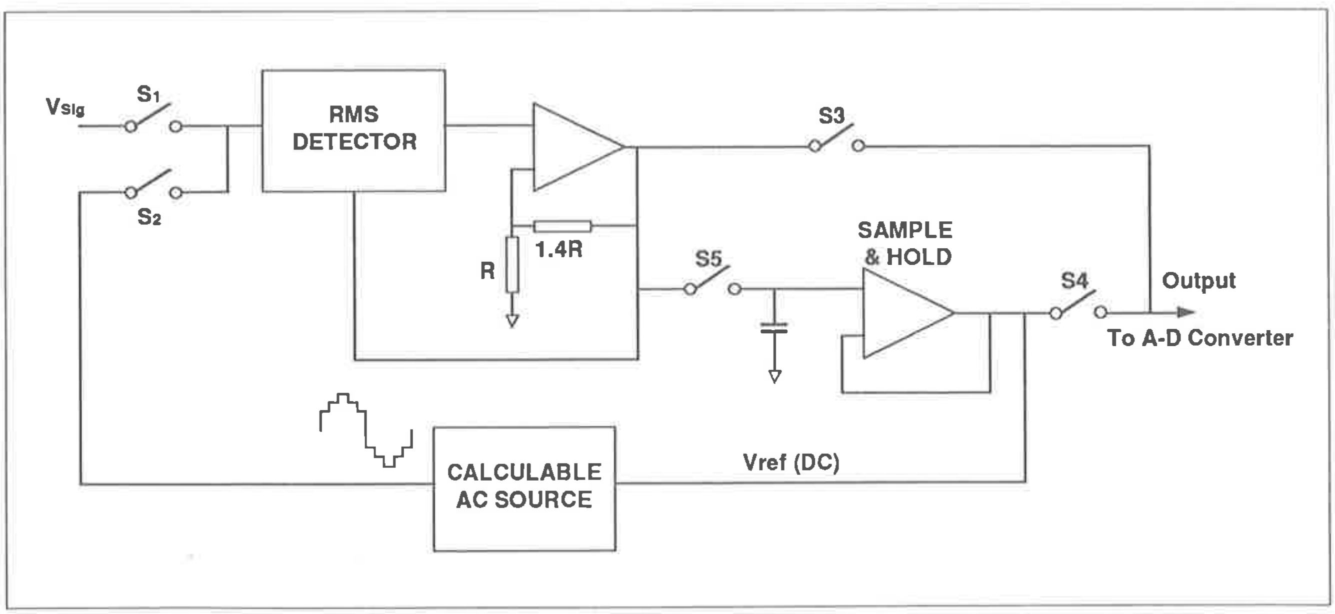


Figure 4 Datron 4920 - Measurement Sequence

Attenuator Design

The 4920 is designed to be used as an absolute broadband measuring device as well as having an AC/DC transfer mode. This requires that the input attenuators have good frequency flatness, good long term stability with time and temperature and minimal self-heating to eliminate linearity errors, especially at high input voltages. The long term stability performance requirement of the 4920 means that the DC stability contribution from each attenuator must be better than 5ppm per year. Only two resistor technologies are able to offer this stability, hermetically sealed wirewound and hermetically sealed bulk metal foil. Wirewound resistors are unsuitable for AC circuits due to the effects of their reactive characteristics at higher frequencies, so bulk metal foil were chosen. The attenuator configuration is shown in Fig 5.

The 1kV chain is of particular interest. To minimise the power coefficient (which leads to self-heating errors that are exhibited as non-linearities), it is made up from 10 near equal chips that each dissipate the same power. The power coefficient is dependent on the temperature coefficient (TC) matching of the chips rather than their absolute TC.

The attenuator system avoids the use of adjustable elements, either resistive or capacitive. The microprocessor system provides all the necessary compensations through mathematical calculations rather than compromizing stability by adding extra components. The absence of mechanical adjustments means that the calibration of the AVMS cannot be affected by mechanical shock, making it suitable for transport by commercial carriers, and ideal for use in audit applications.

Finally, the input impedance of the attenuators has been kept high, both to minimise power dissipation and to reduce connection errors. At the 1 volt level the impedance is 400kΩ - approximately 2000 times higher than a conventional thermal transfer instrument. However, frequency response errors become a problem at these higher impedances and so a proprietary "driven guard" technique has been used together with frequency response correction algorithms applied by the microprocessor to provide excellent HF performance and stability.

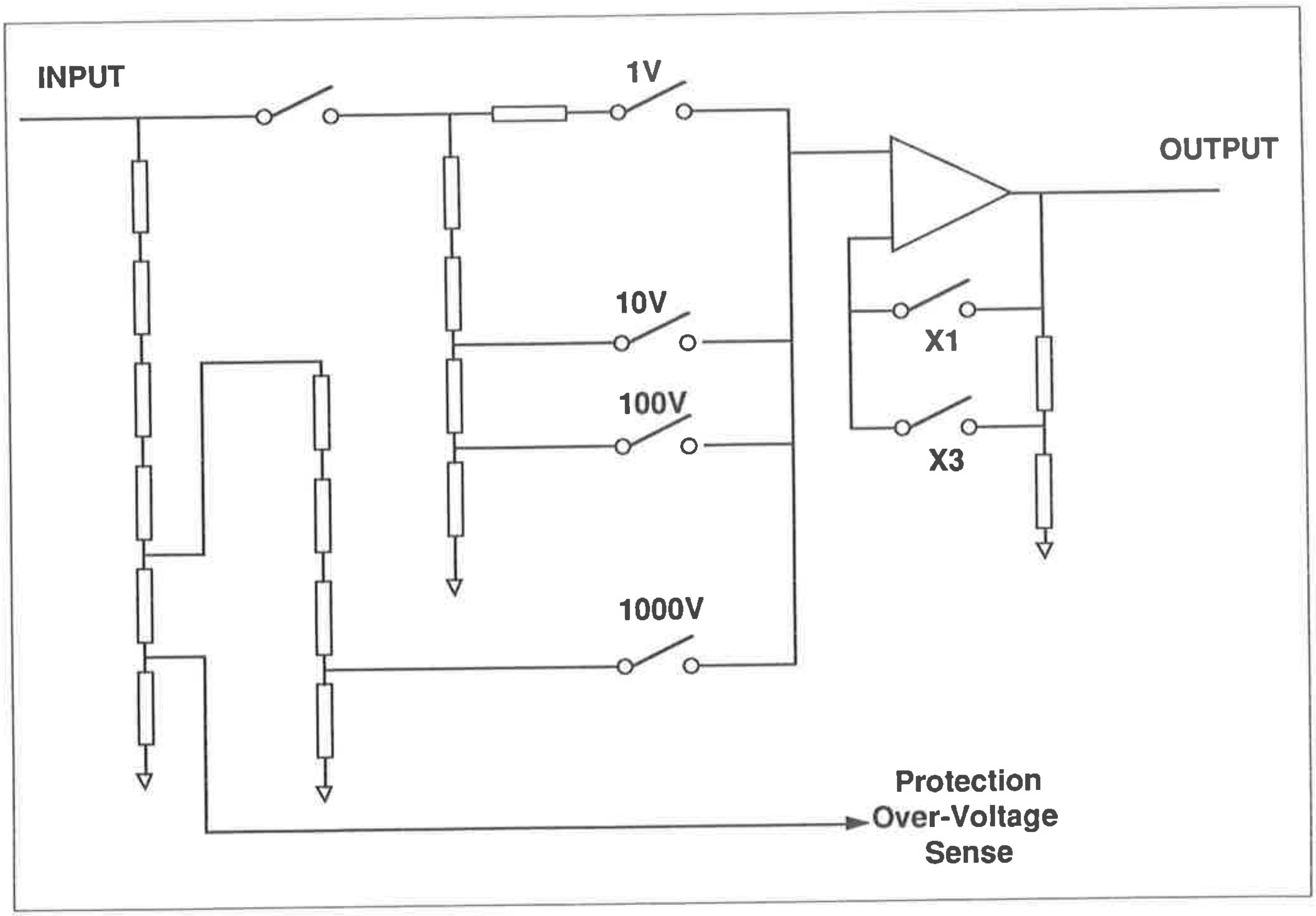


Figure 5 Datron 4920 - High Accuracy Pre-amp and Attenuators

4920 Functional Features

Spot Calibration

Thermal transfer devices, either multi-range or single range co-axial types are capable of high accuracy measurements. However, to use them to these high accuracies, the user must apply AC/DC difference corrections, one for each frequency /voltage range combination of interest. Typically the TTS is certified for these AC/DC differences by a National Laboratory (NIST, NPL, PTB etc) or by a traceable standards lab. These differences are recorded on a calibration certificate and applied manually by the user, as a correction to the measurement. This is an error-prone process, particularly in applying the correction in the right direction!

The 4920 has a similar capability for its best accuracy, but in this case the corrections are stored in internal, non-volatile memory during calibration. They may subsequently be applied by the microprocessor to give highly accurate measurements at specific 'Spot' frequencies - in short, 'Spot' mode corrects for any frequency flatness errors that remain after normal broadband calibration.

Up to one hundred 'spots' may be allocated, during calibration, to particular ranges and frequencies and the internal frequency counter is used to record the particular values of frequency chosen. When operation in 'Spot' mode is selected, the frequency of the incoming signal is measured using the internal frequency counter and compared to the stored frequency for the selected spot correction. If it is outside a ±2% limit, an error message is displayed. If it is inside, the correction is applied.

AC/DC Transfer mode

Although not necessary for normal operation, the 4920 is capable of making AC/DC (or AC/AC) transfer measurements to very high accuracy, particularly at or near full range. It is easier to use in these modes than conventional thermal transfer devices and is much faster. It is also very linear and so is capable of directly indicating AC/DC differences with the sources considerably off null or off balance. This is a particular benefit in an automated system, as iterative loops required to get close to a null are not required.

Transfer Computation

The quality of a thermal transfer element is often interpreted from its turnover error, that is its difference in response to identical magnitude positive and negative direct voltages. Because the 4920 is an electronic device with a high impedance preamplifier, offsets in the input amplifers and attenuators can cause relatively large turnover errors, which can create a poor impression if a direct comparison with a TTS is made.

The 4920, however, computes the RMS value of the positive and negative direct voltage references rather than the arithmetic mean, which eliminates the effect of turnover errors. Consider the presence of an offset Δ, for both direct and alternating voltage signals. Conventionally, when using a TTS, the average direct voltage value is determined by averaging the positive and negative measurements. Therefore, with the offset Δ present, the calculation is as follows.

$$\mathrm{DC} = \frac{+\mathrm{DC} + \Delta - (-\mathrm{DC} + \Delta)}{2}$$

$$= \mathrm{DC}$$

However the offset adds to the AC as follows:

$$\mathrm{RMS}\,(\mathrm{AC} + \Delta) = \sqrt{(\mathrm{AC} + \Delta)^2}$$

$$= \sqrt{(\mathrm{AC}^2 + 2\mathrm{AC}.\,\Delta + \Delta^2)}$$

$$= \sqrt{(\mathrm{AC}^2 + \Delta^2)} \text{ ....(i)}$$

The average of the cross - product is zero and the Δ^2 term is usually assumed to be negligible but it is, nonetheless, an error term since it does not appear in the computation of the effective direct voltage reference value. Clearly, the larger the Δ, offset, the larger the error due to offset induced turnover effects.

The 4920 calculates the RMS of the two direct voltage reference signals rather than the arithmetic mean, according to the following formula:

$$DC_{rms} = \sqrt{\frac{(+DC)^2 + (-DC)^2}{2}}$$

With the offset Δ considered, the calculation is as follows:

$$DC_{rms} = \sqrt{\frac{(+DC + \Delta)^2 + (-DC + \Delta)^2}{2}}$$

$$= \sqrt{\frac{DC^2 + 2\,DC\Delta + \Delta^2 + DC^2 - 2DC\Delta + \Delta^2}{2}}$$

$$= \sqrt{\frac{2DC^2 + 2\Delta^2}{2}}$$

$$= \sqrt{DC^2 + \Delta^2} \quad .....(ii)$$

It can be seen by comparing equation (i) and (ii) that the offset contribution is identical when measuring the alternating and direct voltage and therefore does not constitute an error even if the offset (and thus turnover error) is quite large.

Using AC/DC transfer mode

Programming AC/DC transfer measurements from the front panel or IEEE-488.2 interface is very simple. Once the desired range and any digital filtering is programmed, the positive direct voltage reference input is applied. When the reading has settled, it is stored in the DC+ memory. The same process is repeated with the negative reference input and the DC- memory. When the two reference values are stored, the DCrms value is computed and stored. When the unknown alternating voltage input is applied and transfer mode selected, the data display indicates the difference between the stored DCrms reference value and the unknown alternating voltage input. In remote operation it is even possible to sequence a number of AC/DC transfer measurements such that any steady drift in the external direct voltage reference may be compensated for.

This AC/DC Transfer mode removes two sources of error - drift in the internal DC reference and the input preamplifiers and attenuators with both time and temperature. The 4920 internal reference drift is typically better than 2ppm per year and the attenuators/pre-amp assembly may contribute up to 10ppm per year. These contributions may be eliminated by use of the AC/DC transfer mode, and perhaps more importantly, this gives added confidence where a known direct voltage reference is available.

Input Switching

Although the 4920 contains just one measurement system, as already described, it posesses two input channels that may be switched, under front panel or IEEE-488.2 control, to the measurement system. Channel A is a precision N type female connector, channel B consists of a pair of 4mm binding posts. Difference errors between the two input channels are kept to a minimum by the high inpedance of the measurement system. Since channel switching is programmable, it is possible to perform very efficient AC/DC transfer measurements in an automated system by connecting the unknown alternating voltage input to channel A and the known direct voltage to channel B. Under these conditions fully automated, multi-range, very high accuracy AC/DC transfer measurements are possible.

For safety reasons, the shell of the N-type connector is internally connected to chassis ground, but the binding post Lo input is floating, allowing the ground connections to be made elsewhere in the system. A connection between Lo and ground is generally necessary for precision measurements, but the floating capability allows this to be made elsewhere in the measurement hook-up. For the lowest measurement errors, this connection should be made physically as close to the measurement sense point as possible.

Although channels A and B are switched to the same measurement system, the input to the channel A N-type connector should not exceed 290V peak (205V rms) for conformance with IEC-348 safety specifications.

4920 Calibration Adjustment

The 4920 is an absolute measuring instrument as well as a transfer device, so calibration adjustments to nominal are provided. There are no primary physical or mechanical adjustments and all corrections are made mathematically by the 68000 microprocessor which accesses non-volatile, calibration memory, the integrity of which is ensured with checksums. The 4920 maintains calibration corrections at two levels, 'Normal' cal that is used for routine re-certification, and 'Special' cal that is best considered as maintenance presetting. Special cal is only required if an internal assembly is changed or a major fault has been repaired.

'Normal' (Routine) Cal

The routine cal allows adjustment of gain, offset and frequency response. For gain and offset the process is very simple - for each range a traceable, known, full range 1kHz signal is applied and the calibration triggered. The process is then repeated at $^1/_3$ of range.

The calibration trigger, supplied either from the front panel or IEEE-488.2 interface, initiates a series of readings. The total measurement sequence described earlier is run several times and the average result calculated. If the result is within a predetermined tolerance, the cal stores are updated.

Sometimes it is not possible or convenient to apply a precisely set nominal value. More commonly the calibration source is precisely known but of a non-nominal value (such as 1.000317 volts) especially when the 4920 is calibrated against a TTS that has a certified AC/DC difference. The 4920 may be calibrated to a non-nominal value so long as it is informed of the exact value of the calibration signal.

Calibration of the 4920's frequency response is accomplished by intelligent application of a correction factor derived from a measured value at close to the upper limit of the frequency range. After the low frequency gain and offset calibration at 1kHz is performed, a high frequency point is calibrated, for example, at 1MHz on the low voltage ranges. This calibration, which can also be performed at a non-nominal voltage if necessary, derives a correction factor for high frequency. Subsequent operation of the 4920 at other frequencies is smoothly corrected by an intelligent interpolation algorithm, similar to hand-drawn response curves.

It can be shown that provided poles and zeros in the response are above the measurement frequency band then the frequency response error Ex, relative to a measured error Ec at a higher frequency fc, is as shown in Figure 6.

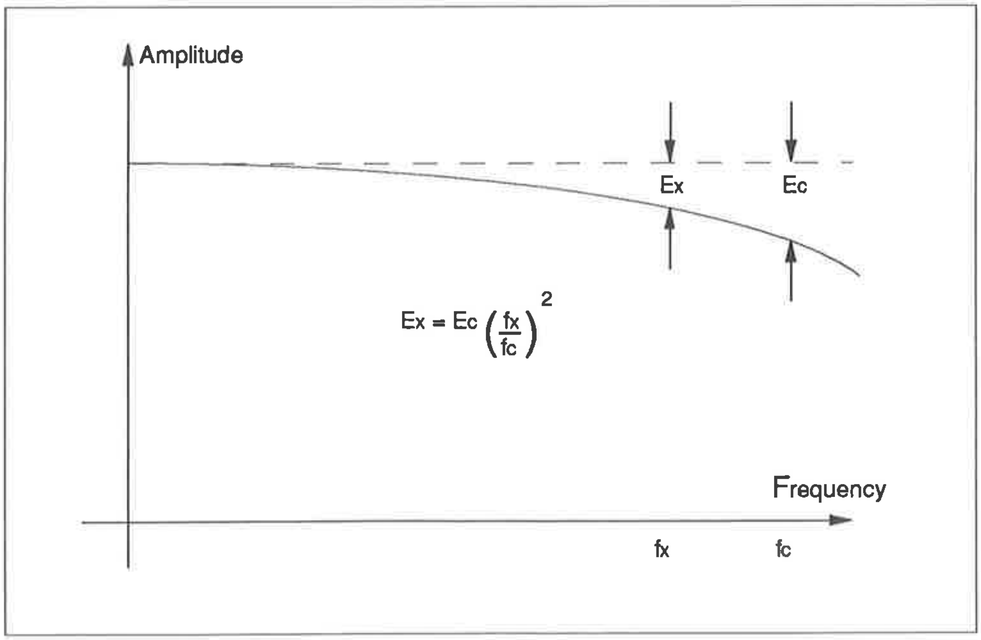


Figure 6 Datron 4920 - Frequency Response

Spot Cal

The three point gain, offset and frequency response calibration described is all that is required to operate the 4920 in 'broadband mode', with specified performance applicable to all valid voltage/frequency combinations on that range. While the 'broadband' mode offers the most operational convenience, there is a small residual frequency response error due to deviations from the flatness prediction algorithm already described.

For applications that require measurement uncertainties lower than those offered in 'broadband' mode, the 4920 may be calibrated at specific voltage range/frequency combinations using the 'Spot Calibration' feature. During calibration, up to 100 'spots' may be calibrated, simply by applying the required signal and the calibration trigger (from the front panel or IEEE-488.2 interface). The spot correction is stored in non-volatile calibration memory, along with the measured signal frequency. In use, when spot mode is selected, the frequency of the input signal is measured and compared to the stored spot frequency, and the stored calibration correction automatically applied. This is analagous to the use of certified AC/DC difference data for a TTS, except that the 4920's spot corrections are applied automatically by the unit's microprocessor.

"Special" (Maintenance) Calibration

If the 4920 is repaired, assemblies changed or total calibration data lost through a fault, then a 'Special' calibration is necessary. This will normally be carried out at a repair facility and is NOT required on a routine basis. It can be likened to the adjustment in manufacturing of preset potentiometers in conventional instruments. However, in this case because they are effectively in memory the potentiometers themselves cannot shift!

The 'Special' calibration facilities available include clearing sections of the non-volatile cal stores, trimming hf linearity and trimming out differences in offset between the lf modes (1Hz, 10Hz, 40Hz & 100Hz). In addition, the simple square law frequency response correction algorithm already described in the routine calibration section has small residual errors due to certain PCB and dielectric properties. 'Special' calibration contains a frequency response compensation mechanism that characterizes and eliminates these additional errors.

Basically the components are characterised by taking four high frequency measurements, for example 10v at 1MHz, 500kHz, 200kHz and 50kHz. These measurements substantially follow a square law but are used to "fine tune" it with a proprietary algorithm. The resulting correction is smooth, with no steps in magnitude or slope of the characteristic, so there are no first or second order discontinuities. This flatness trim is used only to correct for constant component and assembly characteristics, and is valid for the life of the instrument.

Traceability

The calibration philosophy of the 4920 described above assumes that traceable calibration signals are applied to the input terminals with a level of uncertainty appropriate to the 4920's measurement performance. The traceability of Datron's factory calibration system used to calibrate 4920s is a complex issue in itself, and is beyond the scope of this applications note. For further information on this subject, please refer to a companion document, entitled "Datron 4920 AVMS - Calibration and Traceability".

Millivolt Level Measurement

The model 4920 possesses ranges from 300mV to 1000V, with a capability that extends from 30% to 110% of nominal range. The instrument is capable of measuring a 100mV signal at the bottom end of the 300mV range. However, the majority of modern DMM calibrators in use have a 10mV range, and most have a 1mV range.

Modern component technology allows construction of range amplifiers with gain stability, frequency flatness and immunity to temperature fluctuations appropriate to calibrator calibration. Traceable calibration at these levels is the problem however, especially at high frequency. To avoid this problem, Datron's engineers have developed a technique that enables traceable millivolt level measurements that do not require periodic calibration against standards.

The 4920 millivolt measurement option places a by-passable X30 amplifier between the input terminals and the input amplifier/attenuator system, as in Fig 7. To measure a millivolt level signal, the user first initiates a measurement sequence that determines the gain of the amplifier. A nominal 100mV signal at the frequency of interest (the precise amplitude is unimportant, as long as it is stable for the duration of the gain measurement) is applied to the input terminals. A keypress or IEEE-488.2 bus command causes the microprocessor to switch the X30 amplifier in and out of the measurement signal path, taking a reading in each configuration. The amplifier gain at that frequency is then calculated as the ratio of these two measurements. Subsequently, any signal between 1mV and 110mV at that frequency ±1% can then be measured using the traceably calibrated higher ranges.

4920 Selftest

For use as a measurement standard, the user must have full confidence in the correct operation of the 4920 and in the case of instrument failure, a technician needs to isolate faults fast. For this purpose, the 4920 possesses a very comprehensive selftest which may be run at either of two levels; operator and diagnostic.

The operator selftest routine runs automatically on instrument power-up, taking approximately 3 minutes to complete. The digital system, cal memory battery, A-D converter, power supplies, range switching, frequency counter and millivolt option are all tested for correct operation. If the operator test passes, there is a very high probability that the 4920 is operating correctly. If, for any reason, it is not desirable to run the self-test on power-up, for example when attempting to trouble-shoot a faulty unit, it may be inhibited simply by depressing a front panel key during the power-up sequence.

The diagnostic selftest is more comprehensive, taking approximately 5 minutes to run. As each internal measurement is made in the test sequence, the percentage of allowable spread of the measurement is displayed. The servicing manual contains a list of error codes that could be displayed during the diagnostic sequence, along with a signal 'pathway' number. The user is able to select a particular pathway (or self-test setup) from the front panel and the manual identifies which circuit elements are exercised in this pathway along with signal levels expected. This diagnostic technique enables fault finding to circuit block level without the aid of specialist equipment.

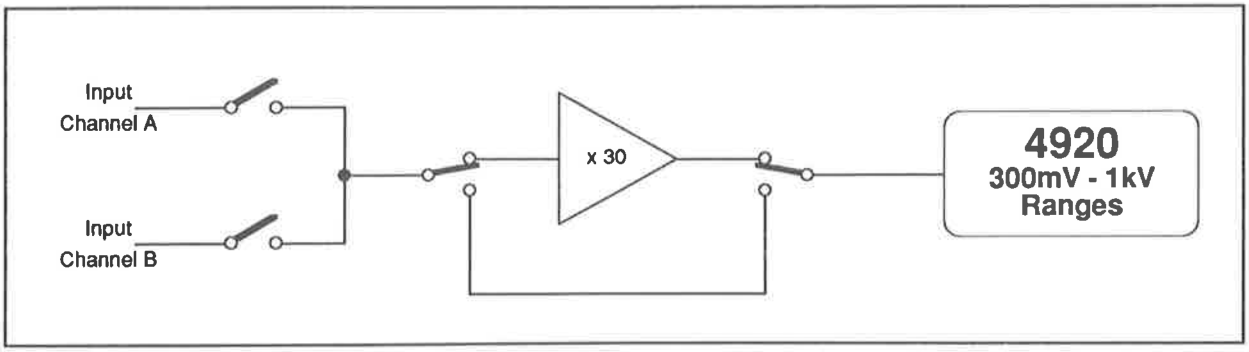


Figure 7 Datron 4920 - Millivolt Amplifier

APPENDIX - Inside the 4920 Specifications

Introduction.

In use, the 4920 offers an alternating voltage measurement capability to a level of precision hitherto unavailable from an easy - to - use programmable device. To calculate the uncertainty in a measurement made using the 4920, the user must understand the origins of the individual uncertainty contributions.

At the highest level, there are two contributions to the measurement uncertainty of the 4920 in use. The first is the measurement performance of the 4920 relative to calibration standards - that is the measurement uncertainty achieveable if the 4920 were calibrated with zero uncertainty. The second is the uncertainty in the calibration of the 4920. If these two contributions are not specified separately, and 'Total Uncertainty" specifications are all that are available to the user, it is not possible to calculate the effects of calibration to different standards. The calibration uncertainty achieved by Datron's 4920 factory calibration system is specified separately to its performance relative to calibration standards, so that a user may substitute different calibration uncertainties if the 4920 is calibrated to standards other than those used in Datron's factory calibration system.

4920 Performance Relative to Calibration Standards.

The specified 4920 performance relative to calibration standards defines the effects of a number of uncertainty contributions, which include:

i) The DC stability (with time and temperature) of the 4920's zener diode reference module.

ii) The DC stability, frequency flatness, linearity and temperature stability of the input attenuator/pre-amplifier system.

iii) The DC stability, frequency flatness, linearity and temperature stability of the RMS converter.

iv) The AC/DC difference stability with time and temperature of the RMS converter.

v) Noise in the RMS converter, A/D converter and attenuator/pre-amplifier system

The individual uncertainty contributions have been quantified by the 4920's designers, by a combination of measurement data and theoretical calculations. Each of them is classified as either a random contribution or a systematic contribution (sometimes a little of both!). The systematic contributions are combined by linear addition to yield a total systematic contribution. Each and every random contribution is calculated to 99.7% (3 sigma) confidence levels according to standard statistical techniques, and combined with the total systematic contribution by a root-sum-squares calculation. This process yields a total instrument performance specification with a 99.7% confidence level.

Finally, at the end of the production process, each and every 4920 is exhaustively tested to performance limits that are tighter than the datasheet specifications, to confirm that it meets 100% of the published specifications.

'Broadband' Operating Mode

The broadband operating mode offers the most convenience, but the highest measurement uncertainties. The specified performance relative to calibration standards includes all of the contributions listed above. To calculate the uncertainty in a broadband measurement made with a 4920 calibrated at the factory, simply add the 4920 performance relative to calibration standards to the corresponding calibration uncertainty. As an example, consider a measurement taken within 1 year and ±5°C of factory calibration at 10V, 1kHz.

4920 Performance Rel. Cal. Stds.:	±30ppm
Factory Cal. Uncertainty:	±8ppm
Total Measurement Uncertainty:	**±38ppm**

'Spot' Operating mode

The use of spot calibrations largely removes the frequency flatness contributions of the input attenuator/pre-amplifier system and the RMS converter. In addition, the slightly reduced dynamic range of the 4920 specifications in spot mode removes a proportion of non-linearities in these elements, although these contributions are very small in comparison with the flatness contributions. Note that the slightly reduced dynamic range, from 50% to 110% of nominal range, still encompasses the cardinal points 1, 2, 3, 5, 10. To calculate the uncertainty in the example shown above (10V at 1kHz) in spot calibrated mode, add the performance relative to calibration standards to the calibration uncertainty.

4920 Performance Rel. Cal. Stds.:	±20ppm
Factory Cal. Uncertainty:	±8ppm
Total Measurement Uncertainty:	**±28ppm**

'Broadband' AC/DC Transfer mode

Using AC/DC transfer mode largely eliminates the DC stability and temperature effects in the zener diode reference, input attenuator/pre-amplifier system and the RMS converter. The contribution due to non-linearities in the input attnenuator/pre-amplifier system (caused by self-heating of the attenuator resistors) is also substantially reduced, but is very small to begin with. However, the uncertainty of the external direct voltage reference used to make the transfer must also be considered in the calculation. Taking the above example of 10V at 1kHz, the uncertainty buildup is as follows:.

4920 Performance Rel. Cal. Stds.: External Direct Voltage reference (typical) Factory Cal. Uncertainty:	±17ppm ±2ppm ±7ppm
Total Measurement Uncertainty:	**±26ppm**

Note that the stated specifications for this mode show an improvement only in the 40Hz - 30kHz region. This is because the 4920's AC/DC transfer performance relative to calibration standards at other frequencies is dominated by frequency-related effects, rather than DC stability effects, giving very small proportional improvements.

Spot Transfer mode

This operating mode uses a combination of AC/DC transfer and 'spot' calibrations. The Transfer portion of this mode eliminates the same contributions that are eliminated by normal transfer mode, and the 'spot' calibrations eliminate the frequency flatness contributions of the input attenuator/ pre-amplifier system and the RMS converter. Taking the above example of 10V at 1kHz, the uncertainty buildup calculations are as follows.

4920 Performance Rel. Cal. Stds.: External Direct Voltage Reference (typical) Factory Cal. Uncertainty:	±7ppm ±2ppm ±7ppm
Total Measurement Uncertainty:	**±16ppm**

Millivolt measurement mode.

The performance specifications for the millivolt measurement function are a complex buildup all of the uncertainty contributions involved, which include:

i) The uncertainty in the amplifier gain measurement using the higher measurement ranges, including their calibration uncertainties,

ii) The total uncertainty in the measurement of the unknown input using the appropriate, traceably calibrated higher ranges

iii) The time stability, temperature stability, linearity and frequency flatness of the millivolt amplifier within 24 hours, ±1°C and 1% in frequency of the amplifier gain measurement.

Consider the measurement of a 10mV signal at 1kHz. The uncertainty contributions in the buildup are:

Measurement of 100mV on 300mV range: Cal uncertainty of 100mV on 300mV range: Measurement of 3V on 3V range: Cal Uncertainty of 3V on 3V range:	±30ppm ±13ppm ±30ppm ±13ppm
Uncertainty of Amplifier Gain Measurement:	±86ppm

At this stage of the measurement process, the unkown 10mV signal is connected to the measurement system and amplified to 300mV, which is measured on the 300mV range. The uncertainty contributions to be considered are the 300mV range performance relative to calibration standards, the calibration uncertainty of the 300mV range and an allowance for the time stability, temperature stability, linearity and frequency flatness (±1% in frequency of the amplifier gain measurement).

Amplifier Gain measurement uncertainty: 4920 Performance Rel. to Cal. Stds@300mV: Cal Uncertainty @300mV: 24 hour, ±1°C, ±1% spec. of amplifier:	±86ppm ±30ppm ±13ppm ±130ppm
Total Measurement Uncertainty: (say)	±259ppm **±260ppm**

To simplify the calculations, the total uncertainty specifications stated for the millivolt measurement function include the Datron factory calibration uncertainties of the higher ranges. While it is understood that the 4920 may be calibrated to standards with different uncertainties, these contributions are insignificant in the total uncertainty buildup.

Note that 'spot' frequency calibrations of the higher ranges cannot be used for the millivolt amplifier gain measurement, since the 4920's millivolt measurement performance is dominated by low level effects, and the incremental performance improvment would be minimal and could not justify the additional complexity of design and operation. Similarly, AC/DC transfer mode is not available in the millivolt measurement function, since the millivolt amplifier is AC coupled to reduce the effects of offset errors in the amplifier, preventing a direct voltage millivolt signal from passing to the measurement system.

Note also, that in all the above calculations, the contributing uncertainties have been added together arithmetically, which yields a worst case total uncertainty. For a measurement made with the 4920 to lie at the edge of the uncertainty band, it would be necessary for all of the contributions to be at their limits, and all in the same direction. In practice, it will be found that the error in a measurement will be significantly less that the calculated uncertainty, which should always be viewed as the worst case.

Calibration Uncertainties.

The traceability of the Datron factory calibration system is a complex subject in itself, and is the subject of a separate applications note entitled "Datron 4920 AVMS - Calibration and Traceability. Please contact the factory or your local representative for a free copy.

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