# Internet-Based Calibration of a Multifunction Calibrator

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***Abstract***

*A new way of providing calibration services is evolving which employs the Internet to expand present capabilities and make the calibration process more interactive. Sandia National Laboratories and the National Institute of Standards and Technology are collaborating to set up and demonstrate a remote calibration of multifunction calibrators using this Internet-based technique that is becoming known as "e-calibration." This paper describes the measurement philosophy and the Internet resources that can provide real-time audio/video/data exchange, consultation and training, as well as web-accessible test procedures, software and calibration reports. The communication system utilizes commercial hardware and software that should be easy to integrate into most calibration laboratories.*

## 1. Introduction

For many years, the National Institute of Standards and Technology (NIST) and other calibration labs have provided what is called a Measurement Assurance Program (MAP) for electrical and other quantities. The philosophy is that it is more valuable to calibrate the customer's calibration process rather than the traveling standard. In a typical MAP, a NIST-owned standard is calibrated and shipped to the customer where it is calibrated as an unknown. The standard and test data are then returned to NIST where a follow-up calibration and data analysis are performed. A calibration report is issued for the customer's test system rather than for the traveling standard. Communication between NIST and the customer during the test is generally by telephone, fax, or email. While it

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has been possible to attach still images to emails, real-time video has been limited to conference rooms with expensive equipment and dedicated communication lines.

In the past several years, hardware and software have become available that makes it possible to communicate with real-time audio and video via the Internet from virtually any workstation. The major breakthroughs have been inexpensive digital video cameras and video conferencing software that compresses and sends audio and video through the Internet at bandwidths as low as 28 kbps.

The advantage of an Internet-based system is that it can be installed on a computer that controls instruments in a calibration laboratory. This allows metrologists at two or more locations to have video collaboration at the test bench, rather than in a conference room. Real-time images of equipment and connections greatly enhance the metrologists' ability to describe test procedures and do remote troubleshooting. Video conferencing software is now available that provides not only audio and video but text tools and electronic notebooks, as well as the ability to transfer data, and share and control applications remotely. Use of these Internet tools for *telemetrology* was demonstrated in 1999 in the SIMnet project, a network of computers designed to facilitate international comparisons of units in the Americas[(1,2,3)].

This paper describes techniques that are being developed at NIST and Sandia National Laboratories to make use of the latest Internet technology to provide traceability for remote electrical measurement systems. As a demonstration, we selected one of the most complex electrical instruments.

## 2. Multifunction Calibrators

Many of the most precise electrical measurements are performed on artifact standards that are ultimately used to support multifunction calibrators. These are the programmable sources of electrical quantities used to calibrate and verify the accuracy of digital multimeters (DMMs), which are used in a wide variety of industrial applications. In many cases these calibrators require traceability to nationally and internationally accepted electrical standards. Like DMMs, calibrators operate over a wide range of ac and dc voltage, current, and resistance, and it is virtually impossible to test all available outputs. One approach is to calibrate them using two or three electrical artifact standards and rely on *self-calibration* software in the calibrator to compensate for errors over the entire parameter space. This is rather painless for the metrologist but many users are uncomfortable relying on this self-calibration feature. Another approach is to calibrate as many points as possible (often over 200) using multiple high-level artifact standards (zener references, resistors, and thermal converters) to verify that the discrete test points are within specification, or to interpolate between points to estimate uncertainties over the entire parameter space. Most users are more comfortable with this *complete* method but, even with semi-automated systems, it can take a skilled metrologist anywhere from a couple of days up to a week to perform such a test. A third approach, one that is gaining popularity, is to use a calibrated DMM. The DMM is characterized using a complete artifact calibrated *reference calibrator* maintained at a national laboratory or an accredited standards laboratory and then used as a transfer standard to calibrate a remote *test calibrator*. This approach limits the laborious complete artifact calibrations to a few laboratories. The calibration of the traveling DMM can be automated and if the DMM is stable enough, it's possible to calibrate the test calibrator at nearly the same level of uncertainty as the reference calibrator. NIST and at least one of the calibrator manufacturers provide traceability using this technique.

### 3. E-Calibration

By focusing on the calibration of remote systems using new Internet communication technology, we are rapidly moving into the era of *e-calibration*. It should be emphasized from the start that the Internet is used to enhance the measurement, not to replace the traveling standard! In this example, we are essentially describing an Internet-assisted measurement assurance program for calibrators.

The proposed procedure[4] is slightly different than existing MAPs in that the traveling standard (in this case a DMM) is owned by the customer. This DMM is first tested using the customer's calibrator. It is then shipped to NIST where it is tested using a NIST reference calibrator and returned to the customer for follow-up tests. An interactive Internet link between NIST and the customer is established to allow NIST metrologists to observe critical parts of the test. With digital cameras and microphones at each location, NIST can provide real-time consultation and assist with troubleshooting during the test. The customer can download the latest test procedures and control software from a NIST website. The customer's *before* and *after* data can be sent electronically to NIST for analysis. Once completed, a password-accessible report, that expresses the test calibrator errors and uncertainties in terms of the NIST reference calibrator, may be posted on a NIST Web site. The status of the system can be monitored by periodic comparisons between the customer's calibrator and DMM. In the future, a database of similar test systems with historical data should make it possible to better predict performance and determine the calibration interval based on uncertainty requirements.

### 4. Sandia National Laboratories

Sandia National Laboratories is interested in e-calibration as a tool to use internally and with other Department of Energy laboratories, as well as a means for obtaining direct NIST traceability. The following is some background on Sandia's Primary Calibration Laboratory (PCL) and information on its workload and calibrator usage levels. The PCL is responsible for calibrating standards and measurement and test equipment for all of Sandia's line organizations. In this capacity, the PCL has six multi-function/multi-product calibrators, two AC measurement standards, and an oscilloscope calibrator. All of these calibrators are used to perform over 5000 calibrations a year. Some of these calibrators are calibrated in-house, while some are sent out externally for annual calibrations. Obviously, anytime a calibrator leaves the facility there are inherent risks in transportation and handling, not to mention the time that the laboratory is without a necessary calibrator. The calibrations that are performed internally are also time-consuming. While the idea of an "artifact calibration" using only a few pivotal standards and the calibrators own internal artifact calibration software has been explored, there are a number of users who would like more data before accepting this method.

One way that Sandia is looking to reduce the number of calibrators calibrated externally is to utilize an e-calibration scheme with NIST. Using a very stable DMM as the transfer standard, Sandia hopes to be able to characterize its own calibrator against one of the NIST reference calibrators, which are fully calibrated against multiple artifact standards quarterly and have been shown to have excellent long-term stability. In many cases the DMM calibration method may be superior and more efficient than existing complete artifact calibration methods.

## 5. Test Protocols[1]

In the initial phase of the project with NIST, Sandia tested a Datron 1281 DMM utilizing a Fluke 5700A calibrator at 10 cardinal points, which covered the parameters of AC voltage and current, DC voltage and current, and resistance. The Datron 1281 was then sent to NIST where metrologists tested the same 10 points using their software and a reference calibrator, whereupon it was returned to Sandia. A series of three tests were run at Sandia interactively with NIST via the Internet. Sandia metrologists ran the three tests using NIST-developed DMM test software. At that time, issues such as equipment setup, cable connections, and types of cables were addressed. During the video conference, Sandia contributed comments on enhancements that would help if they were incorporated into the software. After the final tests were run, the Sandia data were emailed to NIST for review and uncertainty analysis.

In the next phase of this project, it was decided to use an HP 3458A as the traveling DMM. NIST emailed Sandia an enhanced copy of the test software that had been developed at NIST. Because of availability, it was decided to use NIST's HP 3458A DMM instead of Sandia's DMM. NIST ran three sets of 25 test points on their HP 3458A DMM. This DMM was shipped to Sandia where the same tests were run interactively using the Fluke 5700A calibrator. The data was again transferred electronically to NIST, along with the HP 3458A. NIST ran further tests on the DMM, analyzed the various sets of data, and sent the results back to Sandia. Figure 1 shows some of the capabilities of the video conferencing software, including a notebook where images can be saved and transferred.

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[1] Commercial instruments and software are identified in this paper to describe the measurement system. Such identification does not imply recommendation or endorsement by NIST or Sandia, nor does it imply that the instruments or software are necessarily the best available for the purpose.

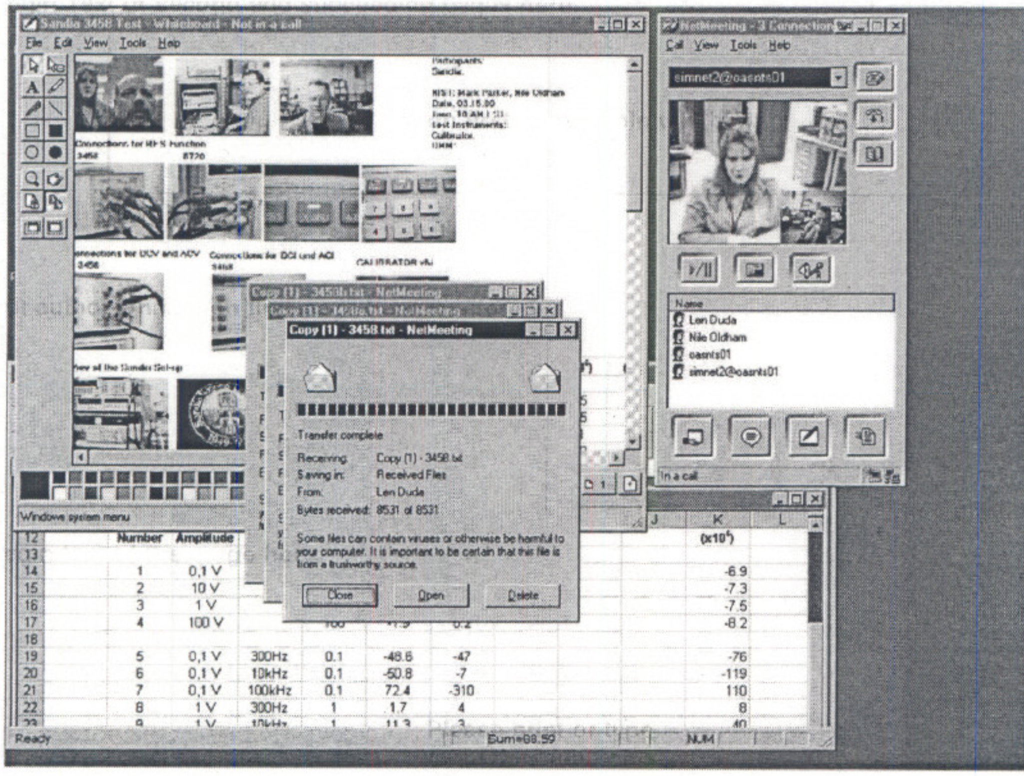


**Figure 1.** Screen image (captured at NIST) showing the use of video conferencing software to enhance calibration communications. The panel on the upper right shows Lisa Bunting Baca at Sandia (large image) with Nile Oldham at NIST (small inset image). On the left is an electronic notebook with the conference participants (including Russ Walker and Mark Parker) and images and descriptions of the setup and connections at Sandia. A shared spreadsheet with data is on the bottom. The panels in the center show data files just transferred from Sandia to NIST.

## 6. Test Results

The results of this test were used to determine the uncertainty at which corrections could be assigned to the Sandia test calibrator using a DMM. Table 1. shows the projected expanded uncertainty of this approach for 25 test points, using the HP 3458A as a transfer standard. The figures include the Type A standard uncertainties at both laboratories and the Type B standard uncertainties of the NIST reference calibrator, combined in accordance with reference (5), with k=2. The table also shows the projected transfer uncertainty as a percentage of the one-year uncertainty specification (95% confidence level) of the Sandia calibrator. The large uncertainty ratios are possible because of the stability of the calibrators. The NIST reference calibrator, which is not physically moved or electrically adjusted, has a calibration uncertainty that is typically four times better than the manufacturer's specifications.

| Function | Amplitude (V, A, kΩ) | F(kHz) | Expanded Uncertainty (parts in $10^6$) | Percent of Calibrator Specification |
|---|---|---|---|---|
| DCV | 0.1 | | 4.5 | 32 |
| DCV | 1 | | 2.4 | 30 |
| DCV | 10 | | 1.3 | 17 |
| ACV | 0.1 | 0.3 | 50 | 27 |
| ACV | 0.1 | 10 | 50 | 27 |
| ACV | 0.1 | 100 | 350 | 32 |
| ACV | 1 | 0.3 | 20 | 25 |
| ACV | 1 | 10 | 21 | 25 |
| ACV | 1 | 1000 | 504 | 17 |
| ACV | 10 | 0.3 | 21 | 26 |
| ACV | 10 | 10 | 21 | 25 |
| ACV | 10 | 1000 | 500 | 14 |
| DCV | 100 | | 2 | 25 |
| ACV | 100 | 1 | 28 | 31 |
| ACV | 100 | 100 | 54 | 9 |
| DCI | 0.01 | | 12 | 23 |
| ACI | 0.01 | 0.3 | 80 | 46 |
| ACI | 0.01 | 5 | 102 | 10 |
| DCI | 1 | | 20 | 19 |
| ACI | 1 | 0.3 | 104 | 15 |
| ACI | 1 | 5 | 201 | 25 |
| RES | 0.01 | | 8.0 | 29 |
| RES | 1 | | 3.0 | 23 |
| RES | 100 | | 5.0 | 36 |
| RES | 10000 | | 30.0 | 75 |

**Table 1.** Preliminary results of tests using a traveling DMM as a transfer standard.

## 7. Challenges Encountered

There were several issues that had to be addressed before Sandia and NIST were able to implement the Internet-based video conferences. One of these was the corporate network firewall issue. The lack of safety features on the video conferencing software made it inadequate for Sandia's corporate security requirements. Thus, an external open network (EON) port had to be established, from which none of Sandia's internal networks could be accessed externally. Unfortunately, Sandia's automated calibration software and email resided on the internal restricted network. Sandia personnel were eventually able to move the automated calibration application software (although not the database) over to the EON for future use in e-calibration conferences. Sandia also set up a separate email account on the EON for easy transfer of test data.

Another issue that hampered communication was the single user headset used in transmitting and receiving audio. Since there were several Sandia personnel collaborating during the conference, it was difficult for everyone to be a participant. A compromise was worked out in which an ISDN speakerphone was utilized for audio communication. This has worked out well for the purposes of the tests that were run at Sandia; however, the limitations of this method are obvious when performing cross-organizational or global e-calibration.

## 8. Conclusions

The use of Internet-based e-calibration has enabled quick, direct transmission of data, test software, troubleshooting techniques, and calibration reports. Future plans between NIST and Sandia National Laboratories are to conduct further testing with various DMM's. A 220-point test is planned, which will be able to better characterize Sandia's calibrators.

Another test that Sandia and NIST will try to perform is to have Sandia personnel run Sandia's own test software on the transfer DMM. The DMM would be shipped to NIST where NIST would then use its own software on the transfer DMM to test the same points as Sandia, while using the internet to ensure that the test set up and configuration are the same as Sandia's test. Using both NIST and Sandia control software (part of the overall calibration process) and comparing the results would give us confidence that both are implementing the same test protocols. Obviously, the more complex the test, the more difficult it is to verify that the software is executing the desired functions. The ability to test one piece of software using independently developed, downloadable software to perform the same measurement will prove to be a powerful tool in e-calibration.

The test procedures described in this paper will be used to verify that a calibrator is within specifications and to characterize it at the specific test points. However, it has been shown that the long-term stability of the calibrators may be much better than their uncertainty specification. NIST and Sandia are interested in working with manufacturers and users to determine if and how tests similar to those described here can be used to enhance the calibrator uncertainty over its entire parameter space.

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