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Operation and Reference Manual for the NIST Automated AC-DC Calibration Systems and Software

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Introduction

Scope

This document supersedes the previous operations manual for the NIST Automated Thermal Transfer Standard Calibration Systems [1]. It provides information regarding the arrangement of the calibration systems, their operation, and in particular the software used to control the systems in the NIST Ac-dc Difference Laboratory. In addition, this document provides instructions for calibrating a variety of commonly-used ac-dc transfers instruments.

Although this document provides a general introduction to thermal converters and ac-dc difference measurements, it is really intended to assist the user of the automated calibration systems in the everyday operation of the systems. For an excellent primer on ac-dc difference measurements, see [2].

Introduction to Ac-dc Difference Metrology

Presently, ac voltage and current are most accurately measured by comparing the heating effects of the alternating signal to those produced by a known dc signal of a magnitude equivalent to that of the root-mean-square (rms) value of the ac quantity. The devices generally used to make this comparison are thermal voltage and current converters (TVCs and TCCs) which are useful, at various uncertainties, from a few hertz to many hundreds of megahertz. These devices usually consist of a thermoelement (TE) either in series with a resistor (for voltage measurements as a TVC) or in parallel with a shunt resistor (for current measurements as a TCC). A thermoelement is composed of a heater structure, which alternately carries the ac and dc signals to be compared, and from one to several hundred thermocouples spaced along the heater. By applying ac and both polarities of dc in sequence, and measuring the thermocouple output, one can use the conventional definition of ac-dc difference, δ, in parts in 10^6 as

$$\delta = 10^6 \times \frac{\left(Q_a - Q_d\right)}{Q_d} \tag{1}$$

where Q_d is that value of dc which, when applied with positive and negative polarities, produces the same mean response as the rms ac quantity.

Present commercially available ac-dc thermal transfer standards[1] are commonly based on either single-junction thermal converters (SJTCs) [3-7] or solid-state transfer standards [8]. The SJTCs have one thermocouple fixed to the heater wire, have outputs of 7 mV to 12 mV for full

[1] In this document, TVC is used as an acronym for Thermal Voltage Converter, TCC for Thermal Current Converter, and TE for Thermoelement. The term Thermal Transfer Standard is used as a general term for any of these devices.

scale input, and respond in a roughly square-law manner to changes in the input signal. These are found in a wide range of commercial instruments and are useful from about 10 Hz to several hundred megahertz. The best uncertainty for these devices, exclusive of the measurement process and any range or shunt resistors, is a few microvolts-per-volt (µV/V) or better at audio frequency and full-scale input. The uncertainty increases at the extremes of the frequency range and at input levels below about half of full scale. Solid-state thermal transfer standards have thermal converters based on transistor sensors and respond linearly to the input signal. The model most often calibrated at NIST, the Fluke Corporation 792A, has an output of 2 V for full-scale input, and is specified at frequencies from 10 Hz to 1 MHz for voltages from 2 mV to 1000. The uncertainties of this instrument are comparable to or better than those of SJTCs at audio frequency, but, owing to the extremely short time constant of the thermal sensor, it is degraded at frequencies below about 40 Hz.

Multijunction thermal converters (MJTCs) [9-11] are the most accurate thermal transfer devices, with uncertainties of less than 1 µV/V at mid-audio frequencies. These consist of a heater wire with multiple thermocouples connected in series-aiding. MJTCs have several advantages over SJTCs. Because the thermal gradients are smaller along the heater, thermoelectric effects are greatly reduced compared to those of SJTCs. The greater number of thermocouples provide an output voltage of several tens of millivolts or more, which is easier to measure than the smaller outputs of the SJTCs, and they are true square-law-responding devices. The disadvantages of MJTCs are their limited frequency response of about 30 Hz to 10 kHz, their long time constants, which make for a lengthy measurement cycle, and their cost. Because of these limitations, MJTCs are generally used only in primary standards laboratories.

The latest advance in thermal transfer devices is the Film Multijunction Thermal Converter (FMJTC) [12,13] which uses thin-film fabrication technology to deposit the heater and thermocouples on a silicon chip. These devices have been fabricated at NIST and elsewhere and have the potential to be used as working standards in place of SJTCs.

Thermal current converters are generally realized as a thermal voltage converter in parallel with a high-precision shunt resistor [14,15] and have uncertainties of tens of µA/A at audio frequency and moderate current. NIST has fabricated FMJTCs that have uncertainties of less that 10 µA/A at low currents and audio frequencies, but these are not in everyday use as ac-dc transfer standards at the time of this publication. Work continues in this area to develop high-current FMJTCs.

Since TEs commonly have a maximum input voltage of from 0.5 V to 2 V, higher voltage ranges are realized by placing a high-precision resistor in series with the TE. To be suitable as multiplying resistors in a TVC, the ac-dc differences of such resistors should be as independent as possible to variations in frequency and voltage. These resistor modules frequently have internal shielding to compensate the capacitance between the resistor itself and the external shield, and are usually either of wire-wound construction or consist of a metal film deposited on

a glass form. In either case, for higher voltages, the resistor makes the dominant contribution to both the ac-dc difference and the uncertainty of a TVC [16,17].

The NIST Automated Systems for Thermal Transfer Standard Calibrations

The present generation of NIST automated thermal transfer standard calibration systems was begun by a prototype system designed by Earl S. Williams and assembled in the early part of the 1980s [18,19]. This system was initially intended for the testing and development of solid-state transistor-based sensors. It became obvious that this automated system was also ideal for routine ac-dc difference measurements as part of the regular NIST calibration service for thermal transfer instruments. Accordingly, it was employed for some routine calibrations in early 1984. Because of the success of this system, a second automated system was assembled and used for routine calibrations beginning in 1985. A third automated system, initially intended for current calibrations, was assembled in 1998, and a fourth in 2000. Because of the availability of high-performance transconductance amplifiers, all four automated systems can be used for both voltage and current calibrations.

Although these three automated systems differ in their exact details, all automated ac-dc calibration systems have several common attributes, as shown in Figure 1. All must have highly-stable and precise sources of ac voltage or current and dc voltage or current, an arrangement for switching between the ac and dc signals, and a method of monitoring the outputs of the thermal converters with adequate precision. In the NIST systems, the ac and dc signals are provided by separate sources, although in principle, a multifunction calibrator might serve as a single signal source, and the switching is accomplished by relays. The millivolt-level output electromotive forces (emfs) of the thermal converters are monitored using sensitive, low-noise digital nanovoltmeters. The systems also have various arrangements of ac and dc voltmeters and frequency counters to monitor the performance of the system.

The calibration systems are controlled by Apple eMac [20] running National Instruments' LabVIEW [21] software. LabVIEW is a graphics-oriented system control package, which acts as a "virtual instrument" (VI) during the calibration procedure, displaying data and results in real time as the measurements proceed. This arrangement is a significant improvement over the older BASIC language-based systems, which, although menu-driven and straightforward to use, nevertheless required the operator to proceed through many screens to operate the system. With the "virtual instrument" concept, the same screen is displayed for the entire calibration run (in most cases) and acts as both the input and output stages of the system.

Software Design Philosophy

The original automated systems were controlled by software written in Hewlett Packard (HP) BASIC for Model 86/87 computers. This software was arranged in one large program, with very

little structure and convoluted program flow. These features made the software extremely difficult to understand and maintain, and its monolithic structure precluded modifications necessary to calibrate various instruments. In addition, the Model 86 computer which ran the original software had no provision for direct cursor addressing, which frequently resulted in measurement data scrolling off the top of the screen.

The second generation of software was written in Hewlett Packard's Rocky Mountain BASIC. This software was arranged in a completely modular fashion, with a relatively short main program and 58 subroutines. This arrangement made the software more readily understandable (particularly since the routines were well documented) and much easier to modify if necessary. The disadvantage of its large size (over 100 000 lines of code) and lengthy program loading times were compensated for by the "package" concept, whereby one did not need to exit the main ac-dc difference program once it was loaded. The HP Series 300 computers that ran this software had facilities for direct cursor addressing, so data no longer scrolled off the top of the screen. The software also included extensive error trapping code, read and wrote a variety of data files to assign appropriate corrections to NIST standards, and archived the data on the Unit Under Test (UUT).

The success of the second generation software is demonstrated by the twelve years of continuous operation on two automated systems, and the two systems were still performing quite well into 1997. Nevertheless, the computers that operated the systems were beginning to show some age (becoming less reliable and more prone to disk problems) and it was decided to replace these computers and software packages before the occurrence of a major problem which might impact the calibration service. The HP Series 300 computers were replaced by Apple Macintosh 7200/120 machines, and the interpreted BASIC software was replaced by the LabVIEW package. The new systems were placed into routine operation in early 1998 and presently control four automated systems.

The design philosophy used in the coding of the Rocky Mountain BASIC software package was again used in the LabVIEW package. A large part of the system control is performed by recursive calls to subroutines (or subVIs as they are known in LabVIEW). The software has extensive native error trapping and file handling routines for archiving data and is easily modified to accommodate new types of instrumentation and new program structures. Data is written to defined sections of the screen, so scrolling is not a consideration (and LabVIEW allows for scrolling windows if necessary). Owing to its graphical user interface and "wiring diagram" coding, LabVIEW programs may be difficult to understand for users who are unfamiliar with the software package; however, following the program flow is straightforward and LabVIEW's self-documenting features facilitate comprehension.

The Macintosh 7200/120 computers were replaced in 2003 by Apple eMac computers. In addition, several Windows-based computers are used on the automated systems.

Future Directions

The LabVIEW-based software is presently in routine operation in the Ac-dc Difference Calibration Service at NIST and no major revision is anticipated. However, as is the case in all information technology ventures, incremental improvements will be made on a regular basis to ensure that the calibration system software remains current and fulfills the mission of the laboratory. Future updates will also render this documentation a bit dated; however, the basic operation of the systems is not expected to change for some time. The only major anticipated change in the operation may be to allow the remote operation of the systems from the Internet.

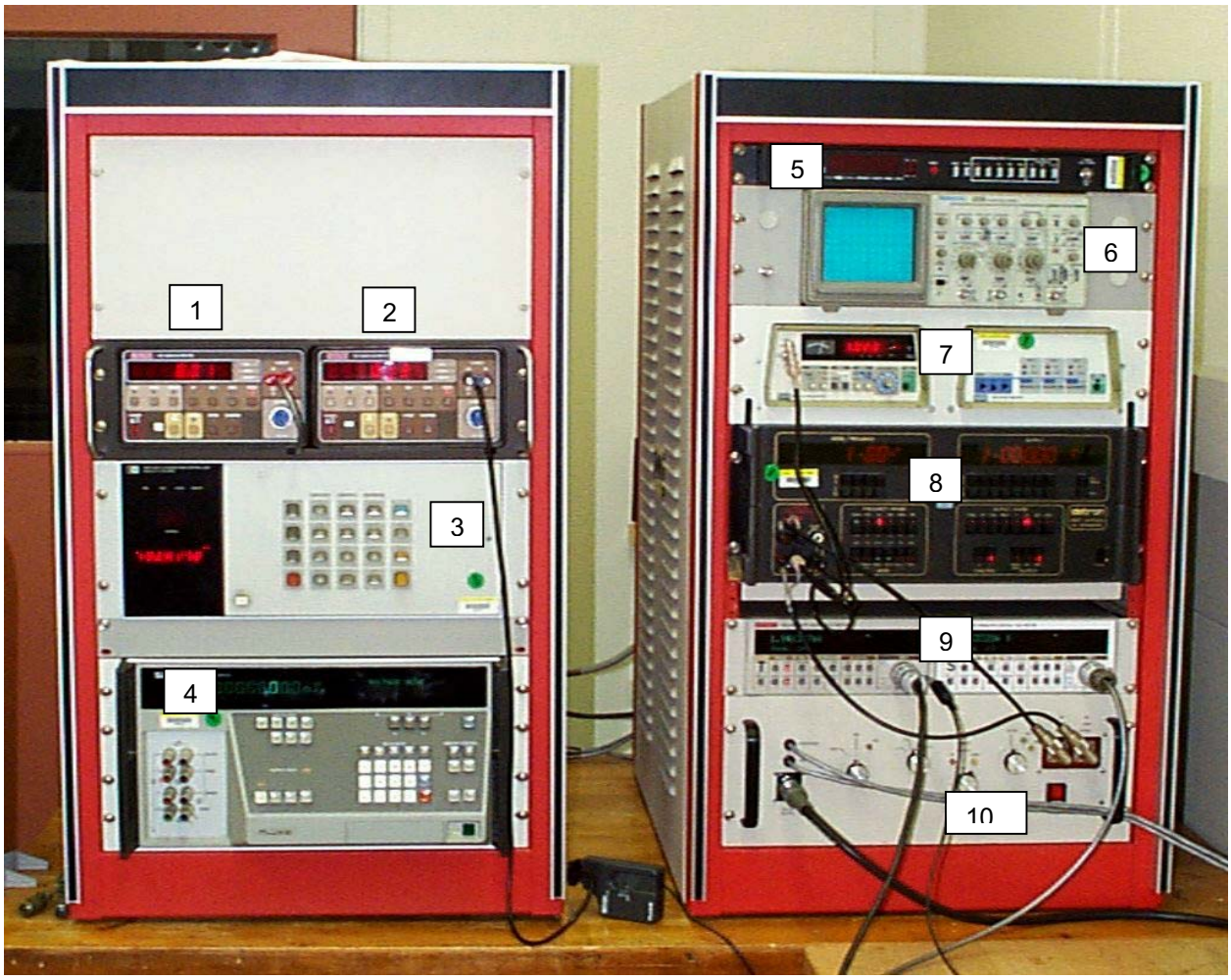

Figure 1. Photograph of NIST Automated System II.
The other three automated systems are similar. The components of the system are shown in Table 1.

Table 1. Components of Automated System II as shown in Figure 1.			
instrument	Function	Instrument	Function
1	Dc voltage monitor voltmeter	6	Oscilloscope
2	Temperature monitor voltmeter	7	Ac voltage monitor DVM
3	Relay controller	8	Ac source
4	Dc source	9	Test and standard detectors
5	Frequency counter	10	Relay box

Conventions Used in This Document

Throughout this document, various text styles represent different parts of the software or the front panel display and affect the way you interact with the software. Table 2 presents the meaning of the different text styles.

Table 2. Meanings of the various text styles used in this document.		
Style	Example	Significance
BOLD	**RUN, START**	Front panel "buttons" you use to control the operation of the automated system. You activate these "buttons" by clicking on them using the mouse.
CAPITAL	ENTER	Keys on the keyboard.
Bold	**Results, System Status**	Groups of indicators on the LabVIEW front panel. These groups are color-coded for identification and are generally used to display information about the measurement process.
Italic	*Freq., N*	Rows or columns in an array or table.
Italic	*Ac-dc Difference*	Front-panel file aliases.
SMALL CAPS	STANDARD CORR	Refers to a LabVIEW subVI.

Disclaimers

Certain product names are used in this document to adequately describe the automated calibration systems and test procedures. Use of these product names does not imply endorsement by NIST nor does it imply that these products are necessarily the best available for the intended purpose.

A challenge of documenting software is keeping up with the rapid changes in software versions. This document describes the automated measurement systems at the time of writing. Updates to both the LabVIEW package and the program itself may create some differences in the way the programs are run that are not included in this manual.

NIST Ac-dc Difference Calibration Software System Requirements

The software for controlling the NIST Ac-dc Difference calibration systems is written in LabVIEW, a graphically-oriented programming language available from National Instruments[1] [1]. Work on the software began in 1997 using LabVIEW 4; presently the software runs under LabVIEW 7.

The combined size of the individual subVIs comprising the ac-dc difference software is 5.7 MB (for a Macintosh).

The minimum system requirements for LabVIEW 7 may be found at

http://www.ni.com/labview/requirements

Minimum requirements for the ac-dc software are not exactly known. The software is cross-platform compatible and has been successfully used on a variety of platforms, as shown in the following table.

Platform	Processor	Speed	OS	Memory	Disk Space
Apple eMac	Apple G4	800 MHz	MacOS 10.2	256 MB	40 GB
Apple iBook	Apple G3	500 MHz	MacOS 9.2	256 MB	10 GB
Apple G4	Apple G4	400 MHz	MacOS 9.2	1.12 GB	10 GB
Apple 7200	PowerPC	120 MHz	MacOS 8.6	128 MB	1 GB
Dell GX	Pentium 4	1.8 GHz	Windows 2000	524 MB	40 GB
AMD	AMD-K6	900 MHz	Windows 2000	132 MB	40 GB
TCP	Pentium 2	400 MHz	Windows 2000	132 MB	10 GB

Because the calibration systems are controlled and data acquired via the IEEE-488 (GPIB) interface, a suitable method for interfacing the controller with the GPIB bus is required. The Ac-dc calibration software has been successfully implemented using the National Instruments NI-488.2 software suite of GPIB drivers controlling the following interfaces:

- National Instruments GPIB-PCI PCI card on both Windows and Macintosh computers (running MacOS 9.2 and below), where appropriate.
- National Instruments GPIB-USB B adapter, on Windows computers

[1] Commercial names are used in this document to fully describe the calibration systems. A reference to a commercial product does not imply endorsement from NIST, nor that the product is necessarily the best available for the application.

- National Instruments GPIB-ENET adapter on Macintosh computers running MacOS 10.2 and higher.

Note that even though the Ac-dc Difference Calibration software is platform independent, the user will need to change the file paths of the various data files used by the program. Instructions for doing this are included in the software documentation.

Running the Voltage System VI

Loading the Voltage System Program

To load the software for the voltage calibration system, double-click the *Voltage System Startup.vi* icon on the desktop. After loading the subVIs required for program execution, the Voltage Calibration front panel will be displayed, along with a dialog window showing a list of the authorized users of the calibration system (Figure 1). Click in the box next to your name to begin the calibration session. After selecting your identity, click in the OK box. To stop the calibration routine and return to the LabVIEW development system, click the Cancel/Stop box.

After you select OK, the system operator ID box vanishes and the ac-dc difference front panel (Figure 2) is presented. Refer to Appendix A for a complete description of the LabVIEW front panel objects and their functions.

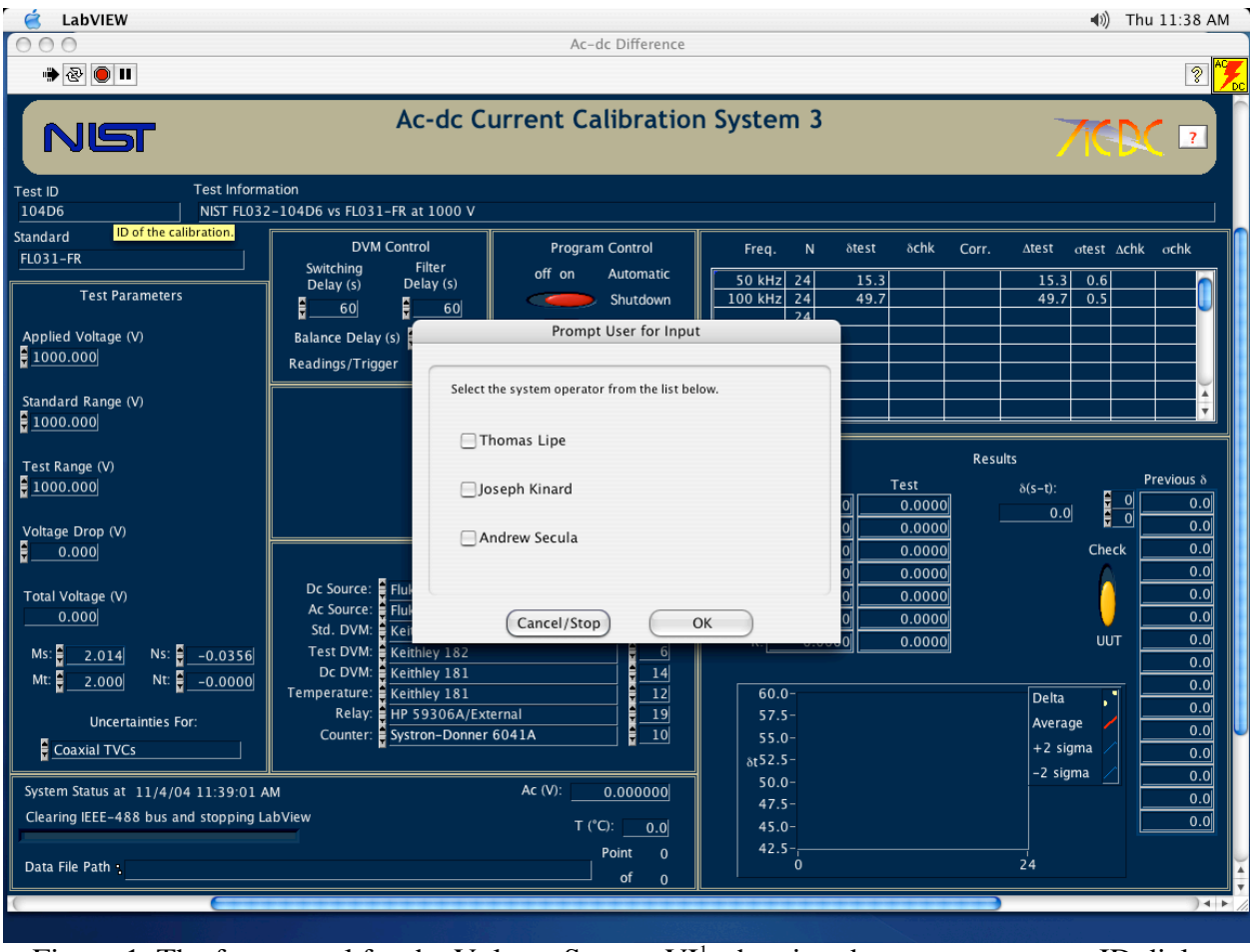

Figure 1. The front panel for the Voltage System VI[1], showing the system operator ID dialog window. Note the help banner (yellow) at the **Test ID** field.

[1] The title banner is initialized after the operator dialog, so occasionally the voltage VI will start up with a banner indicating current mode. After you click on the OK button, the title banner changes to the appropriate function.

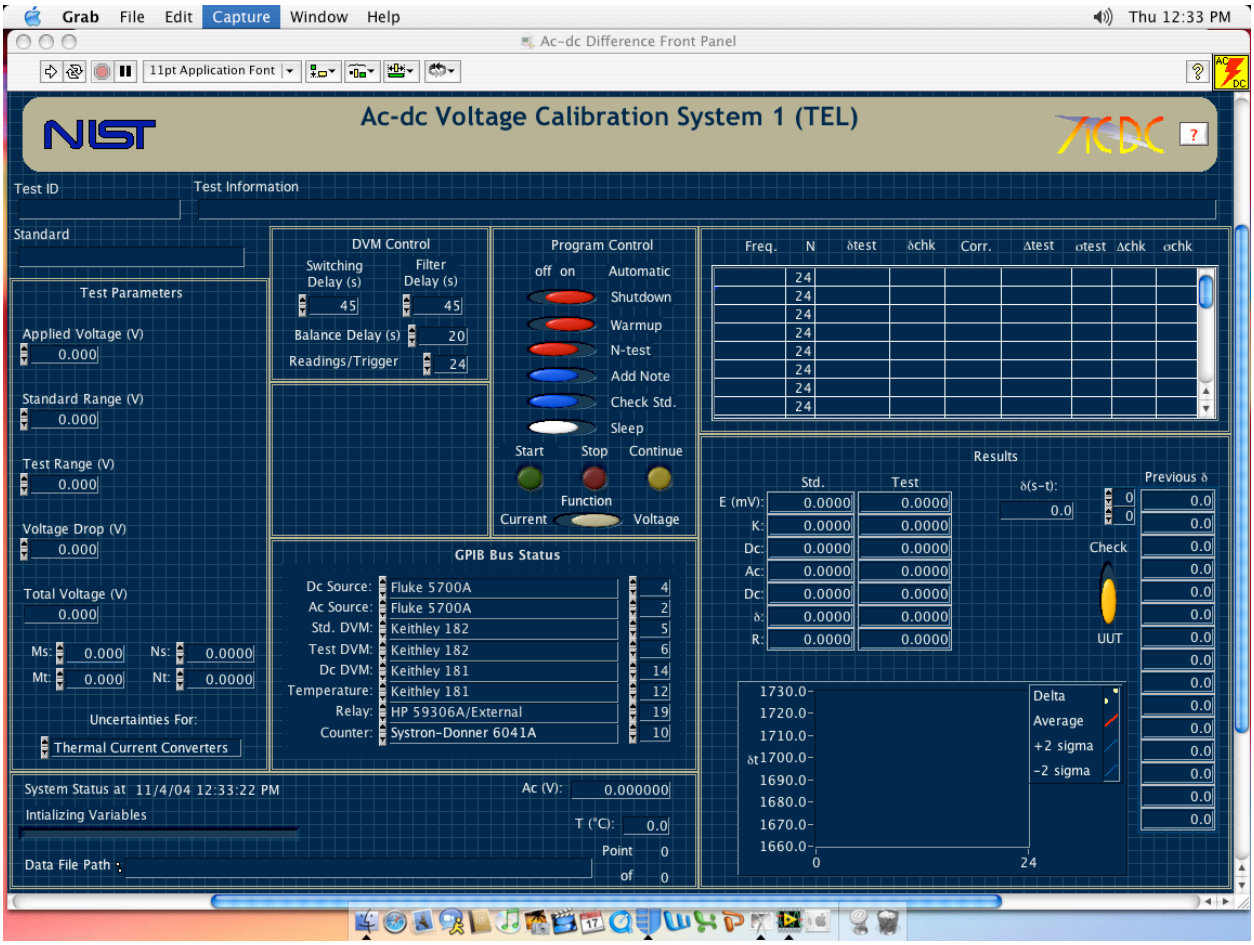

Figure 2. The ac-dc difference front panel. Note the operator's initials in the title banner.

The front panel of the voltage calibration VI is divided into regions that are used for controlling the VI, or for viewing the results of the calibration. These general regions are:

- Test Parameters: This section of the front panel is where you enter the conditions of the calibration; the applied voltage, the voltage ranges of the test and standard TVCs, and the response characteristics of the thermoelements used for the calibration.
- DVM Control: This section allows you to control the operation of the digital voltmeters (DVMs) used to monitor the outputs of the thermal converters.
- GPIB Bus Status: A cluster of enumerated lists, which defines the instruments available on the GPIB (IEEE-488) interface bus.
- System Status: This section presents information about how the calibration is going, including the adjusted ac voltage, the temperature, and the data file path.
- Program Control: This section is where you choose options for the calibration program, like running an n-test, manually warming up the converters, and so forth.
- Results: This section presents the ongoing results of the calibration at a particular frequency.

In addition to these sections, two more regions are shown on the front panel. The table appearing just above the Results section is where you enter the frequencies of the calibration, and where the results for each frequency are presented after the frequency finishes. The fields at the top of the display allow you to enter the identification of the UUT and the standard. Each of these fields and front panel regions will be discussed further below.

Starting the Calibration Software

Before you can enter the test parameters into the calibration program, the Voltage System VI must be running. The Voltage Calibration VI loads in RUN mode, so that it is running when it opens. However, after a calibration is complete, the VI may be rerun without starting it from the *Voltage System Startup.vi* icon. To start the calibration VI, simply click on the **RUN** button in the LabVIEW menu bar.

☛ **Note:** Do not confuse the LabVIEW **RUN** button with the green **START** button on the System VI front panel. The **RUN** button starts execution of the VI. The **START** button breaks the VI out of an idle loop and lets it proceed with the measurement sequence. Similarly, the LabVIEW **STOP** button halts program execution but does not reset the voltage sources or GPIB bus. The red **STOP** button on the VI front panel does reset the voltage sources and the GPIB bus.

When the VI is run, the **Results** table, **Previous Data** arrays, and **Present Data** arrays are cleared, and the date and current time are displayed in the **System Status** region. The test information, test parameter, and DVM control fields, however, are not cleared, as it is sometimes handy to keep this information from run to run. For example, if you a calibrating a thermal voltage converter set, chances are that you will need to change only those parameters that change with range, like the serial number of the TVC, and not re-enter all of the test parameters again.

Getting Help

You may get help at any time by clicking the box with the question mark at the right side of the title banner. Clicking this button launches Adobe Acrobat Reader, and displays the automated system documentation (this document). However, it is probably not a good idea to request help while the system is running, as this is likely to disrupt the timing.

Entering Information Into the Front Panel Fields

Press the TAB key to move the cursor to the **Test ID** field and enter the appropriate information, perhaps the folder number of the calibration or a similar identifier. After you have finished entering this information, press TAB again to complete the data entry and move the cursor to the next field, the **Test Information** field. Enter information about the calibration into this field.

Step through the fields displayed on the front panel, entering information for each field in turn and terminating the data entry using the TAB key. The panel order for the front panel controls and a description of the controls is shown in Table 1.

Table 1. Descriptions of the fields on the Voltage System VI front panel. The number indicates the order in which the fields are entered using the TAB key.		
Panel Order	Field	Type of information.
1	Test ID	An identification for the calibration. Usually the calibration folder number or similar information.
2	Test Information	Information about the Unit Under Test. Usually the type of UUT, its serial number, and customer.
3	Standard	The identifier of the NIST standard. Something like W20#12 or W250#4.
4	Applied Voltage (V)	The applied voltage of the calibration, in volts.
5	Standard Range (V)	The voltage range of the standard TVC, in volts.
6	Test Range (V)	The voltage range of the UUT, in volts.
7	Voltage Drop (V)	The voltage drop of a series resistor.[2]
8	Ms	The value of M for the NIST standard.[3]
9	Ns	The value of N for the NIST standard.
10	Mt	The value of M for the UUT.
11	Nt	The value of N for the UUT.
12	Switching Delay (s)	The time delay between the relay switching and the activation of the DVM filters, in seconds.
13	Filter Delay (s)	The time delay between the activation of the DVM filters and the beginning of data collection, in seconds.
14	Balance Delay (s)	The time delays used for the relay switching and voltmeter filter activation when the system is balancing the voltage sources.[4]
15	DVM Readings/Trigger	The number of readings per trigger taken by the DVMs monitoring the output of the TVCs. These readings are averaged internally by the DVMs.

☛ **Note:** To help you avoid over-ranging the converters, the software compares the value of the applied voltage you request to the voltage ranges of the standard and UUT, and, if the applied voltage exceeds either of these ranges, the **Applied** control turns red and the system beeps to get your attention. This alert condition is cleared when you enter ranges for the converters that are equal to or greater than the applied voltage. But when the Voltage System VI is first loaded, all controls are set to 0; thus the applied voltage will exceed the voltage ranges of the converters (since you enter the applied voltage first), and the alert condition will be activated.

Because LabVIEW recognizes the results summary table above the Results section as a table rather than a control, you cannot use the TAB key to step into this field. Instead, click the cursor in the first cell in the *freq.* column and enter the input signal frequency. If you do not add a unit

[2] For calibrating thermal voltage converters at levels below 1 V or so, it is sometimes helpful to insert a series resistor in the signal path before the Tee. This allows the voltage sources to operate at a higher level where they are generally more stable.
[3] See Chapter 3 for a description of the N-test VI and an explanation of these parameters.
[4] Using a shorter delay while the system is balancing the voltage sources can save some time.

to the frequency, the software interprets the number to be in kilohertz (so that entering .02 sets the frequency to 20 Hz, 10 sets it to 10 kHz, and so on). Alternatively, you can add the units yourself. Advance to the next cell down in the *freq.* column by pressing the RETURN key. When you have entered all test frequencies, terminate the final entry by pressing the ENTER key on the numeric keypad, by clicking somewhere on the front panel, or by clicking on the LabVIEW **ENTER** (√) button. If you wish to change the number of data points for a frequency, double-click in the *N* column beside the frequency of interest. You may step down through the *N* column by pressing the RETURN key. The other columns in the table are for data collected during the measurement sequence, and you need not enter information into these columns.

Entering the Response Characteristics for the Converters

To calculate the ac-dc difference of the thermal converters, the system needs to know how the output of the converters changes in response to small changes in the input voltage or current. This response characteristic is generally called *n* and is discussed at length later in the documentation You can pass the value of *n* to the systems in several ways. The response characteristics of the NIST standards have been compiled and may be entered directly into the Ac-dc Difference VI as the values M and N (fields 8-11 in the Test Parameters section of controls). Alternatively, you may elect to measure the response characteristics of the converters using the n-test procedure described in "Using the Test Option Sliders" section below, or run the stand-alone n-test procedure described in chapter "The N-test VI". Or if you don't know the characteristics for the NIST standard converter, you may leave the **Ms** and **Ns** fields blank and the subVI STANDARD CORR will look up the M and N for you, provided the standard is defined in the subVI.

Choosing the Uncertainty Data File

The Ac-dc Difference Calibration software will calculate the uncertainty of the measurement based on the Type A uncertainty of the calibration and the Type B uncertainty estimates for the thermal converter and measurement system. The Type B uncertainty information is stored in a separate file for each type of thermal converter (coaxial, multirange, Fluke 792A) the system routinely measures. Select the data file to load the Type B uncertainties from by using the LabVIEW Operating Tool to select the appropriate source data file in the **UNCERTAINTIES FROM** enumerated list shown below the response characteristic fields. If you are calibrating an internal standard, select "Internal" from the list. See the description for the subVI CALCULATE UNCERTAINTY for more information.

Using the Test Option Sliders

In the Program Control section of the front panel is a set of six slider controls, which allow you to set various options for the measurement sequence. The sliders are initially set to their default values. To select an option, click on the desired slider with the LabVIEW Operating Tool. The slider will switch from the default setting to the desired setting. A list of these sliders, their default settings, and their functions follow:

- Automatic Shutdown (ON): Normally the system is set to shut itself down after a calibration. The GPIB bus is reset, the voltage removed from the converters, and the software left in its

power-on state. Occasionally you may wish to prevent the system from shutting down following a calibration, perhaps to avoid cooling the converters. To prevent an automatic shutdown, set this slider to OFF. After the measurement cycle finishes, the software is reset, but the GPIB bus is not, so that will still be supplied to the TVCs.

Warning: A potential safety hazard may exist if you deselect the automatic shutdown feature. You should be aware that voltage will still be supplied to the TVCs after the program has stopped, and take steps to ensure that this does not create a hazard for you or anyone else in the laboratory. It is strongly suggested that you use the automatic shutdown feature.

Automatic Warmup (ON): The software will calculate a warmup time for the TVCs based on the applied voltage. The warmup time for each voltage is shown in Table 2. If you wish to select a different warmup time, click on the slider. The slider will be replaced with a LabVIEW control. Click in the control, and enter the desired warmup time in minutes. Terminate the entry by pressing the ENTER key.

Table 2. Default warmup times for various applied voltages

Applied Voltage (V)	Automatic Warmup (m)
0-50	5
51-100	10
101-250	20
251-500	30
500-1000	45

- Automatic N-Test (OFF): In order to calibrate a TCC, the system needs to know how the output of the TCC changes in response to small changes in the input voltage. This response is governed by the equation

$$E = kI^n \tag{2}$$

where E is the TVC output, I is the input current, k is a constant and n is the response characteristic of the TVC, and is the quantity we need to know. To find n, one can either use the stand-alone n-test routine or choose the **AUTOMATIC N-TEST** option slider to run the single-voltage n-test. This subVI determines n at the presently applied voltage. The details of this subVI are found later in this section.

☛ **Note:** A general guideline is to use the stand-alone n-test for thermal converter sets which have multiple TEs, and the single- n-test for single TEs.

- Add Note (OFF): Occasionally you may wish to describe the measurement conditions in more detail than the **Test Information** field has room for. Clicking on this slider opens a window, where you may enter up to five lines of text, which are appended to the results sheet. A detailed description of this utility is found later in this section.

- Chk. Standard (OFF): Click on this slider to measure a check standard simultaneously with the UUT. After you click this slider to ON, LabVIEW opens a window into which you enter information about the check standard and the file to which you wish to save its results. The details are found later in this section.
- Function: This slider is initially set by the *Start Voltage System.vi* routine to be in the voltage position. If you run the Ac-dc Difference VI again with the slider in this position, the front panel defaults to the voltage calibration mode. However, if you use the LabVIEW Selection Tool to set the slider to the current position, the front panel will run in the current calibration mode when you click the LabVIEW **RUN** button.
- Sleep (Macintosh only) (OFF): This slider affects the operation of the system after the final frequency has been completed. If the slider is set to ON, after the final frequency the system waits for three minutes for the results of the measurement to print, then calls an AppleScript script to put the computer to sleep. Note that this action does not stop LabVIEW; the application stops once the computer is awakened. If the default OFF position is selected, the computer just sits there after LabVIEW stops.

Changing the Nanovoltmeter Parameters

The nanovoltmeters used as detectors for the thermoelement outputs are set to internally average multiple readings when triggered. The number of readings to be averaged is displayed in the **DVM Readings/Trigger** control. This parameter is generally set to 24 for Keithley Model 182 nanovoltmeters and 12 for Hewlett Packard Model 34420A voltmeters[5]. To change this parameter, double click on the control and enter the desired number of readings, or use the Operating Tool to click on the up/down arrows beside the control field. The nanovoltmeters are triggered following two separate delays. **Switching Delay** is the time (in seconds) the system waits between switching from ac to dc (or vice versa) and the activation of the nanovoltmeter filters. **Filter Delay** is the time (also in seconds) the system waits for the filter output to settle before beginning data collection. To change either of these parameters, either double-click in the desired field and enter the delay, or click on the up or down arrows with the Operating Tool.

The GPIB Bus Status Cluster

Rather than explicitly define the types and addresses of each instrument on the GPIB bus in the program code, this information is disseminated throughout the program via a LabVIEW cluster of enumerated lists. Each instrument definition box is a list of the instruments presently supported by the Ac-dc Difference system. The address of the associated instrument appears in an integer control beside the list box. This arrangement gives you much more flexibility in choosing the instruments for the calibration system, as you can change instruments without changing the source code.

You may need to modify the GPIB bus definitions. To change the defined instrument, you first need to select the Operating Tool from the LabVIEW Tools palette. The Operating Tool is the one that looks like a hand with its index finger raised (☝) and you can select this tool by

[5] The difference in readings is due to the longer integration times for the Hewlett Packard meters.

either pressing the TAB key until it appears, or by pressing the COMMAND (⌘) key while simultaneously depressing the mouse button. Once you select this tool, you can see a list of the defined instruments in each enumerated box by positioning the Operating Tool over the list box and depressing the mouse button. A list of instruments defined for use with the present software version will be presented, and you may select a different instrument by positioning the hand over the desired instrument and releasing the mouse button. Change the GPIB address, if you need to, by either clicking on the up and down arrows to change the displayed address, or by double-clicking on the address to highlight the text, then typing in the correct address and pressing the ENTER key to terminate the data entry.

☛ **Note:** Because the GPIB cluster is initialized in the first frame of the LabVIEW software, you MUST set the GPIB instruments and their addresses BEFORE clicking on the green **START** button.

Starting the Measurement Sequence

Once you have entered all the appropriate test parameters, click on the green **START** button on the front panel. The button turns a brighter green and begins to flash to indicate that the system is running, and LabVIEW begins to initialize the GPIB bus. The instruments defined in the **GPIB Bus Status** cluster are cleared, and the voltage sources initialized to the proper values and turned on. It is a good idea to watch the voltage displayed on the ac and dc voltmeters to ensure that the sources are functioning correctly and supplying the proper voltages to the thermal converters. Once you are sure that the proper voltage is being supplied, set the system output on/off switch to ON.[6] You may monitor the output emfs of the TVCs as they come up by observing the nanovoltmeter readings.

☛ **Note:** To ensure that the ac-dc differences are calculated properly, the software automatically takes the absolute value of the output emfs shown on the nanovoltmeters. The signs of the thermal converter outputs are irrelevant to the calculations and may be positive or negative.

If you have chosen the automatic warm-up option, the software will calculate a warm-up period based on the applied voltage. The time until the start of data collection is displayed in the **System Status** section, counting down from the chosen warm-up time. If the automatic warm-up option is not selected, the warm-up time will be that defined in the control displayed when you disabled the automatic warm-up feature.

You may override the automatic warm-up by clicking on the yellow button marked **CONTINUE**. Clicking this button breaks the system out of warm-up mode, and it proceeds to the measurement sequence. The button remains a brighter yellow to remind you that the thermal converters did not have a full warm-up, just in case the results are poor.

After the desired warmup time has elapsed, the system will read the initial emf of the thermal converters. Upon reading these emfs, the system calculates the sensitivity, K ($K = nE$), and displays the emf and K for each converter in the appropriate cells in the **Present Data** section.

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[6] On Automated Systems 1 and 2, the output on/off switch is on the front of the relay panel. On Systems 3 and 4, it is on a dedicated switch box located between the ac-dc relay and the GR 874 Tee.

The Measurement Sequence

The measurement sequence begins with the first dc point. Dc has been applied from the beginning, of course, so all the system does for the first point is to call the READ DVM subVI to read the detectors. You will notice that a round yellow LED indicator is displayed on the front panel beside the first **Dc:** box. This indicator signifies the type of applied voltage (dc in this case), and will cycle through the dc, ac, dc sequence as the applied voltage is changed. You may also note the plus sign in the LED, indicating the polarity of the applied dc voltage. After waiting for the filters to settle, the nanovoltmeters are read, and the output emfs of the converters are formatted and displayed in the initial **Dc:** boxes.

The relays are then switched to the ac position, to apply alternating voltage to the converters. Simultaneously, the yellow LED indicator on the front panel moves to the ac position, and the system begins a waiting period for the converters to stabilize after the relay switch. The remaining time for this delay is displayed in the **System Status** block. After the initial wait, the nanovoltmeter filters are activated, and a second wait permits the filtered readings to settle. The emfs are then read and displayed in the **Ac:** box on the front panel, and the relays are switched to the dc position.

While the relays are in the ac position, the polarity of the dc source is reversed, so that the converters are measured with both polarities of dc applied. The yellow LED, now with a minus sign superimposed, indicated that the second dc signal is applied. After waiting for the converters to settle as before, the second dc readings are collected from the nanovoltmeters. The ac-dc difference and dc reversal error for each channel are displayed inside the **δ***:* and **R:** boxes, and the uncorrected ac-dc difference for the unit under test is calculated and displayed in the topmost box of the **Previous δ** column. The calculated (uncorrected) ac-dc difference of UUT is displayed as a yellow point on the graph displayed in the Results section.

If the ac-dc difference of the standard channel is less than 50×10^{-6}, then the ac and dc sources are balanced well enough so that the imbalance in the sources will have a negligible effect on the ac-dc difference. In this case, the system will discard the first data point collected to deal with the Famous First Point Effect[7], and start another triad of measurements with dc. Assuming that the supplies remain in balance, this next point is the first one kept as a measurement point.

If, however, the ac-dc difference of the standard channel is greater than 50×10^{-6}, the system will trim the ac source to approximately balance the dc source, and the measurement sequence will start over. The system will continue with this cycle until the supplies are in balance, and will then go on to begin the calibration. The adjusted ac will be displayed in the **Ac (V):** indicator in the **System Status** block, and reflects how far from nominal the ac source is set to balance the output of the dc source. A large and variable adjustment or an inability to balance the supplies may indicate a failure in one of the voltage sources, or instability in the standard. Note that, as the system attempts to balance the supplies, the system uses the time shown in the **Balance Delay (s)** field as both the delay for the switching and voltmeter filters. You can save some time by setting this value to be smaller than the values shown in the **Switching Delay** and **Filter Delay** fields.

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[7] The Famous First Point Effect is an often-observed but unexplained phenomenon wherein the first data point collected by the system far exceeds Chauvenet's Criterion for acceptance of the data. It is dealt with here by simply always ignoring the first data point.

As the calibration progresses, the uncorrected ac-dc differences are displayed in the **Previous δ** column vector. Although in principle an infinite number (or at least 32 767) of points may be taken, the monitor limits the visible length of this column vector to 15 points, and the displayed length of the vector is set to the smaller of the number of points specified in the *N* column of the **Results** table, or 15. If you wish to view data "below" the end of the column, use the Operating Tool to either increment or decrement the array row index (the upper of the two indices) or double click on the index and enter the row number of the cell you wish to see displayed at the top of the column. You can keep track of which point is being measured by noting the **Point...of...** display at the right side of the **System Status** block.

Once the *N* points have been measured, the subVI Chauvenet is called. This subVI uses Chauvenet's Criterion [22] to test the data against a normal distribution and to identify outliers. Those points not meeting Chauvenet's Criterion are discarded (up to a maximum determined by the number of points measured) and the average and standard deviation of the mean of the remaining data points calculated. This information is displayed in the appropriate cells in the **Results** Table. The arrays are cleared and the ac source is set to the next frequency. After a brief wait to let the system stabilize at the new frequency, the system goes on to measure the first point at the new frequency. The results of the measurements at the just-completed frequency are passed to the subVI PRINTER UTILITY, which puts the information in a presentable format, and sends it to the print queue. Because LabVIEW has the dominant priority for system resources in order to keep the measurement timing consistent, the hardcopy will be printed only after all *N* measurements have been completed. In addition, PRINTER UTILITY writes out the results to a data file, for future reference.

If the automatic shutdown option has been selected, after all the frequencies have been measured the GPIB bus is cleared and the outputs of the voltage sources turned off, all relays are returned to their default positions, and the print queue is freed up to print the results of all the frequencies you specified. If **Automatic Shutdown** has been disabled, the system is left in its operational state, with the supplies set to deliver voltage and relays in the dc position. Since LabVIEW is not actively operating the system, however, the print queue is free to print the test results. An explanation of the data files may be found in Appendix D. The green **START** button is left in its ON state to remind you that the system has indeed been operating.

At any point in the measurement sequence, if you wish to stop the system, you may either pause the system or click on the red **STOP** button[8]. Clicking on this button immediately removes the voltage or current from the converters, clears the GPIB bus and halts processing, leaving the system in its power-on mode. To pause the system, click on the LabVIEW **PAUSE** button on the menu at the top of the LabVIEW window. This halts the system operation at the DATE AND TIME utility, but leaves the sources in their operate modes. Pausing the system also changes the display to the wiring diagram of the ac-dc difference VI. To display the front panel, press the command key (⌘) in unison with E or select the Show Panel option in the LabVIEW WINDOWS menu. To continue with the measurements, click on the LabVIEW **PAUSE** button again.

The Two-Channel N-test VI

The automated system software lets you measure the response characteristic of a thermal converter in two ways. A separate, stand-alone VI (N-test) measures the *n* of one thermoelement

[8] Pressing the ESC key on the keyboard has the same effect as clicking on the **STOP** button.

at a variety of input levels, and then performs a linear regression on the data. The resulting coefficients of the regression (M and N) may then be used to calculate *n* for any output emf for the TVC. This VI comes in handy when you are calibrating a TVC set wherein a single TE is used with several shunts to create multiple voltage ranges.

If you have only one TE operating at a single input level, you may elect to run a two-channel n-test by setting the **AUTOMATIC N-TEST** slider in the Test Options section to ON. The two-channel n-test VI front panel (Figure 3) will be presented. The test information you entered into the main Ac-dc Difference VI front panel will be preserved and displayed in the appropriate fields in the N-TEST subVI.

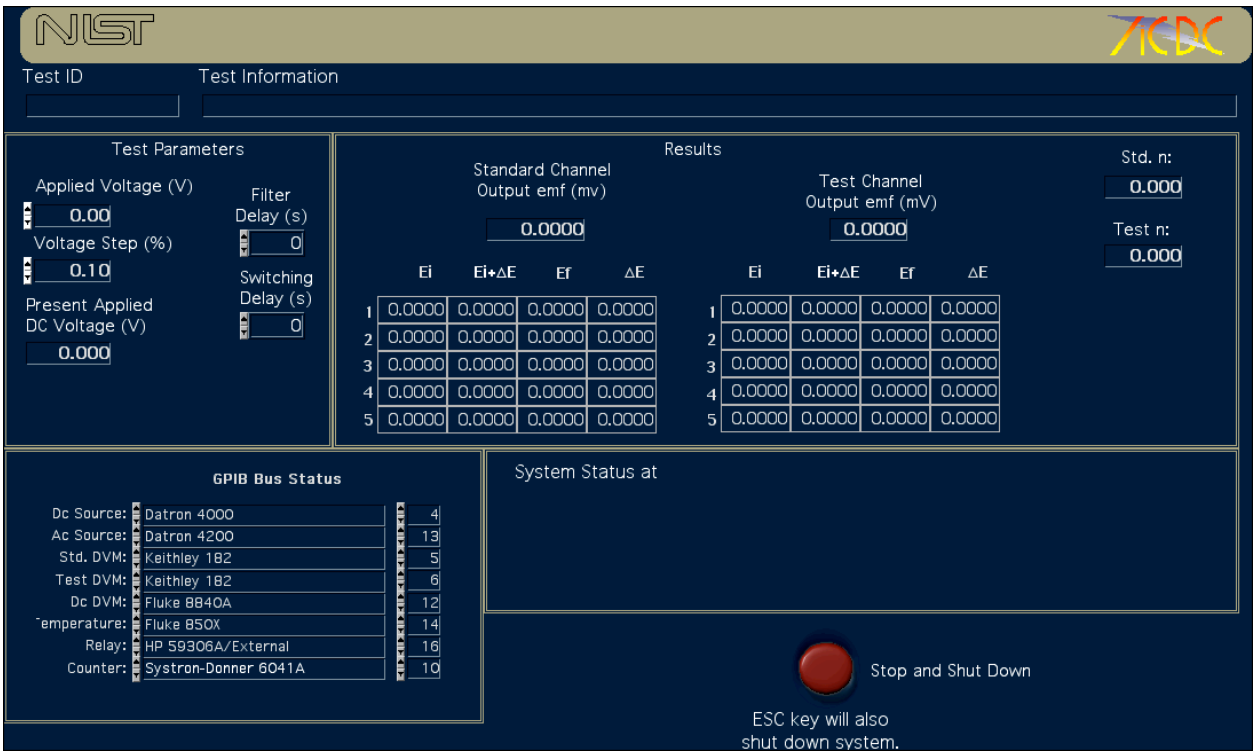


Figure 3. The two-channel n-test front panel.

The N-TEST subVI is called and executed automatically with no intervention on your part. At the end of the n-test measurement, the *n*s of both the standard and test converters will be returned to the calling VI, and the ac-dc calibration sequence will resume with the application of the first dc voltage. If, however, you need to halt the n-test routine before it terminates, click on the red **STOP** button[9] on the n-test front panel. The GPIB bus will be reset and voltage removed from the thermal converters.

☛ **Note:** The *n*s for the standard and test converters are displayed in the **Std. n:** and **Test n:** indicators in the **System Status** block of the front panel, but the n-test front panel is immediately closed and the ac-dc difference front panel reactivated, so you will probably never see these numbers. Since the results of the n-test are returned directly to the ac-dc difference routine, no hardcopy is produced. However; if there is a problem in the continuation of the ac-dc difference

[9] Again, pressing the ESC key has the same effect as clicking on the **STOP** button.

VI, you may view these values by re-launching *N-test (2-channel)*. The last values of *n* for both converters will be displayed in the **System Status** block.

For a more complete description of the mechanics of the n-test VIs, see the section on the n-test VI later in the documentation.

Using the Note Utility

Occasionally, you might need to preserve more information about a measurement than the **Test Information** field allows. To create a note, click on the **ADD NOTE** slider in the Test Option section. A new window, shown in Figure 4, is presented.

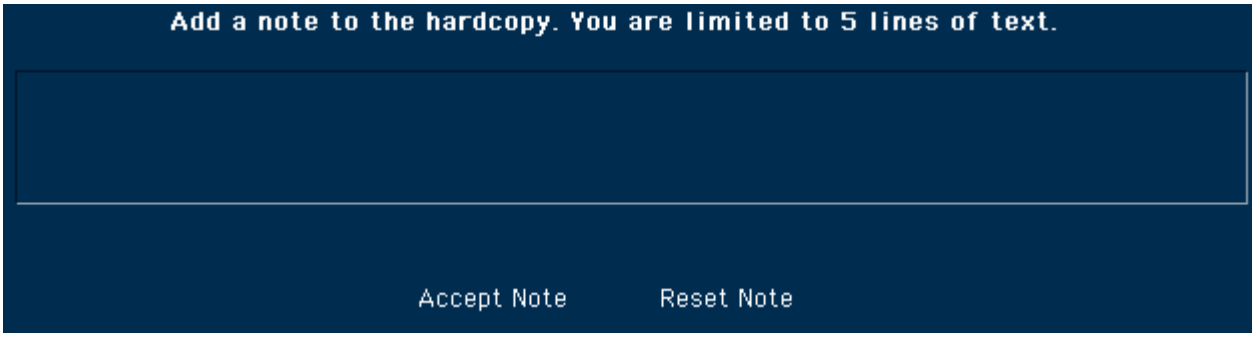


Figure 4. The window displayed after you select the **Add Note** option.

To enter the note, click in the large text field. Enter the annotation. The note can be as long as there is room in the field. When you are finished, click on **ACCEPT NOTE** to accept the note. Click on **RESET NOTE** to clear the field and start over. Make any editorial changes in the note by positioning the cursor at the desired position in the annotation and clicking the mouse button.

After you click on **ACCEPT NOTE**, the window disappears, leaving the Ac-dc Difference front panel visible. The annotation will appear at the bottom of the printed data sheet.

Measuring a Check Standard

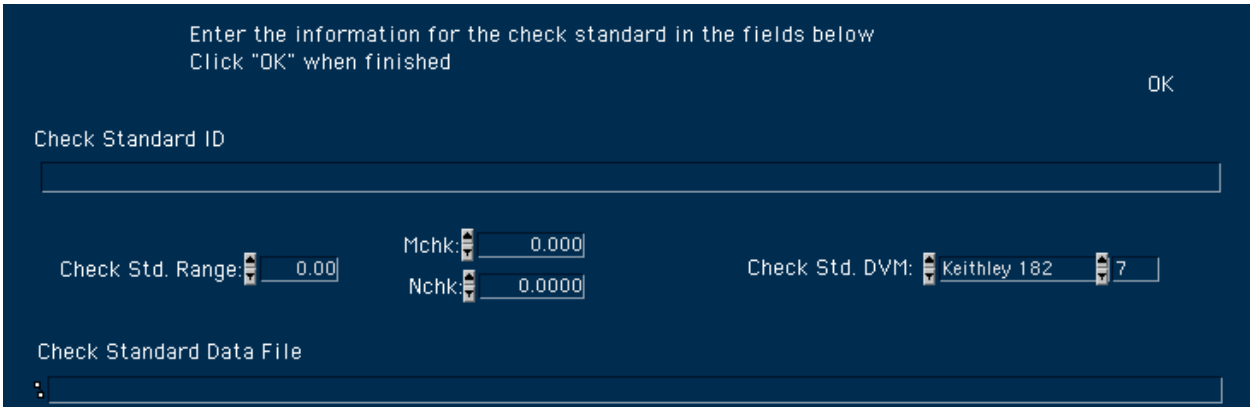
An excellent way to ensure that the calibration process as a whole (systems, software, and standards) is in control is to measure a check standard simultaneously with the UUT. By keeping a history of the check standard results, you can quickly determine if some part of the calibration process is changing with time. The Ac-dc Difference calibration software allows you to measure a check standard as part of a routine calibration.

To tell the system that you wish to measure a check standard, click on the **CHECK STANDARD** slider in the Test Options section of the front panel. A pop-up window (Figure 5) appears. Enter the identification of the check standard by clicking in the **Check Standard ID** field and typing in the identification. Then use the TAB key to step through the other fields, entering the appropriate information for the check standard voltage range and its M and N. If necessary, use the Operating Tool to change the type of nanovoltmeter you wish to use to monitor the check standard, and its GPIB address.

When you are finished entering the check standard information, click on the **OK** button. A third window pops up to let you select the data file to which to save the check standard data. Select a file in an appropriate folder, or create a new folder and/or file if necessary.[10]

After you select the check standard data file, both of the newly-opened windows are closed and the entire Ac-dc Difference front panel becomes visible again.

While the UUT and check standard are being measured, you may use the **CHECK/UUT** slider located next to the **Previous δ** column vector to toggle the graph and previous data displays between the UUT and the check standard.



Security

Strictly speaking, the data collected by the automated systems on customer's instruments is proprietary information and owned by the customer. In the strictest sense, no one but the NIST personnel directly involved with the calibration should be able to view the data. To prevent display of data, select the Operating Tool and click in the lower right corner of the **System Status** area. The **Results** table, **Previous δ** vector, **Present Data** display and graph are all set to be not visible. Clicking on the lower right corner again renders these indicators visible.

[10] The data files created by the calibration program are in tab-delimited ASCII text format, suitable for editing in a spreadsheet application like Microsoft Excel.

Running the Current System VI

Loading the Current System Program

To load the software for the voltage calibration system, double-click the *Voltage System Startup.vi* icon on the desktop. After loading the subVIs required for program execution, the Voltage Calibration front panel will be displayed, along with a dialog window showing a list of the authorized users of the calibration system (Figure 1). Click in the box next to your name to begin the calibration session. After indicating your identity, click in the OK box. To stop the calibration routine and return to the LabVIEW system, click in the Cancel/Stop box.

After you select OK, the system operator ID box vanishes and the ac-dc difference front panel (Figure 2) is presented. Refer to Appendix A for a complete description of the LabVIEW front panel objects and their functions.

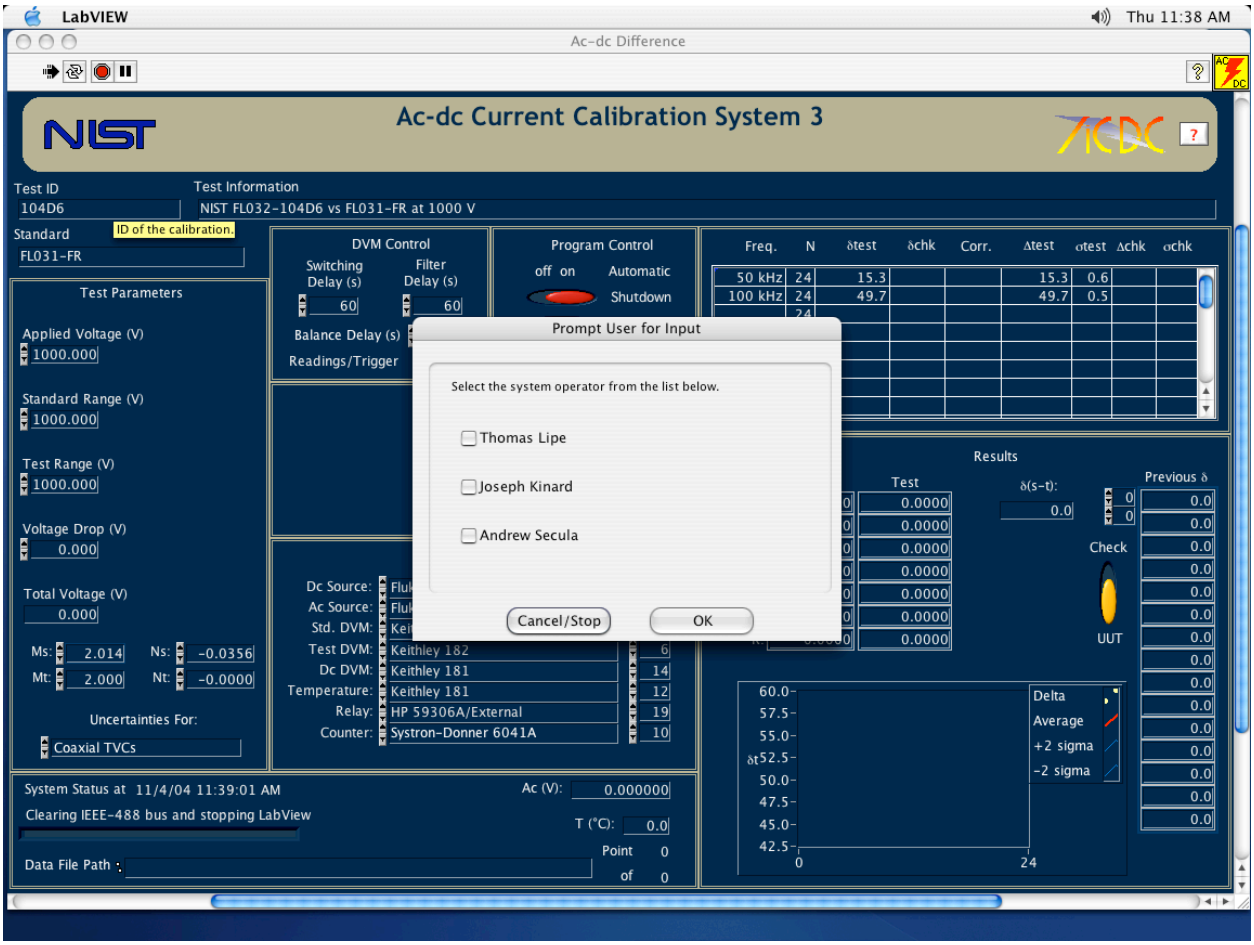


Figure 1. The front panel for the Voltage System VI, showing the system operator ID dialog window. Note the help banner (yellow) at the **Test ID** field.

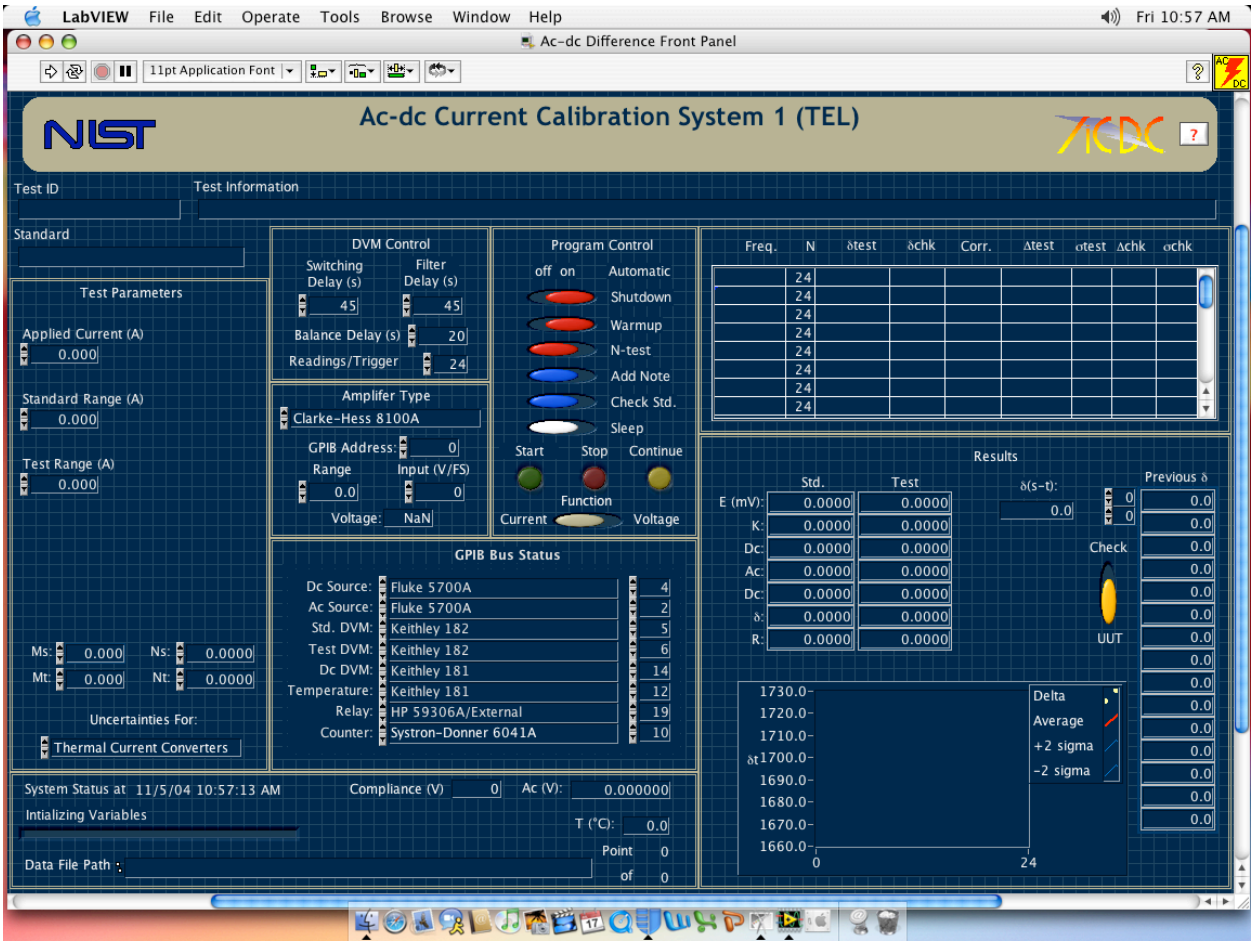


Figure 2. The ac-dc difference front panel. Note the operator's initials in the title banner.

The front panel of the current calibration VI is divided into regions that are used for controlling the VI, or for viewing the results of the calibration. These general regions are:

- Test Parameters: This section of the front panel is where you enter the conditions of the calibration; the applied current, the current ranges of the test and standard TCCs, and the response characteristics of the thermoelements used for the calibration.
- DVM Control: This section allows you to control the operation of the digital voltmeters (DVMs) used to monitor the outputs of the thermal converters.
- Amplifier Type: This section lets you define a particular type of transconductance amplifier (or no amplifier at all), and sets its transconductance.
- GPIB Bus Status: A cluster of enumerated lists, which defines the instruments available on the GPIB (IEEE-488) interface bus.
- System Status: This section presents information about how the calibration is going, including the compliance voltage of the amplifier, the temperature, and the data file path.
- Program Control: This section is where you choose options for the calibration program, like running an n-test, manually warming up the converters, and so forth.
- Results: This section presents the ongoing results of the calibration at a particular frequency.

In addition to these sections, two more regions are shown on the front panel. The table appearing just above the Results section is where you enter the frequencies of the calibration, and where the results for each frequency are presented after the frequency finishes. The fields at the top of the display allow you to enter the identification of the UUT and the standard. Each of these fields and front panel regions will be discussed further below.

Starting the Calibration Software

Before you can enter the test parameters into the calibration program, the Current System VI must be running. The Current Calibration VI loads in RUN mode, so that it is running when it opens. However, after a calibration is complete, the VI may be rerun without starting it from the *Current System Startup.vi* icon. To start the calibration VI, simply click on the **RUN** button in the LabVIEW menu bar.

☛ **Note:** Do not confuse the LabVIEW **RUN** button with the green **START** button on the Current System VI front panel. The **RUN** button starts execution of the VI. The **START** button breaks the VI out of an idle loop and lets it proceed with the measurement sequence. Similarly, the LabVIEW **STOP** button halts program execution but does not reset the voltage sources or GPIB bus. The red **STOP** button on the VI front panel does reset the voltage sources and the GPIB bus.

When the VI is run, the **Results** table, **Previous Data** arrays, and **Present Data** arrays are cleared, and the date and current time are displayed in the **System Status** region. The test information, test parameter, and DVM control fields, however, are not cleared, as it is sometimes handy to keep this information from run to run. For example, if you a calibrating a current shunt set, chances are that you will need to change only those parameters that change with current range, like the serial number of the shunt, and not re-enter all of the test parameters again.

Getting Help

You may get help at any time by clicking the box with the question mark at the right side of the title banner. Clicking this button launches Adobe Acrobat Reader, and displays the automated system documentation (this document). However, it is probably not a good idea to request help while the system is making measurements, as this is likely to disrupt the timing.

Entering Information Into the Front Panel Fields

Press the TAB key to move the cursor to the **Test ID** field and enter the appropriate information, perhaps the folder number of the calibration or a similar identifier. After you have finished entering this information, press TAB again to complete the data entry and move the cursor to the next field, the **Test Information** field. Enter information about the calibration into this field.

Step through the fields displayed on the front panel, entering information for each field in turn and terminating the data entry using the TAB key. The panel order for the front panel controls and a description of the controls is shown in Table 1.

Table 1. Descriptions of the fields on the Current System VI front panel. The number indicates the order in which the fields are entered using the TAB key.		
Panel Order	Field	Type of information.
1	Test ID	An identification for the calibration. Usually the calibration folder number or similar information.
2	Test Information	Information about the Unit Under Test. Usually the type of UUT, its serial number, and customer.
3	Standard	The identifier of the NIST standard. Something like W20#12 or W250#4.
4	Applied Current (A)	The applied current of the calibration, in amperes.
5	Standard Range (A)	The current range of the standard TCC, in amperes.
6	Test Range (A)	The current range of the UUT, in amperes.
7	Ms	The value of M for the NIST standard.[1]
9	Ns	The value of N for the NIST standard.
10	Mt	The value of M for the UUT.
11	Nt	The value of N for the UUT.
12	Switching Delay (s)	The time delay between the relay switching and the activation of the DVM filters, in seconds.
13	Filter Delay (s)	The time delay between the activation of the DVM filters and the beginning of data collection, in seconds
14	Balance Delay (s)	The time delays used for the relay switching and voltmeter filter activation when the system is balancing the voltage sources.[2]
15	DVM Readings/Trigger	The number of readings per trigger taken by the DVMs monitoring the output of the TVCs. These readings are averaged internally by the DVMs.
16	Amplifier GPIB Address	The GPIB address of the transconductance amplifier used in the calibration system.
17	Range	The range of the transconductance amplifier
18	Input (V/FS)	The voltage required for the full-scale current output from the transconductance amplifier.

☛ **Note:** To help you avoid over-ranging the converters, the software compares the value of the applied current you request to the current ranges of the standard and UUT, and, if the applied current exceeds either of these ranges, the **Applied Current** control turns red and the system beeps to get your attention. This alert condition is cleared when you enter current ranges for the converters that are equal to or greater than the applied current. But when the Current System VI is first loaded, all controls are set to 0; thus the applied current will exceed the current ranges of the converters (since you enter the applied current first), and the alert condition will be activated.

Because LabVIEW recognizes the results summary table above the Results section as a table rather than a control, you cannot use the TAB key to step into this field. Instead, click the cursor

[1] See Chapter 3 for a description of the N-test VI and an explanation of these parameters.
[2] Using a shorter delay while the system is balancing the voltage sources can save some time.

in the first cell in the *freq*. column and enter the input signal frequency. If you do not add a unit to the frequency, the software interprets the number to be in kilohertz (so that entering .02 sets the frequency to 20 Hz, 10 sets it to 10 kHz, and so on). Alternatively, you can add the units yourself. Advance to the next cell down in the *freq*. column by pressing the RETURN key. When you have entered all test frequencies, terminate the final entry by pressing the ENTER key on the numeric keypad, by clicking somewhere on the front panel, or by clicking on the LabVIEW **ENTER** (√) button. If you wish to change the number of data points for a frequency, double-click in the *N* column beside the frequency of interest. You may step down through the *N* column by pressing the RETURN key. The other columns in the table are for data collected during the measurement sequence, and you need not enter information into these columns.

Similarly, the **Amplifier Type** field is an enumerated list. Select the type of transconductance amplifier by using the LabVIEW Operating Tool (☝) to pull down the list of available current sources. Release the mouse button to confirm your selection.

Entering the Response Characteristics for the Converters

To calculate the ac-dc difference of the thermal converters, the system needs to know how the output of the converters changes in response to small changes in the input voltage or current. This response characteristic is generally called *n* and is discussed at length later in the documentation You can pass the value of *n* to the systems in several ways. The response characteristics of the NIST standards have been compiled and may be entered directly into the Ac-dc Difference VI as the values M and N (fields 9-12 in the Test Information Group of controls). Alternatively, you may elect to measure the response characteristics of the converters using the n-test procedure described in "Using the Test Option Sliders" section below, or run the stand-alone n-test procedure described in chapter "The N-test VI". Or if you don't know the characteristics for the NIST standard converter, you may leave the **Ms** and **Ns** fields blank and the subVI STANDARD CORR will look up the M and N for you, provided the standard is defined in the subVI.

Using the Test Option Sliders

In the Program Control section of the front panel is a set of six slider controls, which allow you to set various options for the measurement sequence. The sliders are initially set to their default values. To select an option, click on the desired slider with the LabVIEW Operating Tool. The slider will switch from the default setting to the desired setting. A list of these sliders, their default settings, and their functions follow:

- Automatic Shutdown (ON): Normally the system is set to shut itself down after a calibration. The GPIB bus is reset, the current removed from the converters, and the software left in its power-on state. Occasionally you may wish to prevent the system from shutting down following a calibration, perhaps to avoid cooling the converters. To prevent an automatic shutdown, set this slider to OFF. After the measurement cycle finishes, the software is reset, but the GPIB bus is not, so that current will still be supplied to the TCCs.

Warning: A potential safety hazard may exist if you deselect the automatic shutdown feature. You should be aware that current will still be supplied to the TCCs after the program has stopped, and take steps to ensure that this does not create a hazard for you or anyone else in the laboratory. It is strongly suggested that you use the automatic shutdown feature.

Automatic Warmup (ON): The software will calculate a warmup time for the TCCs based on the applied current. The warmup time for each current is shown in Table 2. If you wish to select a different warmup time, click on the slider. The slider will be replaced with a LabVIEW control. Click in the control, and enter the desired warmup time in minutes. Terminate the entry by pressing the ENTER key.

Table 2. Default warmup times for various applied currents.

Applied Current (A)	Automatic Warmup (m)
0-1	5
2-5	15
6-10	30
11-100	45

- Automatic N-Test (OFF): In order to calibrate a TCC, the system needs to know how the output of the TCC changes in response to small changes in the input current. This response is governed by the equation

$$E = kI^n \tag{2}$$

where E is the TCC output, I is the input current, k is a constant and n is the response characteristic of the TCC, and is the quantity we need to know. To find n, one can either use the stand-alone n-test routine or choose the **AUTOMATIC N-TEST** option slider to run the single-current n-test. This subVI determines n at the presently applied current. The details of this subVI are found later in this section.

☛ **Note:** A general guideline is to use the stand-alone n-test for thermal converter sets which have multiple TEs, and the single-current n-test for single TEs.

- Add Note (OFF): Occasionally you may wish to describe the measurement conditions in more detail than the **Test Information** field has room for. Clicking on this slider opens a window, where you may enter up to five lines of text, which are appended to the results sheet. A detailed description of this utility is found later in this section.
- Chk. Standard (OFF): Click on this slider to measure a check standard simultaneously with the UUT. After you click this slider to ON, LabVIEW opens a window into which you enter information about the check standard and the file to which you wish to save its results. The details are found later in this section.
- Function: This slider is initially set by the *Start Current System.vi* routine to be in the current position. If you run the Ac-dc Difference VI again with the slider in this position, the front panel defaults to the current calibration mode. However, if you use the LabVIEW Selection

Tool to set the slider to the voltage position, the front panel will run in the voltage calibration mode when you click the LabVIEW **RUN** button.

- Sleep (Macintosh only) (OFF): This slider affects the operation of the system after the final frequency has been completed. If the slider is set to ON, after the final frequency the system waits for three minutes for the results of the measurement to print, then calls an AppleScript script to put the computer to sleep. Note that this action does not stop LabVIEW; the application stops once the computer is awakened.

Changing the Nanovoltmeter Parameters

The nanovoltmeters used as detectors for the thermoelement outputs are set to internally average multiple readings when triggered. The number of readings to be averaged is displayed in the **DVM Readings/Trigger** control. This parameter is generally set to 24 for Keithley Model 182 nanovoltmeters and 12 for Hewlett Packard Model 34420A voltmeters[3]. To change this parameter, double click on the control and enter the desired number of readings, or use the Operating Tool to click on the up/down arrows beside the control field. The nanovoltmeters are triggered following two separate delays. **Switching Delay** is the time (in seconds) the system waits between switching from ac to dc (or vice versa) and the activation of the nanovoltmeter filters. **Filter Delay** is the time (also in seconds) the system waits for the filter output to settle before beginning data collection. To change either of these parameters, either double-click in the desired field and enter the delay, or click on the up or down arrows with the Operating Tool.

The GPIB Bus Status Cluster

Rather than explicitly define the types and addresses of each instrument on the GPIB bus in the program code, this information is disseminated throughout the program via a LabVIEW cluster of enumerated lists. Each instrument definition box is a list of the instruments presently supported by the Ac-dc Difference system. The address of the associated instrument appears in an integer control beside the list box. This arrangement gives you much more flexibility in choosing the instruments for the calibration system, as you can change instruments without changing the source code.

You may need to modify the GPIB bus definitions. To change the defined instrument, you first need to select the Operating Tool from the LabVIEW Tools palette. The Operating Tool is the one that looks like a hand with its index finger raised (☝) and you can select this tool by either pressing the TAB key until it appears, or by pressing the COMMAND (⌘) key while simultaneously depressing the mouse button. Once you select this tool, you can see a list of the defined instruments in each enumerated box by positioning the Operating Tool over the list box and depressing the mouse button. A list of instruments defined for use with the present software version will be presented, and you may select a different instrument by positioning the hand over the desired instrument and releasing the mouse button. Change the GPIB address, if you need to, by either clicking on the up and down arrows to change the displayed address, or by double-clicking on the address to highlight the text, then typing in the correct address and pressing the ENTER key to terminate the data entry.

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[3] The difference in readings is due to the longer integration times for the Hewlett Packard meters.

☛ **Note:** Because the GPIB cluster is initialized in the first frame of the LabVIEW software, you MUST set the GPIB instruments and their addresses BEFORE clicking on the green **START** button.

Setting the Measurement Uncertainties

Immediately beneath the response characteristic fields for the test and standards thermal converters is an enumerated list that specifies the uncertainties to used for the measurement. For thermal current converter calibrations this is automatically set to the data file used for current calibrations. Should you need to change this option, use the LabVIEW Operating tool to select the uncertainty data file to use.

Starting the Measurement Sequence

Once you have entered all the appropriate test parameters, click on the green **START** button on the front panel. The button turns a brighter green and begins to flash to indicate that the system is running, and LabVIEW begins to initialize the GPIB bus. The instruments defined in the **GPIB Bus Status** cluster are cleared, and the voltage sources initialized to the proper values and turned on. It is a good idea to watch the voltage displayed on the ac and dc voltmeters to ensure that the sources are functioning correctly and supplying the proper voltages to the transconductance amplifier. Once you are sure that the proper current is being supplied, manually set the amplifier range to the appropriate value and then set the system output on/off switch to ON.[4] You may monitor the output emfs of the TCCs as they come up by observing the nanovoltmeter readings.

☛ **Note:** To ensure that the ac-dc differences are calculated properly, the software automatically takes the absolute value of the output emfs shown on the nanovoltmeters. The signs of the thermal converter outputs are irrelevant to the calculations and may be positive or negative.

If you have chosen the automatic warm-up option, the software will calculate a warm-up period based on the applied current. The time until the start of data collection is displayed in the **System Status** section, counting down from the chosen warm-up time. If the automatic warm-up option is not selected, the warm-up time will be that defined in the control displayed when you disabled the automatic warm-up feature.

You may override the automatic warm-up by clicking on the yellow button marked **CONTINUE**. Clicking this button breaks the system out of warm-up mode, and it proceeds to the measurement sequence. The button remains a brighter yellow to remind you that the thermal converters did not have a full warm-up, just in case the results are poor.

After the desired warmup time has elapsed, the system will read the initial emf of the thermal converters. Upon reading these emfs, the system calculates the sensitivity, K ($K = nE$), and displays the emf and K for each converter in the appropriate cells in the **Present Data** section.

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[4] On Automated Systems I and II, the output on/off switch is on the front of the relay panel. On Systems III and IV, it is on a dedicated switch box located between the ac-dc relay and the GR 874 Tee.

The Measurement Sequence

The measurement sequence begins with the first dc point. Dc has been applied from the beginning, of course, so all the system does for the first point is to call the READ DVM subVI to read the detectors. You will notice that a round yellow LED indicator is displayed on the front panel beside the first **Dc:** box. This indicator signifies the type of applied current (note the plus sign in the LED, indicating the positive polarity), and will cycle through the dc, ac, dc sequence as the applied current is changed. After waiting for the filters to settle, the nanovoltmeters are read, and the output emfs of the converters are formatted and displayed in the initial **Dc:** boxes.

The relays are then switched to the ac position, to apply alternating current to the converters. Simultaneously, the yellow LED indicator on the front panel moves to the ac position, and the system begins a waiting period for the converters to stabilize after the relay switch. The remaining time for this delay is displayed in the **System Status** block. After the initial wait, the nanovoltmeter filters are activated, and a second wait permits the filtered readings to settle. The emfs are then read and displayed in the **Ac:** box on the front panel, and the relays are switched to the dc position.

While the relays are in the ac position, the polarity of the dc source is reversed, so that the converters are measured with both polarities of dc applied. Note that the yellow LED now has a minus sign superimposed on it. After waiting for the converters to settle as before, the second dc readings are collected from the nanovoltmeters. The ac-dc difference and dc reversal error for each channel are displayed inside the **δ***:* and **R:** boxes, and the uncorrected ac-dc difference for the unit under test is calculated and displayed in the topmost box of the **Previous δ** column. The calculated (uncorrected) ac-dc difference of UUT is displayed as a yellow point on the graph displayed in the Results section.

If the ac-dc difference of the standard channel is less than 150×10^{-6}, then the ac and dc sources are balanced well enough so that the imbalance in the sources will have a negligible effect on the ac-dc difference. In this case, the system will discard the first data point collected to deal with the Famous First Point Effect[5], and start another triad of measurements with dc. Assuming that the supplies remain in balance, this next point is the first one kept as a measurement point.

If, however, the ac-dc difference of the standard channel is greater than 50×10^{-6}, the system will trim the ac source to approximately balance the dc source, and the measurement sequence will start over. The system will continue with this cycle until the supplies are in balance, and will then go on to begin the calibration. The adjusted ac voltage will be displayed in the **Ac (V):** indicator in the **System Status** block, and reflects how far from nominal the ac source is set to balance the output of the dc source. A large and variable adjustment or an inability to balance the supplies may indicate a failure in one of the voltage sources, or instability in the standard. Note that, as the system attempts to balance the supplies, the system uses time shown in the **Balance Delay (s)** field as both the delay for the switching and voltmeter filters. You can save some time by setting this value to be smaller than the values shown in the **Switching Delay** and **Filter Delay** fields.

As the calibration progresses, the uncorrected ac-dc differences are displayed in the **Previous δ** column vector. Although in principle an infinite number (or at least 32 767) of points

[5] The Famous First Point Effect is an often-observed but unexplained phenomenon wherein the first data point collected by the system far exceeds Chauvenet's Criterion for acceptance of the data. It is dealt with here by simply always ignoring the first data point.

may be taken, the monitor limits the visible length of this column vector to 15 points, and the displayed length of the vector is set to the smaller of the number of points specified in the *N* column of the **Results** table, or 15. If you wish to view data "below" the end of the column, use the Operating Tool to either increment or decrement the array row index (the upper of the two indices) or double click on the index and enter the row number of the cell you wish to see displayed at the top of the column. You can keep track of which point is being measured by noting the **Point...of...** display at the right side of the **System Status** block.

Once the *N* points have been measured, the subVI Chauvenet is called. This subVI uses Chauvenet's Criterion [22] to test the data against a normal distribution and to identify outliers. Those points not meeting Chauvenet's Criterion are discarded (up to a maximum determined by the number of points measured) and the average and standard deviation of the mean of the remaining data points calculated. This information is displayed in the appropriate cells in the **Results** Table. The arrays are cleared and the ac source is set to the next frequency. After a brief wait to let the system stabilize at the new frequency, the system goes on to measure the first point at the new frequency. The results of the measurements at the just-completed frequency are passed to the subVI PRINTER UTILITY, which puts the information in a presentable format, and sends it to the print queue. Because LabVIEW has the dominant priority for system resources in order to keep the measurement timing consistent, the hardcopy will be printed only after all *N* measurements have been completed. In addition, PRINTER UTILITY writes out the results to a data file, for future reference.

If the automatic shutdown option has been selected, after all the frequencies have been measured the GPIB bus is cleared and the outputs of the voltage sources turned off, all relays are returned to their default positions, and the print queue is freed up to print the results of all the frequencies you specified. If **Automatic Shutdown** has been disabled, the system is left in its operational state, with the supplies set to deliver voltage and relays in the dc position. Since LabVIEW is not actively operating the system, however, the print queue is free to print the test results. An explanation of the data files may be found in Appendix D. The green **START** button is left in its ON state to remind you that the system has indeed been operating.

At any point in the measurement sequence, if you wish to stop the system, you may either pause the system or click on the red **STOP** button[6]. Clicking on this button immediately removes the voltage or current from the converters, clears the GPIB bus and halts processing, leaving the system in its power-on mode. To pause the system, click on the LabVIEW **PAUSE** button on the menu at the top of the LabVIEW window. This halts the system operation at the DATE AND TIME utility, but leaves the sources in their operate modes. Pausing the system also changes the display to the wiring diagram of the ac-dc difference VI. To display the front panel, press the command key (⌘) in unison with E or select the Show Panel option in the LabVIEW WINDOWS menu. To continue with the measurements, click on the LabVIEW **PAUSE** button again.

The Two-Channel N-test VI

The automated system software lets you measure the response characteristic of a thermal converter in two ways. A separate, stand-alone VI (N-test) measures the *n* of one thermoelement at a variety of input currents, and then performs a linear regression on the data. The resulting coefficients of the regression (M and N) may then be used to calculate *n* for any output emf for

[6] Pressing the ESC key on the keyboard has the same effect as clicking on the **STOP** button.

the TCC. This VI comes in handy when you are calibrating a TCC set wherein a single TE is used with several shunts to create multiple current ranges.

If you have only one TE operating at a single input level, you may elect to run a two-channel n-test by setting the **AUTOMATIC N-TEST** slider in the Test Options section to ON. The two-channel n-test VI front panel (Figure 3) will be presented. The test information you entered into the main Ac-dc Difference VI front panel will be preserved and displayed in the appropriate fields in the N-TEST subVI.

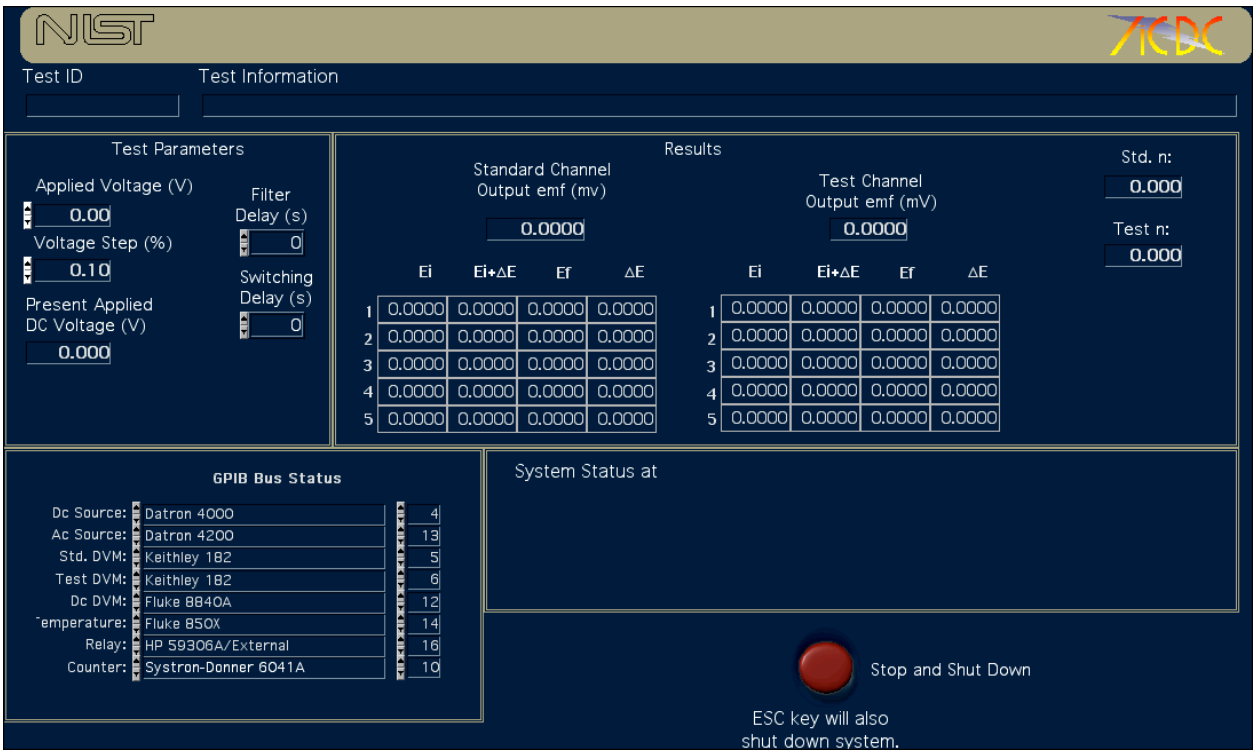


Figure 3. The two-channel n-test front panel.

The N-TEST subVI is called and executed automatically with no intervention on your part. At the end of the n-test measurement, the *n*s of both the standard and test TVCs will be returned to the calling VI, and the ac-dc calibration sequence will resume with the application of the first dc current. If, however, you need to halt the n-test routine before it terminates, click on the red **STOP** button[7] on the n-test front panel. The GPIB bus will be reset and current removed from the thermal converters.

☛ **Note:** The *n*s for the standard and test converters are displayed in the **Std. n:** and **Test n:** indicators in the **System Status** block of the front panel, but the n-test front panel is immediately closed and the ac-dc difference front panel reactivated, so you will probably never see these numbers. Since the results of the n-test are returned directly to the ac-dc difference routine, no hardcopy is produced. However; if there is a problem in the continuation of the ac-dc difference VI, you may view these values by re-launching *N-test (2-channel)*. The last values of *n* for both converters will be displayed in the **System Status** block.

[7] Again, pressing the ESC key has the same effect as clicking on the **STOP** button.

For a more complete description of the mechanics of the n-test VIs, see the section on the n-test VI later in the documentation.

Using the Note Utility

Occasionally, you might need to preserve more information about a measurement than the **Test Information** field allows. To create a note, click on the **ADD NOTE** slider in the Test Option section. A new window, shown in Figure 4, is presented.

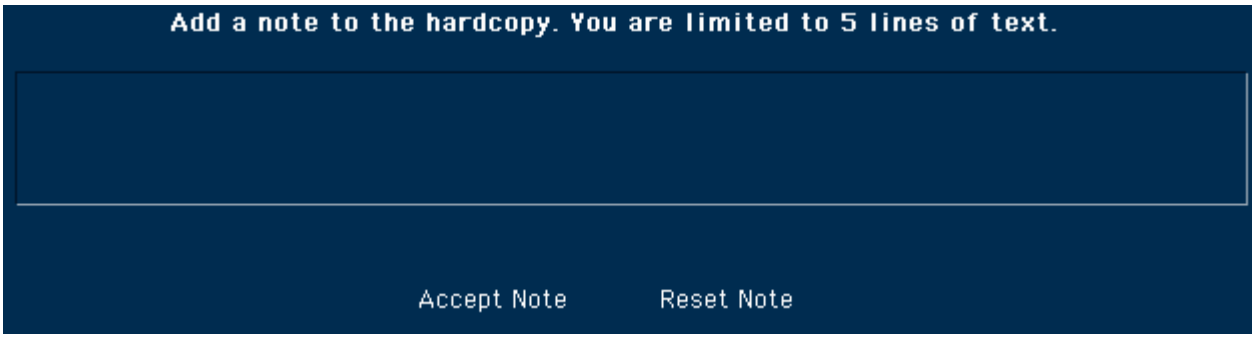


Figure 4. The window displayed after you select the **Add Note** option.

To enter the note, click in the large text field. Enter the annotation. The note can be as long as there is room in the field. When you are finished, click on **ACCEPT NOTE** to accept the note. Click on **RESET NOTE** to clear the field and start over. Make any editorial changes in the note by positioning the cursor at the desired position in the annotation and clicking the mouse button.

After you click on **ACCEPT NOTE**, the window disappears, leaving the Ac-dc Difference front panel visible. The annotation will appear at the bottom of the printed data sheet.

Measuring a Check Standard

Since current converters are measured in series rather than in parallel as are voltage converters, measuring a check standard simultaneously with the UUT is difficult and is not routinely done. For this reason, no provision for measuring a check standard is included in the software for current converter calibrations.

Security

Strictly speaking, the data collected by the automated systems on customer's instruments is proprietary information and owned by the customer. In the strictest sense, no one but the NIST personnel directly involved with the calibration should be able to view the data. To prevent display of data, select the Operating Tool and click in the lower right corner of the **System Status** area. The **Results** table, **Previous δ** vector, **Present Data** display and graph are all set to be not visible. Clicking on the lower right corner again renders these indicators visible.

The N-test VI

Introduction

Changes in the output emf of a thermal converter are related to changes in the input signal by the relation

$$E = kI^n \qquad (1)$$

where E is the output emf, k is a constant, I is the applied current and n is the response characteristic. Since thermal converters are root-mean-square responding instruments, the output of a perfect thermal converter will have a square-law response to changes at its input, and n will be equal to 2. Multijunction thermal converters do exhibit this square-law response, but single junction thermal converters rarely have perfect square-law responses. For these devices, n may vary between about 1.6 and 2.0, depending on the amplitude of the input signal. Since ac-dc difference measurements depend on observing the change in output as the signal is switched between ac and dc, the response characteristic, n, must be known before an instrument can be calibrated.

This quantity is most easily measured by observing the change in the output emf as small changes are made in the input voltage or current. n can then be calculated using the equation

$$n = \frac{I\Delta E}{E\Delta I} \qquad (2)$$

where: n is the response characteristic,
I is the input current,
E is the output emf,
ΔE is the change in the output emf produced by a change, ΔI, in the input current.

In practice, n is determined by recording the output emf (E) at some input level (I), then increasing the input voltage or current (ΔI) by a small step and recording the change in the output emf (ΔE). The results of this test may then be used in (2) to determine the response.

The voltage and current VIs used for measuring ac-dc difference have a built-in n-test feature that will determine the response characteristic at the presently applied voltage or current. Using this built-in n-test is advantageous when the responses of both the test and standard are required, when a small number of measurements are needed, or when separate TEs are used with each current or voltage range to be measured. See the instructions for operating the Ac-dc Difference Calibration VI for more details on this n-test mode. For those cases when one TE is used with multiple resistors or shunts, or when a TE is to be used at various input levels, a more efficient

practice is to measure *n* at several input levels and use a linear regression analysis to fit a line to the resulting data. Then, using the slope and intercept of this line, you can determine *n* at any output level.

☛ **Note:** Since you will usually be measuring the response characteristics of voltage converters (either TVCs or thermoelements used with shunts), the N-test VI defaults to voltage mode. To measure the response for a high-current thermoelement, use the N-test VI with a transconductance amplifier, setting the input voltage to the proper value to generate the required current.

Running the n-test VI

The VI that measures the *n*s at various levels is called *N-test.* To launch the n-test program, double-click on the *N-test* alias. This action starts LabVIEW and loads the main n-test VI and several assorted subVIs. After the n-test VI is loaded, you will see the n-test front panel, as shown in Figure 1. The sections below describe the front panel controls and indicators.

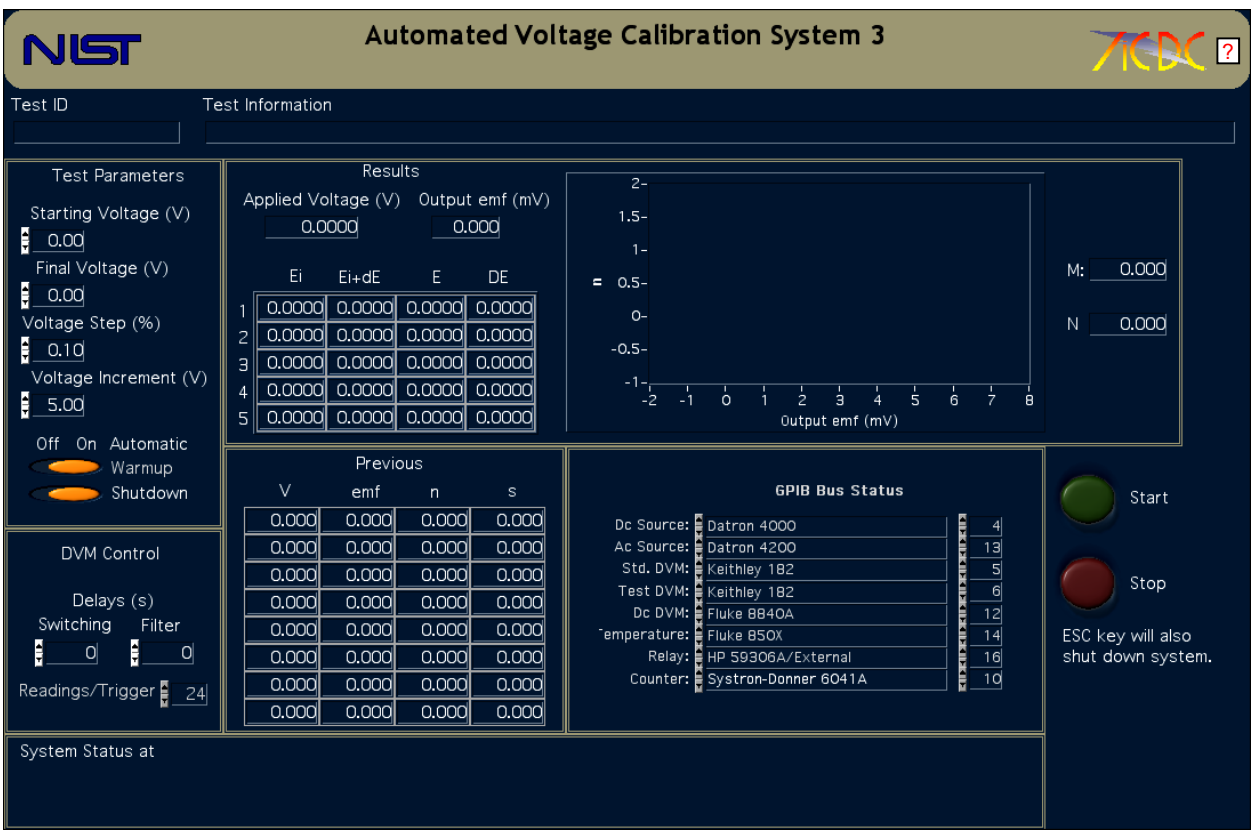


Figure 1. The n-test VI front panel.

The GPIB Bus Status Cluster

Rather than explicitly define the types and addresses of each instrument on the GPIB bus in the program code, this information is disseminated throughout the program via a LabVIEW cluster of enumerated lists. Each instrument definition box is a list of the instruments presently supported by the Ac-dc Difference system. The address of the associated instrument appears in an integer control beside the list box. This arrangement gives you much more flexibility in choosing the instruments for the calibration system, as you can change instruments without changing the source code.

You may need to alter the structure of the GPIB bus before starting the n-test program, perhaps to change the dc source or the address of an instrument.

To change a previously-defined instrument, you first need to select the Operating Tool from the LabVIEW Tools palette. The Operating Tool is the one that looks like a hand with a raised index finger (☝) and you can select this tool by either pressing the TAB key until it appears, or by pressing the COMMAND (⌘) key while simultaneously depressing the mouse button. Once you select this tool, you can see a list of the defined instruments in each list by positioning the Operating Tool over the list box and depressing the mouse button. A list of instruments defined for use with the present software version will be presented, and you may select a different instrument by positioning the hand over the desired instrument and releasing the mouse button. Change the GPIB address, if you need to, by either clicking on the up and down arrows to change the displayed address, or double-click on the address to highlight the contents. Change the address by typing in the correct address and pressing the ENTER key to terminate the data entry.

☛ **Note:** Because the GPIB cluster is initialized in the first frame of the LabVIEW software, you MUST set the GPIB instruments and their addresses BEFORE clicking on the green **START** button.

Starting the N-test Software

Before you can enter the test parameters into the calibration program, the n-test VI must be running. Click on the **RUN** button in the LabVIEW menu bar to run the VI.

☛ **Note:** Do not confuse the LabVIEW **RUN** button with the green **START** button on the *n*-test VI front panel. The **RUN** button starts execution of the VI. The **START** button breaks the VI out of an idle loop and lets it proceed with the measurement sequence. Similarly, the LabVIEW **STOP** button halts program execution but does not reset the voltage sources or GPIB bus. The red **STOP** button on the VI front panel does reset the voltage sources and the GPIB bus.

After you click on the **RUN** button, the **Previous Data** arrays, and **Present Data** arrays are cleared, as are the test information fields, and the current date and time displayed in the **System Status** section.

Getting Help

You may get help at any time by clicking the box with the question mark at the right side of the title banner. Clicking this button launches Adobe Acrobat Reader, and displays the automated system documentation (this document). However, it is probably not a good idea to request help while the system is running, as this is likely to disrupt the timing.

Entering Information Into the Front Panel Fields

Press the TAB key to move the cursor to the **Test ID** field, and enter the appropriate information, which might be the folder number of the calibration or a similar identifier. After you have finished entering this information, press TAB again to complete the data entry and step the cursor to the next field, the **Test Information** field. Enter information about the calibration into this field.

Step through the fields in the Test Information section of the front panel, entering information for each field in turn and terminating the data entry using the TAB key. The panel order for the front panel controls and a description of the controls is shown in Table 1.

Table 1. Description of the fields in the Test Information section of the n-test VI front panel, along with the panel order for the TAB key.

Panel Order	Field	Type of information.
1	Test ID	An identification for the calibration. Usually the calibration folder number or similar information.
2	Test Information	Information about the Unit Under Test. Usually the type of UUT, its serial number, and customer.
3	Starting Voltage (V)	The initial voltage for the n-test.
4	Final Voltage (V)	The highest voltage to be applied during the n-test.
5	Voltage Increment (%)	The small incremental voltage to be applied to the TVC during the *n*-test. Default value is 0.01% of the presently applied voltage.

Table 1. Description of the fields in the Test Information section of the n-test VI front panel, along with the panel order for the TAB key.		
6	Voltage Step (V)	The step between applied voltages. The default value is 5 V.
7	Switching Delay (s)	The delay between the setting of the dc source and the activation of the DVM filters.
8	Filter Delay (s)	The delay between the activation of the DVM filters and the commencement of data collection.

Controlling the VI

Two buttons control the execution of the calibration program. Clicking the green **START** button breaks the n-test VI out of an idle loop and starts the measurement sequence. The red **STOP** button stops program execution and resets the GPIB bus.

☛ **Note:** The escape key (ESC) on the keyboard will also stop program execution and reset the GPIB bus. It acts as though you clicked on the red **STOP** button. Either method may be used to halt the program and reset the voltage sources at any time during program execution.

How the VI runs

After entering the information in the fields described above, click on the green **START** button to begin the n-test. The dc supply will be set to the initial baseline voltage, and this voltage is applied to the thermal converter. The system then waits for five minutes for the output of the converter to settle[1] before triggering the voltmeter to take the first set of readings, which is displayed in the *Ei* column of the **Present Data** array. After the readings are complete, the voltage increment is added to the baseline voltage, this new voltage is applied to the thermal converter, and the system waits for the converter output to stabilize. A second set of readings is taken and displayed in the $E+\Delta E$ column, after which the dc supply is reset to the baseline voltage. After waiting for the converter to settle, a third set of readings is taken and displayed in the *Ef* column. The time the system waits for the converter to settle is the sum of the switching and filter delays as defined on the n-test VI front panel.

The difference in thermoelement output between the application of the baseline voltage and the voltage step, along with the values of the baseline voltage and voltage step, are inserted into (2) to calculate *n* for the baseline voltage. Four more determinations of *n* are made, and the

[1] Although the ac-dc difference of some thermal converters may still be drifting after only five minutes warm-up, the response characteristic of the thermoelement will not change significantly during the *n*-test procedure.

average *n* and standard deviation of the five determinations are calculated and displayed along with the baseline voltage and output emf in the **Previous Data** section of the display.

The baseline voltage is increased by the value of the voltage step, and the dc supply set to the new voltage. After a brief wait to let the converter output stabilize, the procedure described above is repeated at the new baseline voltage.

The system proceeds in this manner until the *n* at the highest desired voltage has been calculated, and the information for the final voltage displayed on the front panel. A linear fit to the *n* versus output emf data is performed, and the slope and intercept of the resulting line displayed along with a plot of the *n* versus emf data displayed. The calculated slope (N) and intercept (M)[2] of the regression are displayed to the right of the n-test plot. You may then use these values in the Ac-dc Difference calibration VI to enter the response characteristics of the thermal converter.

After the final *n* has been calculated and the linear fit completed, the test information will be printed for archival purposes. The resulting archival hardcopy is shown in Figure 2. If the **AUTOMATIC SHUTDOWN** slider is in the ON position, the GPIB bus will be reset and the program halted. If automatic shutdown is not selected, however, the program will halt, leaving the final baseline voltage on the dc source, and applied to the thermal converter.

Warning: It is strongly recommended that you select the automatic shutdown option. If you do not choose the automatic shutdown option, potentially lethal voltages may remain on the output leads and at the input to the thermal converters after the program halts.

The N-test Archival Output

An example of the hardcopy you get from the n-test VI is shown in Figure 2. Table 2 presents a description of the front panel to the n-test report VI ("N-test Report"). Following the completion of the n-test VI, the data gathered during the measurement sequence is passed to the subVI N-TEST REPORT, where the data is displayed in front-panel indicators. LabVIEW prints this front panel to provide an archival record of the n-test.

Table 2. Objects on the N-Test Report front panel and on the archival hardcopy.

Field	Type of information.
Test ID	An identification for the calibration. Usually the calibration folder number or similar information.
Date	The date of the n-test report.
Time of Report	The time of day the report was printed.

[2] The use of the letters M and N for the regression coefficients is historical. They should not be confused with the response characteristic (*n*) of the TE.

Table 2. Objects on the N-Test Report front panel and on the archival hardcopy.	
Test Information	The information you entered into the TEST INFORMATION field.
N-test Data	The data from the n-test. The columns in the real array indicator are: *V*: The baseline voltage for each point. emf: The output emf at the voltage *V*. *n*: The average calculated *n* at the voltage *V*. *s*: The standard deviation of the five determinations of *n* at voltage *V*.
M	The *n*-axis intercept of the equation fit to the *n*-vs.-emf data
N	The slope of the *n*-vs.-emf line.
n-vs-emf Graph	A plot of the *n* versus output emf for each baseline voltage.

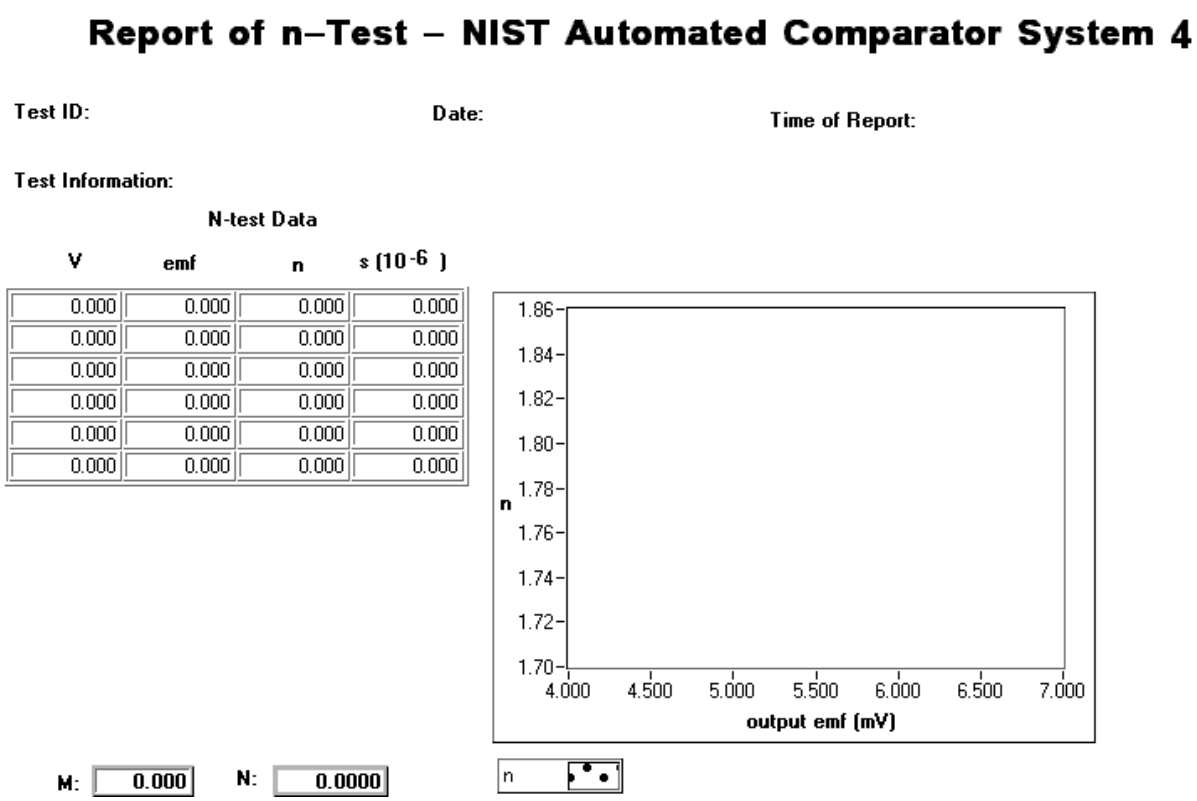


Figure 2. The N-test Report VI front panel. This is the archival record of the n-test.

Appendix A: The SubVIs

Introduction to Appendix A

This appendix presents an alphabetical list of the subVIs used by the voltage and current calibration software. The listing for each subVI includes a brief description of its function and use, the connection diagram, and the arrangement of the front panel. Following this description, information regarding the function of each front panel icon is presented. The information is arranged as follows:

Name of icon: The name of the front panel icon.

Label: The label of the icon. Occasionally, icons on VI front panels will have labels different than their names.

Type: The data type of the icon. Data types include real, integer, and string. Each data type may be included in vectors (one-dimensional arrays), multi-dimensional arrays, clusters of data types, enumerated lists, and data rings.

Direction: The direction of the information flow to the icon. The possible directions are: inbound (data passed to the subVI), outbound (data passed from the subVI to the calling VI), and internal (data used only within the subVI).

Visible on front panel: Yes or no, depending on if the icon is visible on the front panel.

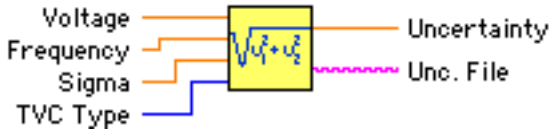
Description: A description of the icon's function.

Although not a subVI, the last entry in Appendix A, **Datron Local** is a useful utility, and is included for completeness. In addition, a description of the Help Facility utility is included.

Calculate Uncertainties

CALCULATE UNCERTAINTIES calculates the root-sum-square (RSS) uncertainties from the standard deviation of the data collected from the measurement sequence and the (already-measured) Type B components of the uncertainty for a particular type of converter and one voltage and frequency. The Type B uncertainties for each type of standard are listed in tables; the appropriate table is read into the subVI, and the appropriate Type B uncertainty component combined with the standard deviation to calculate an uncertainty (with coverage factor 2) of the measurement.

Connector Pane



Front Panel

Voltage:
- Label: Voltage
- Type: Real control
- Direction: Inbound
- Visible on from panel: Yes
  - The applied voltage at which to calculate the uncertainty.

Frequency:
- Label: Frequency
- Type: Real control
- Direction: Inbound
- Visible on front panel: yes
  - The applied frequency at which to calculate the uncertainty.

Sigma:
- Label: Sigma
- Type: Real control
- Direction: Inbound
- Visible on front panel: Yes
  - The calculated standard deviation of the measurement.

TVC Type:
- Label: TVC Type
- Type: Enumerated list
- Direction: Inbound
- Visible on front panel: Yes
  - The type of TVC being measured.

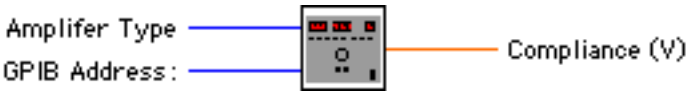
Uncertainty:
- Label: Uncertainty
- Type: Real indicator
- Direction: Outbound
- Visible on front panel: Yes
  - The expanded uncertainty of the measurement.

Unc. File:
- Label: Unc. File
- Type String control
- Direction: Inbound
- Visible on front panel: Yes
  - The data file containing the Type B uncertainty components for the type of TVC at the presently applied voltage and frequency.

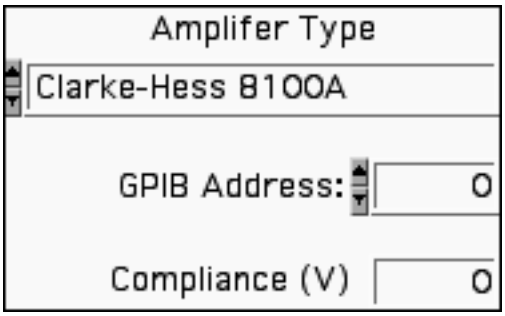
CH8100

CH8100 is used to control a Clarke-Hess Model 8100A transconductance amplifier, and returns the compliance voltage delivered by the amplifier.

Connector Pane



Front Panel



Amplifier Type:
- Label: Amplifier Type
- Type: Enumerated List
- Direction: Inbound
- Visible on front panel: Yes

  The type of amplifier to control. It's a moot point since it'll be a Clarke-Hess 8100A, but we need to specify the amplifier for the internal workings of the subVI.

GPIB Address:
- Label: GPIB Address
- Type: Integer control
- Direction: Inbound
- Visible on Front Panel: Yes

  The GPIB address of the amplifier.

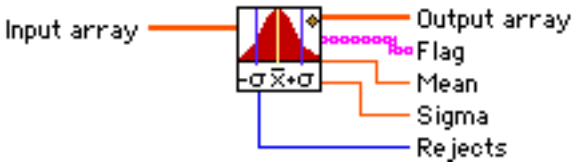
Compliance (V):
- Label: Compliance (V)
- Type: Real indicator
- Direction: Outbound
- Visible on Front Panel: Yes

  The compliance voltage read from the amplifier.

Chauvenet

CHAUVENET checks the data collected from a calibration against a normal distribution and discards points which are outside the 95 % confidence interval of the distribution. The maximum number of discarded points depends upon the number of points specified in the calibration (up to a maximum of 6).

Connector Pane



Front Panel

Input array:
- Label: Input array
- Type: Real vector
- Direction: Inbound
- Visible on front panel: Yes
  - The measurement data to be tested for outliers.

Output array:
- Label: Output array
- Type: Real array
- Direction: outbound
- Visible on front panel: Yes
  - The measurement data, minus the outliers.

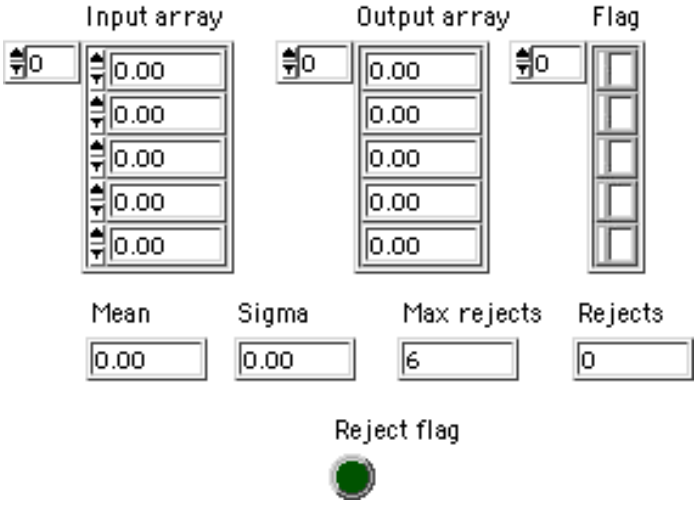
Flag:
- Label: Flag:
- Type: String array
- Direction: Outbound
- Visible on front panel: Yes
  - Array used to mark outliers.

Mean:
- Label: Mean
- Type: Real indicator
- Direction: Outbound
- Visible on front panel: Yes
  - The mean of the remaining data.

Sigma:
- Label: Sigma
- Type: Real indicator
- Direction: Outbound
- Visible on front panel: Yes
  - The standard deviation of the remaining data points.

Rejects:
- Label: Rejects
- Type: Integer indicator
- Direction: Outbound
- Visible on front panel: Yes
  - The number of data points rejected.

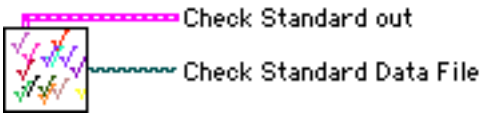
Reject flag:
- Label: Reject flag
- Type: Boolean indicator
- Direction: Internal
- Visible on front panel: Yes
  - Indicates a rejected point. Not used.



Check Std. Info

This subroutine lets the user specify a check standard to be measured simultaneously with the UUT. The subVI opens an appropriate data file to write the measurement information to, and returns the check standard parameters to the calling program. With the exception of the check standard data file path, all the parameters are bundled into the cluster *Check Standard Out*.

Connector Pane



Front Panel

Check Standard ID:
- Label: Check Standard ID
- Type: String control
- Direction: Internal
- Visible on front panel: Yes
  - The information for the check standard.

Check Standard Range:
- Label: Check Standard Range
- Type: Real control
- Direction: Internal
- Visible on front panel: Yes
  - The voltage range of the check standard.

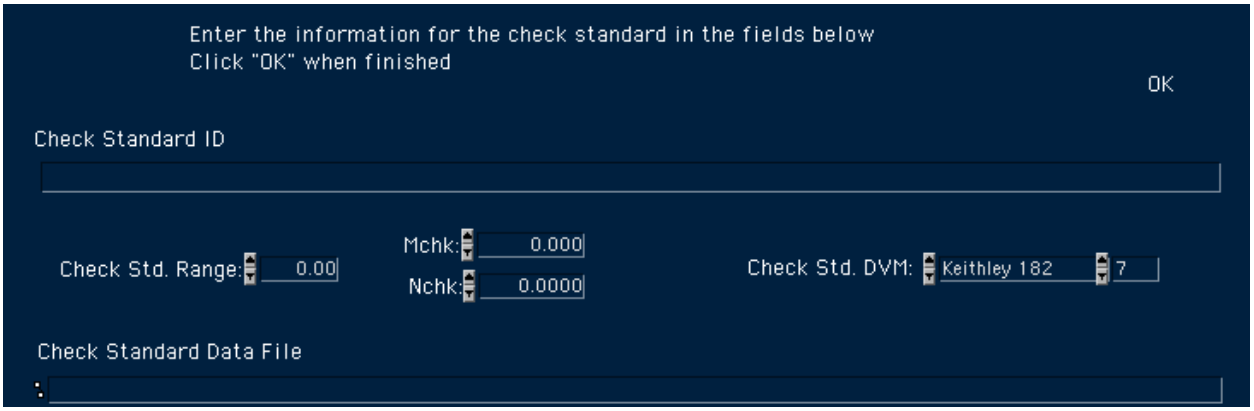
Mchk:
- Label: Mchk:
- Type: Real control
- Direction: Internal
- Visible on front panel: Yes
  - The M of the check standard.

Nchk:
- Label: Nchk:
- Type: Real control
- Direction: Internal
- Visible on front panel: Yes
  - The N of the check standard.

Check Std. DVM:
- Label: Check Std. DVM
- Type: Enumerated list
- Direction: Internal
- Visible on front panel: Yes
  - Enumerated list containing the voltmeter types available for use with a check standard.

Check DVM address:
- Label: None
- Type: Integer control
- Direction: Internal
- Visible on front panel: Yes
  - The address of the check standard DVM.

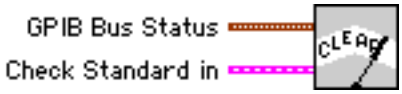
Check Standard Data File:
- Label: Check Standard Data File
- Type: File path
- Direction: Outbound
- Visible on front panel: Yes
  - The file path for the data file created by the subVI.


Enter the information for the check standard in the fields below
Click "OK" when finished
OK
Check Standard ID
Check Std. Range:
0.00
Mchk:
0.000
Nchk:
0.0000
Check Std. DVM:
Keithley 182
7
Check Standard Data File

Clear System

CLEAR SYSTEM resets the defined GPIB-based instruments to their power-on state, places the ac-dc relay in its normally closed position, and halts execution of the ac-dc difference program.

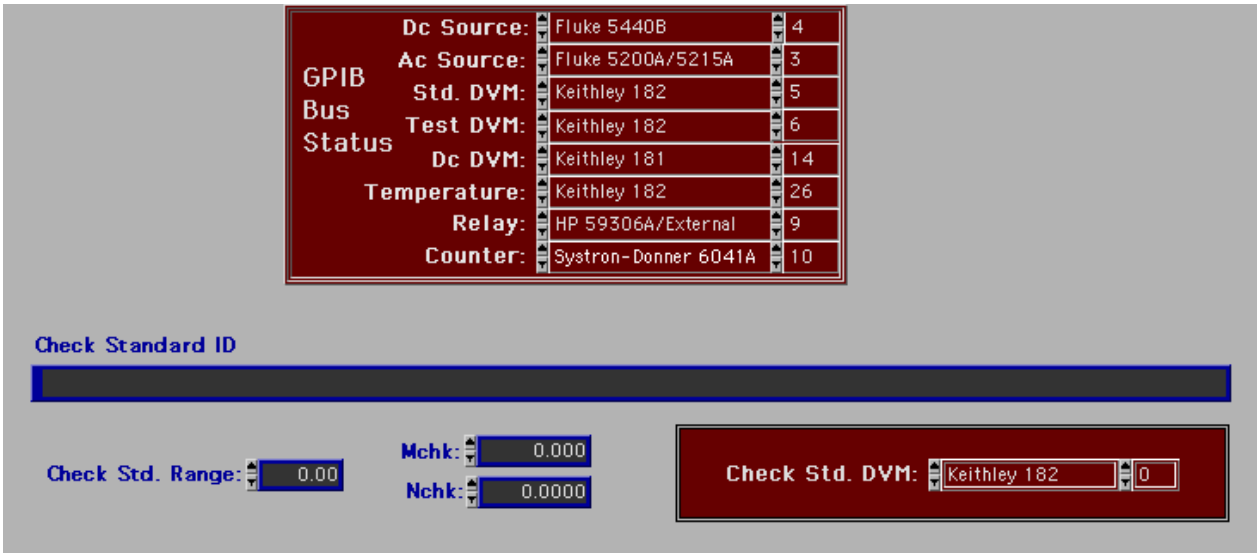
Connector Pane



Front Panel

GPIB Bus Status:
- Label: GPIB Bus Status
- Type: Cluster of enumerated lists.
- Direction: Inbound
- Visible on front panel: Yes
  - The Instrument lists define various instrument types appropriate for that function. The address lists are used to set the GPIB bus addresses of the instrument.

Check Standard in
- Label: Check Standard in
- Type: Cluster of strings
- Direction: Inbound
- Visible on front panel: Yes
  - In particular, passes information about the DVM monitoring the check standard to the subVI.



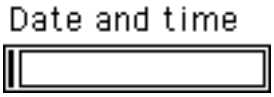
Date and Time

Returns the present system date and time.

Connector Pane

Front Panel

Date and Time:
- Label: Date and Time
- Type: String indicator
- Direction: Outbound
- Visible on front panel: No
  - Returns the present system date and time



Initialize System

INITIALIZE SYSTEM does the following:
> Sets the IEEE-488 instruments defined in GPIB BUS STATUS to their power-on state
> Sets the output voltage on the supplies and puts them in their operate mode
> Checks the output of the sources to see that it is nominally the proper output
> Closes the appropriate relays to supply voltage to the converters.

Connector Pane

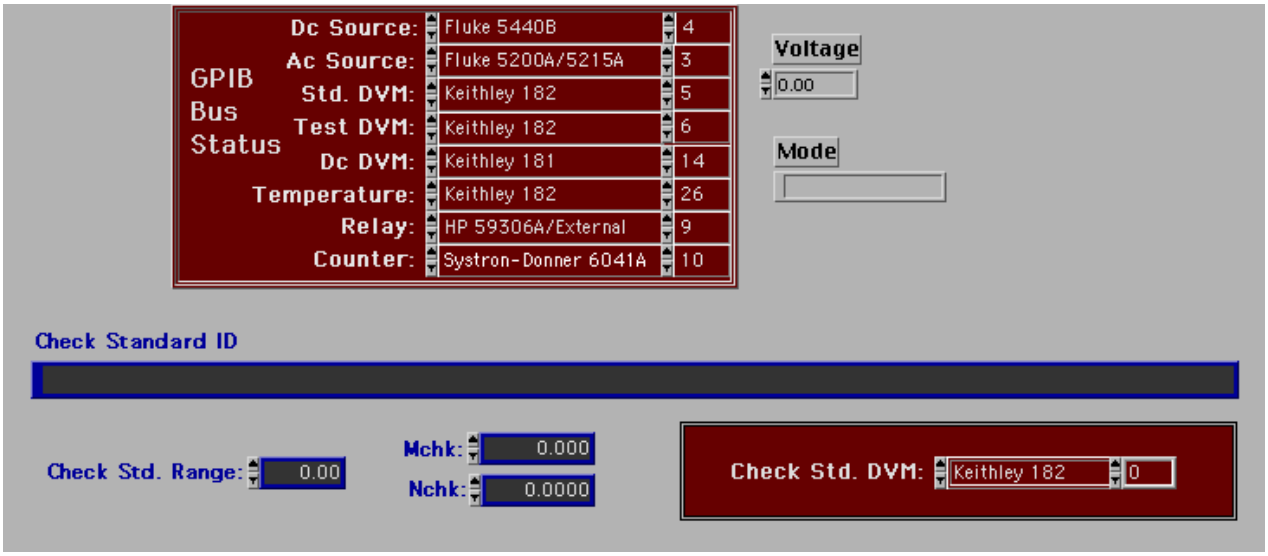
Front Panel

GPIB Bus Status:
Label: GPIB Bus Status
Type: Cluster of enumerated lists.
Direction: Inbound
Visible on front panel: Yes
Defines various instrument types and sets the GPIB bus addresses of the instruments

Voltage:
Label: Voltage
Type: Real control.
Direction: Inbound
Visible on front panel: Yes
Passes the requested output voltage from the calling VI.

Mode:
Label: Mode
Type: String Control
Direction: Inbound
Visible on front panel: Yes
Determines whether a calibration (requiring an ac source) or an n-test (dc source only) is being done.

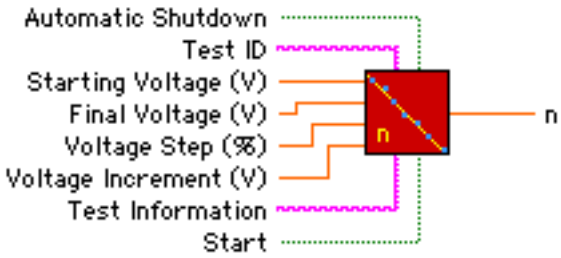
Check Standard in:
Label: Check Standard in
Type: Cluster of strings
Direction: Inbound
Visible on front panel: Yes
Passes information about the check standard DVM to the subVI.



N-Test

This VI measures the n of a thermal converter at applied voltages defined by the user. The VI then fits a straight line to the data, to calculate the M (intercept on the *n* – axis) and N (slope of *n* versus output emf) for the converter.

Connector Pane



Front Panel

GPIB Bus Status:
- Label: GPIB Bus Status
- Type: Cluster of enumerated lists.
- Direction: Inbound
- Visible on front panel: Yes
  - The Instrument lists define various instrument types appropriate for that function. The address lists are used to set the GPIB bus addresses of the instrument.

Starting Voltage (V):
- Label: Starting Voltage (V)
- Type: Real control
- Direction: Inbound
- Visible on front panel: Yes
  - The initial voltage for the n-test.

Final Voltage (V):
- Label: Final Voltage (V)
- Type: Real control
- Direction: Inbound
- Visible on front panel: Yes
  - The maximum voltage for the n-test.

Voltage Step (%)
- Label: Voltage Step (%)
- Type: Real control
- Direction: Inbound
- Visible on front panel: Yes
  - The voltage step added to the current baseline voltage.

Voltage Increment (V):
- Label: Voltage Increment (V)
- Type: Real control
- Direction: Inbound
- Visible on front panel: Yes
  - The increment added to the currently applied voltage to calculate the next voltage. For the n-test, the voltages are applied in the sequence $V_{cur}=V_{prev}+V_I$, where V_{cur} is the present applied voltage, V_{prev} is the previously applied voltage and V_I is the voltage increment.

Automatic Shutdown:
- Label: Automatic Shutdown
- Type: Boolean control
- Direction: Inbound
- Visible on front panel: Yes
  - Boolean switch that determines if the system should shut itself off after completing the n-test (ON position) or if the system should stop the VI but leave the voltages set on the sources and supplied to the converters.

Start:
- Label: Start
- Type: Boolean control
- Direction: Inbound
- Visible on front panel: Yes
  - Boolean switch that starts the n-test when depressed.

Scram
- Label: Stop and Clear System
- Type: Boolean control
- Direction: Internal
- Visible on front panel: Yes
  - Clicking on this button halts the n-test routine and calls CLEAR SYSTEM to reset the measurement system.

Present Data:
- Label: Present Data
- Type: Real Array
- Direction: To display
- Visible on front panel: Yes
  - Displays the data collected at the presently applied voltage.

Applied Voltage (V):
- Label: Applied Voltage (V):
- Type: Real indicator
- Direction: To display
- Visible on front panel: Yes
  - Displays the presently applied voltage.

Output emf (mV):
- Label: Output emf (mV)
- Type: Real indicator
- Direction: To display
- Visible on front panel: Yes
  - Displays the output emf of the thermal converter at the present voltage.

Previous Data:
- Label: Previous Data:
- Type: Real array
- Direction: To display
- Visible on front panel: Yes
  - Displays data from the previous applied voltages. The data includes the applied voltage (V), the output emf (emf), the n calculated at that emf (n), and the standard deviation of the n determination (σ).

System Status:
- Label: System Status
- Type: String indicator
- Direction: To display
- Visible on front panel: Yes
  - Displays information messages during the n-test measurements.

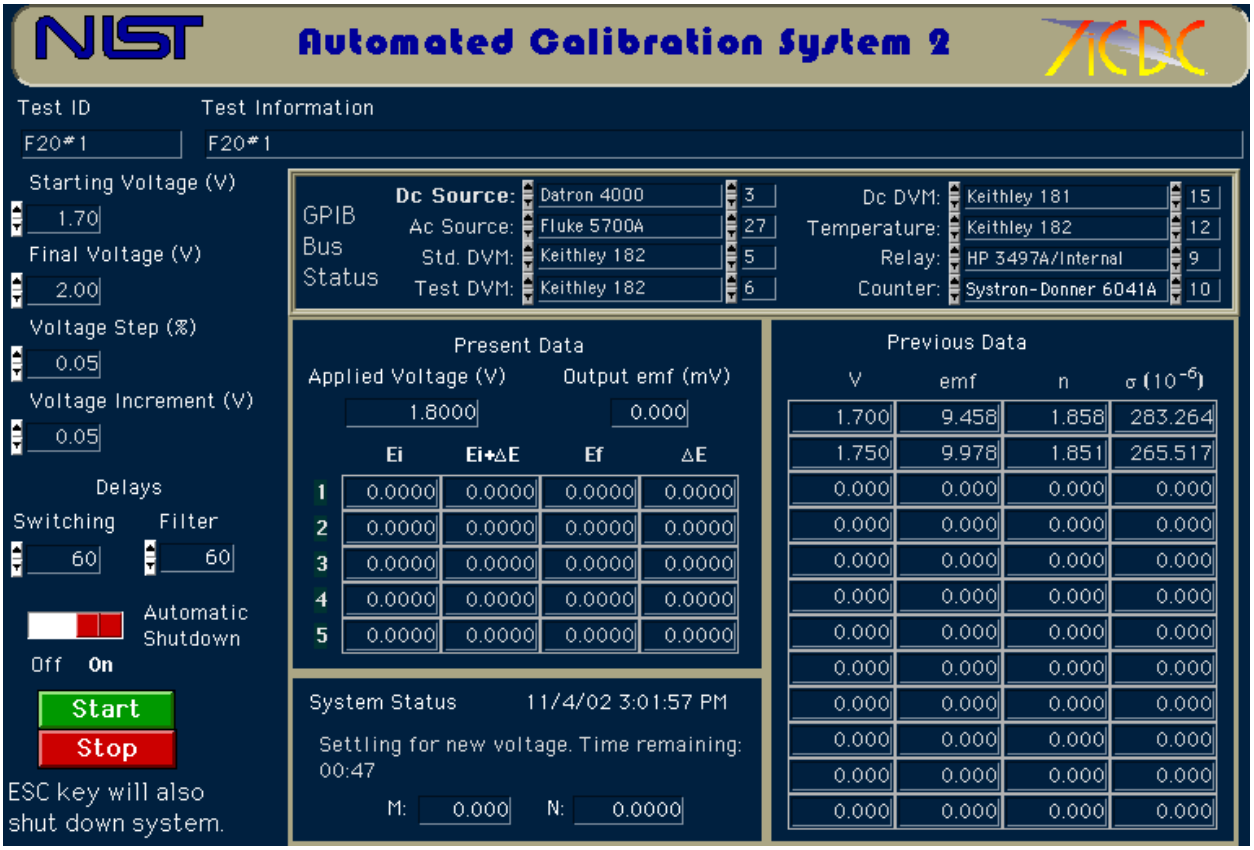
M:
- Label: M
- Type: Real indicator
- Direction: Outbound to display
- Visible on front panel: Yes
  - Displays the calculated x-axis intercept (on the vertical or n axis) of the linear fit to the n-test data.

N:
- Label: N
- Type: real indicator
- Direction: Outbound to display
- Visible on front panel: Yes
  - Displays the slope of the line fit to the n-test data.

n graph:
- Label: n
- Type: XY graph
- Direction: To display
- Visible on front panel: Upon completion of n-test.
  - After the n-test is complete, the n vs. output data are displayed on this graph. The graph is hidden by local variable definition during the n-test itself.

Column Array 1:
- Label: None
- Type: Real vector
- Direction: Internal
- Visible on front panel: No
  - Collects the ΔE data for the standard channel. Used to determine the average ΔE for the standard channel.

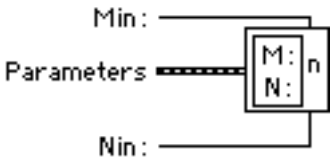
Time:
- Label: Time
- Type: String indicator
- Direction: To display
- Visible on front panel: No
  - Displays the present system date and time.


NIST
Automated Calibration System 2
ICDC
Test ID
F20#1
Test Information
F20#1
Starting Voltage (V)
1.70
Final Voltage (V)
2.00
Voltage Step (%)
0.05
Voltage Increment (V)
0.05
Delays
Switching
60
Filter
60
Automatic Shutdown
Off
On
Start
Stop
ESC key will also shut down system.
GPIB Bus Status
Dc Source: Datron 4000 3
Ac Source: Fluke 5700A 27
Std. DVM: Keithley 182 5
Test DVM: Keithley 182 6
Dc DVM: Keithley 181 15
Temperature: Keithley 182 12
Relay: HP 3497A/Internal 9
Counter: Systron-Donner 6041A 10
Present Data
Applied Voltage (V)
1.8000
Output emf (mV)
0.000
Ei
Ei+ΔE
Ef
ΔE
1 0.0000 0.0000 0.0000 0.0000
2 0.0000 0.0000 0.0000 0.0000
3 0.0000 0.0000 0.0000 0.0000
4 0.0000 0.0000 0.0000 0.0000
5 0.0000 0.0000 0.0000 0.0000
System Status
11/4/02 3:01:57 PM
Settling for new voltage. Time remaining: 00:47
M: 0.000
N: 0.0000
Previous Data
V emf n σ (10^-6)
1.700 9.458 1.858 283.264
1.750 9.978 1.851 265.517
0.000 0.000 0.000 0.000
0.000 0.000 0.000 0.000
0.000 0.000 0.000 0.000
0.000 0.000 0.000 0.000
0.000 0.000 0.000 0.000
0.000 0.000 0.000 0.000
0.000 0.000 0.000 0.000
0.000 0.000 0.000 0.000
0.000 0.000 0.000 0.000
0.000 0.000 0.000 0.000

N-test Report

Captures the data from a one-channel n-test, displays it on the front panel, and then prints the panel. It then returns the processing to the calling VI.

Connector Pane



Front Panel

Min:
- Label: Min
- Type: Real control
- Direction: Internal
- Visible on front panel: No
  - A dummy control that just sets up the indicator to display the calculated standard M.

Nin:
- Label: Nin
- Type: Real control
- Direction: Internal
- Visible on front panel: No
  - A dummy control that just sets up the indicator to display the calculated standard N.

Parameters:
- Label: Parameters
- Type: Cluster
- Direction: Inbound
- Visible on front panel: No
  - Cluster which passes the following parameters to N-TEST REPORT:
    - ID (String control)
    - Test Information (string control)
    - Passed data (2-dimensional real array)
    - Points (Integer control)

M:
- Label: M:
- Type: Real indicator
- Direction: To display
- Visible on front panel: Yes
  - Displays the calculated standard M on the front panel.

N:
- Label: N
- Type: Real indicator
- Direction: To display
- Visible on front panel: Yes
  - Displays the calculated standard n on the front panel.

N-test Data:
- Label: N-test Data
- Type: 2-dimensional real array
- Direction: To display
- Visible on front panel: Yes
  - Displays the data from the n-test, including the applied voltage (V), output emf at each voltage (emf) the calculated n (n) and the standard deviation of the calculated n (σ).

n:
- Label: n
- Type: XY graph
- Direction: To display
- Visible on front panel: Yes
  - Displays graphically the n vs. output data from the n-test.

Date:
- Label: Date
- Type: String indicator
- Direction: To display
- Visible on front panel: Yes
  - Displays the present date.

Time of Report:
- Label: Time of report
- Type: String indicator
- Direction: To display
- Visible on front panel: Yes
  - Displays the present time.

Report of n-Test - NIST Automated Comparator System 2

Test ID:

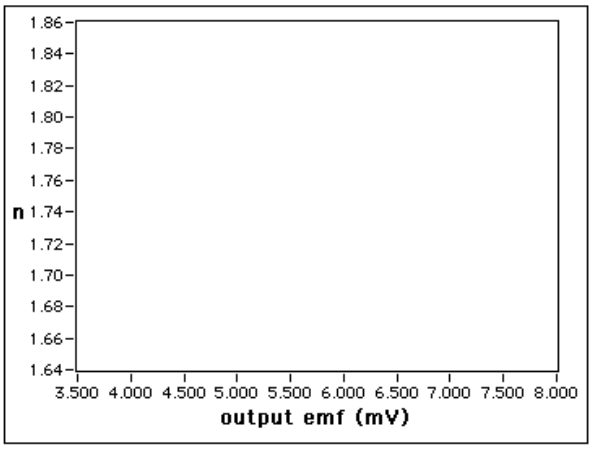
Date:

Time of Report:

Test Information:

N-test Data

V	emf	n	σ (10^{-6})
0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000

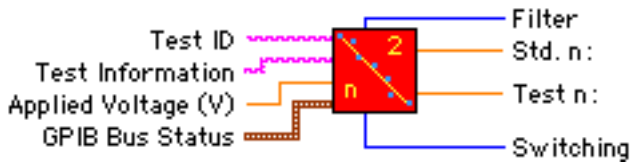


M: 0.000 N: 0.0000

N-Test (2 channel)

This subVI measures the *n* of both TVCs simultaneously at the present applied voltage.

Connector Pane:



Front Panel:

Test ID:
- Label: Test ID
- Type: String control
- Direction: Inbound
- Visible on front panel: Yes
  - The NIST test report number or other appropriate identifier.

Test Instrument:
- Label: Test Instrument
- Type: String control
- Direction: inbound
- Visible on front panel: Yes
  - The user's description of the unit under test.

Applied Voltage (V):
- Label: Applied Voltage (V)
- Type: Real control
- Direction: Inbound
- Visible on front panel: Yes
  - The baseline voltage of the n test.

Voltage Step (%):
- Label: Voltage Step (%)
- Type: Real control
- Direction: Inbound
- Visible on front panel: Yes
  - The voltage step (in percent) between the baseline voltage and the voltage increment.

Present Applied DC Voltage:
- Label: Present Applied DC Voltage (V)
- Type: Real indicator
- Direction: To display
- Visible on front panel: Yes
  - The presently applied voltage, equal to the baseline voltage plus the voltage step, if one is applied.

Scram
- Label: Stop and Clear System
- Type: Boolean control
- Direction: Internal
- Visible on front panel: Yes
  - Clicking on this button halts the n-test routine and calls CLEAR SYSTEM to reset the measurement system.

GPIB Bus Status:
- Label: GPIB Bus Status
- Type: Cluster of enumerated lists.
- Direction: Inbound
- Visible on front panel: Yes
  - The instrument lists define various instrument types appropriate for that function. The address lists are used to set the GPIB bus addresses of the instrument.

Standard Output:
- Label: None
- Type: Real indicator
- Direction: To display
- Visible on front panel: Yes
  - Displays the output emf of the standard channel for the applied voltage.

Test Output:
- Label: None
- Type: Real indicator
- Direction: To display
- Visible on front panel: Yes
  - Displays the output emf of the test channel for the applied voltage.

Standard Channel:
Label: Standard Channel
Type: Two-dimensional real array
Direction: To display
Visible on front panel: Yes
Displays the data for the standard channel. “Ei” and “Ef” are the initial and final readings at the baseline voltage, while “E+ΔE” is the reading with the voltage step applied. “ΔE” is the difference between the baseline voltage and the baseline voltage with the step.

Test Channel:
Label: Test Channel
Type: Two-dimensional real array
Direction: To display
Visible on front panel: Yes
Displays the data for the test channel. “Ei” and “Ef” are the initial and final readings at the baseline voltage, while “E+ΔE” is the reading with the voltage step applied. “ΔE” is the difference between the baseline voltage and the baseline voltage with the step.

System Status:
Label: System Status
Type: String indicator
Direction: To display
Visible on front panel: Yes
Displays any status messages generated by the system as well as the present date and time.

Time:
Label: None
Type: String indicator
Direction: To display
Visible on front panel: Yes
Displays the time of day returned from the date and time subVI.

Std. n:
Label: Std. n
Type: Real indicator
Direction: Outbound
Visible on front panel: Yes
Passes the calculated n for the standard channel.

Test n:
Label: Test n
Type: Real indicator
Direction: Outbound
Visible on front panel: Yes
Passes the calculated n for the test channel.

Column Array 1:
Label: None
Type: Real vector
Direction: Internal
Visible on front panel: No
Collects the ΔE data for the standard channel. Used to determine the average ΔE for the standard channel.

Column Array 2:
Label: None
Type: Real vector
Direction: Internal
Visible on front panel: No
Collects the ΔE data for the test channel. Used to determine the average ΔE for the test channel.

Stop:
Label: None
Type: Integer control
Direction: Internal
Visible on front panel: No
Acts as a switch so that the system will know whether to clear the GPIB bus before stopping the VI (scram mode) or not. For a normal n-test, *Stop* is set to 1, and the n-test subVI stops itself when it’s finished and returns processing to the calling VI. When the STOP button is clicked, *Stop* is still set to 0, so the GPIB bus is reset, and LabVIEW closed.

Switching:
Label: Switching
Type: Integer indicator
Direction: To display
Visible on front panel: Yes
Displays the time, in seconds, between the adjustment of the voltage source and the activation of the DVM filters.

Filter:

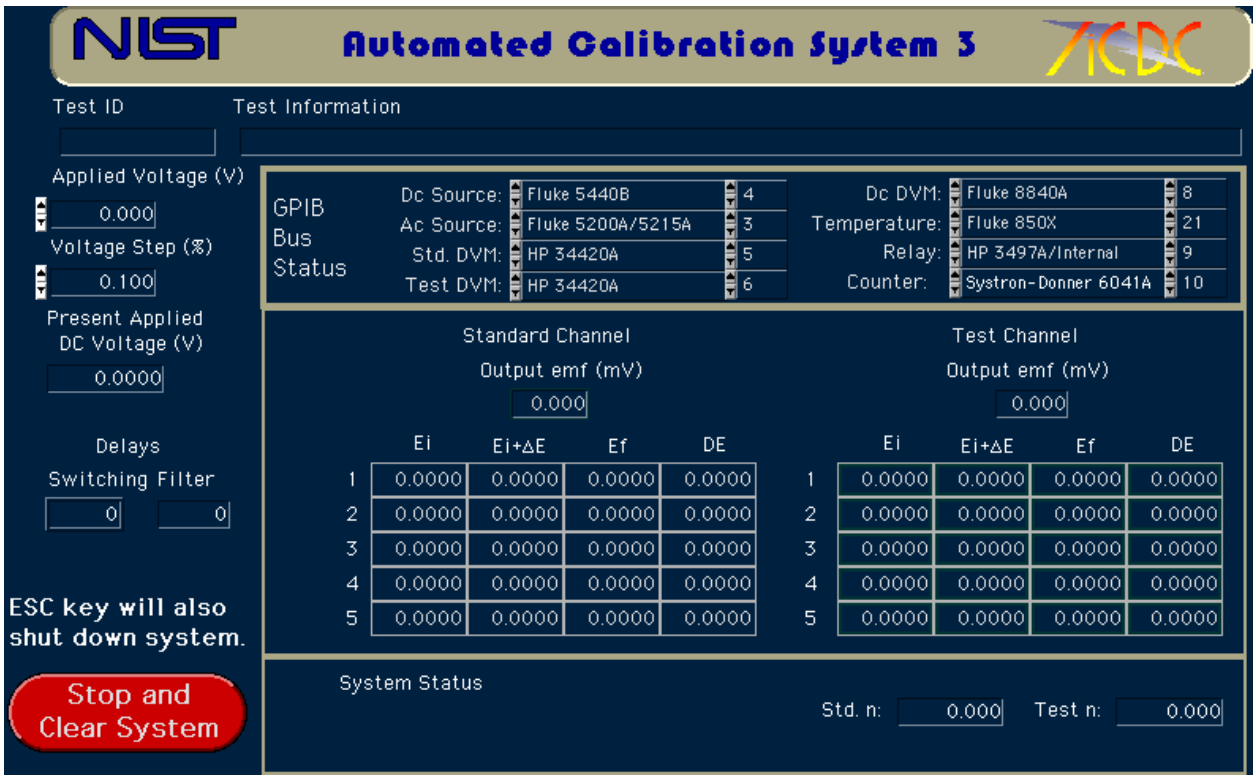
Label: Filter

Type: Integer indicator

Direction: To display

Visible on front panel: Yes

Displays the time between the activation of the filters and the start of data collection.



Note Utility

NOTE UTILITY lets the operator append a note to the calibration data sheet. The note is appended below the graph on the data sheet. Commands are provided to accept the note or reset the text. The note can be edited in the usual manner.

Connector Pane

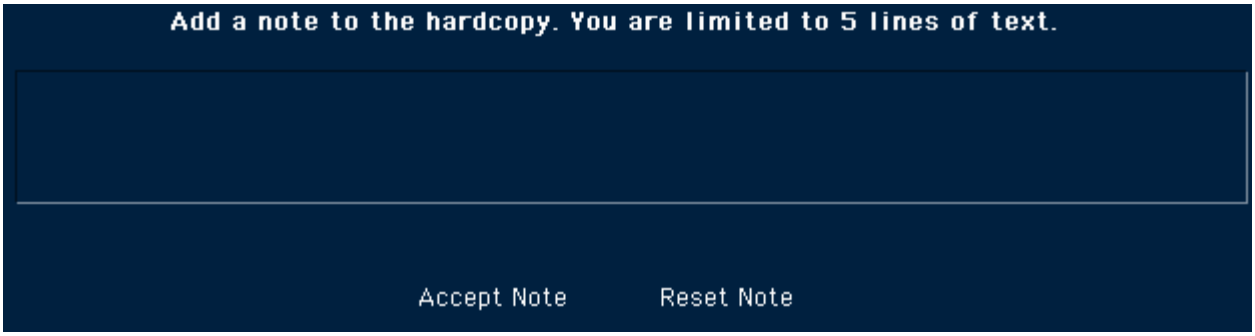
Front Panel

Notes in:
- Label: None
- Type: String control
- Direction: Internal
- Visible on front panel: Yes
  - This is the note the user adds to the data sheet. It's used only to get the text, but is considered to be inbound by the subVI.

Notes out:
- Label: None
- Type: String indicator
- Direction: Outbound
- Visible on front panel: No
  - Returns the text of the note to the calling VI.

Accept Note:
- Label: Accept Note
- Type: Boolean switch
- Direction: Internal
- Visible on front panel: Yes
  - Accepts the text of the note and terminates the subVI.

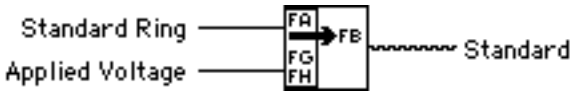
Reset Note:
- Label: reset Note
- Type: Boolean switch
- Direction: Internal
- Visible on front panel: Yes
  - Clears out the note string control so the operator can start over.



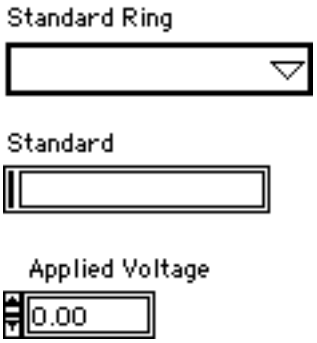
Parse Standard

PARSE STANDARD is used to let the operator select the appropriate standard for a measurement. It selects a set of possible standards based on the applied voltage, and presents this set of standards to the operator in a pull-down ring menu.

Connector Pane



Front Panel



Standard Ring:
- Label: Standard Ring
- Type: Ring control
- Direction: Internal
- Visible on front panel: Yes
  - Used to present a list of standards appropriate for the specified applied voltage. The list is presented in a pull-down menu format.

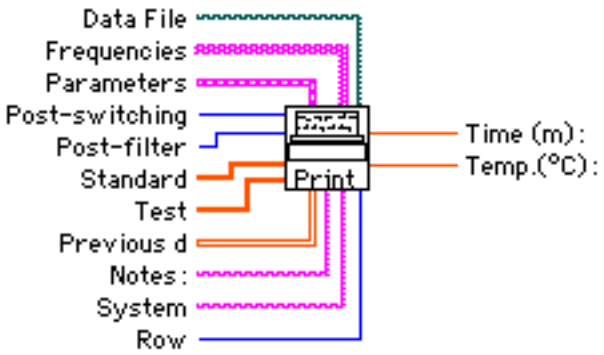
Applied Voltage:
- Label: Applied Voltage
- Type: Real control
- Direction: Inbound
- Visible on front panel: Yes
  - Specifies the applied voltage of the measurement. Used to select the set of standards to display.

Standard:
- Label: Standard
- Type: String indicator
- Direction: Outbound
- Visible on front panel: Yes
  - Returns a string containing the name of the standard to the calling VI.

Printer Utility

This VI is called by AC-DC DIFFERENCE and displays the calibration data for a unit under test. The VI then prints the panel as a permanent record of the calibration.

Connector Pane



Front Panel

Data File:
- Label: File path
- Type: File path
- Direction: Inbound
- Visible on front panel: No
  - The directory and file name of the data file archiving the test information.

Frequencies:
- Label: Frequencies
- Type: Table
- Direction: Inbound
- Visible on front panel: No
  - The summary of the data collected during the test. Includes frequencies, uncorrected and corrected ac-dc differences, standard corrections, standard deviations and reversal errors. Corresponds to "Frequencies" table in the VI *Ac-dc Difference*.

Parameters:
- Label: Parameters
- Type: Cluster
- Direction: Inbound
- Visible on front panel: No
  - Cluster which passes the following parameters to Printer Utility:
    - Test ID (String control)
    - Test Information (String control)
    - Standard (String control)
    - Applied Voltage (Real control)
    - Test Range (Real control)
    - Standard Range (Real control)
    - Voltage Drop (Real control)
    - Shutdown (Boolean switch)
    - Switching (Integer control)
    - Filter (integer control)

Post-switching:
- Label: Post-switching
- Type: Integer control
- Direction: Inbound
- Visible on front panel: No
  - The delay time between operation of the ac-dc switch and activation of the DVM filters.

Post-filter:
- Label: Post-filter
- Type: Integer control
- Direction: Inbound
- Visible on front panel: No
  - The delay time between activation of the DVM filters and start of data collection.

Standard:
Label: Standard
Type: Real vector
Direction: Inbound
Visible on front panel: No
The measurement information for the standard thermal converter, specifically the output emf and K_s.

Test:
Label: Test
Type: Real vector
Direction: Inbound
Visible on front panel: No
The measurement information for the test thermal converter, specifically the output emf and K_t.

Previous d:
Label: Previous d
Type: Two dimensional real array
Direction: Inbound
Visible on front panel: No
The data collected during the ac-dc difference calibration, including the uncorrected ac-dc difference of each converter, dc reversal errors, uncorrected and corrected ac-dc differences of the test converter, the time and temperature of each reading and the ac voltage settings.

Notes:
Label: Notes
Type: String control
Direction: Inbound
Visible on front panel: No, unless the operator has entered a note using the Note Utility
A note to append to the data sheet, if one is specified by the user.

System:
Label: System
Type: String control
Direction: Inbound
Visible on front panel: Yes
The NIST automated measurement system used for the calibration.

Row:
Label: Row
Type: Integer control
Direction: Inbound
Visible on front panel: No
Specifies the row of the “Frequen-cies” table the present data is in.

Time (m):
Label: Time (m)
Type: Real indicator
Direction: Inbound
Visible on front panel: Yes
The total elapsed time in minutes of the calibration.

Temp: (˚C)
Label: Temp (˚C)
Type: Real indicator
Direction: Inbound
Visible on front panel: Yes
The ambient temperature in Celsius

N:
Label: N
Type: Integer vector
Direction: To display
Visible on front panel: Yes
Vector of point numbers from 0 to n-1 where n is the number of points in the calibration.

δs:
Label: δs
Type: Real vector
Direction: To display
Visible on front panel: Yes
Column vector containing the ac-dc differences of the standard channel TVC.

δt:
Label: δt
Type: Real vector
Direction: To display
Visible on front panel: Yes
Column vector containing the ac-dc differences of the test channel TVC.

δ:
Label: δ
Type: Real vector
Direction: To display
Visible on front panel: Yes
Column vector containing the uncorrected ac-dc differences of the unit under test.

Cs:
Label: Cs
Type: Real vector
Direction: To display
Visible on front panel: Yes
Column vector of NIST standard corrections.

Δ:
Label: Δ
Type: Real vector
Direction: To display
Visible on front panel: Yes
Column vector containing the corrected ac-dc differences of the unit under test.

Rs:
Label: Rs
Type: Real vector
Direction: To display
Visible on front panel: Yes
Column vector containing the dc reversal differences of the standard TVC.

Rt:
Label: Rt
Type: Real vector
Direction: To display
Visible on front panel: Yes
Column vector containing the dc reversal differences of the test TVC.

Time:
Label: Time
Type: String vector
Direction: To display
Visible on front panel: Yes
Column vector which displays the elapsed time (in mm:ss format) of the calibration.

Temp:
Label: Temp.
Type: Real vector
Direction: To display
Visible on front panel: Yes
Column vector containing the temperature in degrees Celsius at each point in the calibration.

Ac (V):
Label: Ac (V)
Type: Real vector
Direction: To display
Visible on front panel: Yes
Column vector containing the ac voltage settings at each point in the calibration.

Test ID;
Label: Test ID
Type: String indicator
Direction: To display
Visible on front panel: Yes
Displays the user-defined identifier of the calibration.

Date:
Label: date
Type: String indicator
Direction: To display
Visible on front panel: Yes
Displays the date that the data sheet was printed.

Time of Report:
Label: Time of Report
Type: String indicator
Direction: To display
Visible on front panel: Yes
Displays the time that the data sheet was printed.

Test Information:
Label: Test Information
Type: String indicator
Direction: To display
Visible on front panel: Yes
Displays the user-defined test information.

Standard:
Label: Standard
Type: String indicator
Direction: To display
Visible on front panel: Yes
The identifier of the standard TVC.

Applied Voltage (V):
Label: Applied Voltage (V)
Type: Real indicator
Direction: To display
Visible on front panel: Yes
The applied voltage for the calibration.

Standard Range (V):
Label: Standard Range (V)
Type: Real indicator
Direction: To display
Visible on front panel: Yes
The range of the NIST standard converter.

Test Range (V):
Label: Test Range (V)
Type: Real indicator
Direction: To display
Visible on front panel: Yes
The range of the unit under test.

Voltage Drop of Series Resistor (V):
Label: Voltage Drop of Series Resistor (V)
Type: Real indicator
Direction: To display
Visible on front panel: Yes
The voltage drop of a series resistor, if one is used.

Post-Switch Delay (s):
Label: Post-Switch Delay (s)
Type: Integer indicator
Direction: To display
Visible on front panel: Yes
The delay in seconds between the operation of the ac-dc relay and the activation of the DVM filters.

Post-Filter Delay (s):
Label: Post-Filter Delay (s)
Type: Integer indicator
Direction: To display
Visible on front panel: Yes
The delay in seconds between the activation of the DVM filters and the start of data collection.

Es:
Label: Es
Type: Real indicator
Direction: To display
Visible on front panel: Yes
The output emf (in mV) of the standard.

Ks:
Label: Ks
Type: Real indicator
Direction: To display
Visible on front panel: Yes
The response, K, of the standard.

Et:
Label: Et
Type: Real indicator
Direction: To display
Visible on front panel: Yes
The output emf (in mV) of the unit under test.

Kt:
Label: Kt
Type: Real indicator
Direction: To display
Visible on front panel: Yes
The response, K, of the unit under test.

Freq.:
Label: Freq.
Type: String indicator
Direction: To display
Visible on front panel: yes
The frequency of the calibration.

δ (μV/V):
Label: δ (μV/V)
Type: Real indicator
Direction: To display
Visible on front panel: Yes
The uncorrected ac-dc difference of the unit under test.

Cs (μV/V):
Label: Cs (μV/V)
Type: Real indicator
Direction: To display
Visible on front panel: Yes
The correction to the NIST standard converter.

Δ (μV/V):
Label: Δ (μV/V)
Type: Real indicator
Direction: To display
Visible on front panel: Yes
The corrected ac-dc difference of the unit under test.

σ (μV/V):
Label: σ (μV/V)
Type: Real indicator
Direction: To display
Visible on front panel: Yes
The standard deviation of the n measurements at that particular voltage and frequency.

Rs (μV/V):
Label: Rs (μV/V)
Type: Real indicator
Direction: To display
Visible on front panel: Yes
The dc reversal error of the standard TVC.

Rt (μV/V):
Label: Rt (μV/V):
Type: Real indicator
Direction: To display
Visible on front panel: Yes
The dc reversal error of the test TVC.

D graph
Label: D graph
Type: XY graph
Direction: To display
Visible on front panel: Yes
Graph of the data taken during the calibration.

Report of Ac-dc Difference -

Test ID: **Date:** **Time of Report:**

Test Information:

Standard: **Applied Voltage (V):** 0.00 **Standard Range (V):** 0.00 **Test Range (V):** 0.00

Voltage Drop of Series resistor (V) 0.00

Post-Switch Delay (s) 0

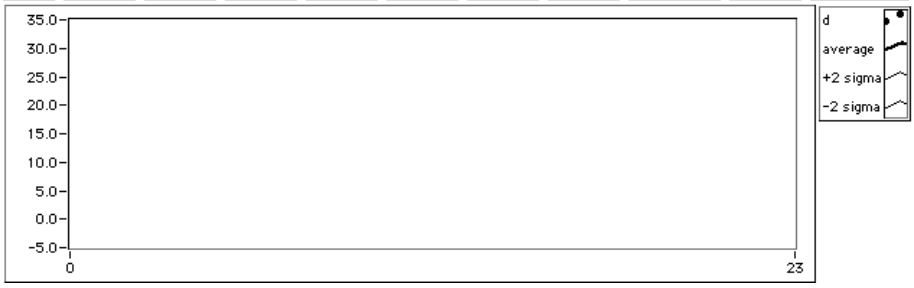
Post-Filter Delay (s) 0

Es: 0.00
Ks: 0.00
Et: 0.00
Kt: 0.00
Freq.:

δ (μV/V): 0.0
Cs (μV/V): 0.0
Δ (μV/V): 0.0
σ (μV/V): 0.0
Rs (μV/V): 0.0
Rt (μV/V): 0.0
Time (m): 0.0
Temp.(°C): 0.0

LabVIEW 5.1

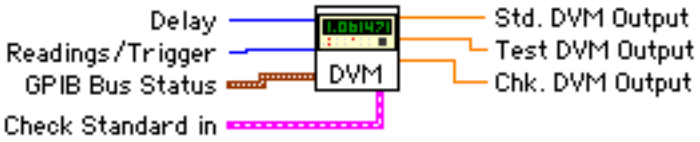
N	δs	δt	δ	Cs	Δ	Rs	Rt	Time	Temp	Ac (V)
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0	0.00000
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0	0.00000
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0	0.00000
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0	0.00000
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0	0.00000
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0	0.00000
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0	0.00000
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0	0.00000
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0	0.00000
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0	0.00000
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0	0.00000
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0	0.00000
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0	0.00000
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0	0.00000
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0	0.00000
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0	0.00000
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0	0.00000
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0	0.00000
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0	0.00000
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0	0.00000
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0	0.00000



Read DVM

READ DVM reads the voltmeters used as detectors for the thermal converters. The user can set the delay between filter activation and triggering, as well as the number of reading per trigger. As of this revision (58) the subVI supports the Hewlett Packard 34420A, Hewlett Packard 3458A and Keithley 182.

Connector Pane



Front Panel

GPIB Bus Status:
- Label: GPIB Bus Status
- Type: Cluster of enumerated lists
- Direction: Inbound
- Visible on front panel: Yes
  - The instrument lists define various instrument models appropriate for the indicated function. The address lists are used to set the GPIB addresses of the associated instrument.

Delay:
- Label: Delay
- Type: Integer control
- Direction: Inbound
- Visible on front panel: Yes
  - Defines the delay time in seconds between when the filters of the DVM are activated and the DVM is triggered.

Readings/Trigger:
- Label: Readings/Trigger
- Type: Integer control
- Direction: Inbound
- Visible on front panel: Yes
  - Sets the number of readings taken at each trigger event. The readings are averaged internally.

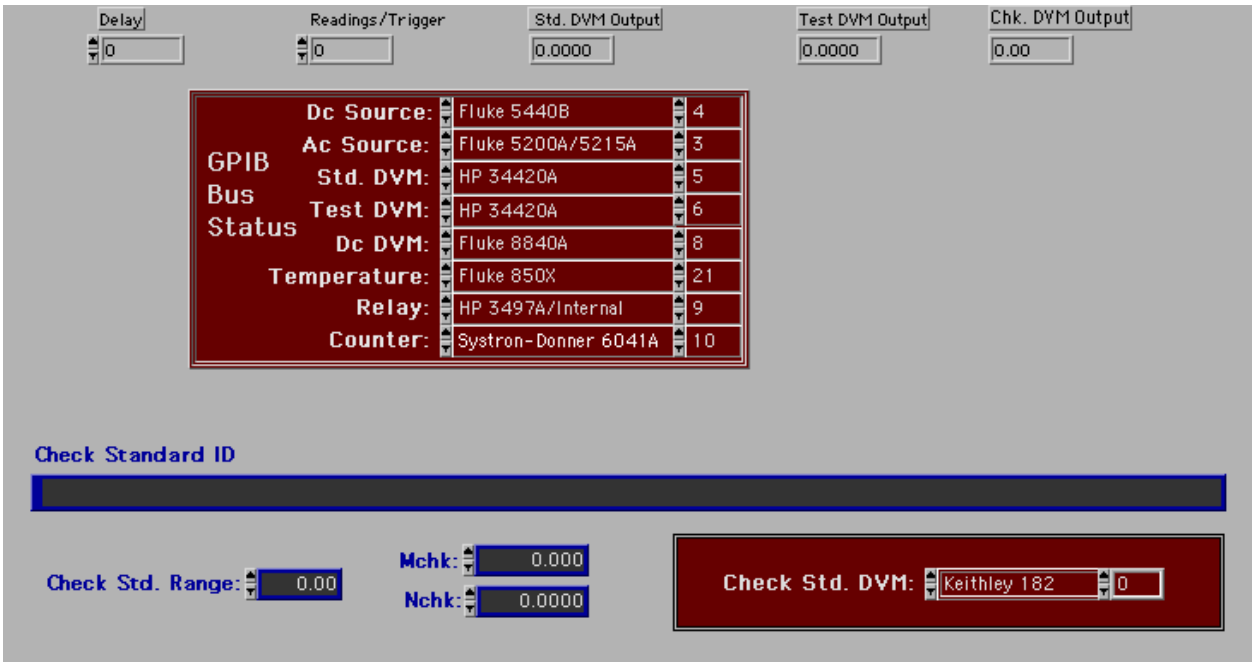
Std. DVM Output:
- Label: Std. DVM Output
- Type: Real indicator
- Direction: Outbound
- Visible on front panel: Yes
  - Returns the output voltage of the standard channel.

Test DVM Output:
- Label: Test DVM Output
- Type: Real indicator
- Direction: Outbound
- Visible on front panel: Yes
  - Returns the output voltage of the test channel

Std. Buffer:
- Label: Std. Buffer
- Type: String indicator
- Direction: Internal
- Visible on front panel: No
  - Used to clear the output buffer of the standard DVM before readings are triggered.

Test Buffer:
- Label: Test Buffer
- Type: String indicator
- Direction: Internal
- Visible on front panel: No
  - Used to clear the output buffer of the test DVM before readings are triggered.

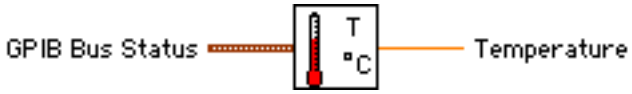
Check Standard in:
- Label: Check Standard in
- Type Cluster of string controls
- Direction: Inbound
- Visible on front panel: Yes
  - Provides the type and address of the check standard DVM.


Delay
0
Readings/Trigger
0
Std. DVM Output
0.0000
Test DVM Output
0.0000
Chk. DVM Output
0.00
GPIB Bus Status
Dc Source:
Fluke 5440B
4
Ac Source:
Fluke 5200A/5215A
3
Std. DVM:
HP 34420A
5
Test DVM:
HP 34420A
6
Dc DVM:
Fluke 8840A
8
Temperature:
Fluke 850X
21
Relay:
HP 3497A/Internal
9
Counter:
Systron-Donner 6041A
10
Check Standard ID
Check Std. Range:
0.00
Mchk:
0.000
Nchk:
0.0000
Check Std. DVM:
Keithley 182
0

Read Temperature

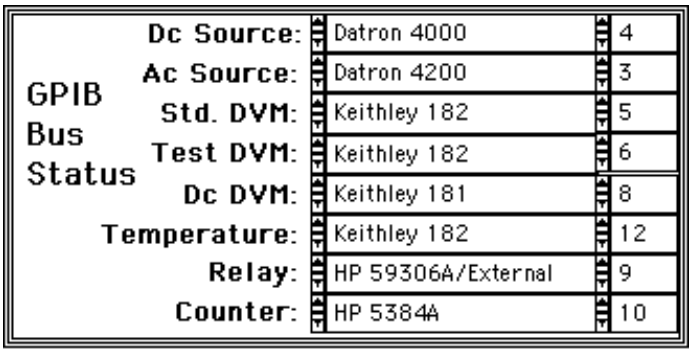
Gets the temperature from an external DVM with temperature probe.

Connector Pane

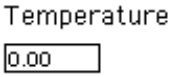


Front Panel

GPIB Bus Status:
- Label: GPIB Bus Status
- Type: Cluster of enumerated lists.
- Direction: Inbound
- Visible on front panel: Yes
  - The Instrument lists define various instrument types appropriate for that function. The address lists are used to set the GPIB bus addresses of the instrument.



Temperature:
- Label: Temperature
- Type: Real indicator
- Direction: Outbound
- Visible on front panel: Yes
  - Returns the temperature read from the DVM

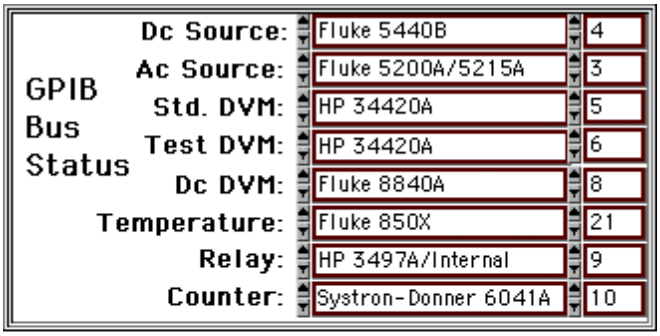


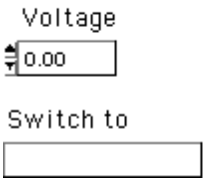
Relay Control

RELAY CONTROL operates the appropriate relay to switch the output voltage from ac to dc or vice-versa. The subVI will recognize both internal and external relay types, and multiple controller types. It also operates any LEDs necessary to indicate the type of voltage applied, and, if necessary, turns off the ac source when the relay switches. This subVI is system specific.

Connector Pane

Front Panel





GPIB Bus Status:
- Label: GPIB Bus status
- Type: Cluster of enumerated lists.
- Direction: Inbound
- Visible on front panel: Yes
  - The Instrument lists define various instrument types appropriate for that function. The address lists are used to set the GPIB bus addresses of the instrument

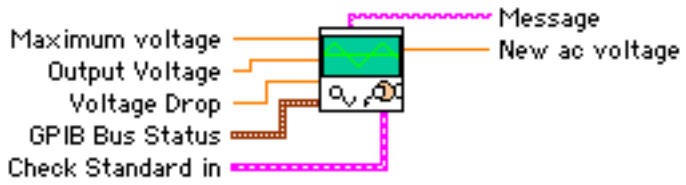
Voltage:
- Label: Voltage
- Type: Real control
- Direction: Inbound
- Visible on front panel: Yes
  - Used to determine which relays to operate in systems with separate relays for high and low voltage

Switch to:
- Label: Switch to
- Type: String control
- Direction: Inbound
- Visible on front panel: Yes
  - Used to determine if the voltage is to be switched from ac to dc or dc to ac.

Set ac voltage

SET AC VOLTAGE calculates the amount of offset to be introduced in the ac signal so that the output from the ac source will match that of the dc source, and sets the ac source to that value. If the calculated ac voltage exceeds the dc voltage by more that 10 %, this may indicate a failure in the ac source. In this case SET AC VOLTAGE will call CLEAR SYSTEM to reset the supplies.

Connector Pane



Front Panel

GPIB Bus Status:
- Label: GPIB Bus Status
- Type: Cluster of enumerated lists
- Direction: Inbound
- Visible on front panel: Yes
  - The instrument lists define various instrument models appropriate for the indicated function. The address lists are used to set the GPIB addresses of the associated instrument.

Maximum Voltage:
- Label: Maximum Voltage
- Type: Real control
- Direction: Inbound
- Visible on front panel: Yes
  - The maximum voltage for the measurement. If the calculated ac voltage will be 100 % of this value, the supplies are reset.

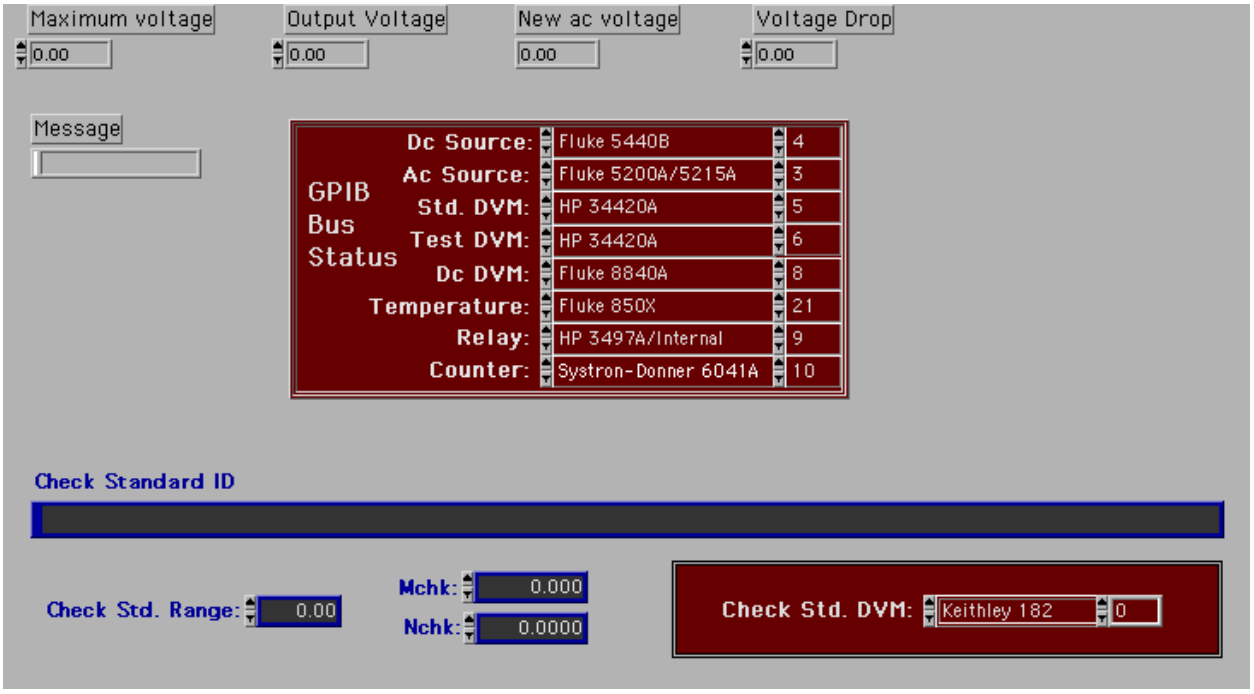
Output Voltage:
- Label: Output Voltage
- Type: Real control
- Direction: Inbound
- Visible on front panel: Yes
  - The presently applied ac voltage. Used to calculate the new voltage level.

Voltage Drop:
- Label: Voltage Drop
- Type: Real control
- Direction: Inbound
- Visible on front panel: Yes
  - The voltage drop due to a series resistor in the signal path.

Message:
- Label: Message
- Type: String indicator
- Direction: Outbound
- Visible on front panel: Yes
  - Returns an information message to the calling VI.

New Ac Voltage:
- Label: New Ac Voltage
- Type: Real indicator
- Direction: Outbound
- Visible on front panel: Yes
  - The adjusted ac voltage. The ac source is set to this voltage by this subVI.

Check Standard in:
- **Label: Check Standard in**
- **Type Cluster of string controls**
- **Direction: Inbound**
- **Visible on front panel: Yes**
  - **Used to pass information about the check standard range to the subVI to prevent overranging.**


Maximum voltage
0.00
Output Voltage
0.00
New ac voltage
0.00
Voltage Drop
0.00
Message
GPIB Bus Status
Dc Source: Fluke 5440B 4
Ac Source: Fluke 5200A/5215A 3
Std. DVM: HP 34420A 5
Test DVM: HP 34420A 6
Dc DVM: Fluke 8840A 8
Temperature: Fluke 850X 21
Relay: HP 3497A/Internal 9
Counter: Systron-Donner 6041A 10
Check Standard ID
Check Std. Range: 0.00
Mchk: 0.000
Nchk: 0.0000
Check Std. DVM: Keithley 182 0

Set dc voltage

Sets the dc source to the proper voltage.

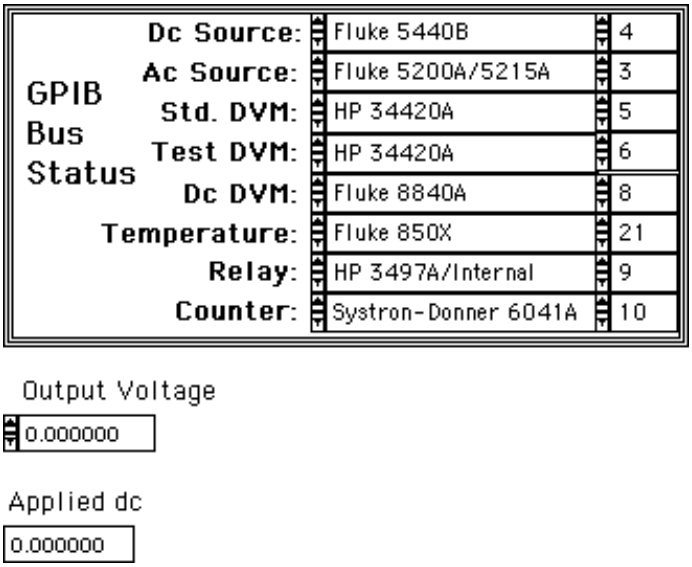
Connector Pane

Front Panel

GPIB Bus Status:
- Label: GPIB Bus Status
- Type: Cluster of enumerated lists.
- Direction: Inbound
- Visible on front panel: Yes
  - The Instrument lists define various instrument types appropriate for that function. The address lists are used to set the GPIB bus addresses of the instrument.

Output Voltage:
- Label: Output Voltage
- Type: Real control
- Direction: Inbound
- Visible on front panel: Yes
  - The voltage requested from the dc source

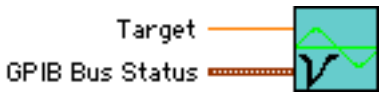
Applied dc:
- Label: Applied dc
- Type: Real indicator
- Direction: Outbound
- Visible on front panel: Yes
  - The dc voltage set on the source. Used for informational purposes by the calling VI.



Set Frequency

Fluke 5200A ac sources may have large frequency offsets at frequencies above about 1 kHz. This may cause significant errors when measuring instruments with large frequency coefficients of ac-dc difference at high frequencies. To help overcome this effect, this subVI adjusts the frequency of the Fluke 5200A until it nominally matches the requested frequency. The frequencies must be defined in the subVI; otherwise, SET FREQUENCY will not adjust the frequency and the default frequency of the Fluke 5200A will remain set.

Connector Pane

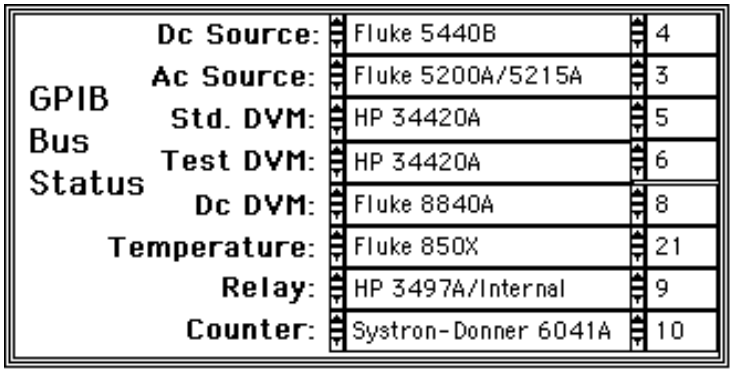


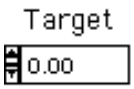
Front Panel

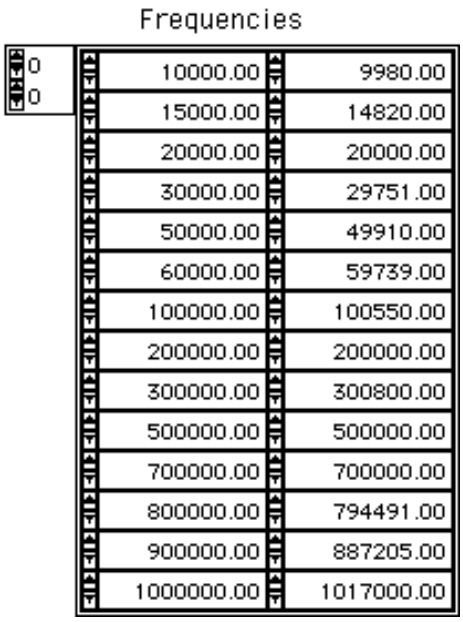
GPIB Bus Status:
- Label: GPIB Bus Status
- Type: Cluster of enumerated lists.
- Direction: Inbound
- Visible on front panel: Yes
  - The Instrument lists define various instrument types appropriate for that function. The address lists are used to set the GPIB bus addresses of the instrument.

Target:
- Label: Target
- Type: Real control
- Direction: Outbound
- Visible on front panel: Yes
  - The nominal frequency (in Hz) to which the 5200A is set

Frequencies:
- Label: Frequencies
- Type: Two-dimensional real array
- Direction: Internal
- Visible on front panel: Yes
  - Two-column array used to compare the 5200A frequency (column 1) to the target frequency (column 0).



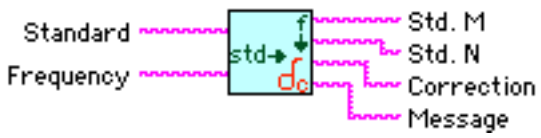




Standard Correction

Given the NIST standard and frequency for a measurement, this subVI uses a LabVIEW table to look up and return the standard correction.

Connector Pane



Front Panel

Standard Corrections:
- Label: Standard Corrections
- Type: Table
- Direction: Internal
- Visible on front panel: Yes
  - Holds the corrections for the standards.

Standard:
- Label: Standard
- Type: String control
- Direction: Inbound
- Visible on front panel: Yes
  - The standard to get the correction for.

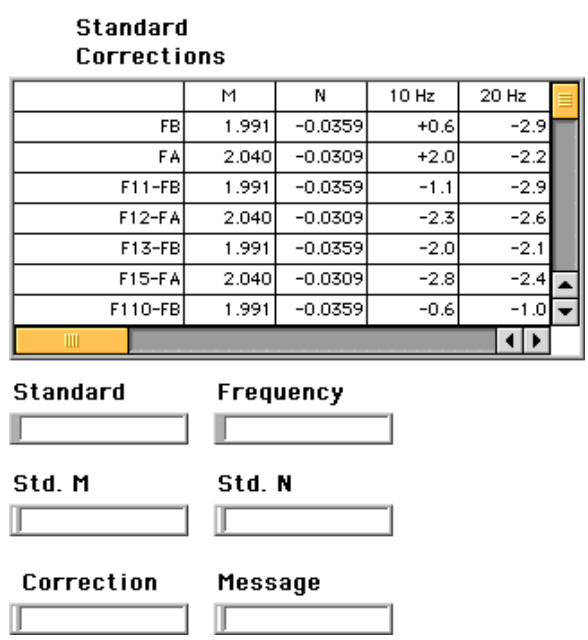
Frequency:
- Label: Frequency
- Type: String control
- Direction: Inbound
- Visible on front panel: Yes
  - The frequency of the measurement.

Correction:
- Label: Correction
- Type: String indicator
- Direction: Outbound
- Visible on front panel: Yes
  - Returns the standard correction.

Message:
- Label: Message
- Type: String indicator
- Direction: Outbound
- Visible on front panel: Yes
  - Returns a status message to the calling VI.

Std. M:
- Label: Std M
- Type: String indicator
- Direction: Outbound
- Visible on front panel: Yes
  - Returns the *n* intercept of the fitted thermoelement response characteristic line.

Std. N:
- Label: Std. N
- Type: String Indicator
- Direction: Outbound
- Visible on front panel: Yes
  - Returns the slope of the fitted thermoelement response characteristic line.

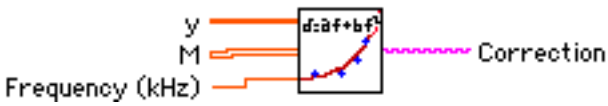


	M	N	10 Hz	20 Hz
FB	1.991	-0.0359	+0.6	-2.9
FA	2.040	-0.0309	+2.0	-2.2
F11-FB	1.991	-0.0359	-1.1	-2.9
F12-FA	2.040	-0.0309	-2.3	-2.6
F13-FB	1.991	-0.0359	-2.0	-2.1
F15-FA	2.040	-0.0309	-2.8	-2.4
F110-FB	1.991	-0.0359	-0.6	-1.0

Std Corr Fit

This subVI calculates standard corrections for non-cardinal frequencies. For frequencies < 1 kHz, and for frequencies > 100 kHz, the corrections are found from square-law fits. For other frequencies, the corrections are calculated by a least-squares fit to the equation $\Delta=a_1f^4+a_2f^2+a_3f+a_4$, the solution of which, in matrix form, is $\Delta=(M^tM)^{-1}M^ty$. In this equation, Δ is the calculated correction, M is the matrix containing the frequencies (f^n), and y is the column vector of corrections at the cardinal frequencies.

Connector Pane



Front Panel

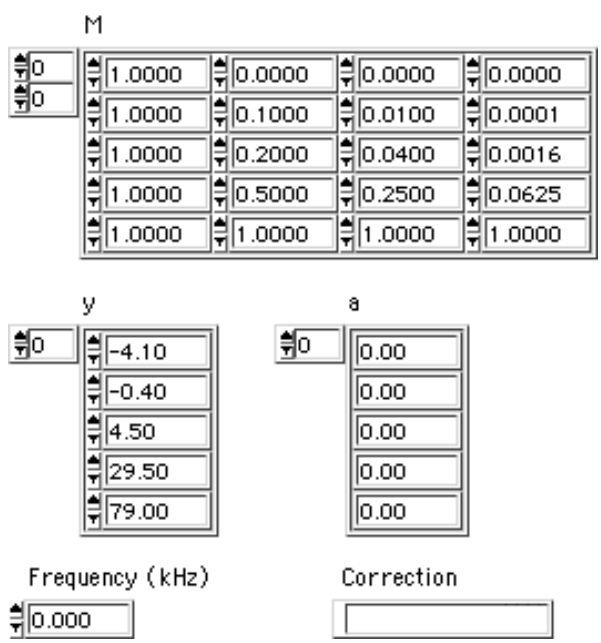
M:
- Label: M
- Type: Two-dimensional real array.
- Direction: Inbound
- Visible on front panel: Yes
  - Matrix containing the cardinal frequencies.

y:
- Label: y
- Type: Real vector
- Direction: Inbound
- Visible on front panel: Yes
  - Vector containing the corrections to the NIST standard at the cardinal frequencies.

a:
- Label: a
- Type Real vector
- Direction: Internal
- Visible on front panel: Yes
  - Augmented matrix used in taking the inverse of the matrix M.

Frequency (kHz):
- Label: Frequency (kHz)
- Type: Real control
- Direction: Inbound
- Visible on front panel: Yes
  - The frequency (in kHz) at which to compute the correction.

Correction:
- Label: Correction
- Type: String indicator
- Direction: Outbound
- Visible on front panel: Yes
  - The computed standard correction. Returned as a string for inclusion in the results table in the main VI.



Datron Local

Datron and Wavetek/Datron calibrators cannot be placed in LOCAL mode from the front panel, unless you turn off the power switch. This routine takes the less radical approach of sending a GTL (Go To Local) command to the instrument address indicated on the front panel. Although intended for use with Datron calibrators, it will also set other types of instruments to local, if necessary.

Connector Pane

Front Panel

Datron Address:

Label: Datron Address
Type: Integer controls
Direction: Internal
Visible on front panel: Yes
Indicates the address of the instrument to be put in local mode.

The Help Facility

Although not really a subVI, the Help Facility does deserve its own mention. The Help Facility is activated by clicking on the box with the question mark to the right of the AC-DC logo in the title banner. When the Help button is clicked, Adobe Acrobat Reader is launched and this documentation opened, using the following two methods.

Apple MacOS: The file “Autosys.pdf” is displayed by a simple Apple Events call from a conditional loop that interrogates the Boolean switch representing the Help button. Opening the document automatically launches Acrobat Reader, which in turn calls the .pdf file. Note that the software makes no attempt to confirm the presence of Acrobat Reader; if the Reader is not resident on the local computer, the document load will fail.

Windows: For the windows version of the software, the system checks the availability of Acrobat Reader using Windows Registry subVIs, and then loads the documentation using the System Exec VI. This code is also resident in a conditional loop. The software returns an error if Acrobat is not found on the local computer.

In both operating systems, the version of Acrobat launched will be the one found on the local computer.

Appendix B: Setting up Thermal Voltage Converters for Calibration

Introduction

Thermal voltage converters (TVCs) are used to compare an unknown ac voltage to a known dc voltage.

This appendix provides instruction on the setup and calibration of various ac-dc thermal voltage converters. These instructions are intended to show how these TVCs are calibrated in the Ac-dc Difference Laboratory at NIST, and should not be used exclusive of the instruction manuals for these instruments.

Several types of instruments are presented here, representing the most widely-used (and hence the most likely to be calibrated) thermal transfer standards. Other instruments may occasionally be received for calibration. In many cases, these instructions are applicable to several different types of transfer standards, as noted.

Coaxial Thermal Voltage Converters

As a class, coaxial thermal voltage converters consist of thermoelements mounted coaxially with range resistors to make a single voltage range. The TE and resistor may or may not be mounted in the same enclosure. For low-frequency measurements (up to 100 kHz), the coaxial TVC is generally comprised of one or more TEs and several resistors in separate enclosures; different voltage ranges are formed from various combinations of TEs and resistors. These devices are used from about 0.5 V up to 1000 V at frequencies up to 1 MHz. High-frequency coaxial TVCs are comprised of a TE and resistor in the same enclosure. These devices are generally used from 0.5 V to 100 V, and at frequencies up to 1 GHz.

Table B-1. Voltage ranges of five common coaxial TVC sets.

Voltage Ranges Included	Ballantine 1398A	Holt Model 11	JRL TNB-102[1]	Holt Model 20[2]	Fluke A55
0.5				X	X
1	X	X	X	X	X
2	X	X	X	X	X
3	X	X	X	X	X
4		X			
6	X	X	X	X	X
10	X	X	X	X	X
12		X			
20	X	X	X	X	X
30	X	X	X	X	X
40		X			
60	X	X	X	X	X
100	X	X	X	X	X
120		X			
200	X	X	X		
300	X	X	X		
400		X			
600	X	X	X		
1000	X		X		
1200		X			

[1] The voltage ranges of the NIST F_7 set are identical to those of the JRL TNB-102.

[2] The voltage ranges of the NIST C set are identical to those of the Holt Model 20.

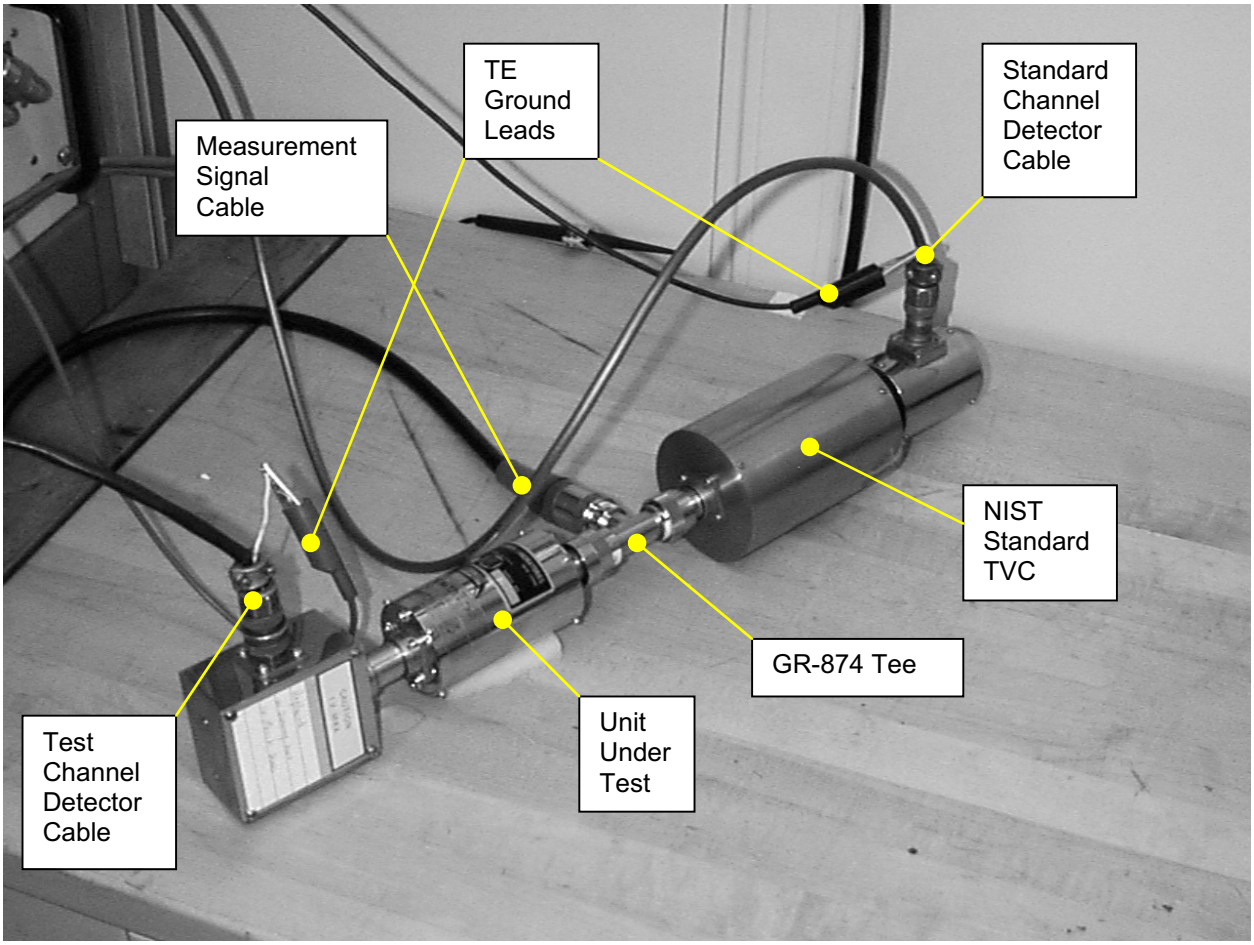


Figure B-1. Photograph of a coaxial thermal voltage converter connected to one of the NIST automated systems.

☛ To calibrate a coaxial thermal voltage converter, follow these steps:

i. Connect the UUT to one leg of a GR 874 Tee. You may need to use an adapter to connect the UUT to the Tee, since some high-frequency thermal converters use BNC or Type N connectors for the input signal.
ii. Connect the NIST standard to a second leg of the Tee,[3]
iii. Connect the cable from the automated system to the third leg of the Tee.

[3] Theoretically, all GR 874 Tees in use in the Ac-dc Difference Laboratory have symmetrical legs, so it should not matter which legs you use for the TVCs and which you use for the input signal. In practice, the different legs make a contribution to the ac-dc difference at less than the 10^{-6} level at frequencies below about 100 kHz, and contribute only a few parts in 10^{6} up to 1 MHz. By convention, the input is applied to the center leg of the Tee, and the converters are connected to the cross legs.

iv. Connect the detector cables to the thermoelements, making sure that the standard channel detector cable is connected to the NIST standard, and the test channel cable to the UUT.

v. Connect the ground wires from the low side of the thermoelement output connector to the shell of the detector cable for both channels.

vi. Cover the TVCs, if necessary, to prevent problems with changes in ambient temperature.

vii. Launch the Ac-dc Difference VI and proceed according to the instructions in the Voltage System VI section.

Fluke 792A Thermal Transfer Standards

The Fluke 792A Thermal Transfer Standard is a multirange device consisting of a solid-state thermal sensor and a set of range resistors mounted on a rotary switch. A separate battery pack provides power for amplifiers internal to the Fluke 792A. These are used on the millivolt ranges to amplify the input voltage to a level suitable for the sensor chip, and at low frequencies where they buffer the output emf of the sensor.

The output of the Fluke 792A is 2 V for full-scale input. The output banana terminals may be connected directly to a high-performance voltmeter, or a suitable thermoelement may be connected to these output terminals, and the output of the external thermoelement sensed by the automated systems. In general, in the NIST Ac-dc Difference Laboratory, the Fluke 792A output is sensed using a thermoelement. The advantage of this method is that the systems and software are already configured to measure thermoelements, so no modification is necessary to calibrate a Fluke 792A. In addition, an external thermoelement completely isolates the output signal path and eliminates common-mode voltages in the instrument.

The following photographs illustrate the connections to a Fluke 792A.

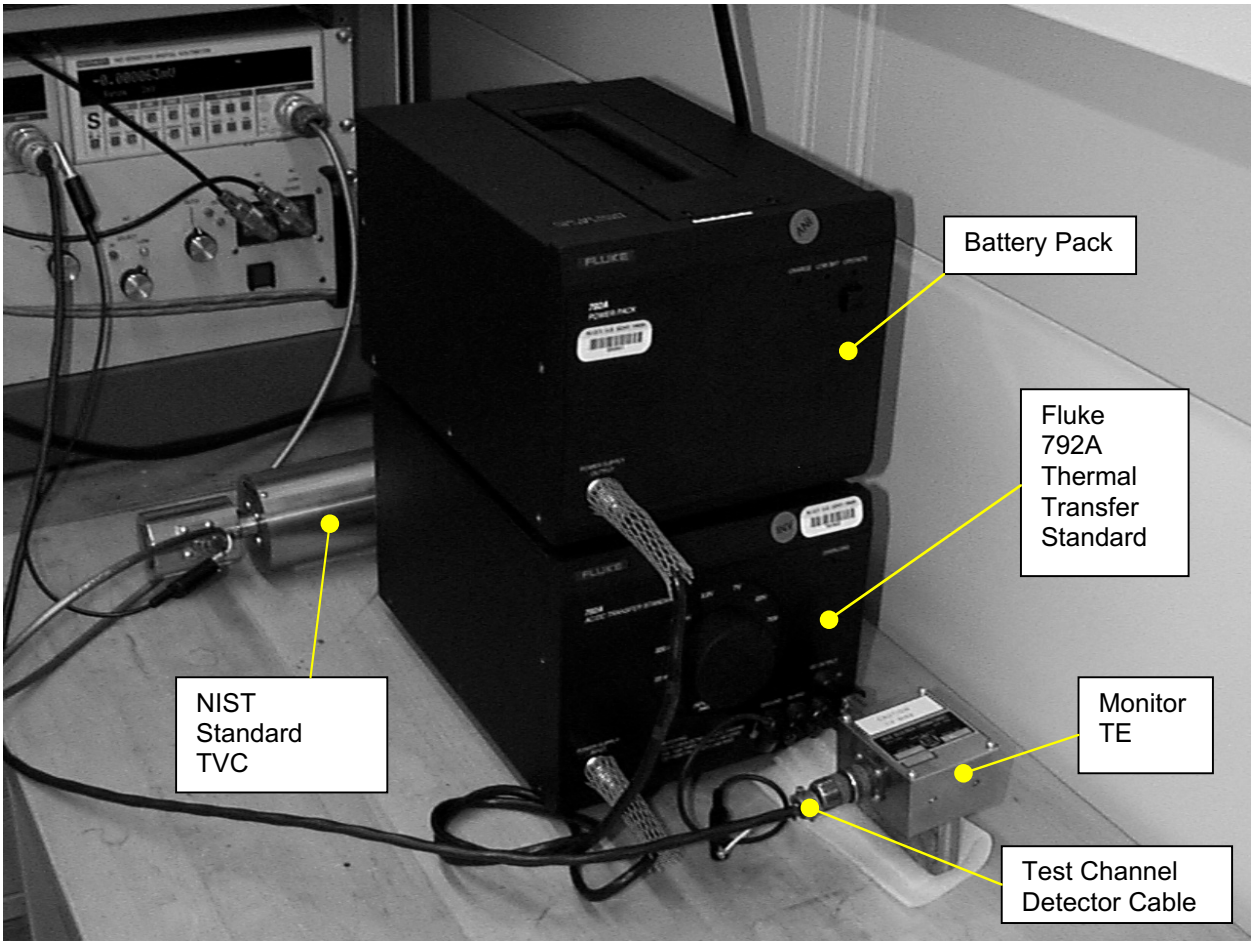


Figure B-2. Front view of a Fluke 792A connected to one of the NIST automated systems.

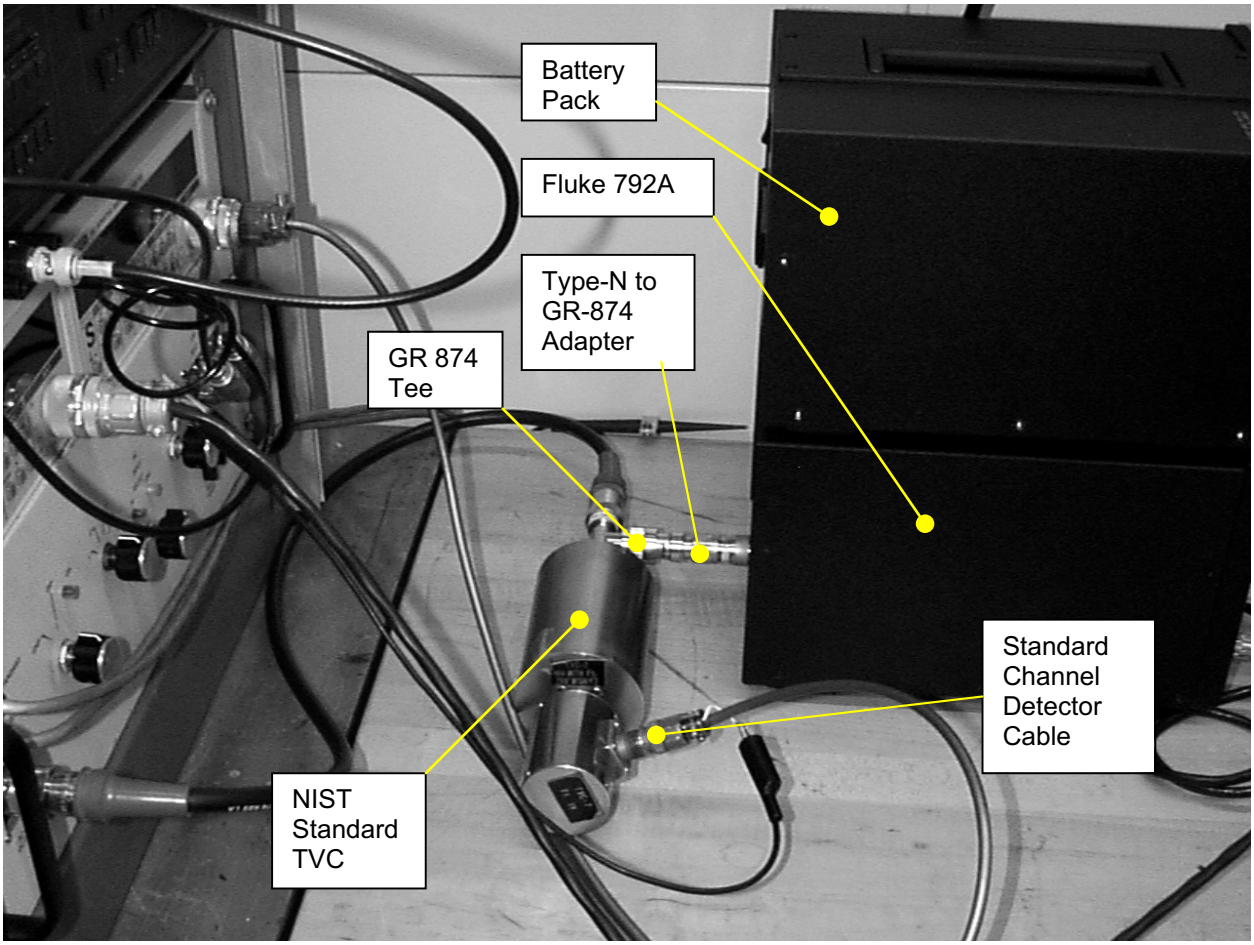


Figure B-3. Rear view of Fluke 792A and NIST standard TVC connected to one of the NIST automated systems.

☛ To calibrate a Fluke 792A, follow these steps:

i. Connect the power supply to the transfer standard using the cable provided with the 792A. The most efficient arrangement of the two boxes will often be with the power pack situated atop the transfer standard, as shown in the photographs.

ii. The Fluke 792A uses a male-to-female Type-N feedthrough to extend the Type-N female input connector (otherwise it's difficult to get the 1000-V resistor connected properly). The extension also prevents damage to the input connector when tightened. Make sure that the Type-N extension is screwed firmly onto the input connector.

iii. Connect a Type-N to GR-874 adapter to the Type-N extension. This adapter will have a negligible effect on the ac-dc difference of the 792A at high frequencies, compared to the calibration uncertainties.

iv. Ensure that both the Type-N to GR-874 adapter and the Type-N extension are firmly connected to the Fluke 792A. You may need to use pliers to ensure an adequate connection.

v. Connect one leg of a GR-874 Tee to the Type-N to GR-874 adapter.

vi. Connect a second leg of the Tee to the NIST standard TVC.

vii. Connect the signal lead from the automated system to the third leg of the Tee.

viii. At NIST, a thermoelement is generally connected to the output terminals of the Fluke 792A. This lets you run the normal LabVIEW voltage VI without change, and isolates the 792A output from the measurement circuit. To connect a thermoelement to the 792A, first insert a banana plug to GR-874 adapter into the output terminals of the 792A. Then connect an appropriate TE to the adapter.

☛ Note: The 792A supplies 2 V for full-scale input. Make sure you choose a thermoelement appropriate to the output of the 792A.

ix. Connect the test detector lead to the TE attached to the 792A output terminals.

x. Connect the standard detector lead to the NIST standard TVC.

xi. Depress the power switch on the 792A power pack to energize the instrument.

viii. Connect the ground wires from the low side of the thermoelement output connector to the shell of the detector cable for both channels.

ix. Cover the standard TVC, if necessary, to prevent problems with changes in ambient temperature.

x. Launch the Ac-dc Difference VI and proceed according to the instructions in the section covering the operation of that VI.

Warning: The Fluke 792A has an internal protection circuit that guards against accidental overvoltage. However, the instrument may be damaged if the power supply is activated while voltage is applied to the Type-N input connector. **Always turn the power switch ON before applying a signal to the input connector.**

Fluke 540B and Holt 6A Transfer Standards

These instruments represent an earlier generation of multirange thermal transfer standards. The two instruments are generally similar; both contain a set of range resistors on a rotary switch, both use UHF connectors for the input signal, and both contain two thermoelements arranged so that the dc reversal errors in the TEs are relatively small. The Fluke 540B has an internal battery pack that powers the internal galvanometer circuitry and the protection switch; the Holt 6A is powered from the ac mains. With the increasing popularity of the Fluke 792A and high-performance digital voltmeters, these two instruments are no longer frequently calibrated at NIST; however, the Fluke 540B is used as a detector for the A40 and A40A current shunts, and it is possible that you may calibrate an occasional instrument in this capacity.

A photograph of a Fluke 540B connected to one of the NIST automated systems is shown below. The connection of a Holt 6A is similar.

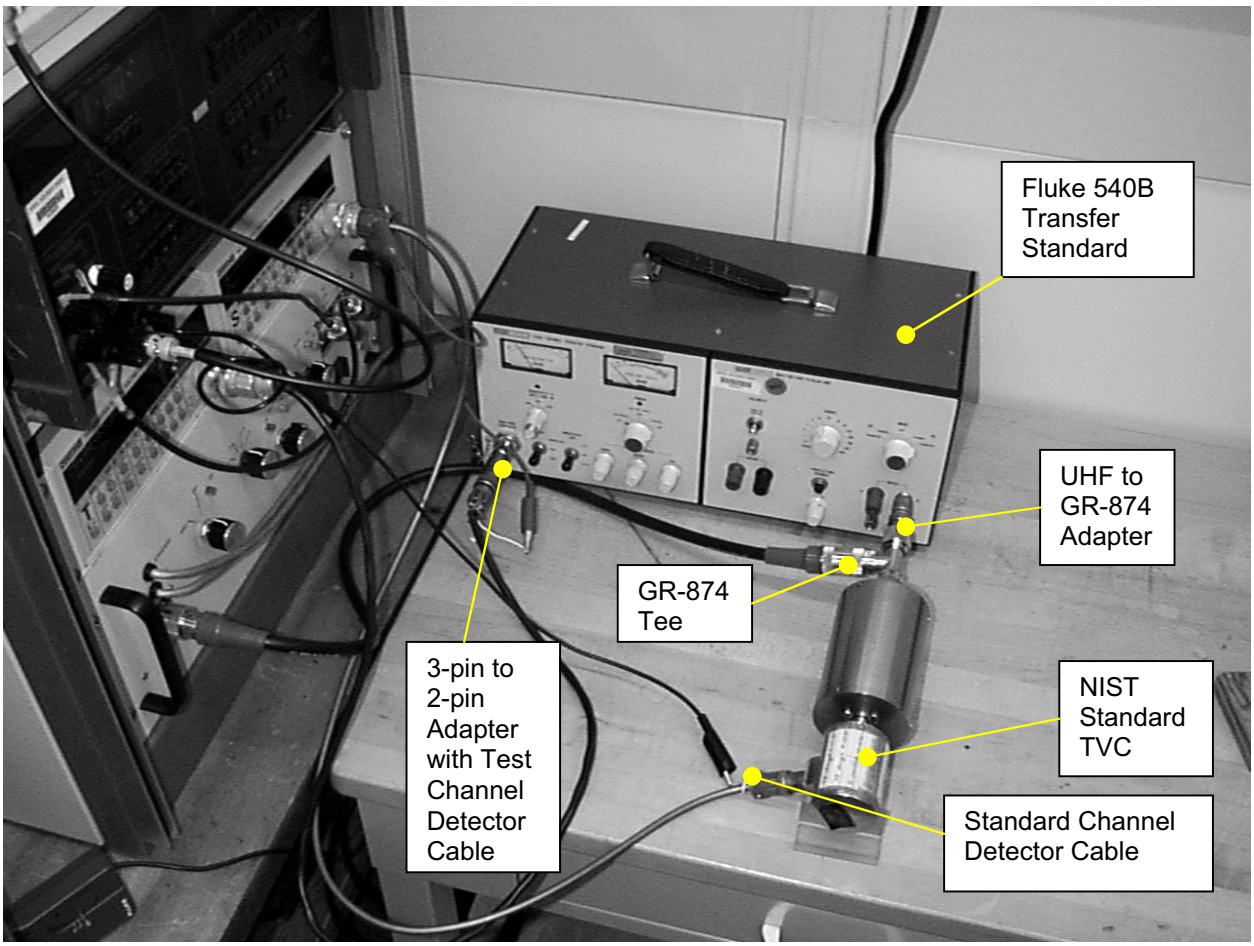


Figure B-4. Fluke 540B connected to one of the NIST automated systems.

☛ To calibrate a Fluke 540B or Holt 6A, follow these steps:

i. Ensure that the transfer standard is powered. For the Holt 6A, this involves connecting the instrument to the ac power mains and turning the toggle switch to ON. For the Fluke 540B, check the batteries using the rotary POWER switch on the front panel. To calibrate a Fluke 540B using the NIST method, the batteries must be charged only in the **SEARCH** position; the **GALVANOMETER** and **REFERENCE** settings are not needed. Ascertain that the battery indicator is in the **Bat OK** region while the switch is in the **SEARCH** position, then turn the switch to the **ON** position to power up the instrument.

ii. Both the Fluke 540B and Holt 6A have two sets of input terminals. In normal operation the dc source is connected to the banana terminals and the ac source to the UHF connector; the operator then switches the input signal using the MODE switch (Fluke 540B) or the FUNCTION switch (Holt 6A). Only the UHF connector is used for a NIST calibration. Connect a UHF to GR-874 adapter to the UHF connector on the front panel. Then set the MODE switch to **AC TRANSFER** (Fluke 540B) or the FUNCTION switch to **AC** (Holt 6A).

iii. Connect one leg of a GR-874 Tee to the UHF to GR-874 adapter.

iv. Connect the NIST standard TVC to a second leg of the GR-874 Tee.

v. Connect the signal lead from the automated system to the third leg of the Tee.

vi. Connect a 3-pin to 2-pin adapter to the High-Frequency Thermal Converter (HFTC) connector on the front panel.

vii. Connect the standard channel detector cable to the output of the NIST standard TVC.

viii. Connect the test channel detector cable to the 3-pin to 2-pin adapter on the HFTC connector.

ix. Connect the grounding leads from the outer conductors of the detector cables to the low side of the thermoelement outputs for both channels.

x. Set the rotary RANGE switch to the appropriate voltage range.

xi. Cover the NIST standard TVC, if necessary, to prevent problems with changes in ambient temperature.

xii. Launch the Ac-dc Difference VI and proceed according to the instructions in the Voltage System VI section.

Ballantine Models 1600A and 1605A

Ballantine Laboratories produced these instruments, the Models 1600A and 1605A, in the 1970s and 1980s. Few examples were sold, especially of the Model 1605A, and the likelihood that you will calibrate one at NIST is remote. Nevertheless, at least one Model 1600A is still in circulation, and for completeness, a description of the connection to the automated systems is presented here. Unfortunately, no photographs were available of these instruments; however, connection diagrams are presented.

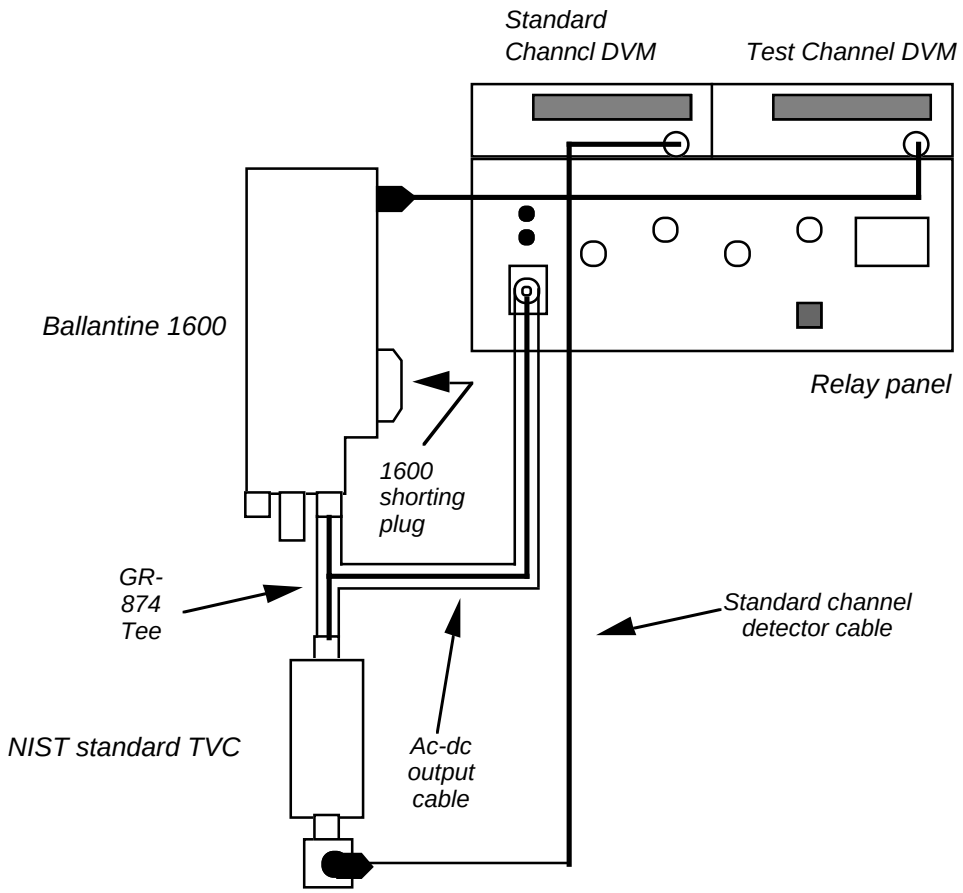


Figure B-5. Diagram for connecting a Ballantine 1600A to the automated system.

☛ To calibrate a Ballantine 1600A, follow these steps:

i. The Ballantine 1600A has two modules, the dc autobalancing module, and a separate module containing the power supply, range resistors (mounted on a rotary switch), and

thermoelement. This module can be calibrated independently of the autobalancing module, and is generally sent to NIST without the rest of the instrument. The measurement module connects to the autobalancing module via a 50 pin D-connector. To calibrate this instrument, insert a custom-made, 50 pin shorting plug into the interface connector[4].

ii. Power up the instrument by plugging the power cord into the ac mains and depressing the green power button.
iii. This instrument has separate inputs for low and high voltage. Insert one leg of a GR-874 Tee into the appropriate GR-874 input connector.
iv. Connect the NIST standard TVC to a second leg of the GR-874 Tee.
v. Connect the signal lead from the automated system to the third leg of the Tee.
vi. Set the appropriate input voltage range using the rotary switch on the front panel.
vii. Connect the test channel detector lead to the Ballantine 1600A output connector through a 3-pin to 2-pin adapter.
viii. Connect the standard channel detector cable to the NIST standard TVC output connector.
ix. Ensure that the low sides of the thermoelements are grounded to the shell of the detector cables.
x. Launch the Ac-dc Difference VI and proceed according to the instructions in the Voltage System VI section.

The Model 1605A is roughly similar to the Model 1600, with a few exceptions. The input to the instrument is identical, with the input ranges split between a high-voltage connector and a low-voltage connector. The ranges are switch selectable, as in the 1600, and it is operated on ac mains power. However, the Model 1605A has no separate thermal converter module, so the instrument is calibrated as a whole. The Model 1605A is not a passive device like the 1600, and its autobalancing feature must be disabled before calibration. The output emf of the Model 1605A is available at the 3-pin connector on the back panel. You may need to remove a cover plate to gain access to the emf output connector. The connections to the automated system are shown in Figure B-6.

☛ To calibrate a Ballantine 1605A, follow these steps:

i. Power up the instrument by plugging the power cord into the ac mains and operating the toggle switch.
ii. This instrument has separate inputs for low and high voltage. Insert one leg of a GR-874 Tee into the appropriate GR-874 input connector.
iii. Connect the NIST standard TVC to a second leg of the GR-874 Tee.
iv. Connect the signal lead from the automated system to the third leg of the Tee.

[4] A plug of this type is kept in the Ac-dc Difference Laboratory.

v. Set the appropriate input voltage range using the rotary switch on the front panel.
vi. Connect the test channel detector lead to the Ballantine 1600A output connector through a 3-pin to 2-pin adapter. The output connector is on the rear panel. You may need to remove a cover to access the connector.
vii. Connect the standard channel detector cable to the NIST standard TVC output connector.
viii. Ensure that the low sides of the thermoelements are grounded to the shell of the detector cables.
ix. Disable the autobalancing mode by depressing the **TRANSFER-RESET** and **STANDBY** buttons on the front panel. The OUTPUT and OPERTATE sections of the buttons should be lit.
x. Set the **MODE** switch to AUTO NORM and take the 1605A out of AUTO RECYCLE mode by pressing the button until the LED is extinguished.
xi. Launch the Ac-dc Difference VI and proceed according to the instructions in Voltage System VI section.

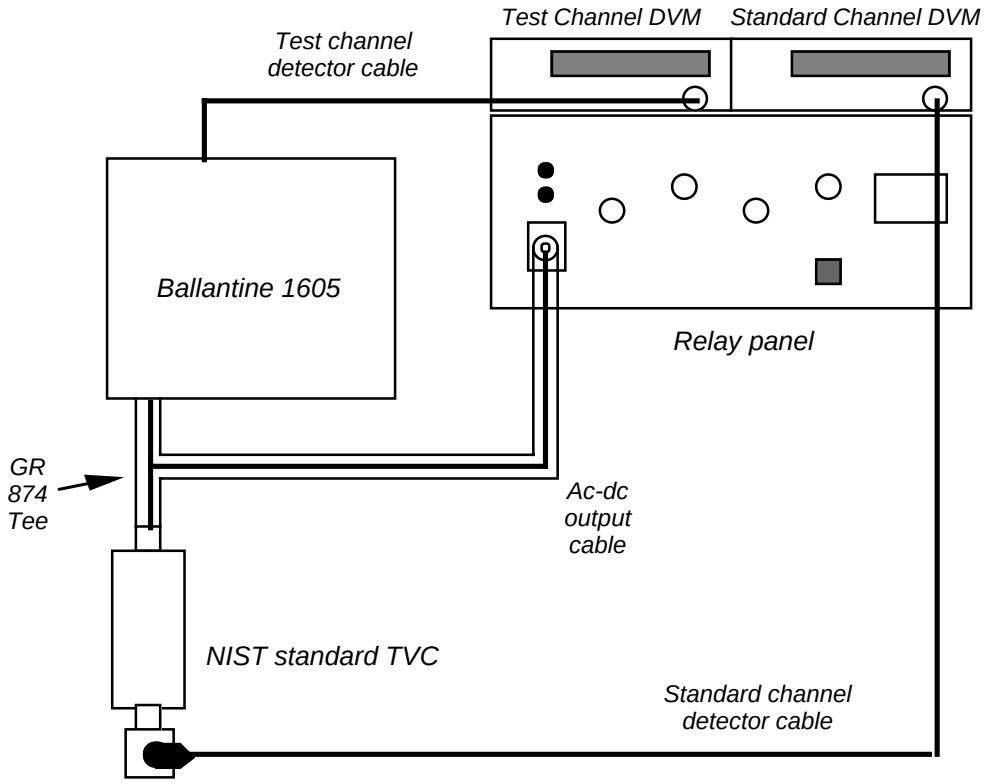


Figure B-5. Diagram for connecting a Ballantine 1605A to the automated system.

Appendix C: Setting up Thermal Current Converters for Calibration

Introduction

Thermal Current Converters (TCCs) are used to compare an unknown ac current to a known dc current. These devices are used to compare the voltage drop through a resistance structure when ac current is applied to the resistor, to that when dc is applied to the resistor. This voltage can then be measured externally using a voltmeter or thermal converter, and the ac-dc difference of the shunt determined by the differences in the output when ac and dc signals are applied in sequence.

Fluke A40 and A40A Current Shunts

The Fluke A40 (for currents up to 5 A) and A40A (10 A and 20 A) currents shunts are designed to plug into the banana sockets on the front panel of a Model 540B Thermal Transfer Standard. However, they can also be used with thermoelements provided that the thermoelement case is constructed to fit the wide spacing of the banana plug potential output of the shunts. The resistance element of the A40 is a U-shaped sheet of resistance material, with the potential leads connected perpendicularly to the resistor and brought to the surface of the shunt on banana plugs.

The A40A shunt is coaxial in design, with UHF connectors for both the current and potential terminals.

Photographs of a A40 and an A40A connected to the automated current calibration system are shown in Figures C-1 and C-2, respectively.

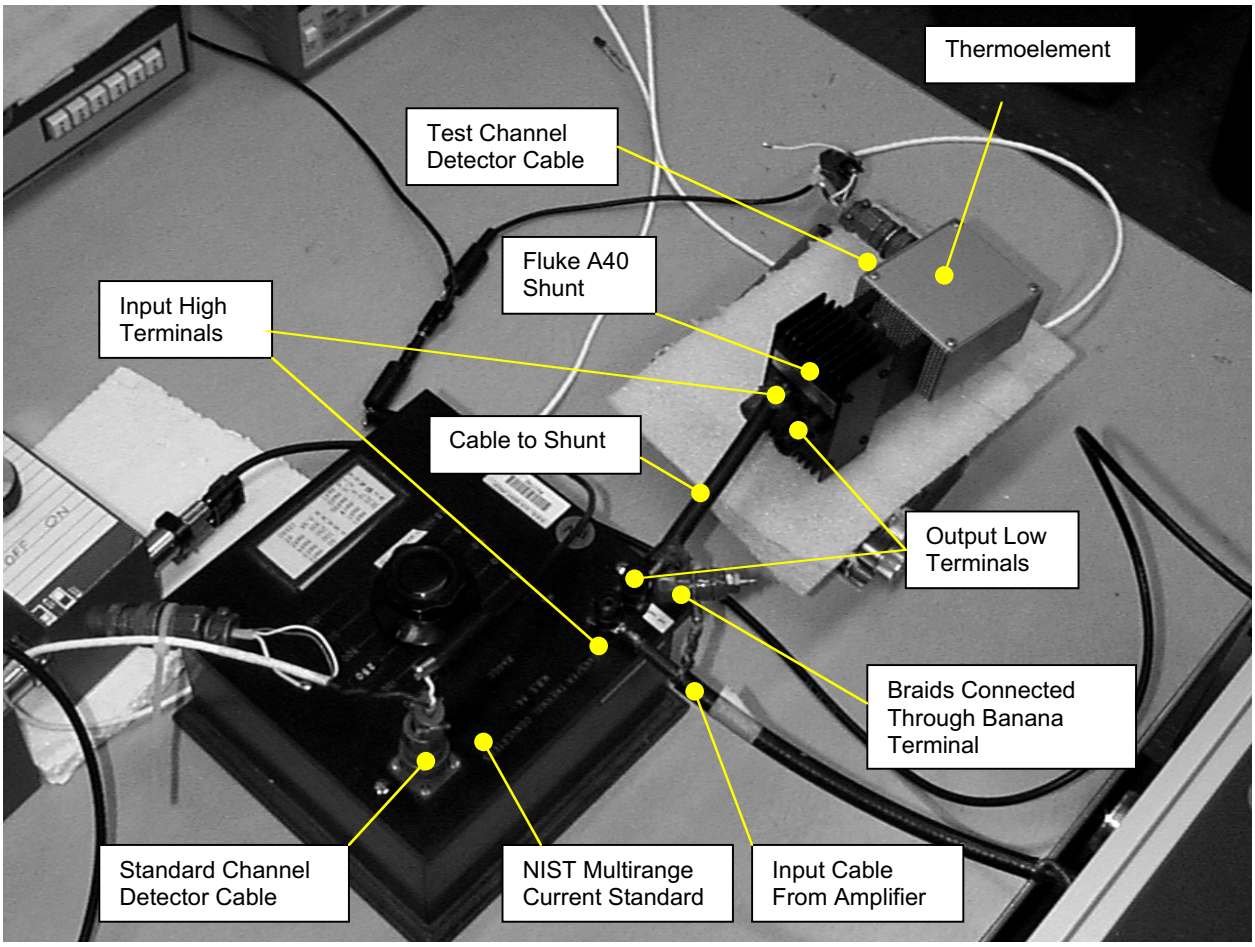


Figure C-1. Fluke A40 current shunt with separate thermoelement connected to one of the NIST automated systems.

☛ To calibrate a Fluke A40, follow these steps:

i. Select a suitable transconductance amplifier. A transconductance amplifier passes voltage from the sources in the automated systems through a resistor to generate a current which is proportional to that voltage. At present, two such amplifiers are used in the NIST Ac-dc Difference Laboratory. The Guildline 7620 is suitable for use at currents up to 20 A at 100 kHz. The Clarke-Hess 8100 is suitable for use up to 100 A at 100 kHz.

WARNING: The Guildline 7620 has no dedicated standby state. Large current spikes may be generated when the instrument is turned on. In addition, if the output is an open circuit, the output current will ramp up to the maximum current permitted for the set current range. To protect the thermal converters, **ALWAYS** short the output connector of the amplifier before you switch the power on. The Clarke-Hess 8100 has a true standby state and is immune to this hazard.

ii. Connect an RG8/U cable from the amplifier to the NIST current standard. The amplifier you use will determine the type of cable you need. For the Guildline 7620, you will need a cable with a UHF connector at one end and spade lugs on the other. The Clarke-Hess 8100 uses banana sockets for output currents up to 2 A and an LC connector for currents above 2 A. If you wish to use the high-current ranges, you will need an LC to UHF adapter.

iii. For currents of 0.5 A and below, the NIST standard is a multirange box with TEs mounted on a rotary switch. For currents above 0.5 A, the NIST standards are separate high-current thermoelements. Both types of standards use banana screw terminals as the input and output connectors. Connect the inner conductor of the input cable to the high terminal of the NIST standard by placing the spade lug beneath the banana terminal and screwing it down firmly.

iv. Connect the UUT in series with the NIST standard using a RG8/U cable with spade lugs on each end. Connect the inner of the cable to the low terminal of the NIST standard, and to the high (red) terminal of the A40. Connect the spade lug on the braid of the cable to the low (black) terminal of the A40.

v. Complete the current circuit by connecting the braids of the two cables together. This is most efficiently accomplished by placing the spade lugs on each braid in a banana socket and screwing the terminal firmly down.

☛ **Note:** Loose connections may result in increased scatter in the measurements. Make sure that all screw terminals are firmly tightened. A nut driver or pliers may be helpful in making tight connections.

☛ **Note:** Owing to the geometry of the resistance element in Fluke A40 shunts, the orientation of the leads at the face of the A40 effects the measurement results, often dramatically. It is NIST practice to bring the input leads perpendicular to the face of the A40, with the spade lugs bent at a right angle to connect to the banana terminals. This minimizes the interaction of the input signal with the electromagnetic fields induced in the resistor.

vi. Connect an appropriate TE or Fluke 540B to the potential terminals of the A40. Note that the terminals on the A40 have a wider spacing than standard twin banana terminals, and a dedicated thermoelement must be constructed accordingly. To use a 540B, simply plug the shunt into the shunt terminals of the transfer standard, ensuring that the high and low terminals are aligned.

vii. Connect the detector leads to the outputs of the NIST current standard and to the output of the UUT. If you are monitoring the output of the A40 with A Fluke 540B, see the section on the 540B for instructions on connecting the output lead.

viii. Ensure that the NIST standard is set to the appropriate current range. Also make sure that the UUT is set to an appropriate range. For a 540B, this means that the rotary range switch is set to the shunt position. However, since the shunt terminals on the Fluke 540B bypass the protection, the instrument need not be under power for these measurements.

ix. Launch the Current System VI and follow the instructions provided in the section on the Current System VI.

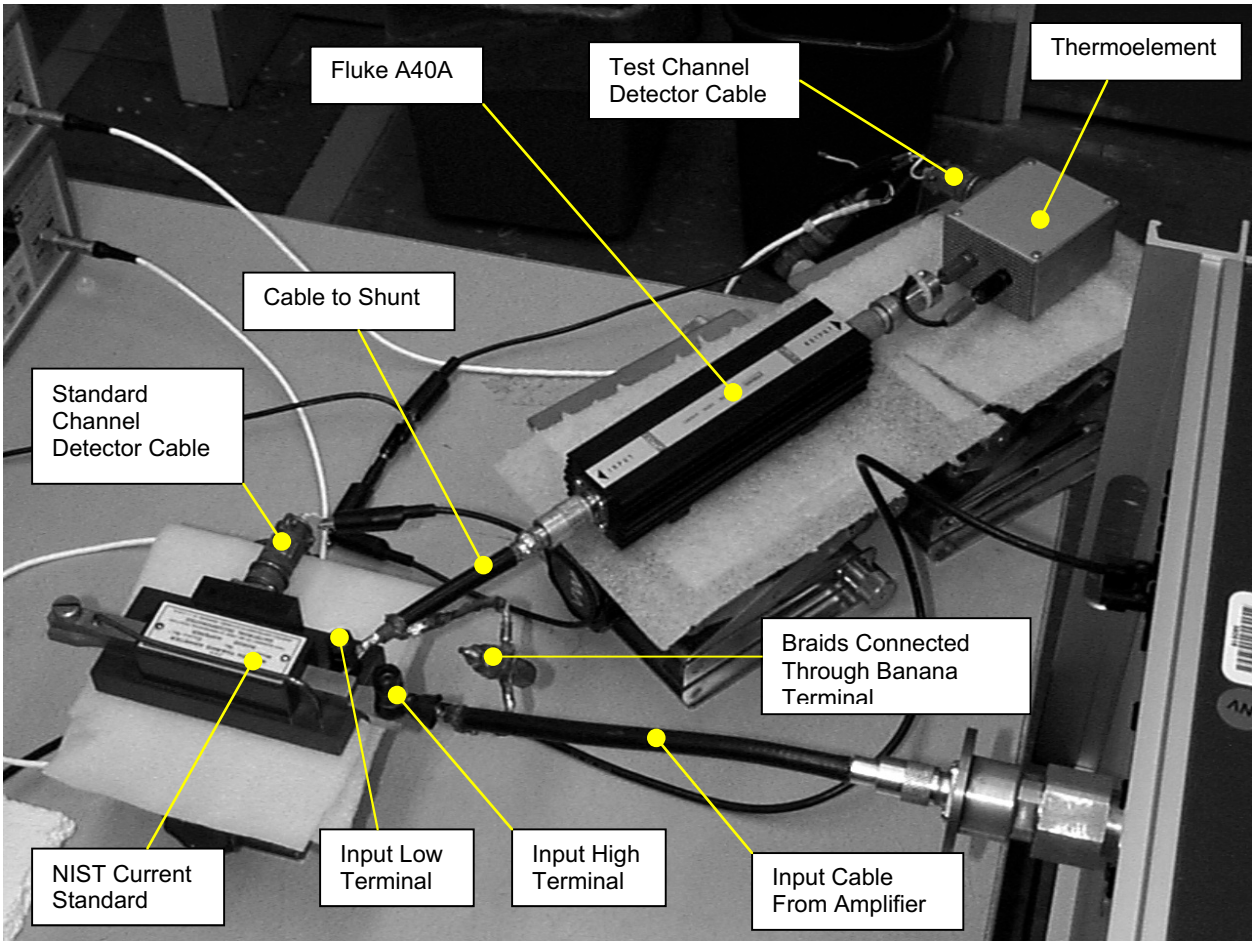


Figure C-2. Fluke A40A current shunt with separate thermoelement connected to one of the NIST automated systems.

☛ To calibrate a Fluke A40A, follow these steps:

i. Select a suitable transconductance amplifier. A transconductance amplifier passes voltage from the sources in the automated systems through a resistor to generate a current which is proportional to that voltage. At present, two such amplifiers are used in the NIST Ac-dc Difference Laboratory. The Guildline 7620 is suitable for use at currents up to 20 A at 100 kHz. The Clarke-Hess 8100 is suitable for use up to 100 A at 100 kHz.

WARNING: The Guildline 7620 has no dedicated standby state. Large current spikes may be generated when the instrument is turned on. In addition, if the output is an open circuit, the output current will ramp up to the maximum current permitted for the set current range.

To protect the thermal converters, **ALWAYS** short the output connector of the amplifier before you switch the power on. The Clarke-Hess 8100 has a true standby state and is immune to this hazard.

ii. Connect an RG8/U cable from the amplifier to the NIST current standard. The amplifier you use will determine the type of cable you need. For the Guildline 7620, you will need a cable with a UHF connector at one end and spade lugs on the other. The Clarke-Hess 8100 uses banana sockets for output currents up to 2 A and an LC connector for currents above 2 A. If you wish to use the high-current ranges, you will need an LC to UHF adapter.

iii. For currents of 0.5 A and below, the NIST standard is a multirange box with TEs mounted on a rotary switch. For currents above 0.5 A, the NIST standards are separate high-current thermoelements. Both types of standards use banana screw terminals as the input and output connectors. Connect the inner conductor of the input cable to the high terminal of the NIST standard by placing the spade lug beneath the banana terminal and screwing it down firmly.

iv. The Fluke A40A is a coaxial shunt with UHF connectors at each end. Use a coaxial cable with a UHF connector at one end to connect the A40A to the NIST standard.

x. Complete the current circuit by connecting the braids of the two cables together. This is most efficiently accomplished by placing the spade lugs on each braid in a banana socket and screwing the terminal firmly down.

☛ **Note:** Loose connections may result in increased scatter in the measurements. Make sure that all screw terminals are firmly tightened. A nut driver or water pump pliers may be helpful in making tight connections.

xi. Connect an appropriate TE or Fluke 540B to the potential terminal of the A40A. Note that the potential connector is a UHF connector and that you may need to use an adapter to connect the TE. To use a Fluke 540B, use the dedicated UHF to banana cable that should have been supplied with the shunts and transfer standard.

xii. Connect the detector leads to the outputs of the NIST current standard and to the output of the UUT. If you are monitoring the output of the A40 with A Fluke 540B, see the section on the 540B for instructions on connecting the output lead.

xiii. Ensure that the NIST standard is set to the appropriate current range. Also make sure that the UUT is set to an appropriate range. For a 540B, this means that the rotary range switch is set to the shunt position. However, since the shunt terminals on the Fluke 540B bypass the protection, the instrument need not be under power for these measurements.

xiv. Launch the Current System VI and follow the instructions provided in the section on the Current System VI.

Holt HCS-1 Current Shunts

The Holt HCS-1 current shunts are of a coaxial design, the resistor being a web of wire arranged coaxially about the axis of the shunt. The input terminal is a female UHF connector at one end, and the potential terminal is a male UHF at the other. The lowest current ranges in the HCS-1 set are contained in a multirange module, the current ranges being selected using a switch.

A photograph of a Holt HCS-1 connected to a NIST automated system is shown in Figure C-3.

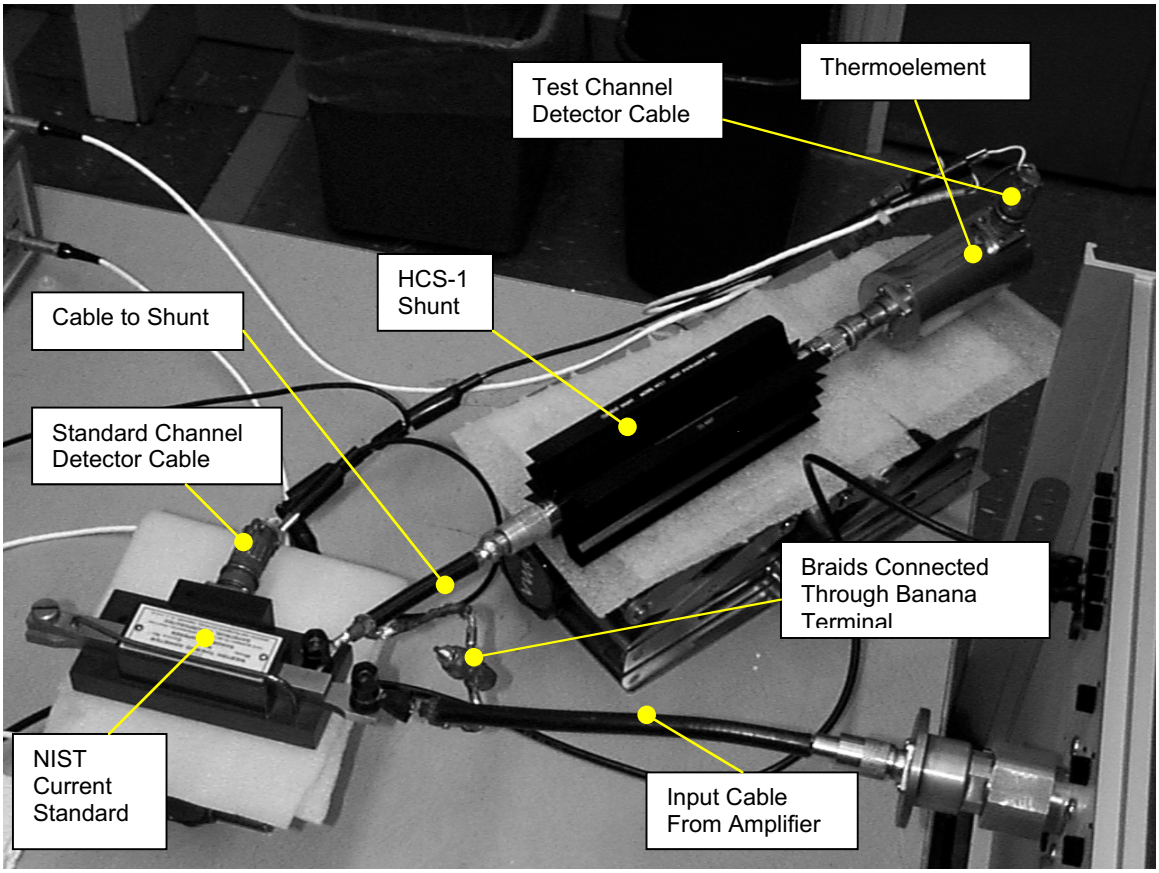


Figure C-3. Holt HCS-1 with a dedicated TE connected to one of the NIST automated systems.

☛ To calibrate a Holt HCS-1, follow these steps:

i. Select a suitable transconductance amplifier. A transconductance amplifier passes voltage from the sources in the automated systems through a resistor to generate a current which is proportional to that voltage. At present, two such amplifiers are used in the NIST Ac-dc Difference Laboratory. The Guildline 7620 is suitable for use at currents up to 20 A at 100 kHz. The Clarke-Hess 8100 is suitable for use up to 100 A at 100 kHz.

WARNING: The Guildline 7620 has no dedicated standby state. Large current spikes may be generated when the instrument is turned on. In addition, if the output is an open circuit, the output current will ramp up to the maximum current permitted for the set current range. To protect the thermal converters, **ALWAYS** short the output connector of the amplifier before you switch the power on. The Clarke-Hess 8100 has a true standby state and is immune to this hazard.

ii. Connect an RG8/U cable from the amplifier to the NIST current standard. The amplifier you use will determine the type of cable you need. For the Guildline 7620, you will need a cable with a UHF connector at one end and spade lugs on the other. The Clarke-Hess 8100 uses banana sockets for output currents up to 2 A and an LC connector for currents above 2 A. If you wish to use the high-current ranges, you will need an LC to UHF adapter.

iii. For currents of 0.5 A and below, the NIST standard is a multirange box with TEs mounted on a rotary switch. For currents above 0.5 A, the NIST standards are separate high-current thermoelements. Both types of standards use banana screw terminals as the input and output connectors. Connect the inner conductor of the input cable to the high terminal of the NIST standard by placing the spade lug beneath the banana terminal and screwing it down firmly.

iv. The Holt HCS-1 is a coaxial shunt with UHF connectors at each end. Use a coaxial cable with a UHF connector at one end to connect the HCS-1 to the NIST standard.

v. Complete the current circuit by connecting the braids of the two cables together. This is most efficiently accomplished by placing the spade lugs on each braid in a banana socket and screwing the terminal firmly down.

☛ **Note:** Loose connections may result in increased scatter in the measurements. Make sure that all screw terminals are firmly tightened. A nut driver or water pump pliers may be helpful in making tight connections.

vi. Connect an appropriate TE to the potential terminal of the HCS-1. Note that the potential connector is a UHF connector and that you may need to use an adapter to connect the TE.

vii. Connect the detector leads to the outputs of the NIST current standard and to the output of the UUT.

viii. Ensure that the NIST standard is set to the appropriate current range. Also make sure that the UUT is set to an appropriate range.

ix. Launch the Current System VI and follow the instructions provided in the section on the Current System VI.

Precision Measurements 9000 Series Shunts

This is a set of four current shunts intended to cover ranges of 10 A to 100 A. These shunts are coaxial in design, the resistance element being a circular array of small resistors sandwiched between two circular plates. The current path is coaxial through the shunt, and the potential leads are brought through the shunt casing perpendicularly to the resistor array. The input and output connectors are Type LC. These shunts are designed to be used coaxially in series, so that the shunt at the bottom of the series (the test, in the NIST convention) must have a shorting plug connected to its output current terminal. A photograph of a PMI shunt connected to an automated system is shown in Figure C-3.

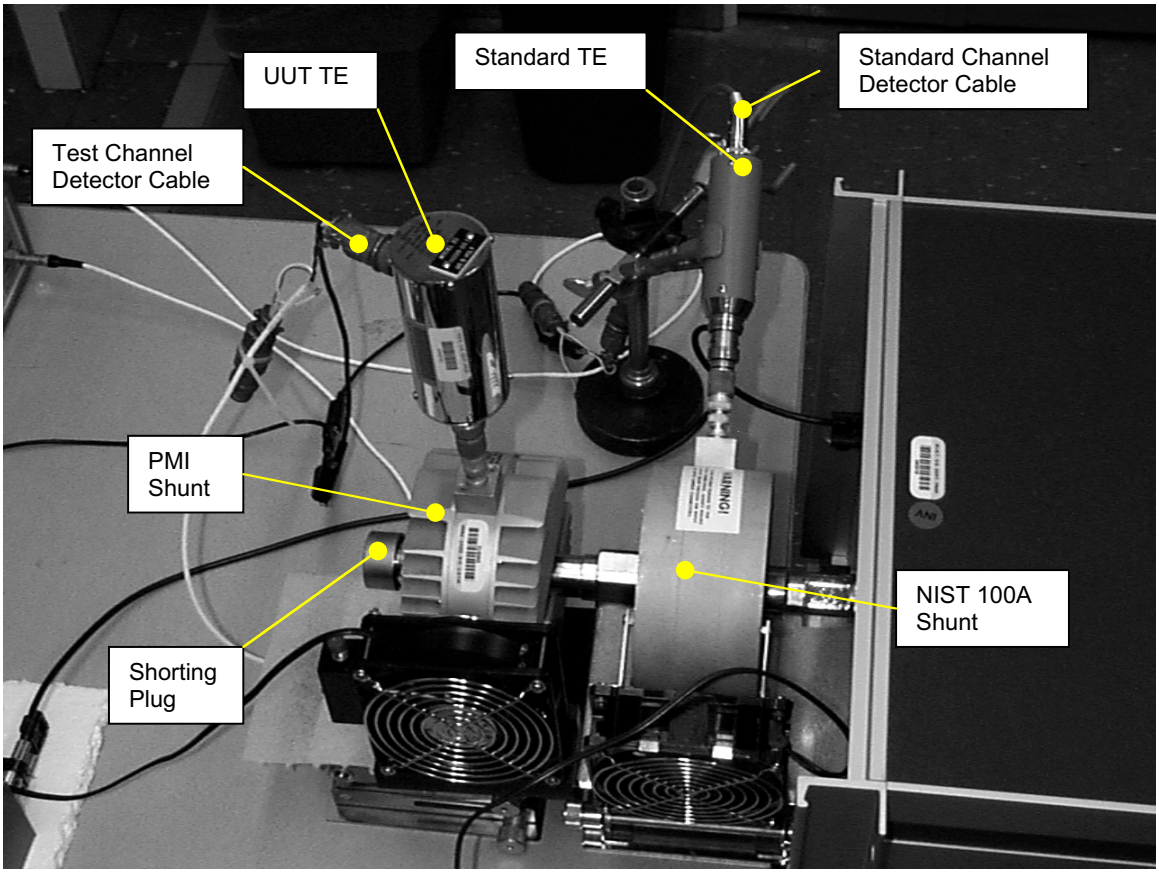


Figure C-3. A Precision Measurements shunt connected in series to a NIST shunt on one of the automated systems.

☛ To calibrate a Precision Measurements, Incorporated (PMI) shunt, follow these steps:

i. PMI shunts are coaxial and may be used two terminally or three terminally. In the NIST measurement scheme, the UUT is always at the bottom of the two current converters in series, so that the UUT is grounded. For PMI shunts, this means that you must install a shorting plug on the output LC connector to complete the current path.

ii. For currents greater than 20 A, the NIST standard will also be a high-current shunt as shown in Figure C-3. Screw this 100 A shunt onto the output connector of the Clark-Hess 8100 amplifier.

iii. Screw the appropriate PMI shunt onto the output connector of the NIST 100 A shunt.

☛ **Note:** Although it has been claimed that the LC connectors on the amplifier can support the combined load of a NIST shunt and a PMI shunt, it is a good idea to support both shunts.

iv. At NIST, thermoelements are used to monitor the potential outputs of the shunts. Select appropriate TEs and connect them to the BNC connectors of each shunt. You will need a adapter to make the connection to the TE.

☛ **Note:** The 1255-n series of thin-film multijunction thermal converters fabricated at NIST make excellent thermoelements for monitoring high-current shunts, due to their large dynamic range.

☛ **Note:** At low currents, the output from the NIST 100 A shunt will be quite small and difficult to measure. You may need to use a Fluke 792A Thermal Transfer Standard to monitor the output on one of its millivolt ranges.

v. Connect the test and standard channel detector cables to the TEs monitoring the potential outputs of the shunts.

vi. Connect the power cords to the integrated fans on the shunts and turn the fans on.

vii. Launch the Current System VI and follow the instructions provided in the section on the Current System VI.

Appendix D: Data Files

Introduction

The ac-dc difference calibration routine writes out a tab-delimited, plain-text data file at the completion of each frequency. The data file, named for the voltage or current range of the calibration, contains a record of the data taken during the calibration, and is written into a folder named for the identification of the test (in the **Test Information** field of the Ac-dc Difference VI). The calibration data file may be imported into a spreadsheet application, such as Microsoft Excel, for annotation and archiving.

The Calibration Data File

An example of an archival data file is shown in Figure D-1. It presents the results of a calibration of a NIST standard 100 V thermal voltage converter. The text file was named "100 V" for the TVC voltage range, and was written to a folder named to reflect the measurement. The file has been formatted slightly to improve the readability.

The data file is formatted in the following manner:

- The topmost line repeats the information you entered into the **Test Information** field in the voltage or current VI.
- The second line presents the frequency of the measurement, and the date and time.
- The next line presents the voltage or current range of the UUT and the applied voltage or current.
- The fourth line identifies the NIST standard and presents the voltage drop of a series resistor (for voltage measurements) or the current range of the transconductance amplifier used for current calibrations.
- The fifth line identifies the automated system used for the calibrations.

Beneath this line are 12 columns that present the data from the measurements. The number of rows is determined by how many determinations you specified in the voltage or current VI. The columns present the following information:

Column Heading	Information
X	An “x” in this column indicates that a particular point was excluded from the average ac-dc difference because it failed Chauvenet’s Criterion
N	The determination number
ds	The ac-dc difference of the standard channel
dt	The ac-dc difference of the test channel
d (µV/V)	The uncorrected ac-dc difference of the UUT
Cs (µV/V	The correction to the NIST standard
D (µV/V)	The corrected ac-dc difference of the UUT (D = d + Cs)
Rs	The dc reversal error of the standard
Rt	The dc reversal error of the UUT
Time	The time elapsed from the beginning of the measurement sequence
Temp (ºC)	The ambient temperature recorded by the sensor for the system
Ac (V)	The ac voltage (or current) required to match the dc reference voltage or current

The bottommost line in the data file presents the average values of the data in each column, along with the standard deviation of the measurements (s) and the k = 2 calculated uncertainty of the calibration (uc:).

Each frequency specified in the current or voltage VI will be appended to the data file for the voltage or current range being calibrated. This can lead to a mixing of dates and possibly converters, so some care is required when you import the data file into a spreadsheet application for analysis.

File Paths

Although the calibration software is independent of platform (having been run on both Apple Macintoshes and Windows computers) you will need to set the file paths for the data files used by the software. To set the file path, identify the folder in which you wish the folders for discrete calibration to be placed. Note the file path to this folder. Then launch the ac-dc difference application, and advance the view to frame 3. Note the file path indicated by the string constant shown in red text in the yellow box. Change this text to the appropriate file path. When a calibration is started, the software will create or open the appropriate subfolder for the calibration, and create or append data to the appropriate data file. This procedure is explicitly displayed in the following examples:

Example 1: Macintosh file hierarchy

The file hierarchy on an Apple Macintosh goes something like this:

Data Disk:Calibration Files:Calibration Data:Test Folder:123456:10V.dat

To direct the ac-dc software to use this file path when writing files, put this text in the box:

Data Disk:Calibration Files:Calibration Data:Test Folder:

The software will append the appropriate folder and data file name, open a path to the file, and write out the calibration data as required.

Example 1: PC file hierarchy

The file hierarchy on a windows-based PC goes like this

C$:Calibration Files\Calibration Data\Test Folder\123456\10V.dat

To direct the ac-dc software to use this file path when writing files, put this text in the box:

C$:Calibration Files\Calibration Data\Test Folder\

The software will append the appropriate folder and data file name, open a path to the file, and write out the calibration data as required.

Appendix E: Instrument Definitions

Introduction to Appendix E

As described in the sections pertaining to running the voltage and current VIs, the software supports the use of many different types of instruments in the calibration systems. In general, you need only set the appropriate instrument definitions in the enumerated lists in the **GPIB Bus Status** cluster; the software handles all GPIB bus commands. As of February 2003, when this document was assembled, the instruments pre-defined in the enumerated lists were sufficient to enable the automated systems to calibrate all thermal transfer standards routinely encountered in the calibration service over the entire parameter space offered by the service. Any expansion of the parameter space or the development of new transfer standards may prompt additional instrumentation to be added to the lists.

Adding Instrument Definitions

Adding instruments to the GPIB bus definitions is relatively straightforward, although, since the addition of instruments requires some programming, the user should be well versed in LabVIEW before attempting to add instrument definitions. To add an instrument to an enumerated list, first select the LabVIEW Operate tool (✋) and select the instrument definition at the bottom of the enumerated list to which you wish to add. Then press the command key (⌘) simultaneously with the mouse button and select the **Add Item After** option. Enter the name of the new instrument in the box provided, and press the ENTER key on the numeric keypad. The new instrument will now be available in the **GPIB Bus Status** cluster for your selection.

Now comes the fun part. As soon as you changed the **GPIB Bus Status** cluster, the VI became unexecutable because the **GPIB Bus Status** cluster no longer matches the cluster in all the subVIs that use this structure. So, you will need to find all the subVIs that access the **GPIB Bus Status** cluster and insert the new instrument into each subVI. To find a list of the subVIs that have errors, press COMMAND-L (⌘+L). This opens a window that shows you the subVIs that are now in error because of the change in the main VI. You may double-click on each entry to open the subVIs. Modify the cluster in the subVIs as you did in the main VI.

Several of the subVIs are used to interact with the GPIB bus. You will need to select the VI(s) that control the instrument you just added to the **GPIB Bus Status** cluster, and add appropriate code so that the VI can control the instrument. See Appendix A for more information on the function of the subVIs.

GPIB Instrument Definitions

The instrument definitions included in the present version of the automated system software are presented in the tables below. The addresses of the instrument may vary according to system, but all GPIB instruments will have addresses in the range of 1 to 30.

Table E-1. Automated system instrument definitions.

Instrument Type	Instrument	Description
DC Source	Fluke 5440B	Dc Calibrator. 0 V to 1000 V.
	Fluke 5700 Series	Multifunction Calibrator. 0 V to 1000 V in dc mode. Fluke Models 5700 and 5720 share common bus commands.
	Datron 4000	Dc Calibrator. 0 V to 1000 V.
	Datron 4700	Multifunction Calibrator, 0 V to 1000 V in dc mode.
	Systron-Donner M-107	Dc calibrator. 0 V to 1000 V.
Ac Source	Fluke 5700 Series	Multifunction Calibrator. 0 V to 220 V rms, 10 Hz to 100 kHz; 0 V to 30 V rms, 100 kHz to 1 MHz; 0 V to 1 V, 30 MHz in ac mode. Fluke Models 5700 and 5720 share common bus commands.
	Fluke 5700A/5215A	Ac Calibrator and Power Amplifier. 0 V to 1000 V rms, 10 Hz to 100 kHz in combination;
	Fluke 5200A/5215A[1]	Ac Calibrator and Power Amplifier. 0 V to 1000 V rms, 10 Hz to 100 kHz in combination; 0 V to 120 V rms, 10 Hz to 1 MHz for Fluke 5200A alone.
	Datron 4200	Ac Calibrator. 0 V to 1000 V rms, 10 Hz to 30 kHz; 0 V to 750 V rms[2], 10 Hz to 100 kHz; 0 V to 20 V rms, 10 Hz to 1 MHz.
	Datron 4700	Multifunction Calibrator. 0 V to 1000 V rms, 10 Hz to 30 kHz; 0 V to 750 V rms[1], 10 Hz to 100 kHz; 0 V to 20 V rms, 10 Hz to 1 MHz in ac mode.

[1] The Fluke 5215A is a 100:1 power amplifier that will supply 1000 V from 10 Hz to 100 kHz. It is ac coupled and therefore cannot be used separately from the Model 5200A ac calibrator.

[2] In practice, the maximum available voltage will depend on the capacitance of the load.

Table E-1. Automated system instrument definitions.		
Instrument Type	Instrument	Description
	Fluke 5700/PA-25[3]	Multifunction Calibrator and Power Amplifier. 0 V to 100 V rms, 10 Hz to 1 MHz. Fluke Models 5700 and 5720 share common bus commands.
	Fluke 5200A/PA-25	Ac Calibrator and Power Amplifier. 0 V to 100 V rms, 10 Hz to 1 MHz.
	Datron 4200/PA-25	Ac Calibrator and Power Amplifier. 0 V to 100 V rms, 10 Hz to 1 MHz.
	Datron 4200/PA-1182[4]	Ac Calibrator and Power Amplifier. 0 V to 1000 V rms, 10 Hz to 100 kHz.
Transconductance Amplifier	Clarke-Hess 8100A	Used in combination with ac and dc calibrators: 0 A to 100 A, 10 Hz to 100 kHz, voltage switched at the input.
	Guildline 7620A	Used in combination with ac and dc calibrators: 0 A to 20 A, 10 Hz to 100 kHz, voltage switched at the input.
Std. DVM	Keithley 182	High-performance nanovoltmeter.
	HP 3458A	High-performance voltmeter, used in dc mode.
	HP 34420A	High-performance nanovoltmeter.
Test DVM	Keithley 182	High-performance nanovoltmeter.
	HP 3458A	High-performance voltmeter, used in dc mode.
	HP 34420A	High-performance nanovoltmeter.
Dc DVM	Keithley 181	Digital Voltmeter
	Fluke 8506A	Digital Voltmeter
Temperature	Keithley 181	Digital Voltmeter
	Fluke 8506A	Digital Voltmeter
Relay	HP 3497A/Internal	Relay controller with internal relays[5].
	HP 59306A/External	Relay controller with external relays.
	HP 59306A/HP8761A	Relay controller with high-frequency relay.

[3] The Optimation PA-25 is a 20:1 power amplifier that will supply 100 V from dc to 1 MHz.

[4] The Optimation PA-1182 is a 100:1, dc coupled amplifier, suitable for use on both dc and ac. The system supplies low-voltage ac and dc signals to its input terminals.

[5] Internal relays refer to relays built into the systems in dedicated switching panels (See Figure 1 on page Introduction – 3 for a photograph of System II, showing the relay panel). External relays refer to relay boxes separate from the system. The coil voltages of external relays must be furnished from external power supplies.

Appendix F: A Brief Explanation of Uncertainty Analysis

The uncertainties quoted by the NIST Ac-dc Difference Calibration Service are calculated in accordance with NIST Technical Note 1297. The combined standard uncertainty of a measurement is the root-sum-of-squares (RSS) method of combining uncertainty components as standard deviations.

These uncertainty components may be evaluated as either Type A or Type B, where the former can be evaluated using statistical means and the latter cannot. For a determination of ac-dc difference using a NIST automated calibration system, the Type A uncertainty is the standard deviation of the points that are averaged to determine the ac-dc difference. The contributions to the uncertainty arising from the thermal converters themselves and the measurement system are evaluated as Type B components. These two uncertainty components are combined using the RSS method to calculate the combined standard uncertainty. The expanded uncertainty (the "final" uncertainty provided to the customer or for NIST standards in a recharacterization) is the combined standard uncertainty multiplied by a coverage factor (k) of 2, corresponding to a confidence level of approximately 95 %.

To assist in assigning uncertainties to the measurements made by the automated systems, the software will automatically calculate the uncertainty by combining the standard deviations of a determination with the Type B components previously evaluated for a particular type of thermal converter at a voltage and frequency combination. The Type B uncertainties are stored in tab-delimited data files as described in Table F-1.

Table F-1. The names and descriptions of the data files storing the Type B uncertainty information for the NIST automated ac-dc difference calibration system.

Data File Name	Description
Internal.dat	Type B components for NIST standards
Coaxial.dat	Type B components for coaxial thermal voltage converters
792A.dat	Type B components for Fluke 792A thermal transfer standards
Multirange.dat	Type B components for multirange thermal transfer standards
TCC.dat	Type B components for thermal current converters

☛ **Note:** You must indicate the type of thermal converter to calculate the uncertainties for by choosing the data file to use in the **Uncertainties For:** list box on the Ac-dc Difference front panel.

Appendix G: References

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