datron
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MODEL 4920

Alternating Voltage Measurement Standard

DESIGN, APPLICATION AND PERFORMANCE

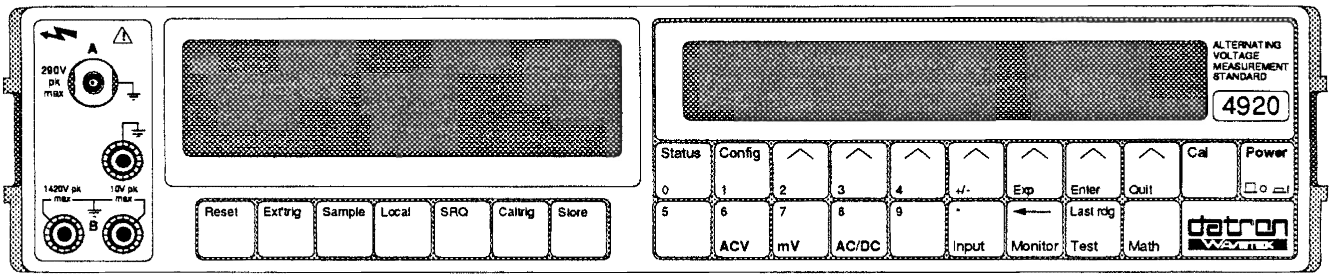
4920 Design, Application and Performance

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 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, it is possible to reduce this skill level, and therefore operating costs.

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 AV 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, some of the more common designs of TTS require 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 constrants. As a result, calibration of the AV 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 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 AV against the known DV 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 micropoteniometers at higher frequencies. A major design requirement of the Datron AVMS was to simplify this process and enable it to be automated.

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 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:

$$Iout = \frac{Vsig^2}{R^2 Ib}$$

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 thermal techniques, especially at low percentages of range.

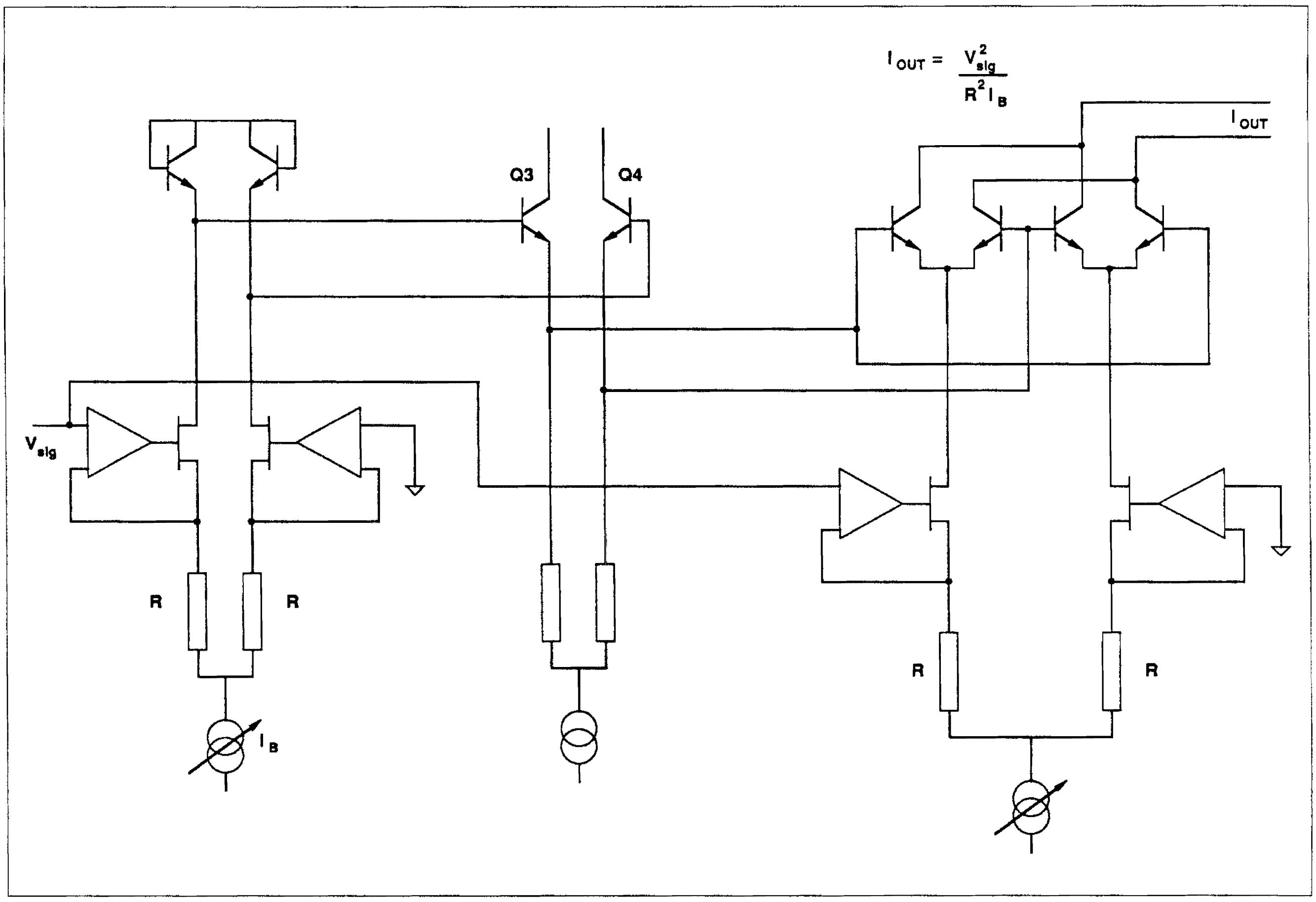


Figure 1 Datron 4920 - RMS Converter Design

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 an uncertainty 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.

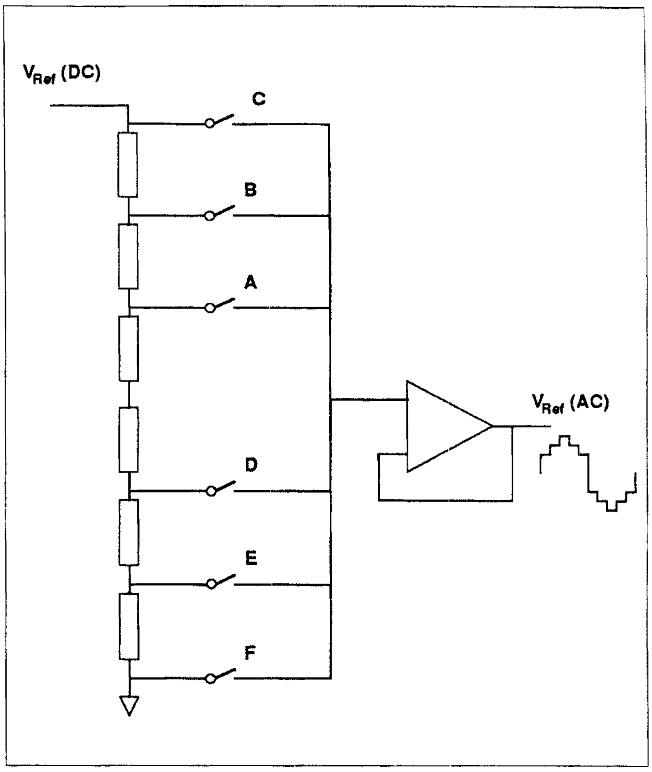


Figure 2 Datron 4920 - Quasi-Sine Generator

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 detectors' power law (i.e. any higher order multiplication). The levels are easily chosen such that

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

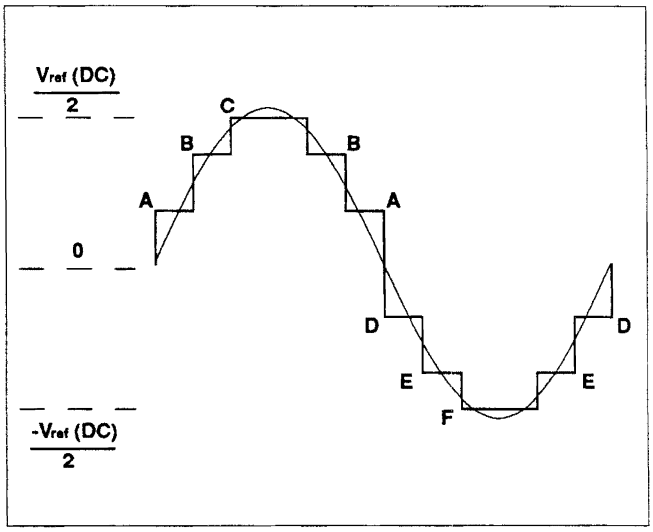


Figure 3 Datron 4920 - Quasi-Sinewave

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 andS_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:

$$M_1 = G.Vsig(RMS)$$

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:

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

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.

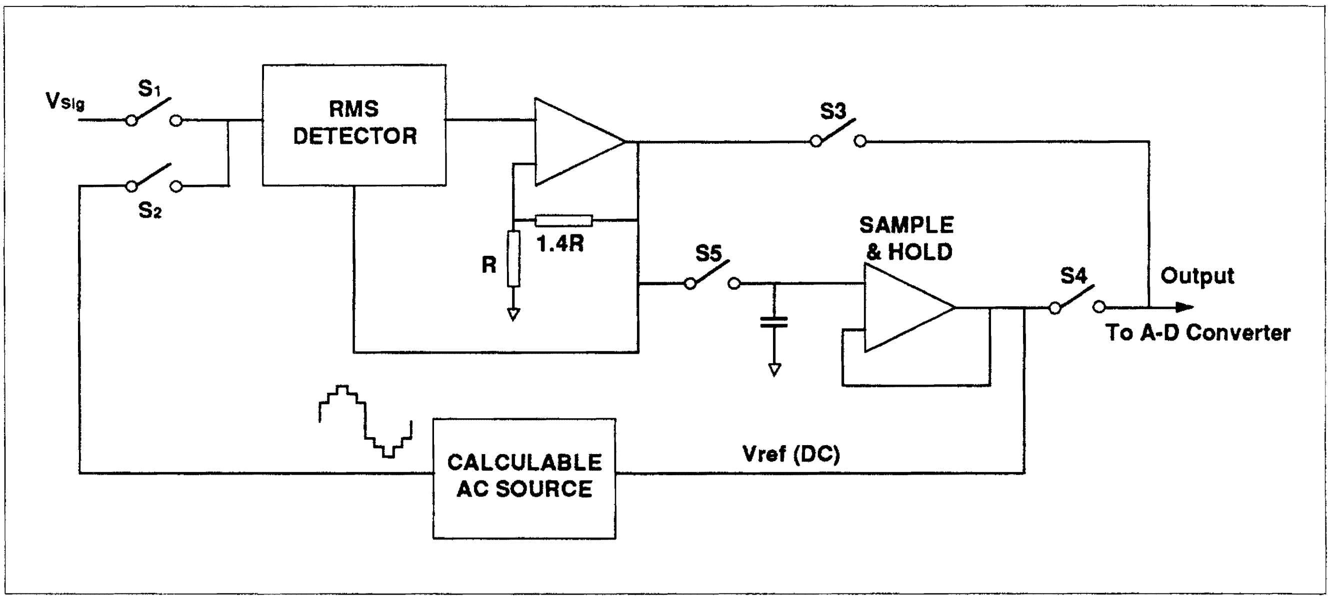


Figure 4 Datron 4920 - Measurement Sequence

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 contribution from each attenuator must have a DC stability of the order of 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.

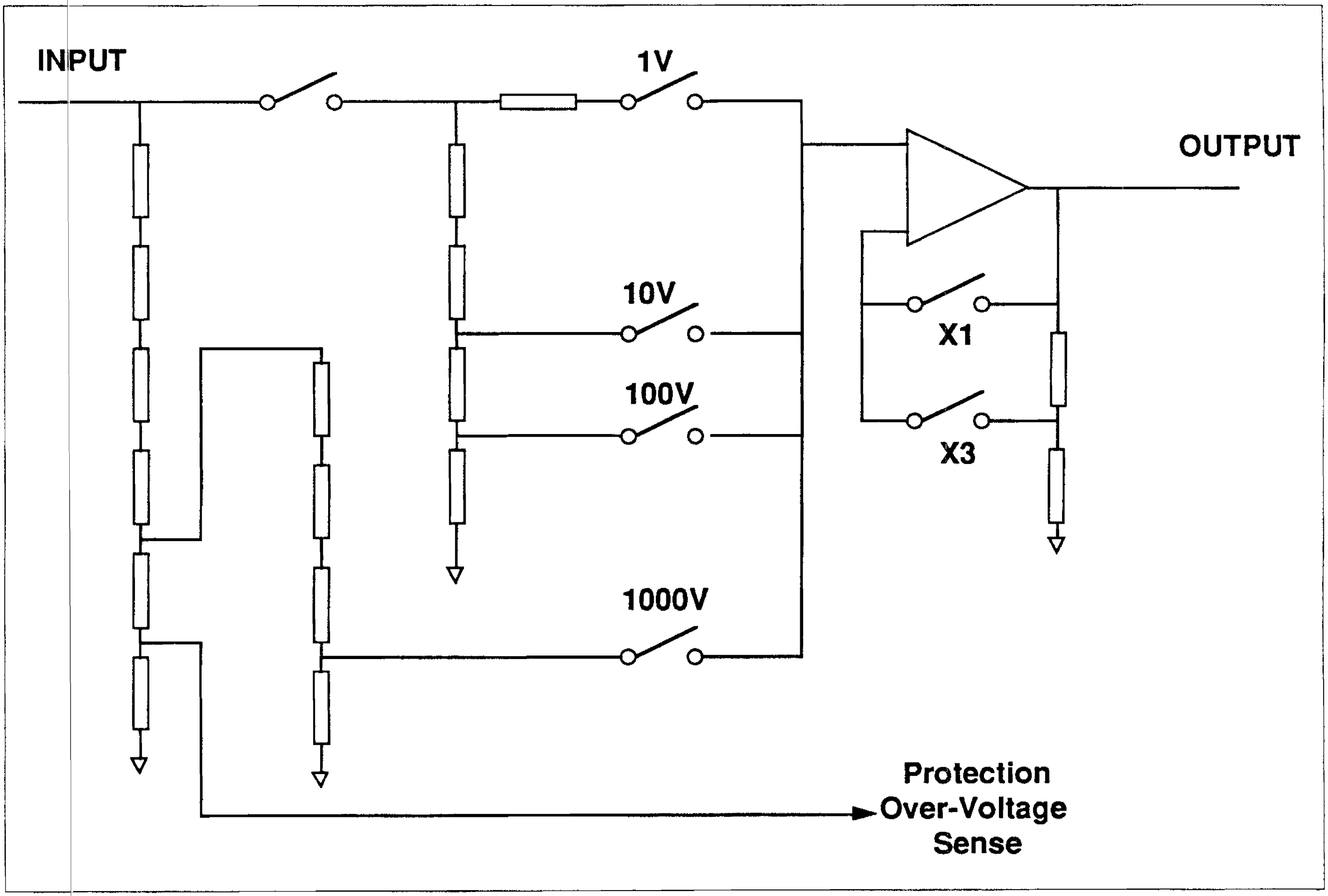


Figure 5 Datron 4920 - High Accuracy Pre-amp and Attenuators

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, 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 of a ±2% limit, an error message is displayed. If it is inside, the correction is automatically applied.

AC/DC Transfer mode

Although not necessary for normal operating 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 DC turnover error, that is its difference in response to identical magnitude positive and negative DC signals. Because the 4920 is an electronic device with a high impedance preamplifier, offsets in the input amplifers and attenuators can cause turnover errors, which create a poor impression if a direct comparison with a TTS is made.

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

$$\begin{aligned} \mathrm{DC} &= \frac{+\mathrm{DC} + \Delta - (-\mathrm{DC} + \Delta)}{2} \\ &= \mathrm{DC} \end{aligned}$$

However the offset adds to the AC as follows:

$$\begin{aligned} \mathrm{RMS}\,(\mathrm{AC} + \Delta) &= \sqrt{(\mathrm{AC} + \Delta)^2} \\ &= \sqrt{(\mathrm{AC}^2 + 2\mathrm{AC}.\,\Delta + \Delta^2)} \\ &= \sqrt{(\mathrm{AC}^2 + \Delta^2)} \text{ ....(i)} \end{aligned}$$

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 DC 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 DC signals rather than the arithmetic mean, according to the following formula:

$$\text{DCrms} = \sqrt{\frac{(+\text{DC})^2 + (-\text{DC})^2}{2}}$$

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

$$\text{DCrms} = \sqrt{\frac{(+\text{DC} + \Delta)^2 + (-\text{DC} + \Delta)^2}{2}}$$

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

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

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

It can be seen by comparing equation (i) and (ii) that the offset contribution is identical when measuring the AC and the DC 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 DC input is applied. When the display has settled, this reading is stored in the DC+ memory. The same process is repeated with the DC- input and the DC- memory. When the two DC values are stored, the DCrms value is computed and stored as a reference. When the AC input is applied and transfer mode selected, the data display indicates the difference between the stored DCrms reference value and the unknown AC input. In remote operation it is even possible to sequence a number of AC/DC transfer measurements such that any steady drift in DC offset is substantially cancelled.

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 reference is typically better than 2ppm per year and the attenuators may contribute up 10ppm per year. These uncertainty contibutions may be removed by use of the AC/DC transfer mode, and perhaps more importantly, gives added confidence where a known DC source is available.

Input Switching

The 4920 has two input channels, called A and B. Channel A is a precision N type female connector, channel B consists of a pair of binding posts. Both connectors are switchable to the input channel under front panel or IEEE-488.2 control, with negligible difference errors due to the high input impedance of the measurement channel. Since these switches are programmable, it is possible to perform very efficient AC/DC transfer measurements in an automated system by connecting AC input to channel A and DC to channel B. Under these conditions fully a automated, multi-range and 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 surement hook-up. For the lowest measurement errors, this connection should be made physiaclly as close to the measurement sense point as possible.

Note that the input applied to the N-type, channel A, input must not exceed 290V peak to conform with IEC-348 safety specifications. Althoug this input is tested at 1100V rms the channel B, binding post input, however, is rated to a full 1000Vrms.

4920 Calibration Adjustment

Since the 4920 is an absolute measuring instrument as well as a transfer device, calibration adjustments to nominal are provided. There are no primary physical or mechanical adjustments and all corrections are made arithmetically by the 68000 microprocessor which accesses non-volatile, calibration memory, the integrity of which is ensured with checksums. The system maintains calibration corrections at two levels, 'Normal' cal that is used for routine re-certification, and 'Special' cal that should be considered as maintenance presetting. A user will never need to use the 'Special' cal unless an internal assembly is changed or a major fault has been repaired.

'Normal' or Routine Cal

The routine cal allows adjustment of gain, offset and frequency response. Optionally the user may elect to set calibration values for "SPOT" cal. 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 and the process then repeated at $^1/_3$ of range.

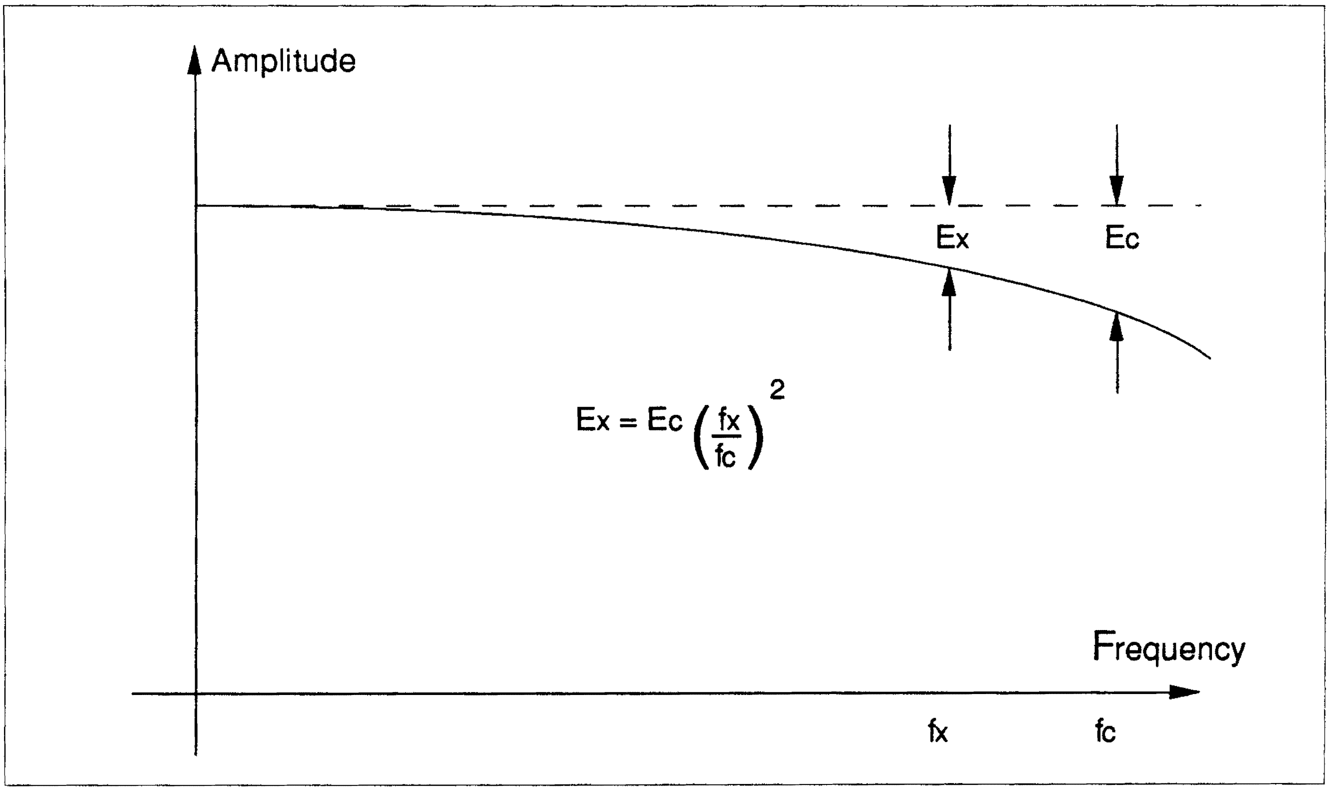
The calibration trigger, supplied either from the front panel or IEEE-488.2 interface initiates a series of readings. The total measurement sequence described earlier is run several times and the average result calculated. If the result is within a predetermined tolerance, the cal stores are updated.

Sometimes is is not possible or convenient to apply a precisely set nominal value. More commonly the calibration source is precisely known but of a non-norminal value such as 1.000317 volts, especially in the case where the 4920 is calibrated against a TTS that has a certified AC/DC difference (see Datron Application Note : "4920 AVMS Calibration & Traceability). The 4920 may be calibrated to a non-nominal value so long as it is informed of the exact value of the calibration signal.

HF Trim

HF Trim flatness calibration is the 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 calibration at 1kHz is applied, a high frequency point is calibrated, for example, at 1MHz on the low voltage ranges. This calibration, which can 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.

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.



$$Ex = Ec\left(\frac{fx}{fc}\right)^2$$

Figure 6 Datron 4920 - Frequency Response

Spot Cal

After the routine flatness calibration described above, there will be a small residual frequency response error. This is a feature, not just of the 4920, but of TTSs also, except that a TTS's 'Spot' calibrations are stored on a piece of paper. Or, put another way, the 4920 has its certificate stored in its SPOT CAL memory. So, for spot calibration a specific signal amplitude and frequency is applied and upon the relevant IEEE-488.2 or front panel trigger the amplitude correction is stored, together with the measured frequency.

Subsequently a spot correction is applied in SPOT mode provided the range is valid and the frequency is within 2% of that stored during calibration. Each SPOT is treated as an independent range/function with no interpolation between them.

"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 the potentiometers themselves can't 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 frequency response compensation mechanism that characterizes and eliminates these additional errors.

Basically the components are characterised by taking 4 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.

Whilst the HF trim may need routine adjustments, primarily due to possible mechanical disturbances of the attenuators, the flatness trim is used only to correct for almost totally constant component and assembly characteristics, and so is valid for the life of the instrument.

Millivolt Measurement

The standard model 4920 posesses ranges from 300mV to 1000V, with a capability that extends from 30% to 110% of nominal range. Therefore, the standard 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 sufficient gain stability, frequency flatness and a low TC that require yearly calibration. Traceable Calibration at these levels is the problem, however, especially at high frequency.

Datron's engineers have developed a technique that enables traceable millivolt level measurements that does not require periodic calibration against standards.

Between the input terminals and the input amplifier/attenuator system is by a by-passable x30 amplifier. To measure a millivolt level signal, the user must first initiate a measurement sequence that determines the gain of the amplifier. A nominal 100mV signal at the frequency of interest (the precise value 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 then switches the amplifier into the measurement ciruit and then out. The amplifier gain is then calculated and any signal between 1mV and 110mV at that frequency ±x% 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 powering, taking approximately 3 mins to complete. The digital system, 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.

The diagnostic selftest is more comprehensive, taking approximately 5 minutes to run. As each internal measurement is made in the test sequence, the %age 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 'pathway' number. The operator 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 singal levels expected. This diagnostic technique enables fault finding to circuit block level without the aid of specialist equipment.

Notes