Application Note

A system to measure two terminal high resistance standards at voltages up to 6 kVdc

Abstract
IET Labs wanted a solution for measuring high resistance standards from 10 MΩ to 1 TΩ at voltages above 1000 Vdc with a measurement uncertainty MU of 0.5% or less at a confidence level of k = 2.

There are commercially available meters such as; the Keithley 6517B, IET Labs 1865 Plus, and Measurements International 6652A that measure over a wide range however these instruments are generally limited to 1000 Vdc.

This paper will explore a system comprised of a programmable voltage source, current meter, voltage divider, DVM and LabView software to create a system for measuring 2 terminal resistors at voltages up to 6 kVdc.

The intent was to provide calibrated resistances on a variety of standards, such as the IET labs VRS-100 High Resistance Standards, used to calibrate various megohmmeters and similar instruments that measure at 5 kVdc or higher voltages.

Introduction
The concept was to use a high voltage source, measure the voltage across the device under test DUT and current flowing through the DUT.   The resistance can then be calculated using Ohm's Law.

The voltage and current would be sampled multiple times during the measurement time and resistance plotted over time along with the standard deviation of the average.

A LabView program would be written to: control all instruments, collect data, graphically display the data, calculate standard deviation of the average and report the average resistance value back to the user.

The setup would have to minimize leakage in parallel with the DUT, and address errors due to the input resistance of the current measurement instrument.

Measurement uncertainties would then be calculated for the system taking into account Type A and Type B uncertainties associated with; repeatability, reproducibility, uncertainty of the standards, environmental factors, resolution, and stability.

The system would then be tested against calibrated resistance standards from 10 MΩ to 1 TΩ at 1000 Vdc and higher voltages.

System design and setup

The system consists of the following instruments;

1. Chroma/QuadTech Guardian 6000 Electrical Safety Tester or current Chroma model 19032
2. Fluke 8845A 6 ½ Digit DMM (fluke_8845a DMM)
3. Ohm-Labs KV-VB Voltage Divider 10,000 to 1 (kvvb-compact-divider)
4. IET Labs 1865 Plus Megohmmeter (1865-megohmmeter)
5. National Instruments LabView and GPIB-USB-HS adapter

Figure 1: Instruments used for system along with IET Labs HRRS High Voltage Decade Resistor

The Guardian 6000 was used as it was available, it can provide up to 20 mA of current and has a GPIB interface.

The KV-VB voltage divider has an input impedance of 2000 Ω/V. So just over 2.5 mA of current is needed or around 2.5 W of power depending upon programmed voltage and resistance being measured.

Application Note

The 1865 Plus can be configured to measure and display current rather than just resistance. When measuring current the "-" and Guard terminals are used. This is described further in the application note at the following link 1865_as_a_current_meter.pdf . The 1865 Plus was also easy to control using LabView drivers.

The Ohm-Labs KV-VB Voltage Divider and Fluke 8845A DMM provided an accurate way of measuring the voltage across the DUT.

Figure 2 shows a basic block diagram and wiring diagram. All wiring was 10 kV silicon hook-up wire except for the connection between the low side of the DUT and the "-" terminal of the 1865 Plus which was RG-174U coaxial cable combined with two Pomona 4684 BNC (F) to single banana plug with ground lead.

The signal on the coaxial cable is very close to ground potential so leakage was not a significant contributor to error, when RG-174U coaxial cable was chosen.

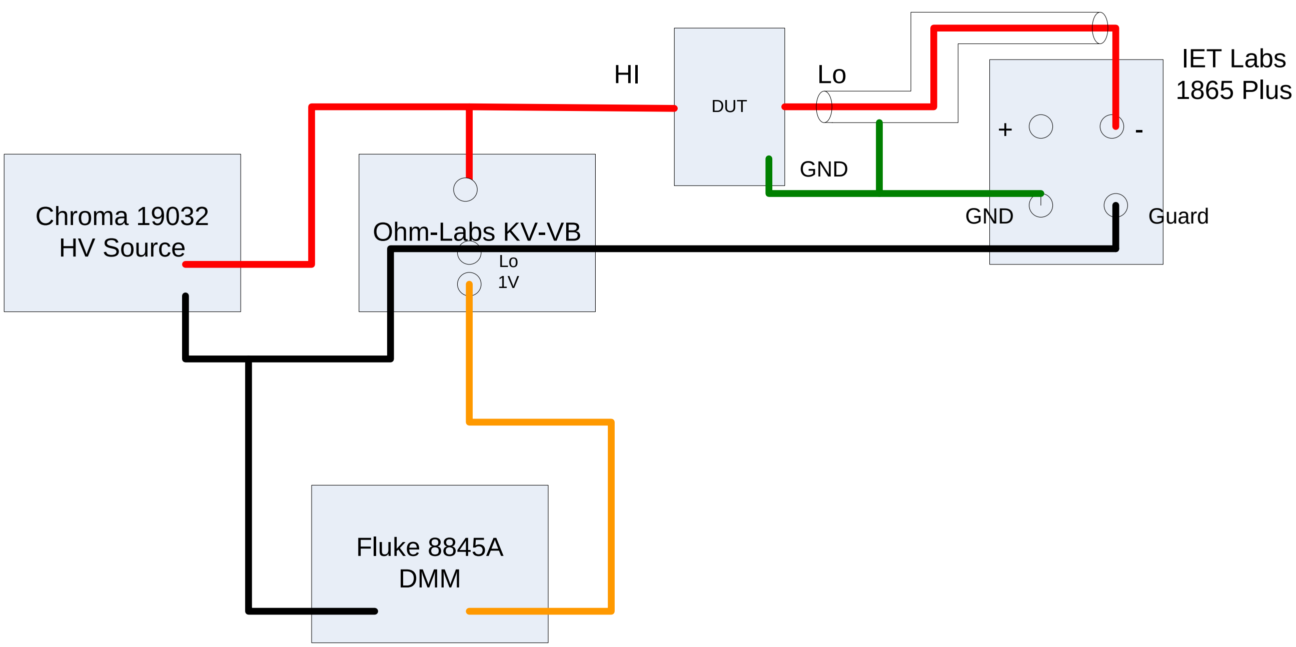

Figure 2: Simplified interconnection diagram

Figure 3: MegBridge in measuring resistance on a HRRS High Voltage Decade Resistor

Theory of operation

The basic operation is simple measure the voltage across the device under test and measure the current flowing through the device under test and use Ohm's Law to calculate the resistance.

The current is measured with the 1865 Plus IR/Megohmmeter Meter. The 1865 Plus can measure current as well with a current accuracy of (0.5% of reading + 0.05% of range + 2 pA).

The Ohm-Labs KV-VB Voltage Divider was chosen, as it has an ratio accuracy of 0.025% and ratio of 10 000 : 1. So 5000 V input results in 0.5 V output to the DMM.

The Fluke 8845A 6 ½ Digit DMM was chosen as it is used in other IET Labs test systems and had already been integrated into our Test Manager Program for control and collection of laboratory data. The dc accuracy of the Fluke 8845A is 0.01% of reading and 0.004% of range. This results in overall accuracy of 0.015% at 5000 Vdc.

A LabView program was written to control the all three pieces of test equipment and provide a user interface to set voltage, number of samples, and provide a graphically display the resistance data over time.

The program configured each instrument, started the dc source and then began alternately taking measurements of current and voltage over the desired number of samples.

Once the number of samples was reached the last 25% of the number of samples was averaged to get a final resistance number. The final resistance number was reported along with the standard deviation of the average.

The test program also provides an intuitive interface to show connections between all instruments.

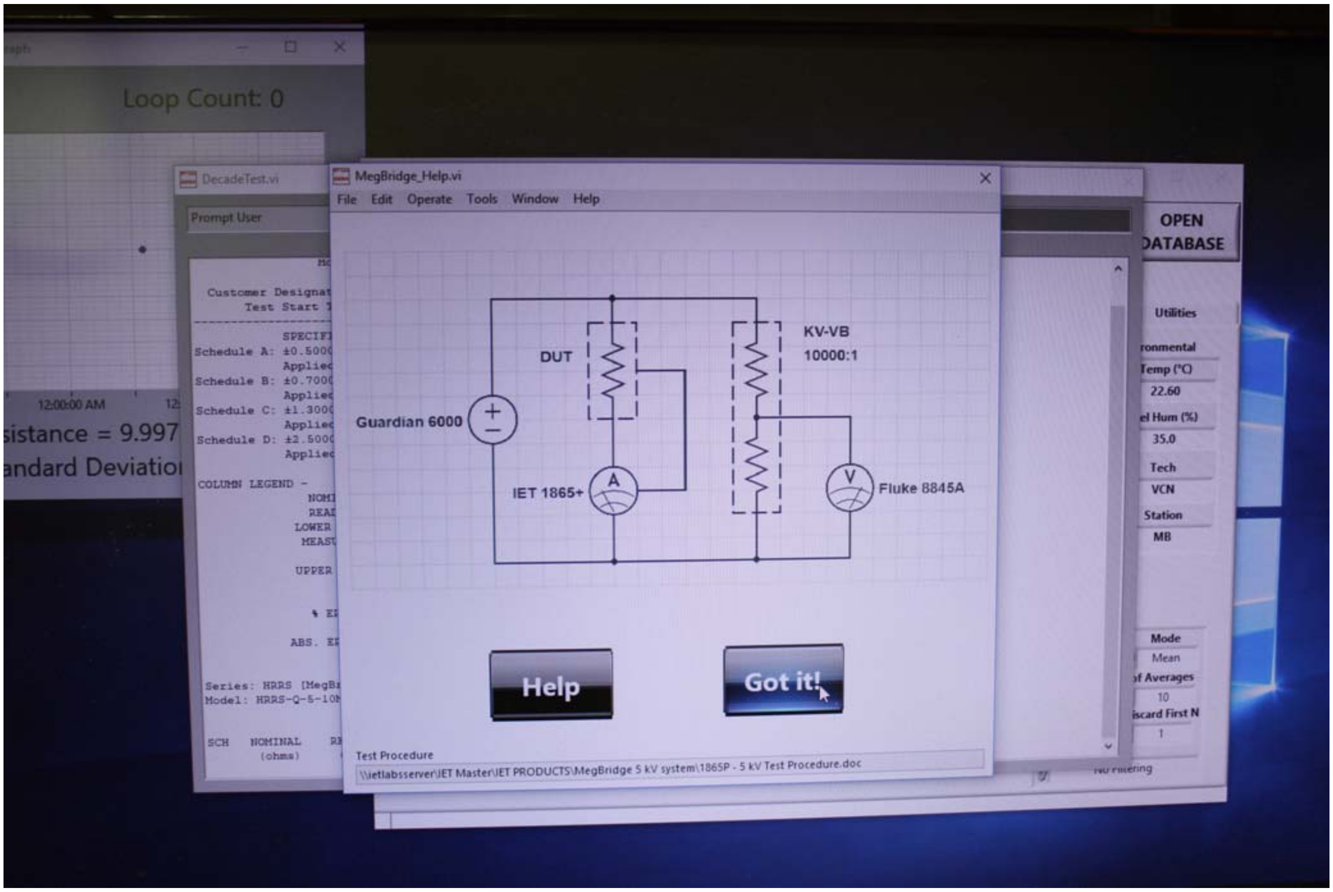

Figure 4: LabView Program prompts operator to verify connections

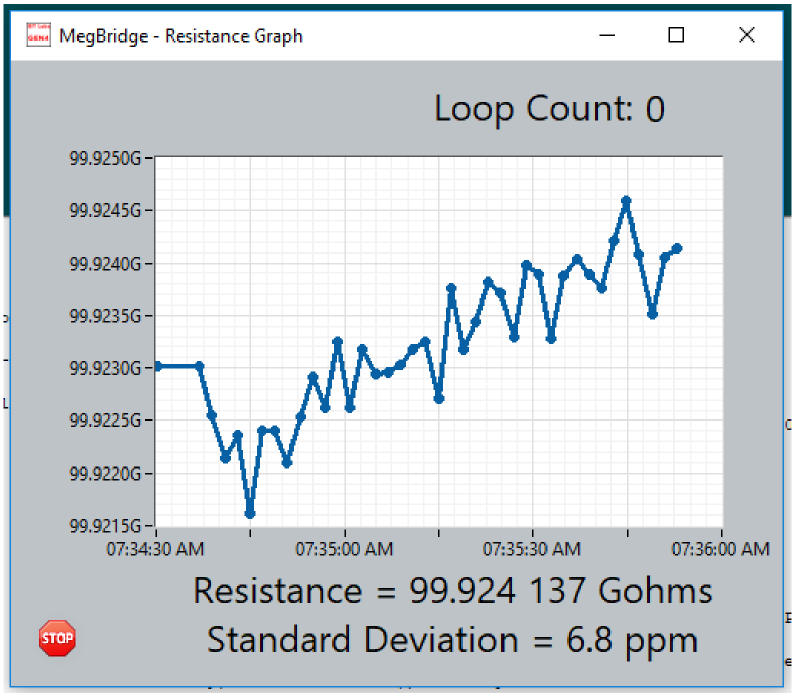

Figure 5: Display of resistance data and standard deviation

The resistance data is plotted during the test. The graph gives a good idea as to when the resistance value begins to level-off.

The number of measurements and the number of values to be used for statistics such as the final average and standard deviation are all programmable.

In the example in Figure 5, 40 measurements were performed which took approximately 90 seconds. The final 10 measurements were used for the average resistance value and standard deviation.

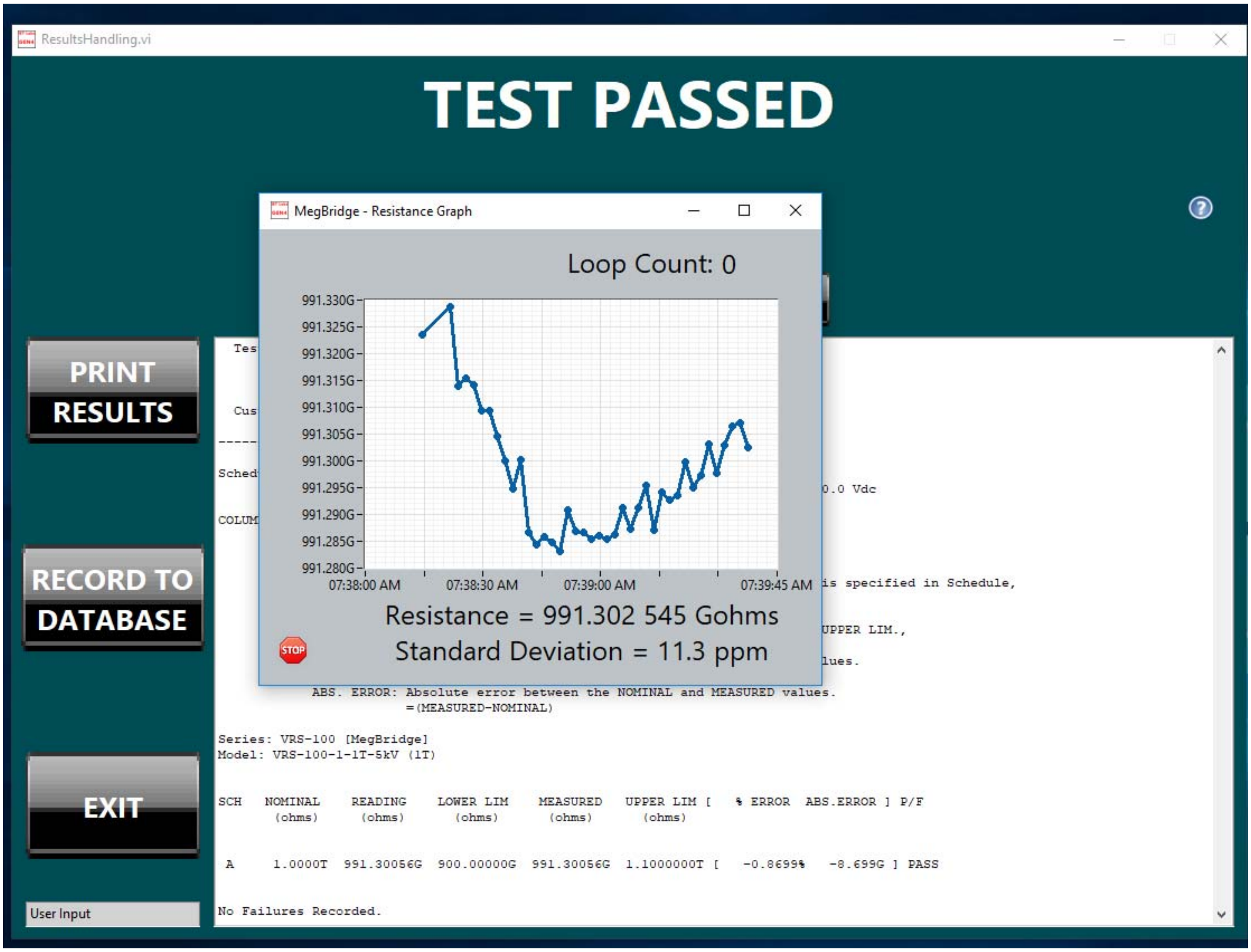

Figure 6 Graph and Results

Once the test has completed the graph is shown along with test data showing nominal value, measured value, pass/fail limits, error from nominal in % and absolute. This data can be printed or stored into a database.

Uncertainty Calculations

The total uncertainty of the system is calculated based upon the individual CMCs for the Fluke 8845A, Ohm-Labs KV-VB and IET Labs 1865 Plus.

1865+ Current Meas	Resolution 5 digits (ppm)	Divisor based on rectangular distribution. Note 4 and Note 7	Resolution @ k=1 (ppm)	1865 Plus Accuracy (0.5% reading + 0.005% range) (1 year 0 to 50 °C < 45% RH)	Divisor based on k=2	1865 Plus Abs unc in capacitance @ k = 1 (ppm)	Type A Repeatability and Reproduciblity of Measurement (ppm) k =1	Environmental Note 11 k=1 (ppm)	Stability Note 12 k = 1 (ppm)	MU I measurement, RSS sum of columns J, P, (ppm) k=1
10 MΩ	10.000	3.464	2.89	0.50%	2.000	2500	100	0	0	2502
100 MΩ	10.000	3.464	2.89	0.50%	2.000	2500	100	0	0	2502
1 GΩ	10.000	3.464	2.89	0.50%	2.000	2500	100	0	0	2502
10 GΩ	10.000	3.464	2.89	0.50%	2.000	2500	100	0	0	2502
100 GΩ	10.000	3.464	2.89	0.50%	2.000	2500	100	0	0	2502
1 TΩ	10.000	3.464	2.89	0.50%	2.000	2500	100	0	0	2502
10 TΩ	10.000	3.464	2.89	0.50%	2.000	2500	100	0	0	2502

Table 1: CMC calculation of KV-VB Voltage Divider

The Ohm-Labs KV-VB Voltage Divider was chosen, as it has an ratio accuracy of 0.025% and ratio of 10 000 : 1. So 5000 V input results in 0.5 V output to the DMM.

Julie Research KV-VD-10				KV-VD-10 Accuracy (%)	Divisor based on k=2	JR KV-VD-10 Abs unc in capacitance @ k = 1 (ppm)	Type A Repeatability and Reproduciblity of Measurement (ppm) k =1	Environmental k=1 (ppm)	Stability (Farads) Note 12 k = 1 (ppm)	MU Vdivider, RSS sum of columns P, T, V (ppm) k=1
				0.025%	2.0	125	0	5	0	125

Table 2: CMC calculation of KV-VB Voltage Divider

The Fluke 8845A 6 ½ Digit DMM was chosen as it is used in other IET Labs test systems and had already been integrated into our Test Manager Program for control and collection of laboratory data. The dc accuracy of the Fluke 8845A is 0.01% of reading and 0.004% of range. This results in overall accuracy of 0.015% at 5000 Vdc.

DMM V Measure Fluke 8845A	Resolution (ppm) 1uV on 1 V range)	Divisor based on rectangular distribution. Note 4 and Note 7	Resolution @ k=1 (ppm)	Fluke 8845A Accuracy (%) (1 year 23 ± 5°C)	Divisor based on k=2	Fluke 8845A unc in capacitance @ k = 1 (ppm)	Type A Repeatability and Reproduciblity of Measurement (ppm) k =1	Environmental note 11a k=1 (ppm)	Stability (Farads) Note 12 k = 1 (ppm)	MU V meas., RSS sum of columns J, P, R, T, V (ppm) k=1
500.0E-3	2	3.464	0.58	0.005%	2.0	24	5	0	0	24

Table 3: CMC calculation of DMM

The total uncertainty of the system is then calculated based upon the individual CMCs for the Fluke 8845A, Ohm-Labs KV-VB and IET Labs 1865 Plus.

There is also an internal 10 kΩ resistor in the 1865 Plus that has to be accounted for and becomes significant for the 10 MΩ value.

IET LABS, INC.
www.ietlabs.com
TEL: (516) 334-5959 • (800) 899-8438 • FAX: (516) 334-5988

The LabView program reports the average resistance using the last 25 % of the programmed number of measurements, as well as standard deviation of the population which was accounted for in the repeatability.

Nominal value of resistance	Nominal Value of Resistor	voltage	Current	Range	Type A Repeatability and Reproduciblity of Measurement (ppm) k =1	Error due to Technique (10 kΩ input impedance of 1865P)	Uncertanty RSS Combined I+divider+V k=1 (ppm)	MU combined K=2 (%)
10 MΩ	1.00E+07	5000	500.0E-6	1.0E-3	31	1000	2698	0.54%
100 MΩ	1.00E+08	5000	50.0E-6	100.0E-6	22	100	2507	0.50%
1 GΩ	1.00E+09	5000	5.0E-6	10.0E-6	242	10	2517	0.50%
10 GΩ	1.00E+10	5000	500.0E-9	1.0E-6	72	1	2506	0.50%
100 GΩ	1.00E+11	5000	50.0E-9	100.0E-9	39	0.1	2506	0.50%
1 TΩ	1.00E+12	5000	5.0E-9	10.0E-9	170	0.01	2511	0.50%
10 TΩ	1.00E+13	5000	500.0E-12	1.0E-9	9421	0.001	9749	1.95%

Table 4: CMC calculation of MegBridge System

Results

Initial testing was performed on various SRL standards from 1 GΩ to 1 TΩ at voltages from 1000 V to 3000 V. Testing was only performed up to 3000 V to minimize the power applied to the standards.

The calibrated value of the standards was measured using a guarded dual source bridge with measurement uncertainties of ≤ 250 ppm.

Voltage coefficient of the standards was considered as ≤ 1 ppm/V for the Ohm-Labs 112 and ≤ 0.1 ppm/V for other values.

	SRL-1 GΩ	SRL-10 GΩ	SRL-100 GΩ	Ohm-Labs 112
Serial Number	J1-0809131	SRC-10G-1	916	11013
Nominal Resistance	1 GΩ	10 GΩ	100 GΩ	1T
Calibrated Value (GΩ)	1.000474	9.99373	100.0015	999.915
Calibrated Value from MegBridge @ 1000 V (GΩ)	1.001860	10.01304304	100.416139	1008.614762
difference	0.14%	0.19%	0.41%	0.86%
Calibrated Value from MegBridge @ 2000 V (GΩ)	1.001907439	9.98071	100.2862	1004.3281
	0.14%	-0.13%	0.28%	0.44%
Calibrated Value from MegBridge @ 3000 V (G)		10.00768024	100.2309933	1002.60983
		0.14%	0.23%	0.27%

	VRS Testing E3-1916505		
	Date: Oct 2019		
	Keithley 6517A @ 1000 V	Megbridge @ 5000 V	Difference
			%
10 MΩ	10.000108	9.998714	-0.014%
100 MΩ	99.998862	99.889398	-0.109%
1 GΩ	0.9967792	0.994497	-0.229%
10 GΩ	10.00529	9.9925383	-0.127%
100 GΩ	100.5469	99.926992	-0.617%
1 TΩ	0.985566	0.968363	-1.745%

https://www.ietlabs.com/using-an-1865-plus-megohmmeter-for-high-voltage-resistance-measurements

