Australian Government
Department of Industry, Science, Energy and Resources
National Measurement Institute

Linking DC voltage scale up to 1000 V to quantum standards

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Thank you

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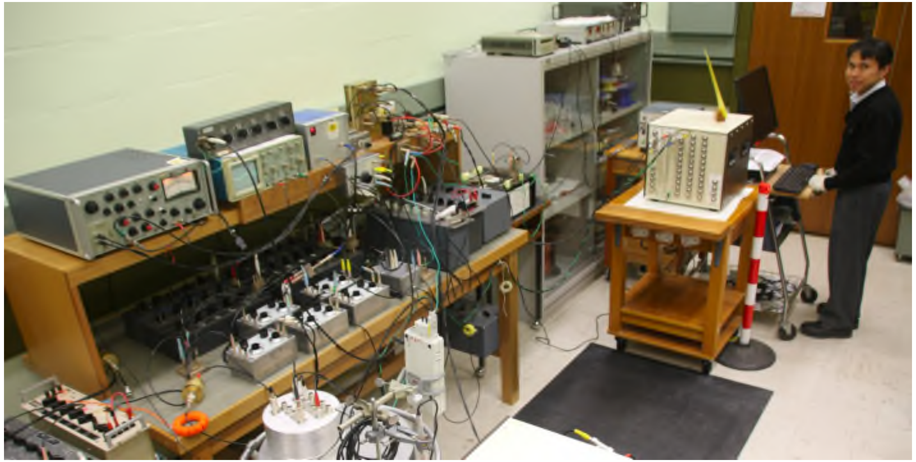
Motivation

- Josephson quantum voltage standards provide ultimate dc voltage traceability at voltages up to 10 V.
- Scaling of dc voltages from 10 V to 1000 V dominates uncertainty budgets.
- A new calibration method has been proposed, taking advantage of the combination of:
  - an inductive voltage divider (IVD) with an ultimate life-time stability of its ac voltage ratio, and
  - a resistive voltage divider (Transfer RVD) with low and stable ac-dc difference but relatively large voltage dependence and modest long-term stability of the dc ratio
- Target uncertainty of dc voltage / volytage ratio 1 x 10^{-7}.

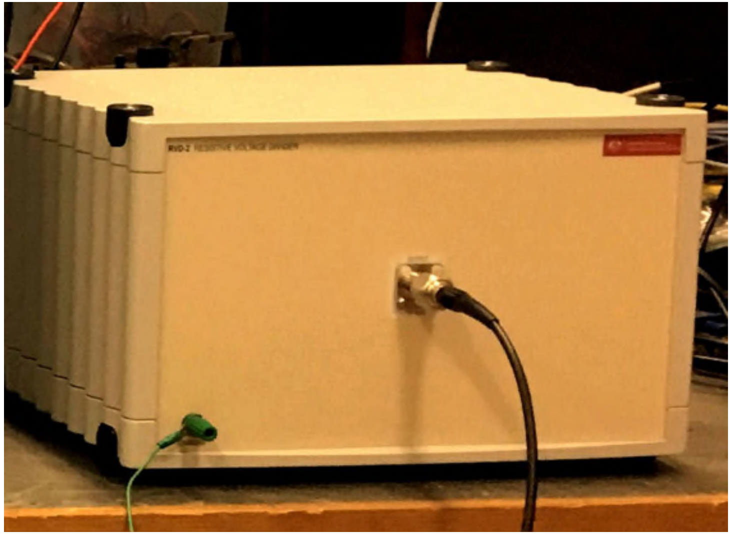
NMIA 1000 V Precision Inductive Voltage Divider

Typical ratio errors at power frequencies:

in-phase 1 part in 10^{10} of input
quadrature 5 parts in 10^{10} of input



NMIA Precision Resistive Voltage Divider



Nominal Input Impedance: 200 kΩ

Nominal input voltage: 1000 V

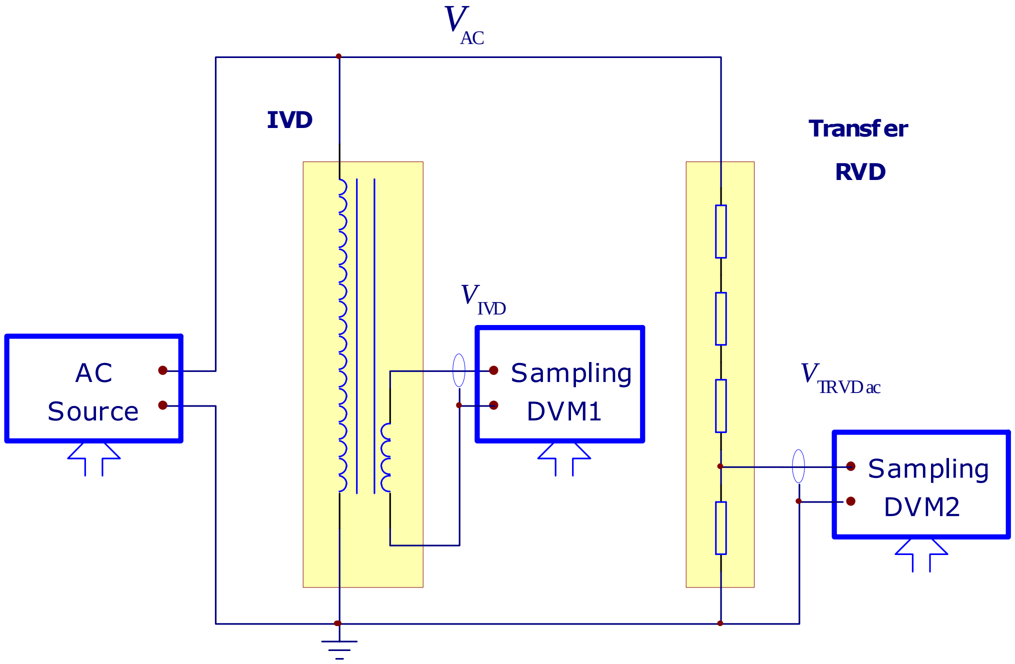
Nominal frequency range: DC to 1 kHz

Ac-dc transfer difference and of the ratio at power frequencies: less than 1 part in 10^6

Phase error at power frequencies:

less than 5 µrad

Basic Principle



Ac stage:

two measurements with Sampling DVMs interchanged

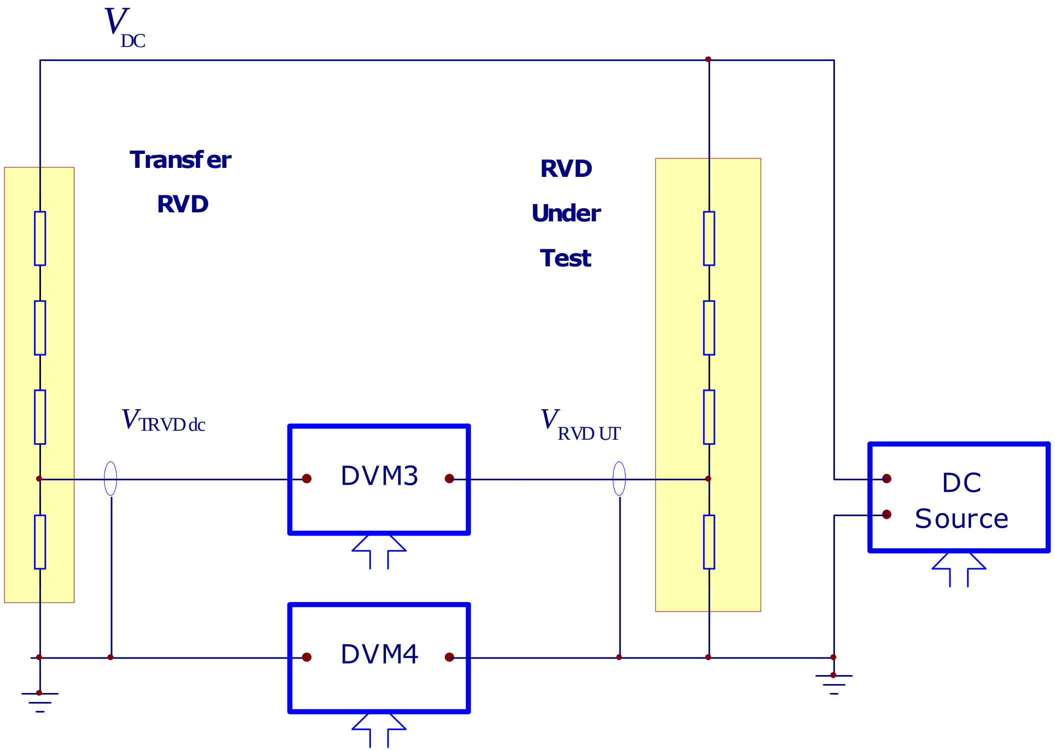
$$M^{C}{}_{ac} = \frac{V_{TRVDac} - V_{IVD}}{V_{IVD}}$$

Basic Principle

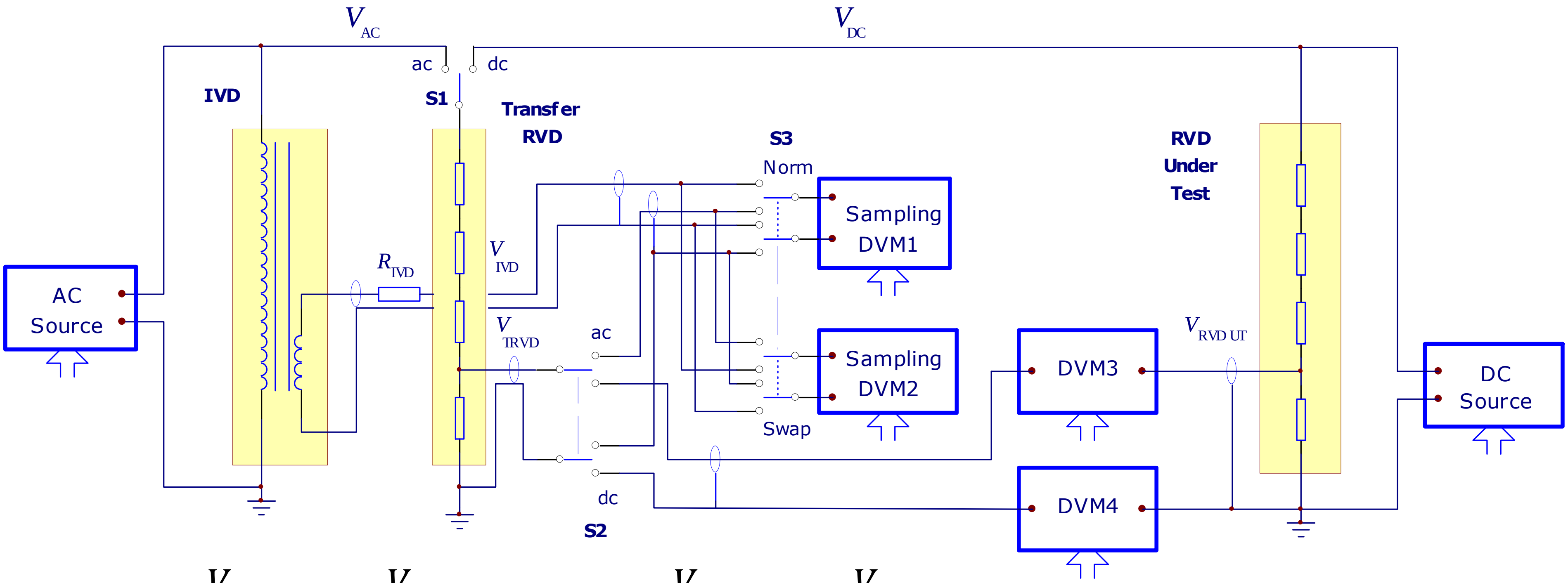
Dc stage:

two measurements with positive and negative voltage

$$M^{C}{}_{dc} = \frac{V_{TRVDdc} - V_{RVD\ UT}}{V_{TRVDdc}}$$

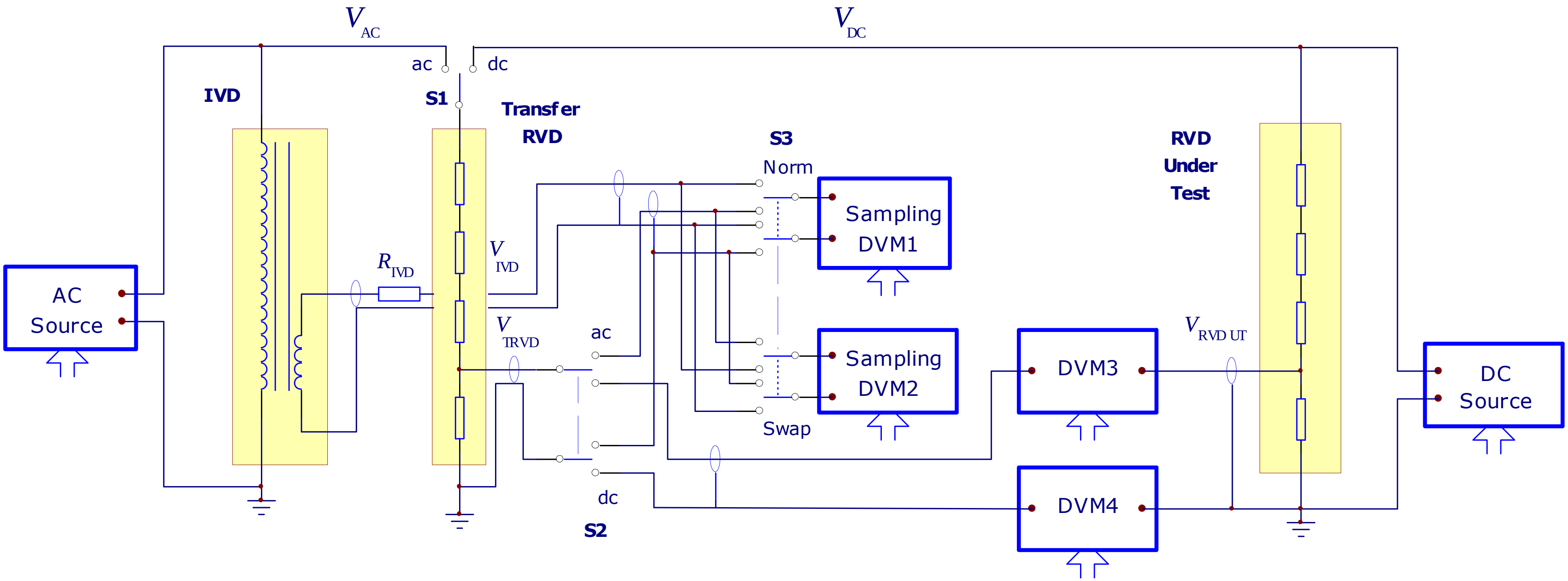


Calibration Setup



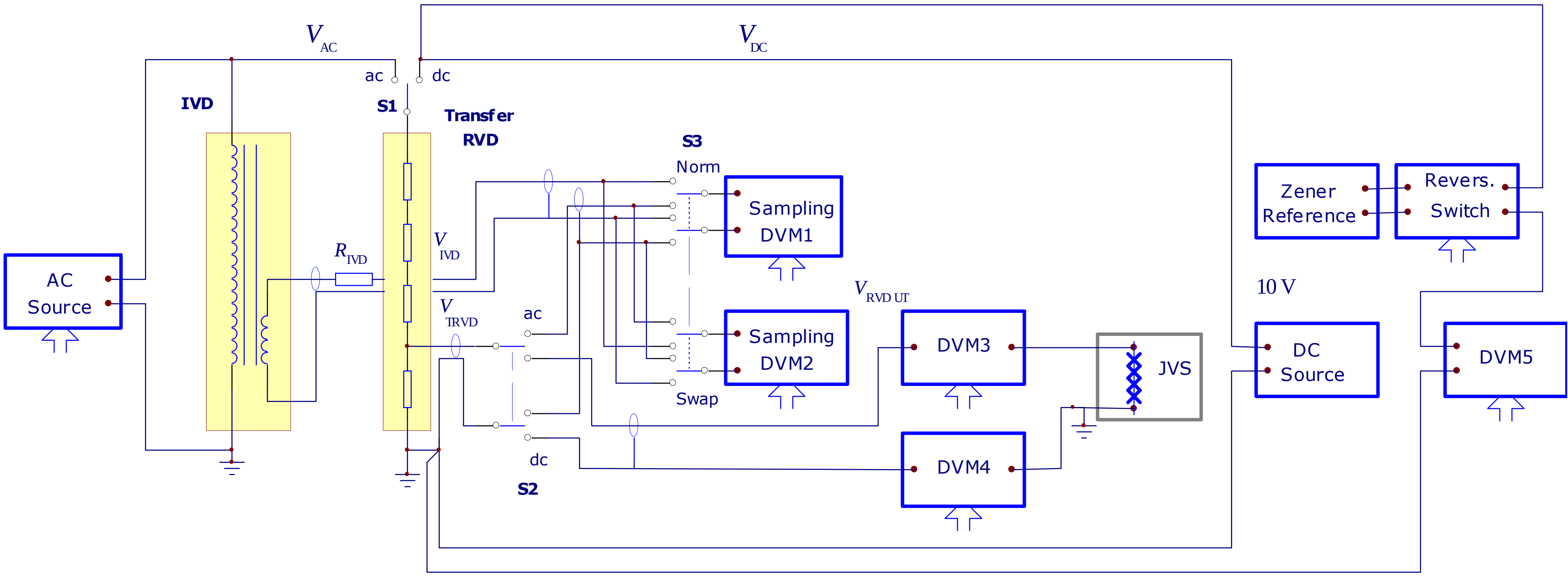
$$M^{C}_{ac} = \frac{V_{TRVDac} - V_{IVD}}{V_{IVD}} \qquad M^{C}_{dc} = \frac{V_{TRVDdc} - V_{RVD\,UT}}{V_{TRVDdc}}$$

Calibration Setup



$$M^{C}{}_{ac} - M^{C}{}_{dc} = \delta_{TRVD\ ac-dc} - \delta_{IVD} + \delta_{RVD\ UT}$$

System Verification



$$M^{V}{}_{ac} - M^{V}{}_{dc} = \delta_{TRVD\ ac-dc} - \delta_{IVD} + \delta_{JVS} - \delta_{Zener}$$

Combining the two measurements

$$M^{C}{}_{ac} - M^{C}{}_{dc} = \delta_{TRVD\ ac-dc} - \delta_{IVD} + \delta_{RVD\ UT}$$

$$M^{V}{}_{ac} - M^{V}{}_{dc} = \delta_{TRVD\ ac-dc} - \delta_{IVD} + \delta_{JVS} - \delta_{Zener}$$

Combining the two measurements

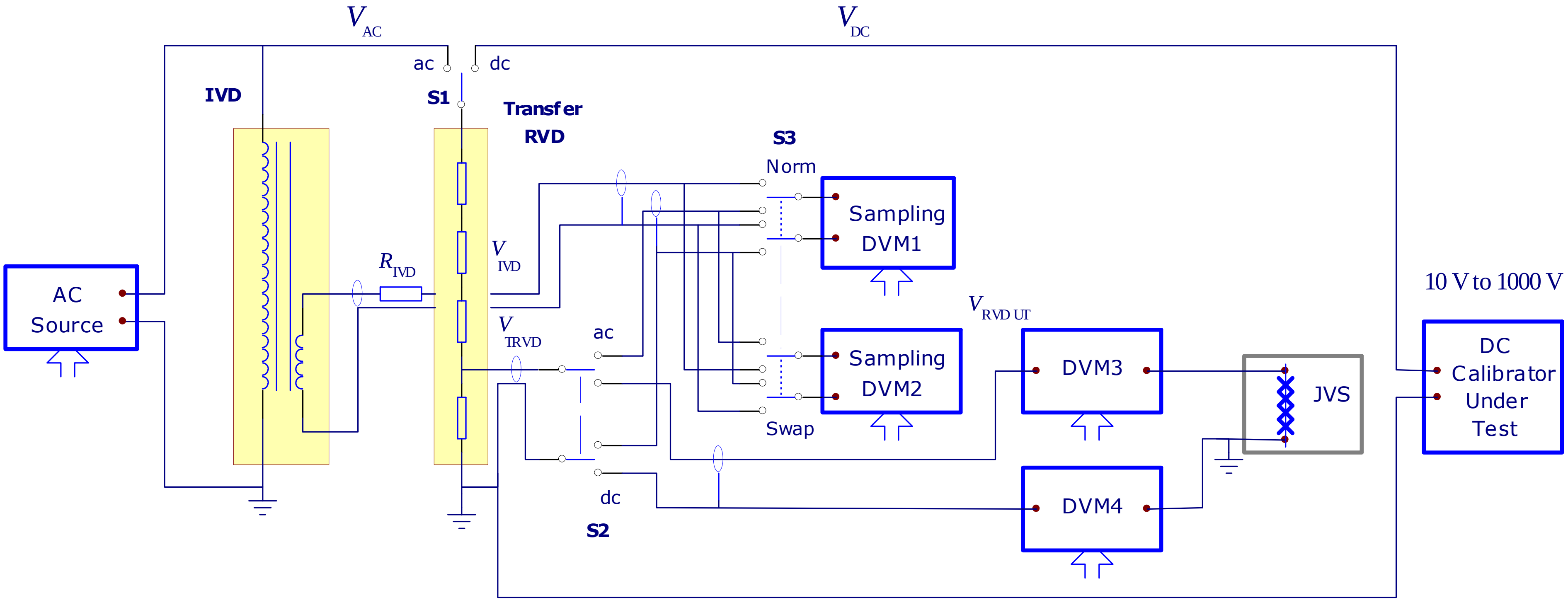
$$M^{C}{}_{ac} - M^{C}{}_{dc} = \delta_{TRVD\ ac-dc} - \delta_{IVD} + \delta_{RVD\ UT}$$

$$M^{V}{}_{ac} - M^{V}{}_{dc} = \delta_{TRVD\ ac-dc} - \delta_{IVD} + \delta_{JVS} - \delta_{Zener}$$

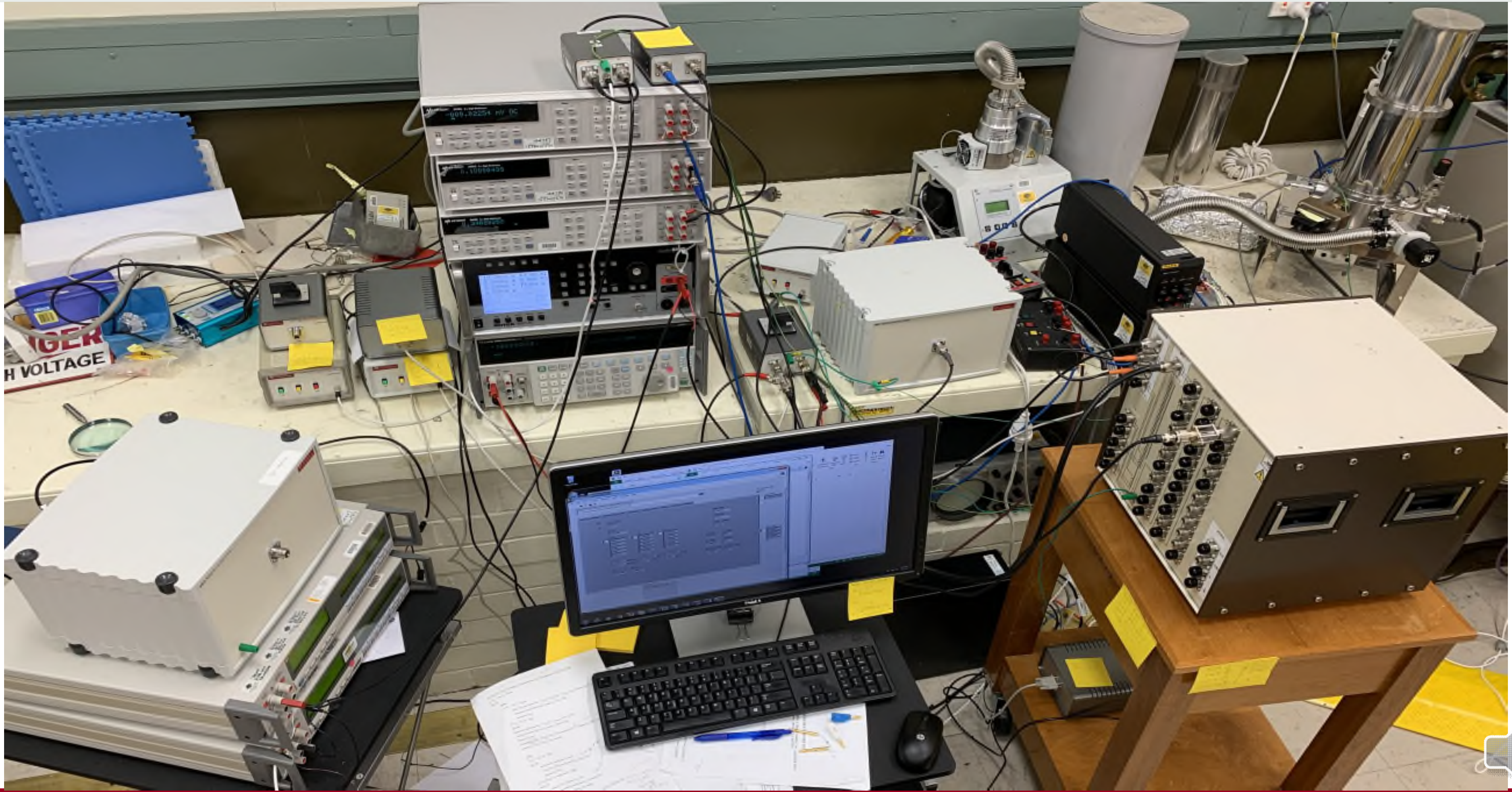
$$M^{C}{}_{ac} - M^{C}{}_{dc} - M^{V}{}_{ac} + M^{V}{}_{1dc} = \delta_{RVD\ UT} - \delta_{JVS} + \delta_{Zener}$$

Combining the two measurements eliminates the errors of the IVD and the Transfer RVD

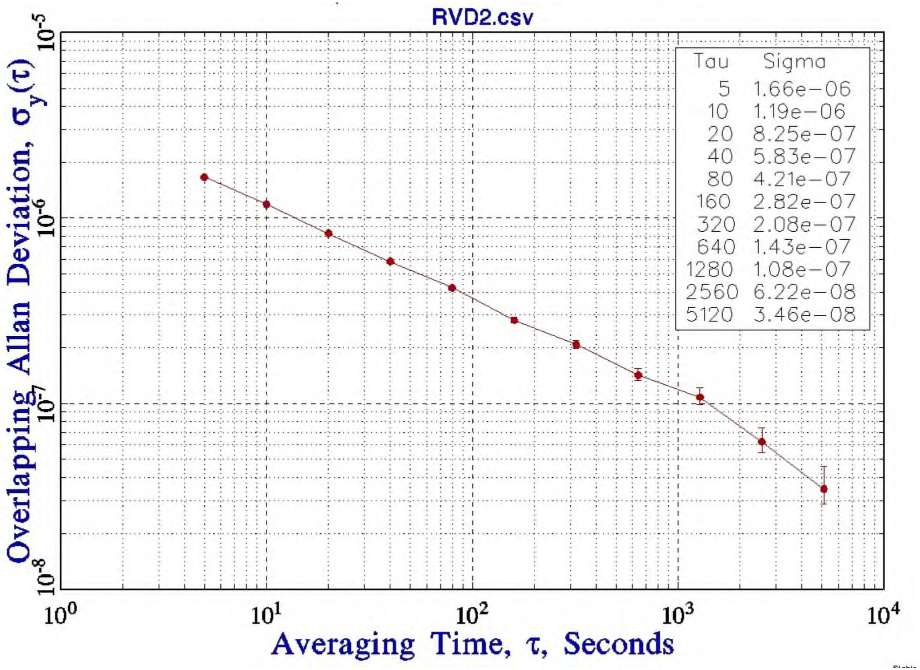
Calibration of DC Calibrators up to 1000 V



Measurement Setup



System Evaluation



Alan deviation of ac ratio error measurement of a 500:1 Transfer RVD against the IVD with an input voltage of 10 V @ 63 Hz.

System Evaluation

Reference IVD Errors and Uncertainties

(from NMIA Calibration Report)

Frequency (Hz)	Ratio Error (µV/V)		Uncertainty (µV/V)	
	100/1	1000/1	100/1	1000/1
40	-0.02	-0.01	0.02	0.13
63	-0.05	-0.05	0.02	0.13
400	-2.02	-2.20	0.08	0.60
1000	-12.5	-13.2	0.09	0.60

System Evaluation

IVD Level Dependence

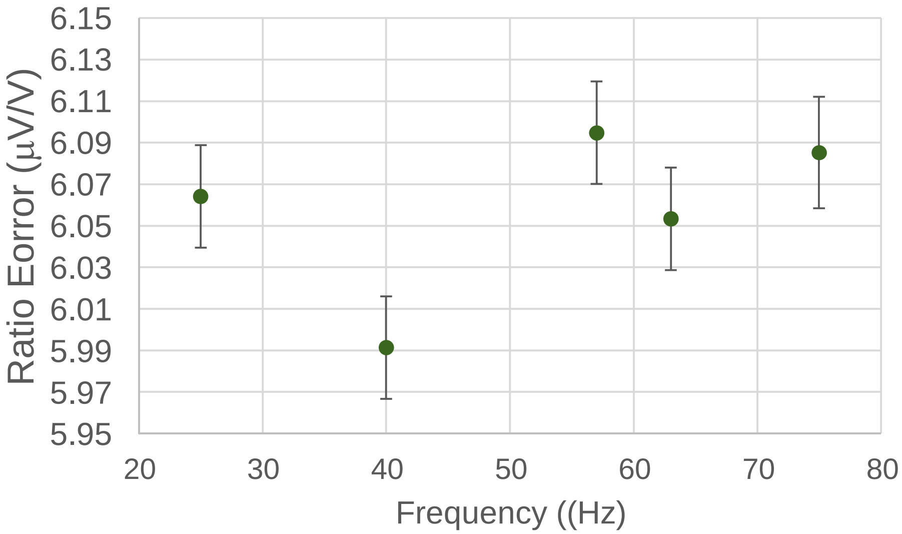
(comparing two IVDs)

Frequency (Hz)	Ratio Error (µV/V)	
	10 V	80 V
40	-0.031	-0.048
63	-0.041	-0.032
400	1.507	1.719
1000	10.041	10.535

System Evaluation

Transfer RVD Frequency Response

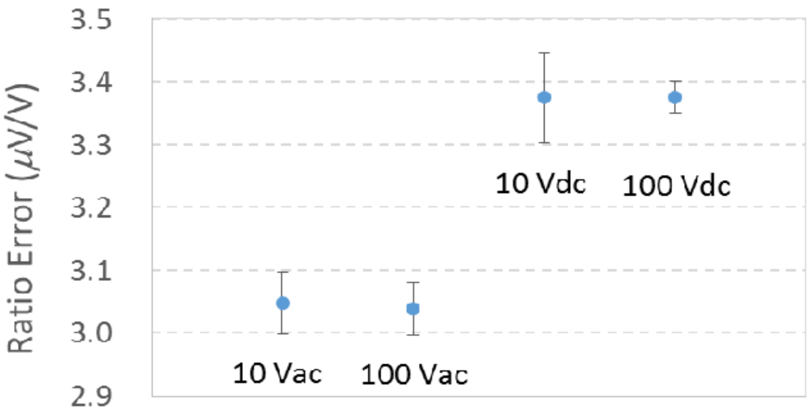
(by comparison with the Reference IVD)



System Evaluation

System Voltage Dependence

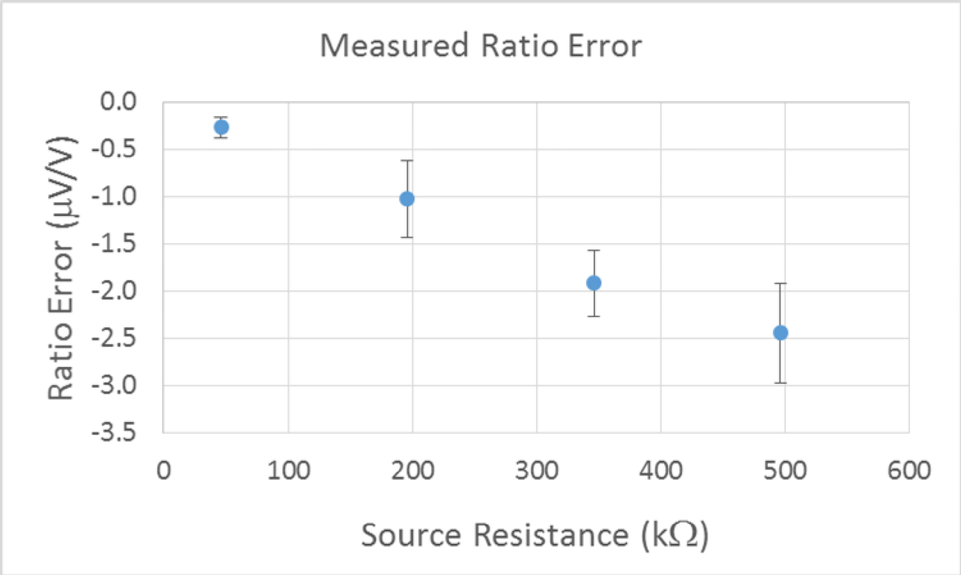
(IVD ratio + RVD ac-dc difference)



Voltage dependence of the Transfer RVD with a nominal ratio of 0.01 measured at 63 Hz and at dc. The uncertainty bars represent the estimated standard deviation of the mean.

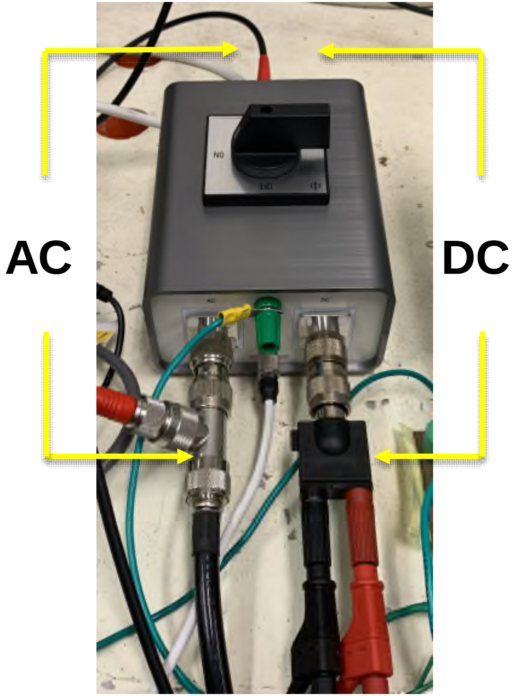
System Evaluation

DC Voltmeter Loading Error



Evaluated by measuring inserting resistors in series the output of the RVD Under Test

System Evaluation

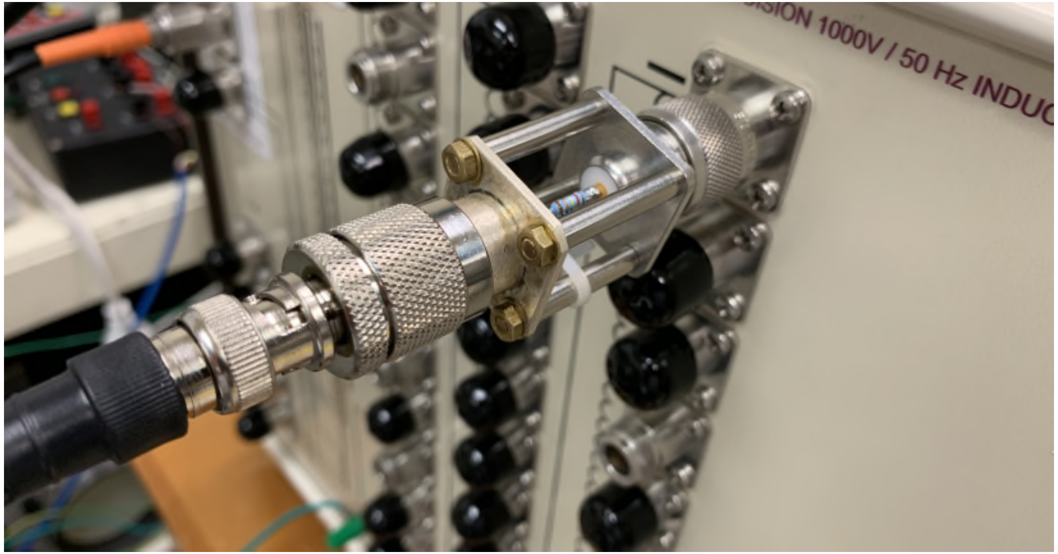


Ac-dc switch error

Transfer RVD Resistance (kohm)	Swith Error	Uncertainty Contribution
35	-4.5E-07	1.6E-08
50	-3.1E-07	1.1E-08
100	-1.6E-07	5.7E-09
200	-7.8E-08	2.8E-09

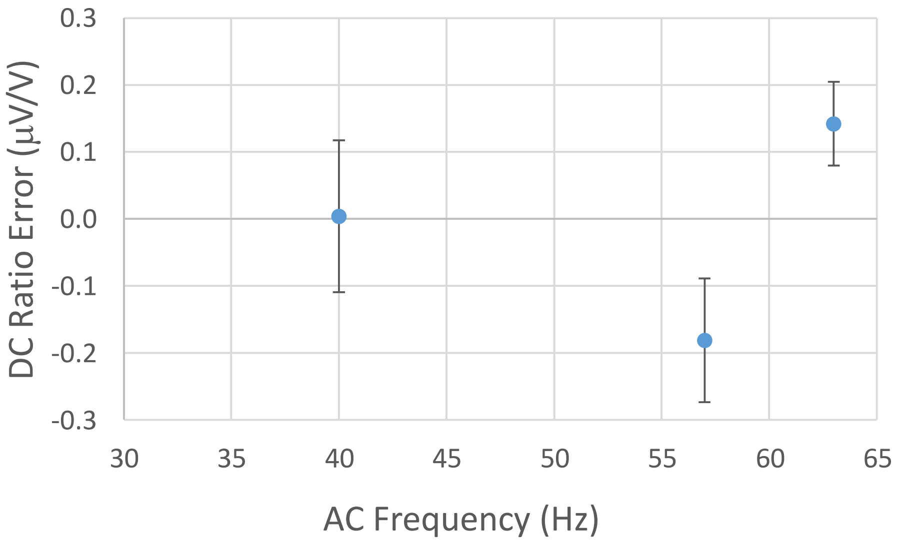
Evaluated by measuring voltage drop over the ac and dc path of the switch

AC loading errors



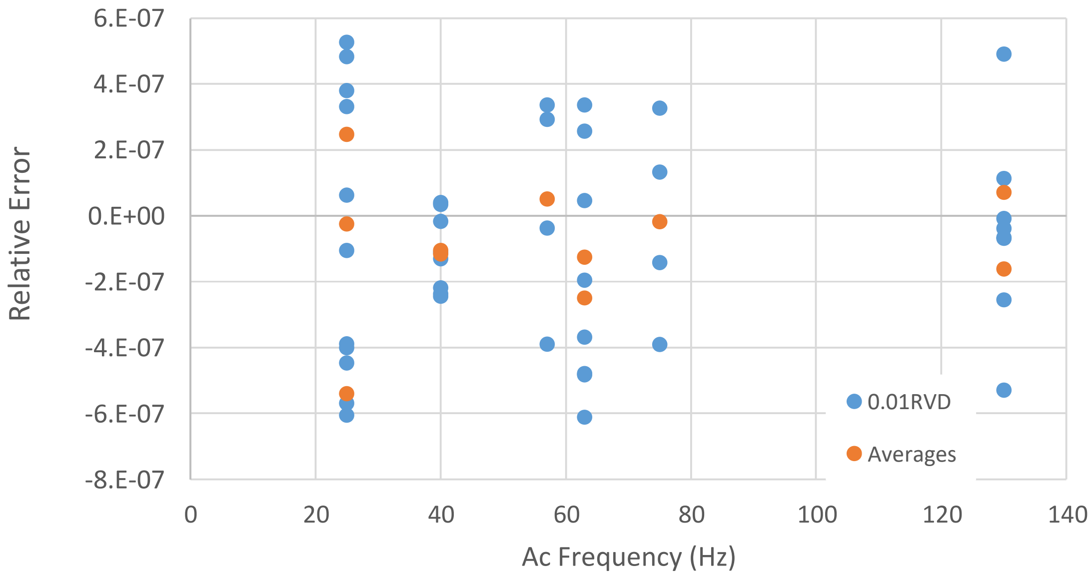
- Mitigated by inserting a closely matched series resistor at the output of the IVD and ensuring equal length of IVD and RVD output cables.

System Verification against Programmable Josephson Voltage Standard



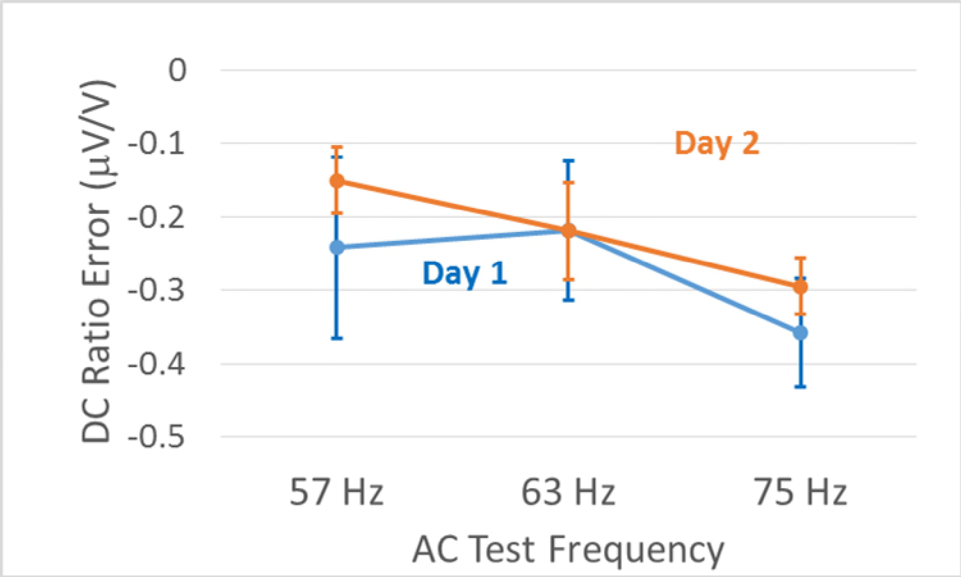
Total error of system at DC voltage ratio of 0.01 measured against a 10 V Zener reference and a 0.1 V programmable Josephson voltage standard. Error bars show standard error of the measurement

System Verification against Programmable Josephson Voltage Standard



Difference in the relative error of a DC calibrator at 10 V measured against a 10 V Zener reference and an IVD/RVD with 0.01 ratio plus a 0.1 V programmable Josephson voltage standard.

Measurement on a Commercial RVD



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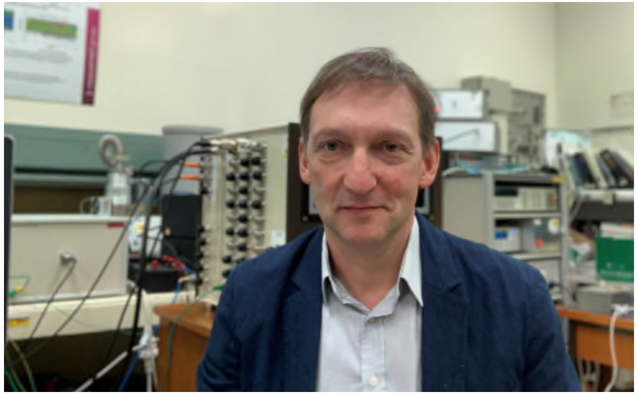
Measured ratio error of a 0.001 ratio at 200 V

Conclusions

- A novel measurement method has been proposed to calibrate dc resistive voltage dividers, calibrators and voltmeters up to 1000 V.
- We are on target for uncertainty of dc voltage ratio 1 x 10^{-7} in a fully automated setup.
- When verification (calibration) against a Josephson voltage standard is employed, the method does not require state of the art IVD and Transfer RVD.

Thank you!



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