# Enhancing Long Scale Digital Multimeters and Multifunction Calibrators

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**Abstract**

This paper discusses some developments in utilizing automation of a Direct Current Comparator based resistance measurement system [1] to improve the working specification of long scale Digital Multimeters and Multi-Function Calibrators Resistance Functions. With the use of automation in the Direct Current Comparator based system, minimal user intervention is required to perform a complete traceable characterization for the resistance functions of these devices that will allow short term specifications be applied with long term type calibration. It now becomes practical to utilize frequent complete characterization of the resistance functions in both Long Scale Digital Multimeters, and Multifunction Calibrators. This frequent calibration cycle enables the use of these standards as transfer devices and operate them beyond the manufacturer's specification.

## 1. Introduction

Traditionally the maintenance of Long Scale Digital Multimeters and Multifunction Calibrators was accomplished through frequent artifact validation/calibration with the use of check standards with the requirement to return these instruments for a complete characterization through the use of high order standards on an annual basis. Artifact cal is a simplistic approach designed, typically using three standards or less, that ensures the instrument will meet the manufacturer's specification. Guildline uses artifact type calibration on some of its own high order instrumentation such as our 6520 Programmable Teraohmmeter. It is an excellent tool for adjusting or realignment of an instrument easily, but should be followed in-conjuction with a full and complete calibration/characterization to ensure that all the calculated values are within their specifications. The full characterization of these instruments, which can be very extensive, must also be performed generally on the annual basis as part of the maintenance of the published specification.

As accreditation comes into the workforce, more and more calibration laboratories are requiring a full characterization for all ranges. In fact, the trend is to perform the full characterization on a more frequent basis, such as quarterly basis, allowing the calibration laboratory to use the short term specifications (90 days or less) of the instrumentation. One of the challenges of these instruments has been the resistance function. Take for example, a high order type calibrator such as the Fluke 5720. Complete verification of the resistance function can be a very manual and time intensive operation. The 5720 Service Manual, Resistance Calibration function calls out for multiple values of resistance standards, a second calibrator, and a long scale DMM. Through the use of switching leads (Transfer methods), calculations and comparisons, values generated by the calibrator are verified, but not all. Other intermediate values capable of being generated by the calibrator are then derived from this process.

What if the full characterization could be performed more easily and more importantly - accomplished via complete automation. What if ALL outputs of the calibrator were independently verified by primary standards? What if the method used allowed for tracking the history, drift and standard deviation of <u>every</u> value on the instrument or standard? By incorporating a method such as this, the standards can operate at a enhanced specifications and with using statistical methods reduce the requirements of more frequent calibrations.

## 2. Scope of This Paper

This paper discusses the theory behind both the calibration of the Long Scale Digital Multimeter and the Multifunction Calibrator and the improvement in specifications. An overview of the Direct Current Comparator based system architecture is also discussed. This paper then further analyzes test data on an industry standard Digital Multimeter and Multifunction Calibrator, as well as demonstrates the effectiveness of the methodology. The software automated quality assessment process is explained and how it benefits by increasing the productivity of the calibration method without compromising the measurement requirements.

## 3. System Architecture

A typical Direct Current Comparator based resistance measurement system is outlined in Figure 1. The major components of such a system consist of the Direct Current Comparator Bridge any range extension peripherals, low thermal matrix scanners, computer system with control software and printer, a set of temperature stabilized reference resistors, a set of working resistors, as well as the device under test.

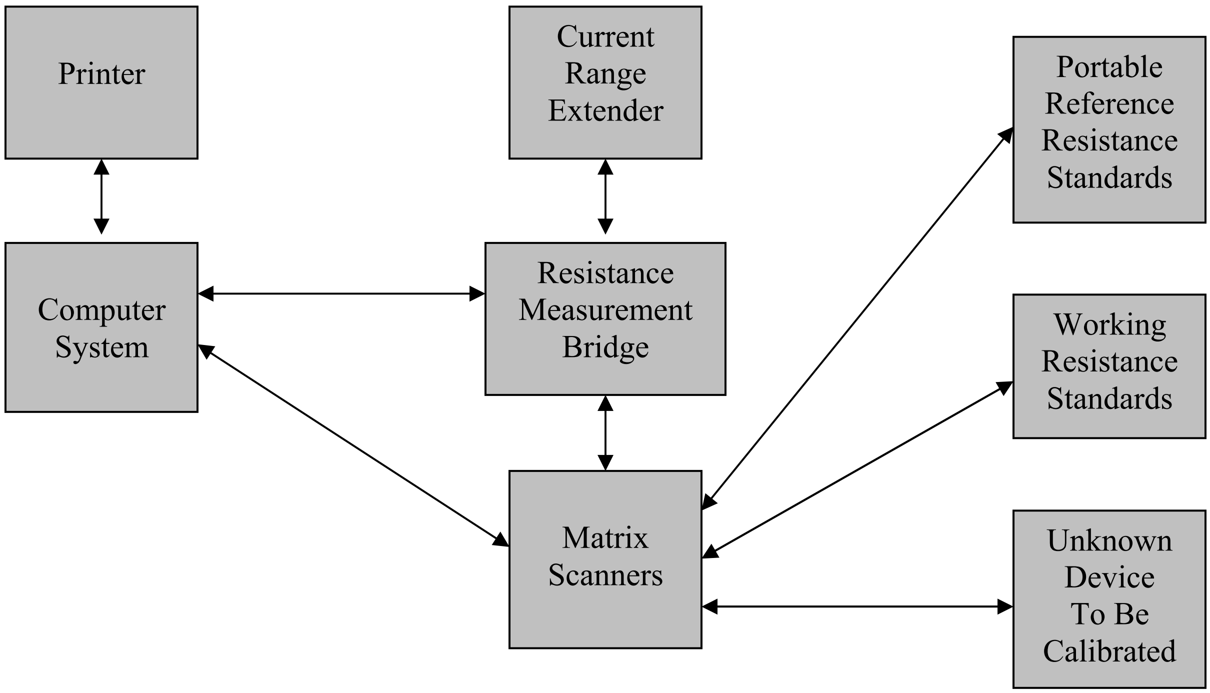


Figure 1. Resistance measurement system architecture.

The Direct Current Comparator Bridge [2] within the system is used to transfer resistance value from one (known) standard device to another (unknown) unit under test. The bridge is a true ratio metric device with accuracies sufficient for maintaining traceable resistance uncertainties of better than 10:1 of commercially available Long Scale Digital Multimeters and Multifunction Calibrators. The range extender associated with this example system allows for extension to lower resistance values and higher test currents.

The matrix scanners are of low noise and high isolation design, also having low thermal EMF characteristics as to not introduce errors into the measurements. The scanners also carry a full four-terminal measurement as to maintain best practice for high accuracy resistance measurement.

There are two main sets of resistors for a typical measurement system, one for routine calibration work and one to serve a primary transfer to the primary or national lab. Both sets should always be temperature controlled for best stability. The primary set is usually not connected to the system and is only temporarily connected for system calibration. This calibration process determines a traceable set of values for the working set of resistors [1], which can then be used on a more routine basis, including the procedures outlined in the paper.

For the examples given in this paper a Guildline model 6625 Resistance Measurement System is used. This system consists of a 6622 Direct Current Comparator automatic bridge with a resistance ratio transfer as low as 0.1 ppm. The system also contains a 6623-2A range extension, for lower resistance values down to 0.001 ohm with a current drive of 2 Amps. The typical specifications for these devices are outlined in Table 1.

| Unknown Resistance Range (Ohms) | 6622 With 6623-2A Relative Uncertainty (±ppm over 1 year) |
|---|---|
| 0.001 to 0.01 | 99 |
| 0.01 to 0.1 | 9 |
| 0.1 to 1 | 0.6 |
| 1 to 10 | 0.1 |
| 10 to 100 | 0.1 |
| 100 to 1k | 0.1 |
| 1k to 10k | 0.1 |
| 10k to 100k | 0.35 |
| 100k to 1M | 0.5 |
| 1M to 10M | 0.75 |
| 10M to 100M | 2.5 |

Table 1. 6622 with 6623-2A typical specifications.

The working set of resistors used are a 6634A 10 element temperature stabilized rack mount standard. The 6634A contains the values outlined in Table 2. This device is a direct replacement for the traditional oil bath with resistors.

| Nominal Resistance Value (Ohms) | Calibration Uncertainty (+/-PPM) | Stability 24 Hour Period (+/-PPM) | Stability 12 Months (+/-PPM) | Temperature Coefficient (+/-PPM/°C) |
|---|---|---|---|---|
| 0.1 | 0.5 | 0.1 | 3 | 0.01 |
| 1 | 0.3 | 0.005 | 2 | 0.005 |
| 10 | 0.3 | 0.005 | 2 | 0.005 |
| 100 | 0.3 | 0.005 | 2 | 0.005 |
| 1k | 0.3 | 0.005 | 2 | 0.005 |
| 10k | 0.3 | 0.005 | 2 | 0.005 |
| 100k | 1 | 0.02 | 2 | 0.01 |
| 1M | 7 | 0.04 | 7 | 0.02 |
| 10M | 15 | 0.2 | 10 | 0.2 |

Table 2. 6634A resistance elements.

The 6634TS is the primary standard used to support the system for traceability to the National lab. The 6634TS is a battery backed up temperature regulated resistor that is calibrated at the national lab. These traceable values are then transferred to the working set. The values and typical uncertainties are outlined in Table 3.

| Nominal Resistance Value (Ohms) | Calibration Uncertainty (+/-PPM) | Stability 24 Hour Period (+/-PPM) | Stability Next 12 Months (+/-PPM) | Temperature Coefficient (+/-PPM/°C) |
|---|---|---|---|---|
| 1 | 0.2 | 0.004 | 1.5 | 0.005 |
| 10k | 0.2 | 0.004 | 1.5 | 0.005 |
| 1M | 5 | 0.03 | 6 | 0.01 |
| 100M | 18 | 0.5 | 21 | 0.3 |

Table 3. 6634TS resistance elements.

Lastly there are two 6664A scanners supplying 32 channels of automated, four terminal interconnectivity for devices in the system. This allows all the resistance devices listed, as well as the unknown devices to be connected automatically to the system for measurement.

All of these items are controlled via the system controller consisting of a personal computer with an IEEE-488 controller and a printer. The system controller performs all automation associated with data acquisition and report generation.

## 4. Long Scale Digital Multimeter Calibration

The automatic calibration of a Long Scale Digital Multimeter utilizes the working set of resistors for their absolute traceable value to determine the meter error. To accomplish this, the bridge and range extender connections are removed from the system. The scanner output channels that were connected to the Rs and Rx terminals of the bridge are then shorted together as shown in Figure 2 (next page). This allows connection of any of the working set elements to be made available to any of the scanner channels in which the meter(s) are connected. A suitable 8 pole 2 position switch can simplify this process. This switch must be of high isolation and low noise design as well as have low thermal EMF characteristics congruent of that with the scanners. The Long Scale Digital Multimeter is also connected to the IEEE-488 communication link of the computer.

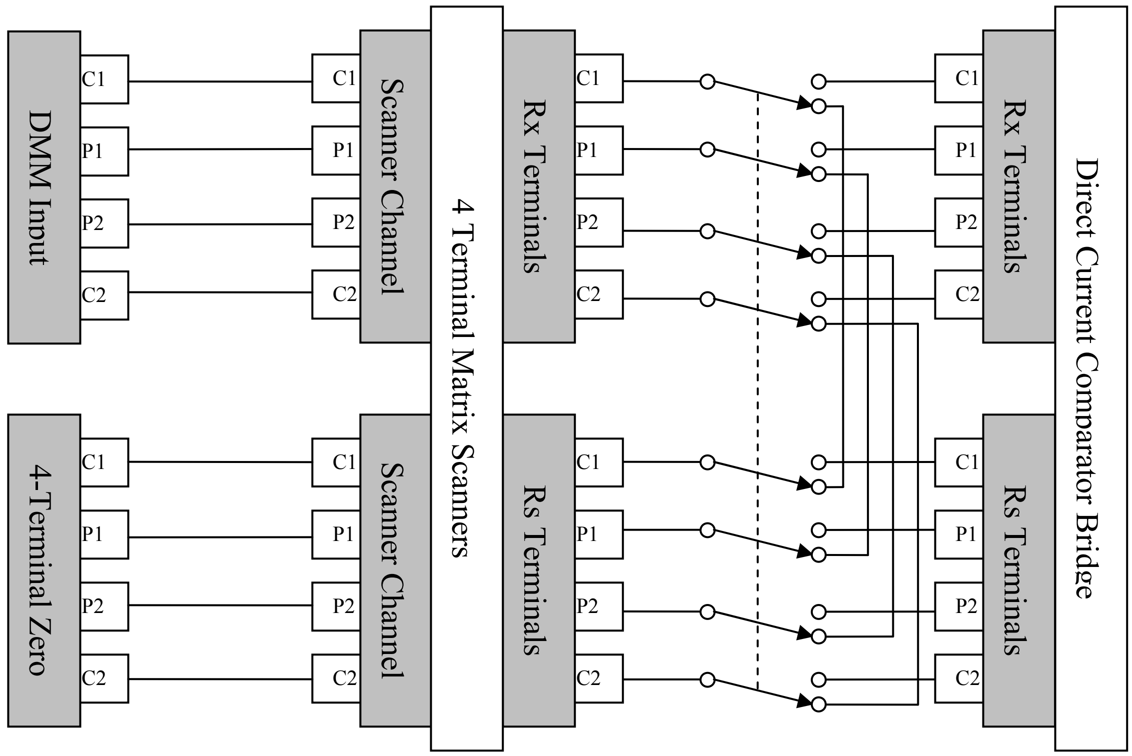


Figure 2. Long scale digital multimeter wiring diagram.

As a first step one channel of the scanner is connected to a four wire zero that also compensates for any measurement inherent to the system interconnections. This channel is selected by the computer and attached to the Long Scale Digital Multimeter. Readings are captured to determine the zero offset error.

The computer then reads the data from the Long Scale Digital Multimeter(s) as it sequences through all of the necessary working set resistors. When data of sufficient quality (see Section 6) is retrieved the computer determines the Long Scale Digital Multimeter average value and compares that to the traceable value associated to the working set resistor. The meter error is determined against this traceable value and given a traceable uncertainty.

Using the Automated Quality Assessment technique outlined in Section 6 ensures a good quality measurement in the minimum time required making it reasonable to characterize an industry standard 8 ½ digit meter such as the HP3458 in a couple hours. Multiple Long Scale Digital Multimeters can be connected to the system allowing a batch of these devices to be run over night or over the weekend completely unattended.

4.1. Long Scale Digital Multimeter Data

The data presented in Table 4 (next page) is representative of that collected from characterizing a HP/Agilent 3458 Long Scale Digital Multimeter. This data is compared the HP/Agilent 3458 published 1 year and 24 hour specifications, in conjunction with the transfer uncertainty associated with the bridge measurement.

| Nominal Value | 1 Year Uncertainty | 24 Hour Relative Uncertainty | Traceability Uncertainty | Target Deviation | Total 24 Hour Uncertainty |
|---|---|---|---|---|---|
| 1 | 65 | 53 | 0.3 | 0.5 | 53.01 |
| 10 | 20 | 8 | 0.3 | 0.5 | 8.07 |
| 100 | 17 | 6 | 0.3 | 0.3 | 6.04 |
| 1 k | 10.5 | 2.2 | 0.3 | 0.2 | 2.26 |
| 10 k | 10.5 | 2.2 | 0.3 | 0.2 | 2.26 |
| 100 k | 10.5 | 2.2 | 1 | 0.2 | 2.45 |
| 1 M | 17 | 11 | 1 | 1 | 11.22 |
| 10 M | 60 | 55 | 7 | 5 | 56.34 |
| 100 M | 510 | 510 | 15 | 5 | 510.32 |
| 1G | 5010 | 5010 | 80 | 50 | 5011.64 |

Table 4. 3458 uncertainty analysis.

As seen in the analysis the largest contribution of uncertainty comes from the Long Scale Digital Multimeter in the uncertainty budget. The calibration accuracies of the working set of resistors are well suited to correct the Long Scale Digital Multimeter. The dramatic improvement here is primarily throughout the mid-range of the meter. The characterization process being fairly rapid at a couple of hours, it is a conceivable process to run daily, or even run multiple units overnight such that all characterized units may be used the improved specification on daily basis.

## 5. Multifunction Calibrator Calibration

The automatic calibration of a Multifunction Calibrator utilizes the absolute traceable value of the working set of resistors and the Direct Current Comparator Bridge to characterize the resistance output function. The Multifunction Calibrator is connected to the matrix scanners as a resistance device as shown in Figure 3 (next page). This allows inter-comparison of the resistance output to the traceable working set through the bridge. In the example given below the second connection to the scanner is to allow for the 2-terminal resistance functions to be calibrated as well. The Multifunction Calibrator is connected to the IEEE-488 communication link of the computer as well.

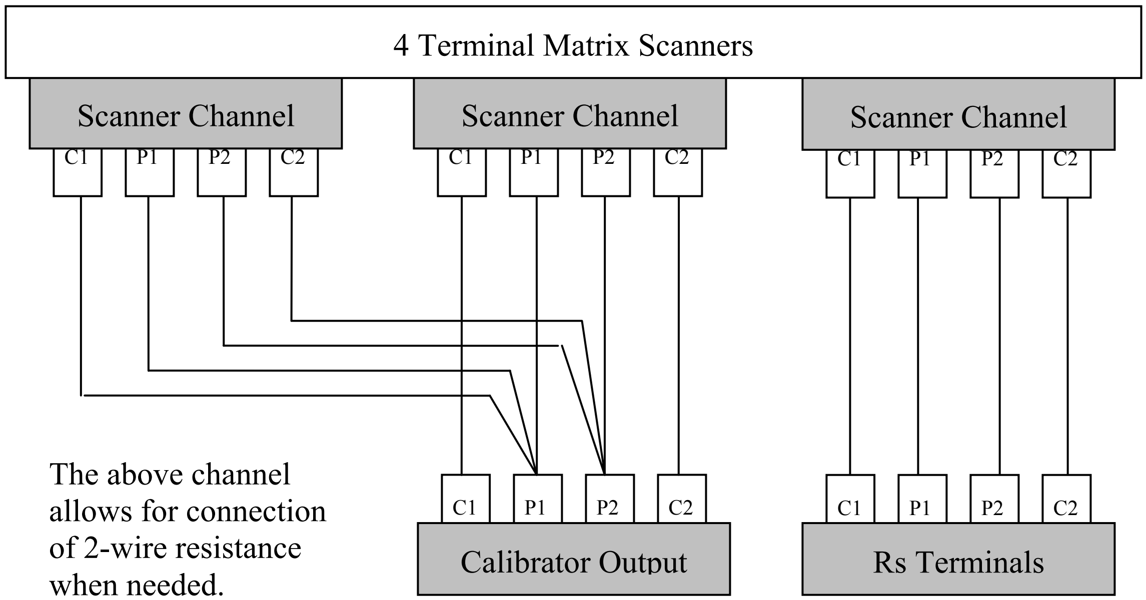


Figure 3. Multifunction calibrator wiring diagram.

The computer configures the Multifunction Calibrator to output a resistance value and selects an appropriate working set resistor for comparison using the bridge. The computer then reads the data from the bridge as it sequences through all of the Multifunction Calibrator resistance output values. When data of sufficient quality (see Section 6) is retrieved the computer determines the ratio data from the bridge is converted to ohms using the known working set value. Each resistance output is given a traceable value and given a traceable uncertainty.

This process also uses the Automated Quality Assessment technique outlined in Section 6 to ensure a good quality measurement in the minimum time required. This makes it reasonable to characterize an industry standard calibrator such as the Fluke 5700/A in about 4-6 hours. Multiple Long Scale Digital Multimeters can be connected to the system allowing a batch of these devices to be run over night or over the weekend completely unattended.

## 5.1. Multifunction Calibrator Data

The data presented in Table 5 (next page) is representative of that collected from characterizing a Fluke 5700A Multifunction Calibrator. This data is compared the Fluke 5700A published 1 year and 90 day specification, in conjunction with the transfer uncertainty associated with the bridge measurement.

| Nominal Value | 90 Day Relative Uncertainty | Traceability Uncertainty | Target Deviation | Total 90 Day Uncertainty | 1 Year Uncertainty |
|---|---|---|---|---|---|
| 1 | 35 | 0.3 | 0.1 | 35.00 | 95 |
| 1.9 | 26 | 0.3 | 0.1 | 26.00 | 95 |
| 10 | 7 | 0.3 | 0.1 | 7.01 | 23 |
| 19 | 6 | 0.3 | 0.1 | 6.01 | 23 |
| 100 | 3.5 | 0.3 | 0.1 | 3.52 | 10 |
| 190 | 3.5 | 0.3 | 0.1 | 3.52 | 10 |
| 1 k | 2.5 | 0.3 | 0.1 | 2.53 | 8.5 |
| 1.9 k | 2.5 | 0.3 | 0.1 | 2.53 | 8.5 |
| 10 k | 2.5 | 0.3 | 0.1 | 2.53 | 8.5 |
| 19 k | 2.5 | 0.3 | 0.1 | 2.53 | 8.5 |
| 100 k | 2.5 | 1 | 0.1 | 2.70 | 11 |
| 190 k | 2.5 | 1 | 0.1 | 2.70 | 11 |
| 1 M | 4 | 1 | 0.2 | 4.14 | 20 |
| 1.9 M | 4 | 1 | 0.4 | 4.20 | 21 |
| 10 M | 12 | 7 | 3 | 15.13 | 40 |
| 19 M | 20 | 7 | 4 | 22.65 | 57 |
| 100 M | 50 | 15 | 4 | 52.81 | 100 |

Table 5. 5700A uncertainty analysis.

As seen in the analysis the bulk of the uncertainty comes from the Multifunction Calibrator as it is the largest component of the uncertainty budget. The use of the Multifunction Calibrator under its 90 day relative (transfer) specification dramatically enhances its specification. The use of the Direct Current Comparator bridge and working standard resistors is still of sufficient accuracy to maintain this improved specification, and with this level of automation, it is now much more feasible to characterize the resistance output of the Multifunction Calibrator on a quarterly basis.

## 6. Automated Quality Assessment

The Automated Quality Assessment is a tool developed in software to define rules based on measurement quality to allow an automated decision between a good and a bad measurement. This decision process is to take place in real time to create an allowance for the earliest acceptance of measurement data. This process will reduce the test time to the minimum required for acceptable data.

Using a defined window of measurements the software updates the calculation of standard deviation as each new reading is available. The window only includes the last *n* number of samples measured. This meaning that the new sample measured will replace the oldest sample in the window. This standard deviation is compared to a defined target standard deviation. When the measured standard deviation over the window is less than the defined target the measurement is accepted and the mean of the window is reported as the measured value.

## 7. Conclusion

The use of this high level of automation in a Direct Current Comparator based resistance system makes it possible to allow frequent calibration on Long Scale Digital Multimeters and Multifunction Calibrators. The more frequent characterization of the Long Scale Digital Multimeter allows the use of the meter as a transfer device [4]. This more accurate specification however does not require the operator to change the way they normally operate the Long Scale Digital Multimeter. The improvement it realized completely within the calibration method.

The more frequent calibration and historical trending, allows the operation of Multifunction Calibrator to a more stringent specification then provided by the manufacturer or allows a practical achievement of published transfer/relative specification. Having this higher accuracy, lower uncertainty will add allow the use of the Multifunction Calibrator in more demanding applications. These applications being, where lower uncertainties and direct traceability is required.

This high level of automation can also be utilized by high volume calibration labs to minimize valuable hands-on time, reduce operator error, and promote measurement consistency when calibrating these devices. The process has been tested and proven with the HP/Agilent 3458 Long Scale Digital Multimeter as well as the Fluke 5700/A Multifunction Calibrator resistance functions.

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