Setting new standards for DC voltage maintenance systems

Application Note

Many organizations rely on 10V standards as their primary reference. However, the routine maintenance of such devices is not only labor intensive, but requires a high degree of metrological skill to perform the measurements and analyze the accumulated historical data. This application note describes an innovative new integrated voltage maintenance system and analytical software that fully automates the voltage measurement process from import of traceability through to certification.

Volt-maintenance system

The Fluke 7000 voltage maintenance system has been designed comprising the following components:-

- "Nanoscan" Controller/Detector and Rack
- Array of up to 10, 10V Zener Modules
- Optional Switch-only Modules
- "Transref" 4 cell Transportable Standard

The "Nanoscan" is a combined scan-controller and high-sensitivity digital detector mounted in a special 19" rack capable of taking up to 10 independent Zener modules. The detector has a very high input impedance ($>10^9\Omega$), a resolution of 0.01ppm and an operational range of ±10mV.

Zener linear technology

The individual Zener modules each contain a Lineartech LTZ1000 device with a substrate heater operating at 45°C. Special TaN statistical resistor arrays[1] are used to control the gain of the reference module's amplifiers to provide the main output of 10V. Similar arrays are used to provide a 1.018V or 1V output. A patented high-isolation power supply[1] minimizes line noise to allow the references to be measured under line power. Internal power dissipation of each reference module is less than 1W. Up to 15 hours battery life is available from an integral "AA" size, 10 cell, NiMH battery pack. Line power for routine operation and charging is provided by a small external 12V d.c. supply. A patented hysteresis safeguard[1] is provided to minimize the effects of temperature shock during cold shipment or complete power failure.

The 10V output of each Zener module can be switched through an integral electronic (Photo-MOS) switching system to route the output to a system hardware average and the Nanoscan detector.

Electronic, rather than electromechanical switches were chosen to improve reliability and reduce thermal e.m.f.s. This was made possible by the availability of very low "on" resistance devices from the telecom industry. These have proved to be very effective and require very little stabilization time after switching. They also provide a high isolation and very low capacitance between the control and measurement circuits and benefit from not having the heating effects that can result from energizing relay coils. The "on" resistance has no significant effect on the performance of the system because of the high input impedance of the Nanoscan detector. The "on" resistance is also quite stable in relation to the hardware averaging circuit and does not significantly effect

Figure 1 7010N Integrated Volt-Maintenance System

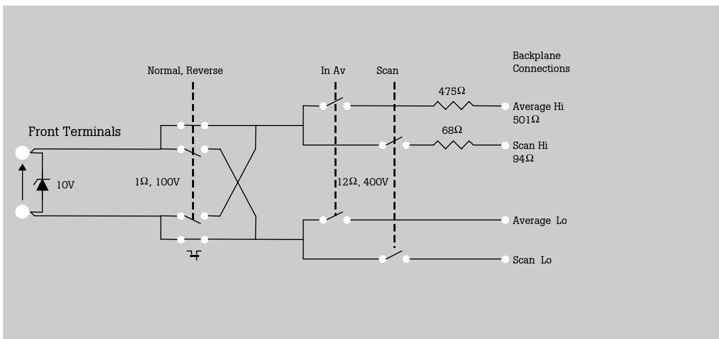


Figure 2 7000 Reference Module Integral Switching

the accuracy of the average output. The switching time (typically 2 ms) is much faster than relays and minimizes the time that measurement circuits are left open during the scan process. Separate switches are used for voltage reversals (to eliminate any residual thermal e.m.f.s), and for switching the Zener module outputs to the scan-bus and hardware average.

The switching arrangement is such that the detector Lo may be connected to the hardware average (HAV), while the detector Hi may be connected to any individual 10V module output Hi under scan control (up to a maximum of 20 modules). There is also provision for automatic reversal of the connections throughout the system to eliminate any spurious thermal offset voltages. The use of iso-thermal planes within the integral analog connections ensures that thermal e.m.f.s are kept to a minimum.

In addition to the Zener modules, the system can also use modules that contain only the electronic switching system. This allows existing external standards to be included in the measurements. An external standard may also be connected to the front panel terminals of the Nanoscan. This allows the system to be calibrated - either against a 10V Josephson system, or another Zener-based standard. Where a Josephson system is used, the Nanoscan provides a switch-closure to control the polarity switching of the Array as part of the scanning process. The Nanoscan also provides the 10V Average output, a 4-wire output (taken from the buffered average) for driving external loads, and a 1V output.

The Nanoscan unit has a status display to allow individual readings to be monitored - including the difference between any module and the hardware average, as well as the Zener chip temperature of each module. A duplex optical fiber serial link between the Nanoscan and the computer's serial port provides total immunity from cable-born noise. Proprietary software (generated with National Instruments LabWindows™ CVI) is used to control the measurement process, capture the data, and process it via a special macro used in conjunction with Microsoft Excel™. The macro makes use of the graphing and statistical functions of Excel to determine the historical and future performance of the system.

Software control

The 7000 series reference modules were designed to facilitate system operation. Each reference module has a rear panel connector that carries not only the analog signals, but also operation status information about the module. This information includes the module electronic ID (type and serial number), correct Zener heater operation and temperature, power supply status, Zener conditioning (hysteresis safeguard) and hardware average enabled. The status information is read each time the module is scanned by the Nanoscan controller/detector and stored together with the other measurement results in a tab delimited ASCII file. This file is automatically imported into Microsoft Excel using a special macro that is part of the Fluke 7050 Excel "Add-In".

To make a series of measurements, the user selects options from a "scan-base" dialogue box. The scan-base may be the same as used previously, or a new one for a specific measurement type. The scan-base determines the following:

- Start Date and Time
- Number of Scans
- Delay Between Scans
- Storage Action (Append/Overwrite)
- Scan Base File Name/Path
- Channels to be Included
- Number of Samples
- Delay Between Channels
- Measurement Mode (Normal/Reversal)

Unless a preliminary scan has already been made, completion of the scan-base dialogue box will initiate a scan of the system to determine which modules are connected. It will check each channel in turn and report the module ID against the 22 available channels. Channel 0 is always the Nanoscan module and system zero, while channel 21 is the external reference input/output. Check boxes are used to select whether a fitted module is to be included in the measurement scan.

Once a measurement scan is in progress, a measurement status dialogue box appears showing the following:

- Channel Number
- Module Difference with respect ot HAV in µV
- Module ID
- % Total Scans Completed
- Current Scan Completed

The measurement process benefits from the fact that a Hardware Average (HAV) is continuously available. Each 10V module output is sequentially compared against the 10V average and its µV difference relative to the average is stored. The process can include full reversals of the system inter-connections to eliminate the effects of thermal e.m.f.s. The measurement sequence is also designed to remove the

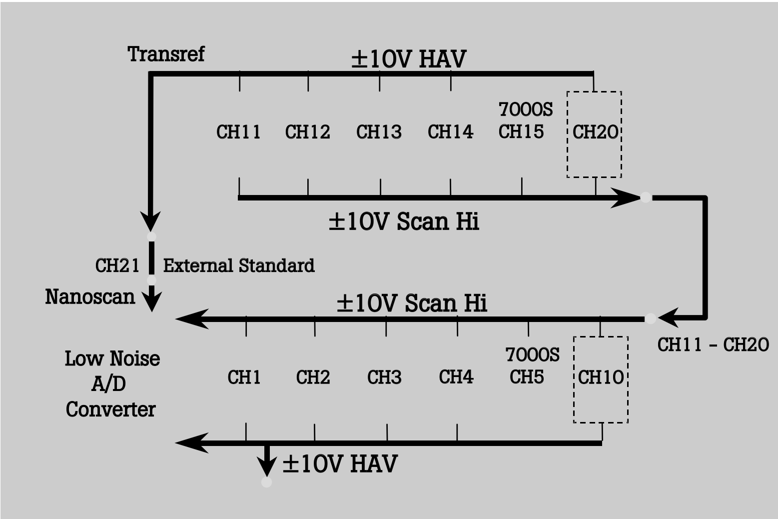


Figure 3 7000 Nanoscan System Analog Bus

effects of any drift or changing offsets within the system. When reversals are made, the Nanoscan detector is required to operate over a 20V common-mode range. Careful design of the detector zero circuit and measurement process ensures that any potential common-mode errors are eliminated.

The scan-control software can be run in the background while the PC is used for other tasks. On completion of the measurements, the results can be imported into Excel for analysis. The data is stored within Excel as a series of worksheets arranged by process and channel number. The worksheets include a summary of all the measurements of all the channels, import results, export results and detailed data for each specific channel individually.

The Import and Export options are for calibrating the system (import of traceability) and calibrating external references (exporting traceability). The latter would normally be connected to channel 21 (External Standard), but could be an individual module within the system, or an external standard connected to a 7000S scan module. The process of importing traceability and determining the on-going voltage capability of the system is called voltage maintenance.

The volt-maintenance process

In a volt-maintenance system the expanded uncertainty is determined by the following:

- Import Standard Calibration Uncertainty
- Importation Process
- Number of Standards in Group
- Time Stability of the Standards
- Temperature Stability of the Standards
- System Inter-Comparison Noise and UUT

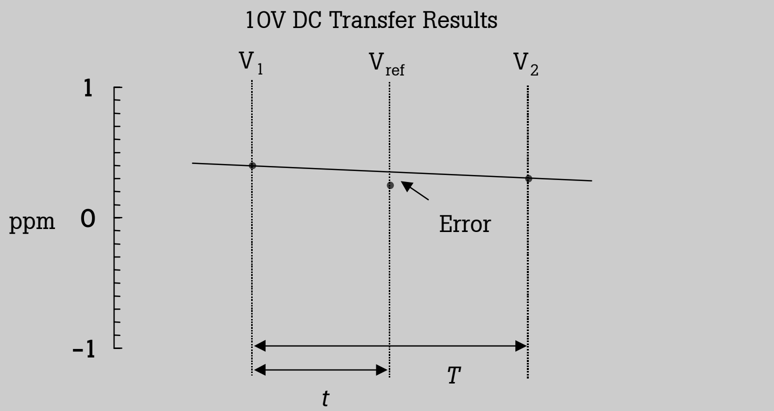
The uncertainty available from national laboratories (usually based on a 10V Josephson Array standard) is dependent upon the performance of the UUT Zener device. Typically, the expanded uncertainty quoted on a calibration certificate will be around ±0.1ppm. Where a conventional one-way, top-down importation process is used, the uncertainty allowance for the importation process may be greater than the calibration uncertainty. Careful choice of the process and type of import standards used can generally reduce the importation uncertainty to less than 0.1ppm - particularly when an AVT (see below) process is used. The noise and short-term stability of any UUT offered up to the system for calibration will contribute to the overall uncertainty. A single 7000 10V module has a specified noise level of <0.10ppm rms. Combining 4 or more modules can make further improvements to the noise level resulting in very low type "A" uncertainty contributions for the measurement system. The Fluke 7004T is designed specifically for this purpose and can be linked to the Nanoscan system to provide a fully automated transfer.

AVT process

In the UK, laboratories with an accredited expanded uncertainty of 1ppm or better are expected to participate in an Audit Via Traceability[2] (AVT). This process uses the laboratory's own transfer standard to audit their technical competency. This evolved from the large number of long-established accredited laboratories. Generally, in the European Accreditation system, accredited laboratories are expected to "own" all of their reference standards and maintain the history. Furthermore, the technical competency on which the accreditations are based requires the laboratories to be able to maintain all aspects of their traceability systems.

Briefly, the AVT process is as follows:

1. The originating laboratory measures it's transfer standard before shipment against the rest of the working reference group and declares a value (V1) for each of its outputs.
2. The transfer standard is sent to the national laboratory together with its assigned value.
3 The national laboratory measures the transfer standard against the national standard over a 10 day period.
4. The transfer standard is collected from the national laboratory and returned to the originating laboratory.
5. The originating laboratory measures the transfer standard after shipment against the rest of the working reference group and declares a value (V2) for each of its outputs.
6. The national laboratory, on receipt of the declared values, informs the laboratory of the certified values (Vref).



$$Error = V_1 + \{[(t / T) \times (V_2 - V_1)] - V_{ref}\}$$

Figure 4 AVT Importation Process

7. From the three sets of results, the originating laboratory can determine the error in its "Volt" (and make a correction) and remove the effects of drift in the importation process.

This process has been in place since 1985 and gives a reliable indication of a laboratory's whole capability - including management of the import from national standards. It also allows the accreditation body to monitor (via the national laboratory) the laboratory's real capability - without having to maintain or manage a large number of their own audit devices.

The importation process used by Fluke's 7000 series voltage maintenance system is based on this very successful method.

A laboratory must be able to determine it's measurement capability at all times. With voltage standards, it is important to know their stability between calibrations to an external standard. The calibration interval may be as long as a year, so knowledge of the drift characteristic of the standard is essential. Voltage standards of a particular type tend to have similar characteristics - particularly if they have been subjected to special selection and conditioning processes designed to optimize stability and remove potentially bad devices. The LTZ1000 is no exception to this and its employment in the 7000 series voltage reference is the result of many years of testing and evaluation. Initially, stability predictions are based on the expected -0.7ppm/year drift rate.

Once historical data from successive calibrations has been accumulated, the 7050 software can be used to curve-fit the data to determine the actual drift rate for each reference module within the system. The drift rates are then used to make predictions of the future values of the hardware average over the next calibration cycle. As more data is accumulated, the drift rates can be revised and applied as corrections to the values used in the volt maintenance process. All the data processing is performed by Fluke's 7050 Excel "add-in". This provides all the analysis tools, graphing, report and certificate templates necessary to allow the user to perform routine volt maintenance tasks. This approach was chosen so that users could perform data analysis to their own specific requirements (within the extensive functionality of Excel).

Acknowledgements
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References

[1] "A practical approach to maintaining DC reference standards". Author P.B. Crisp, Fluke.
[2] "Uncertainty Analysis for Laboratory Accreditation". Author P.B. Crisp, Fluke.

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