SI-traceable Calibration and Nonlinearity Measurement and Uncertainties of Current-to-Voltage Convertors

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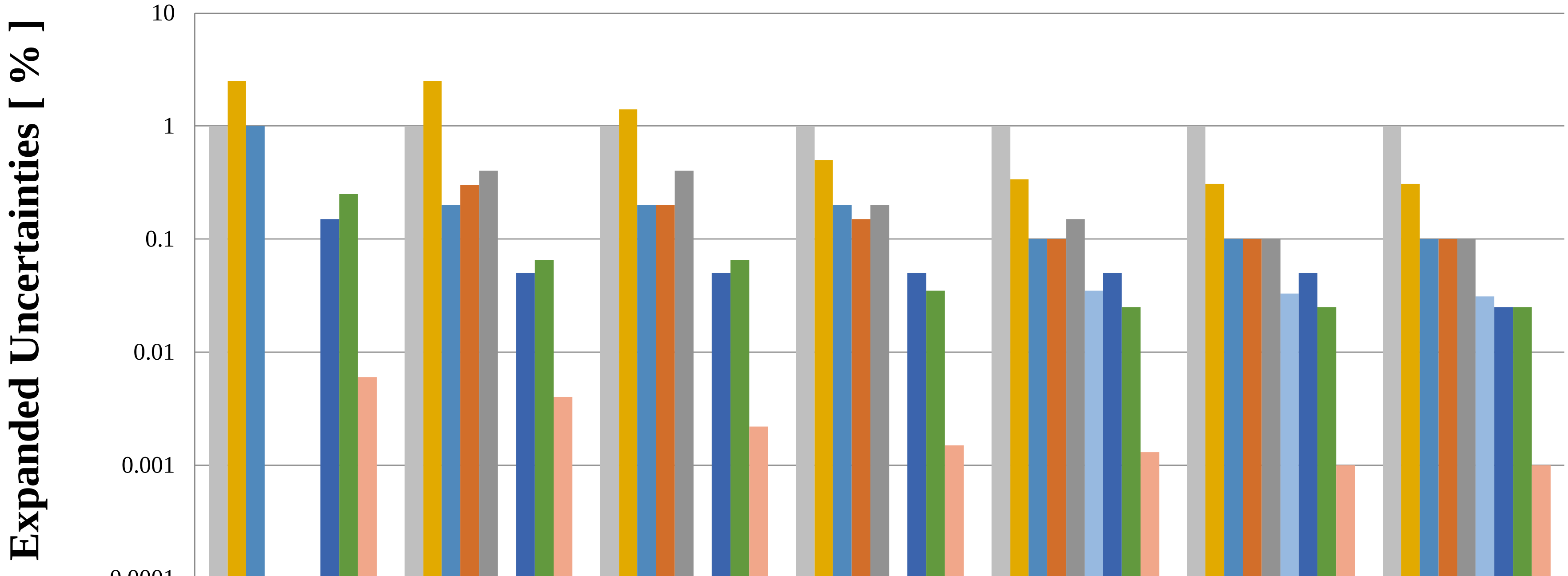
Outline

1. Introduction / Background
2. NIST Traceability of the Current Source to the SI
3. Setup and Measurements
4. Validation
5. Results and Discussion
6. Repeatability
7. Conclusions
8. Future Work

Current Measurement Electrometers or Preamps Accuracy (%)

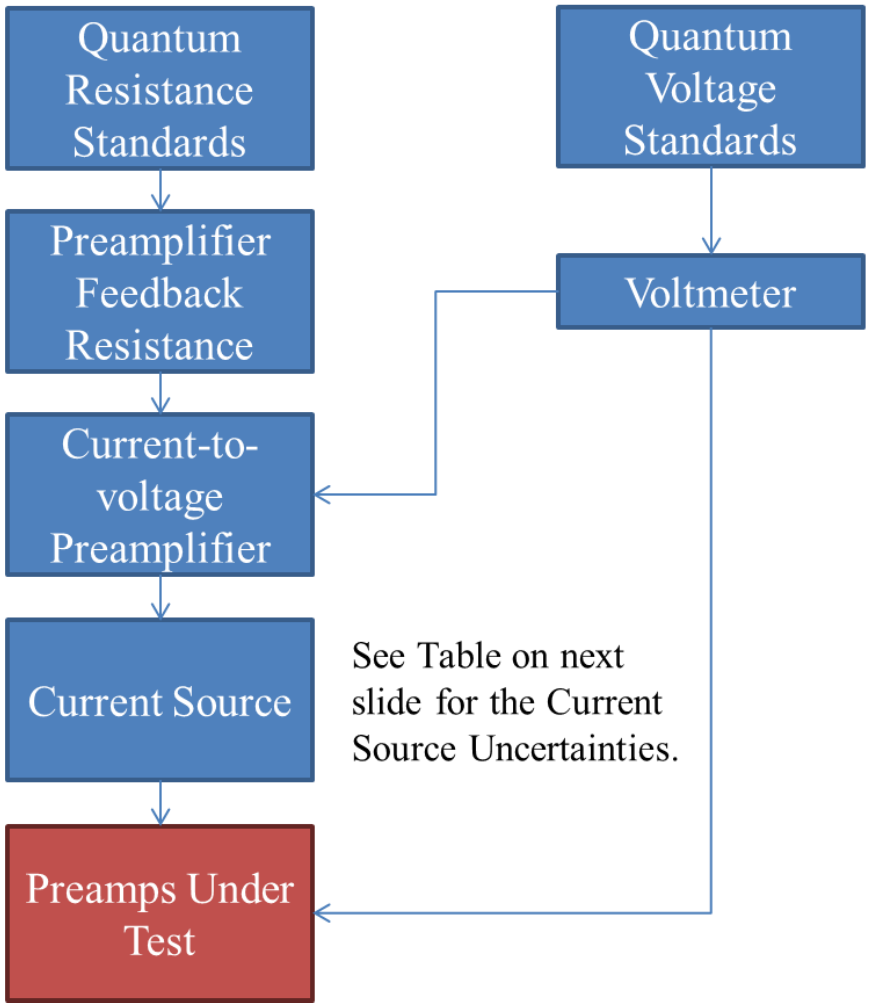
Comparison of Current Measurement Capability



	1.00E-10	1.00E-09	1.00E-08	1.00E-07	1.00E-06	1.00E-05	1.00E-04
Stanford SR570	1	1	1	1	1	1	1
Keithley/428	2.5	2.5	1.4	0.5	0.34	0.31	0.31
Keithley/6517	1	0.2	0.2	0.2	0.1	0.1	0.1
Keithley/6487		0.3	0.2	0.15	0.1	0.1	0.1
Keithley/6485		0.4	0.4	0.2	0.15	0.1	0.1
Keithley/2400					0.035	0.033	0.031
Keithley/6430	0.15	0.05	0.05	0.05	0.05	0.05	0.025
Keithley/263	0.25	0.065	0.065	0.035	0.025	0.025	0.025
NIST SDX	0.006	0.004	0.0022	0.0015	0.0013	0.001	0.001

NIST Traceability of Current Measurements to the SI

SI-Traceability of the Preamplifier Calibrations



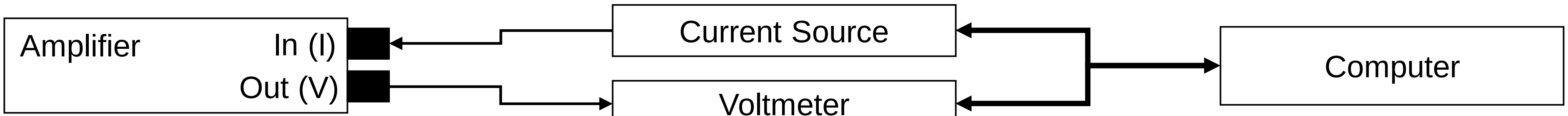
See Table on next slide for the Current Source Uncertainties.

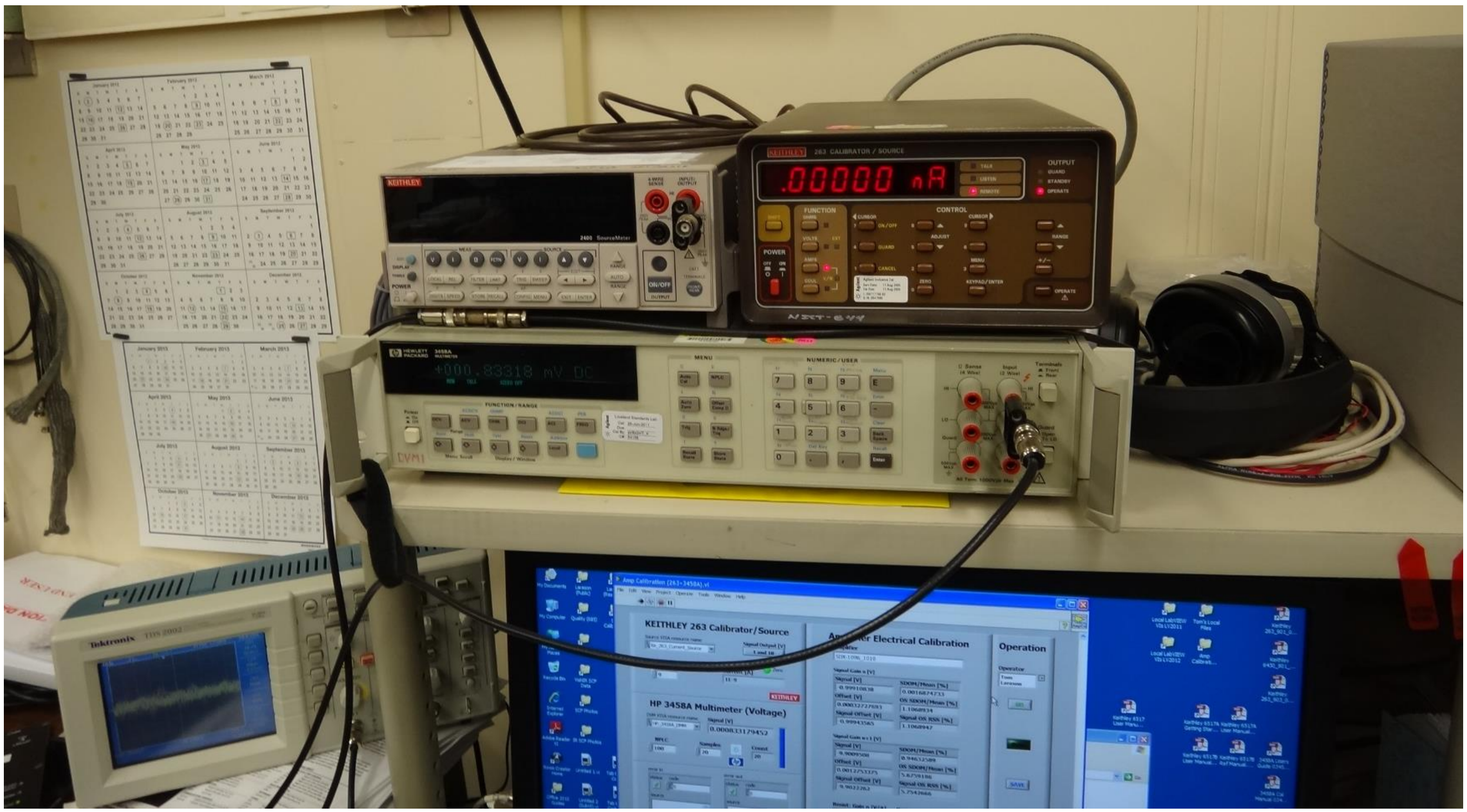
NIST Current Source Calibration Uncertainties

Transfer Standard I-V Convertor #1010

		Relative uncertainty [ppm]						
Uncertainty components	**Type**	**$1x10^4$ V/A**	**$1x10^5$ V/A**	**$1x10^6$ V/A**	**$1x10^7$ V/A**	**$1x10^8$ V/A**	**$1x10^9$ V/A**	**$1x10^{10}$ V/A**
Feedback resistance	B	0.15	0.4	0.4	3	3	9	25
Short-term instability of input current I	A	0.28	0.23	2.8	3.0	3.9	4.7	14
V_1 voltage measurement (HP 3458A)	B	2	2	2	2	2	2	2
Output noise and drift (12 days)	A	5.8	6.7	16	13	20	84	986
Loop gain	A	2	2	2	2	2	2	2
Combined standard uncertainty of I measurement		6.5	7.3	16	14	21	85	990
Expanded total uncertainty (k =2) of I measurement		13	15	32	28	42	170	2000

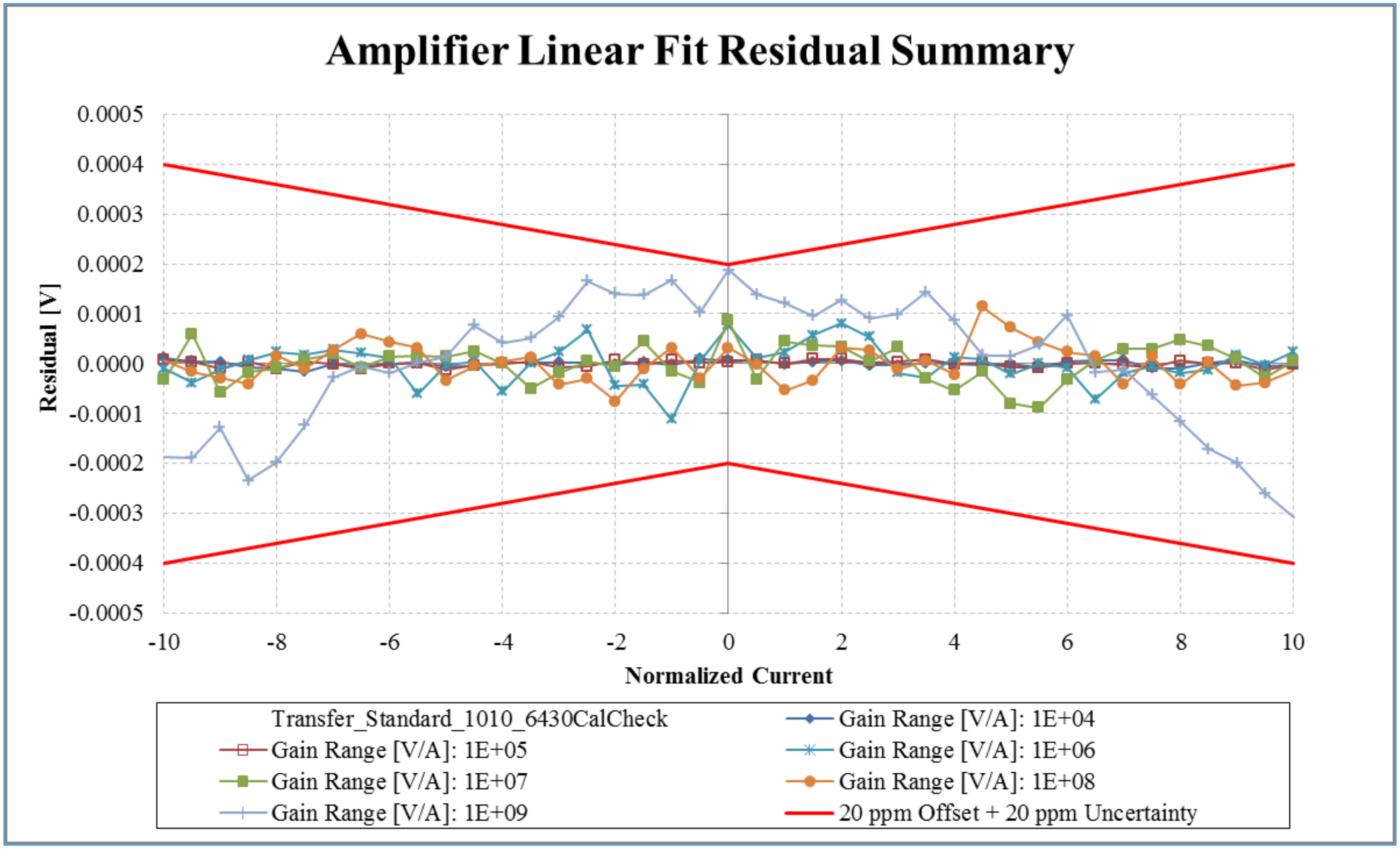
Measurement Setup





Transfer Standard I-V Convertor Linear Fit Residuals

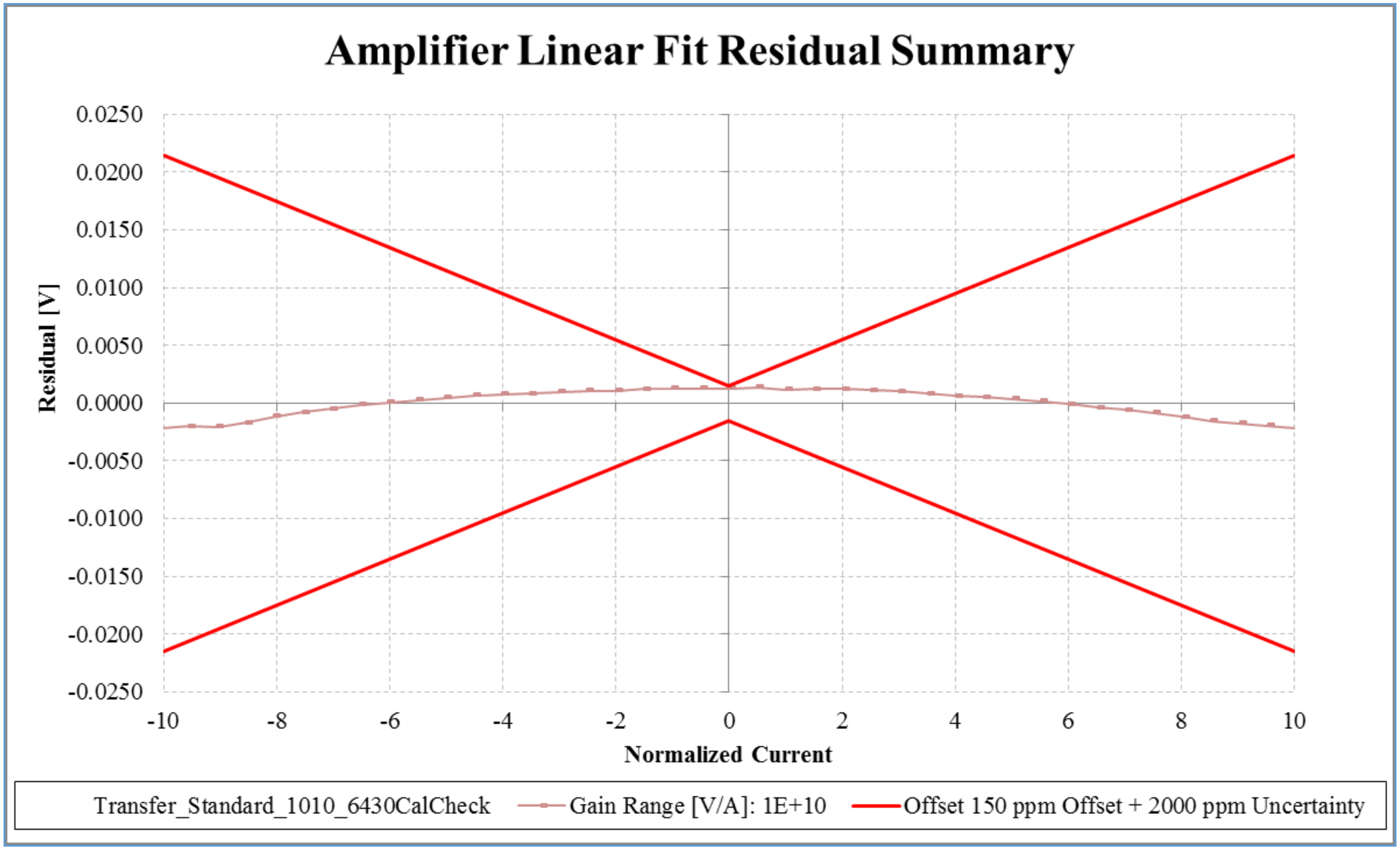
Gain Ranges 10^4 to 10^9. The straight lines indicate 20×10^{-6} (20 ppm) offset uncertainty with a gain uncertainty of 20 ppm.



Gain Range 10^{10}

Transfer Standard I-V Convertor Linear Fit Residuals

Gain Range 10^{10}. The straight lines indicate 20×10^{-6} (20 ppm) offset uncertainty with a gain uncertainty of 2000 ppm.



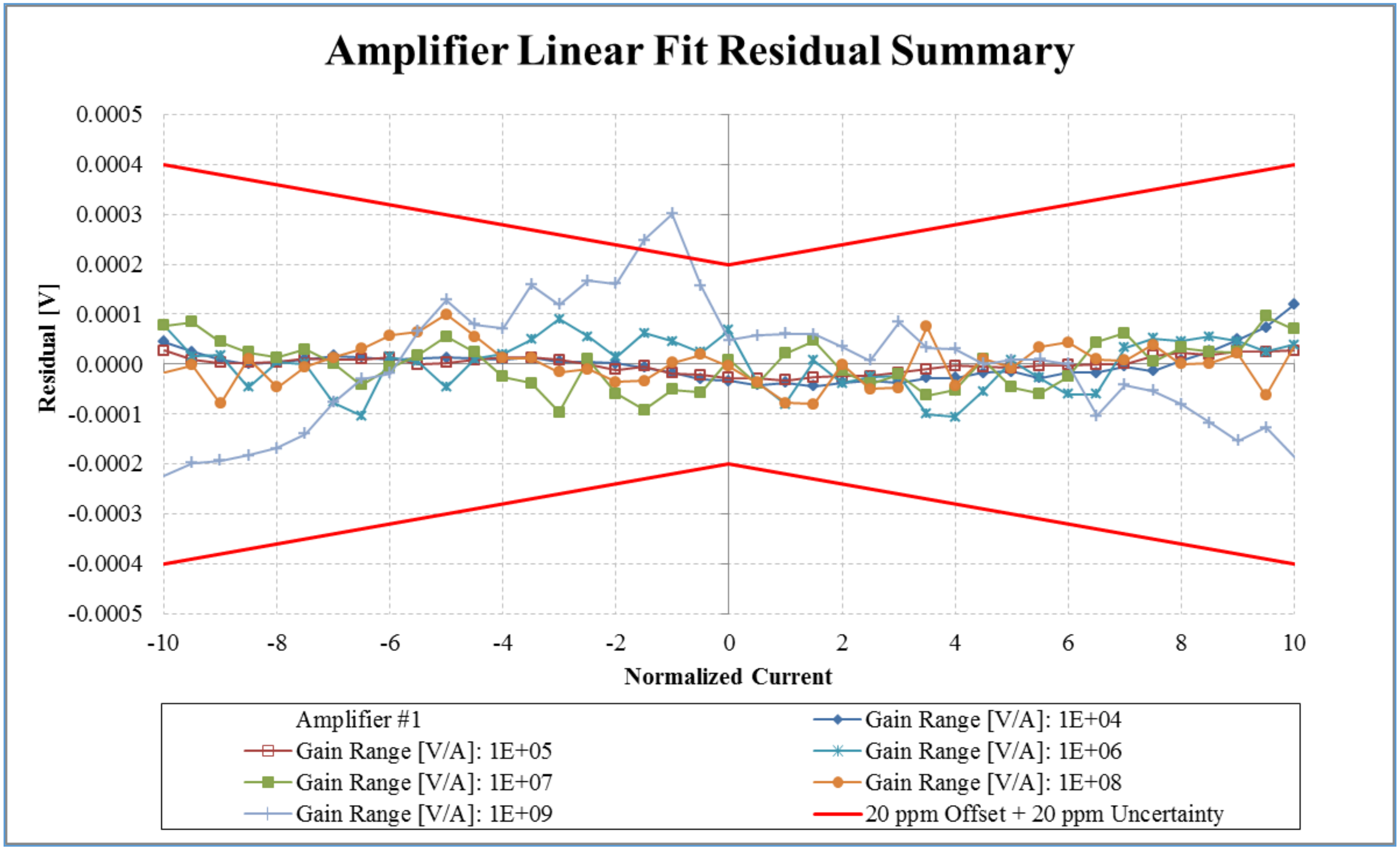
NIST Amplifier Calibration Uncertainties

Current-to-Voltage Conversion Gain and Uncertainty of Test Amplifier

				Uncertainty components						
Gain range (10^x)	Calibration gain [V/A]	x 10^x	Decade nominal gain correction factor	Current measurement [%] Type B	Short-term instability of input current [%] Type A	Voltage measurement (HP3458A) [%] Type B	Output noise and drift [%] Type A	Loop gain [%] Type A	Gain relative expanded uncertainty (k=2) [%]	Source output resistance [Ohms]
4										10E+6
5										100E+6
6	9.99946	5	1.000054	0.00064	0.00006	0.00020	0.00044	0.00020	0.0017	1E+9
7	1.000001	7	0.999999	0.00072	0.00007	0.00020	0.00162	0.00020	0.0036	10E+9
8	1.001176	8	0.998826	0.00104	0.00027	0.00020	0.00130	0.00020	0.0034	100E+9
9	1.03272	9	0.968312	0.00192	0.00217	0.00020	0.00245	0.00020	0.0076	1E+12
10	9.9743	9	1.00258	0.00315	0.00697	0.00020	0.01080	0.00020	0.026	1E+12

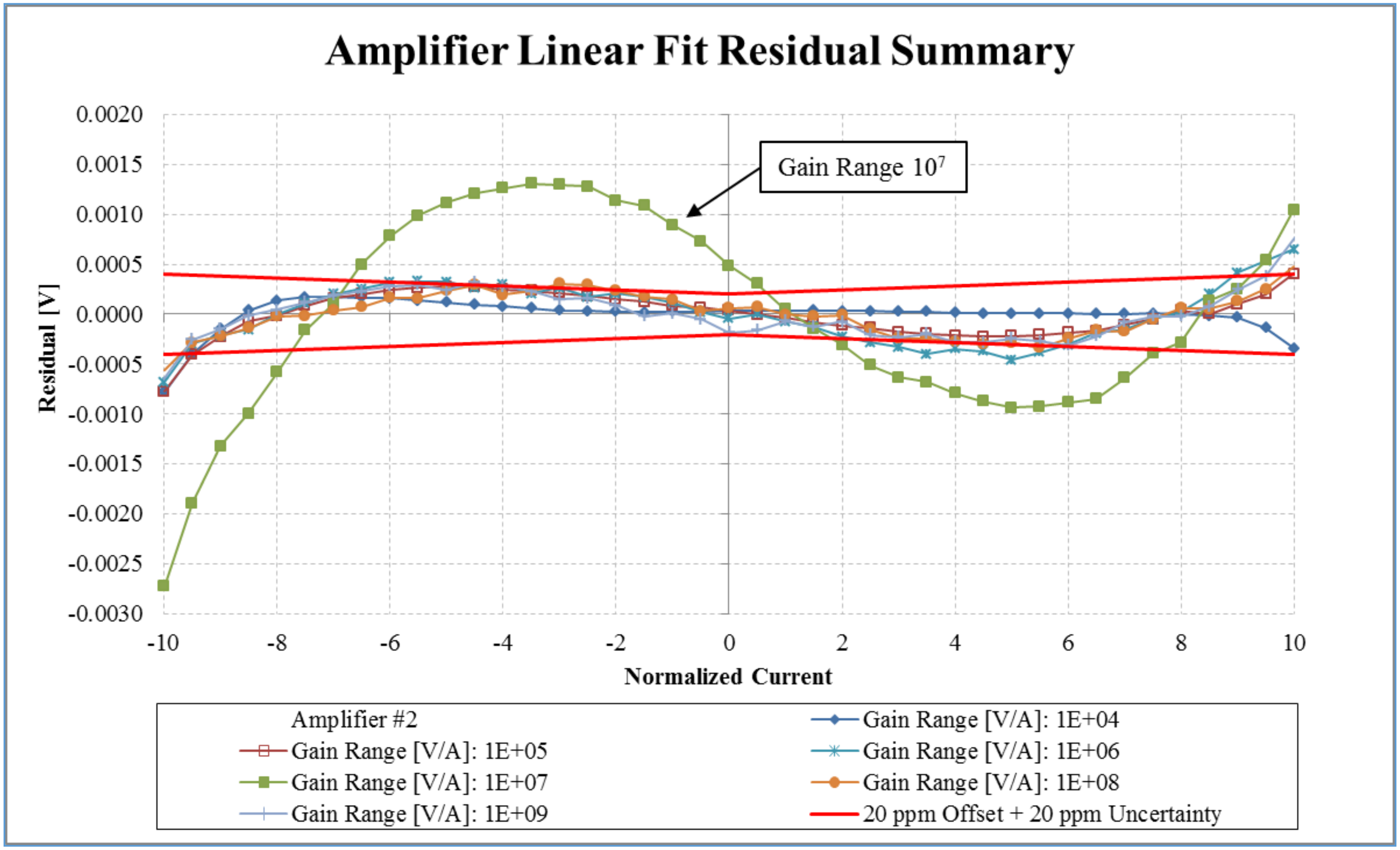
Amplifier #1 Linear Fit Residuals

The straight lines indicate 20x10^{-6} (20 ppm) offset uncertainty with a gain uncertainty of 20 ppm.



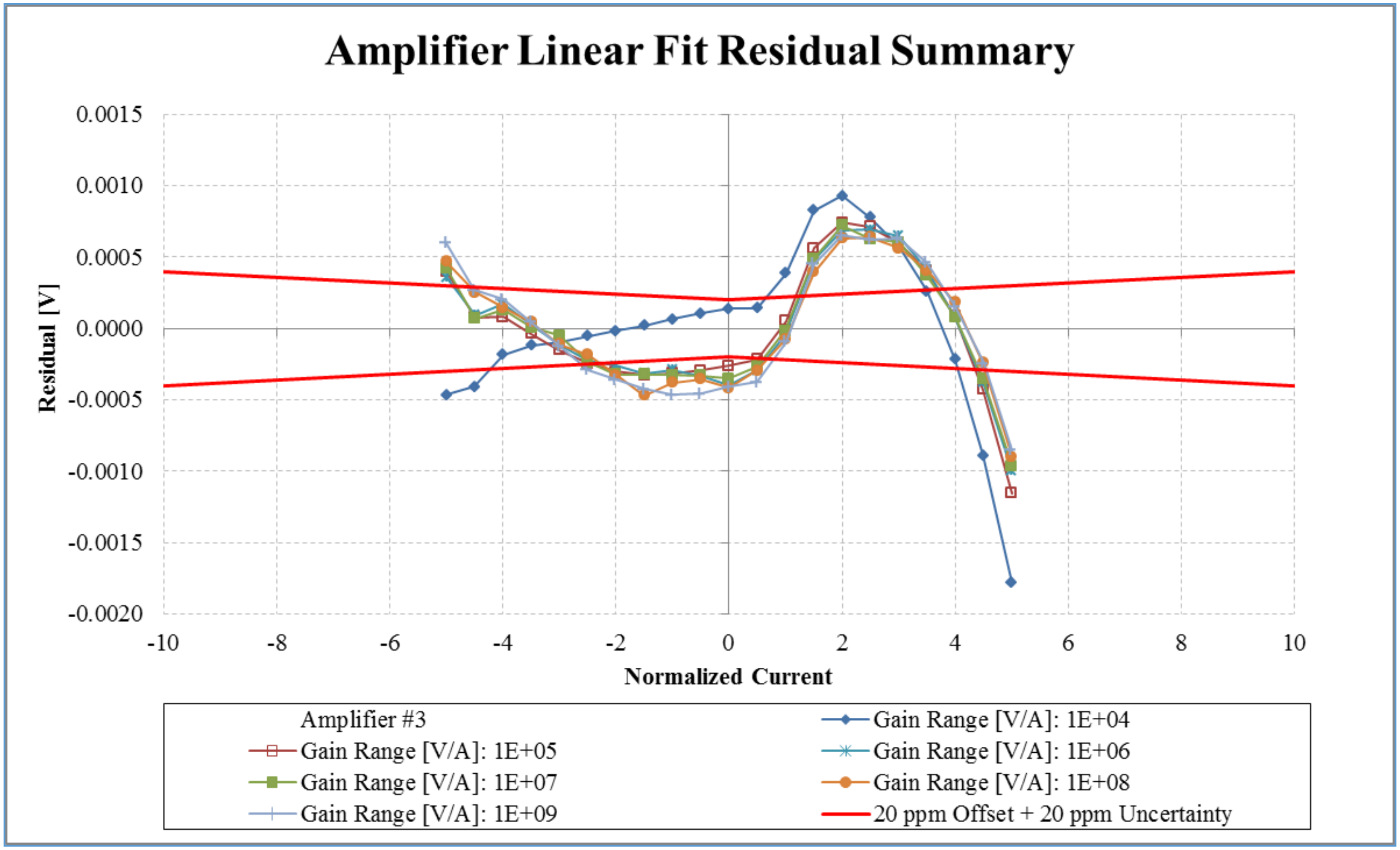
Amplifier #2 Linear Fit Residuals

The straight lines indicate $20x10^{-6}$ (20 ppm) offset uncertainty with a gain uncertainty of 20 ppm. Gain 10^7 residuals are outside the uncertainties.



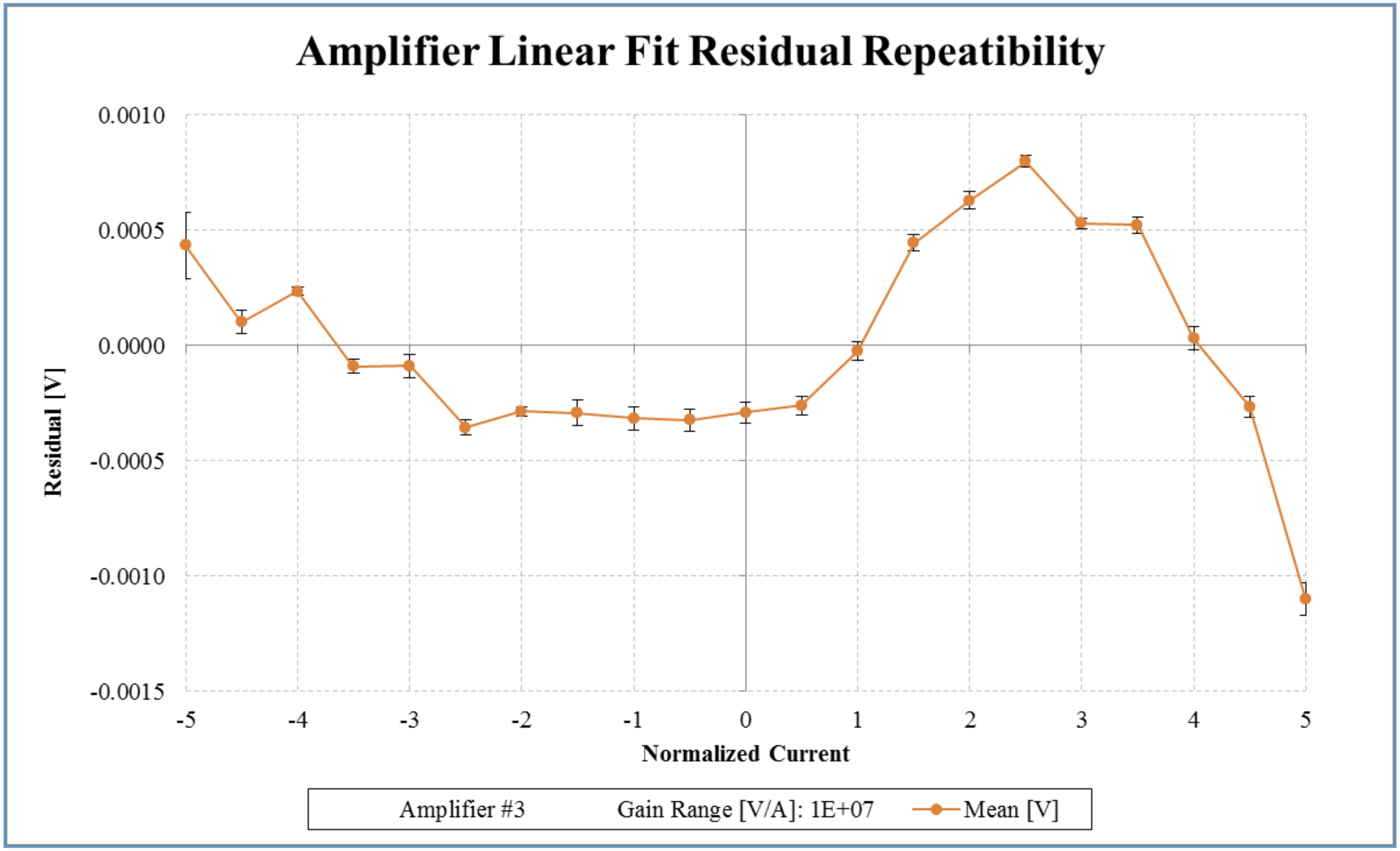
Amplifier #3 Linear Fit Residuals

The straight lines indicate 20×10^{-6} (20 ppm) offset uncertainty with a gain uncertainty of 20 ppm.



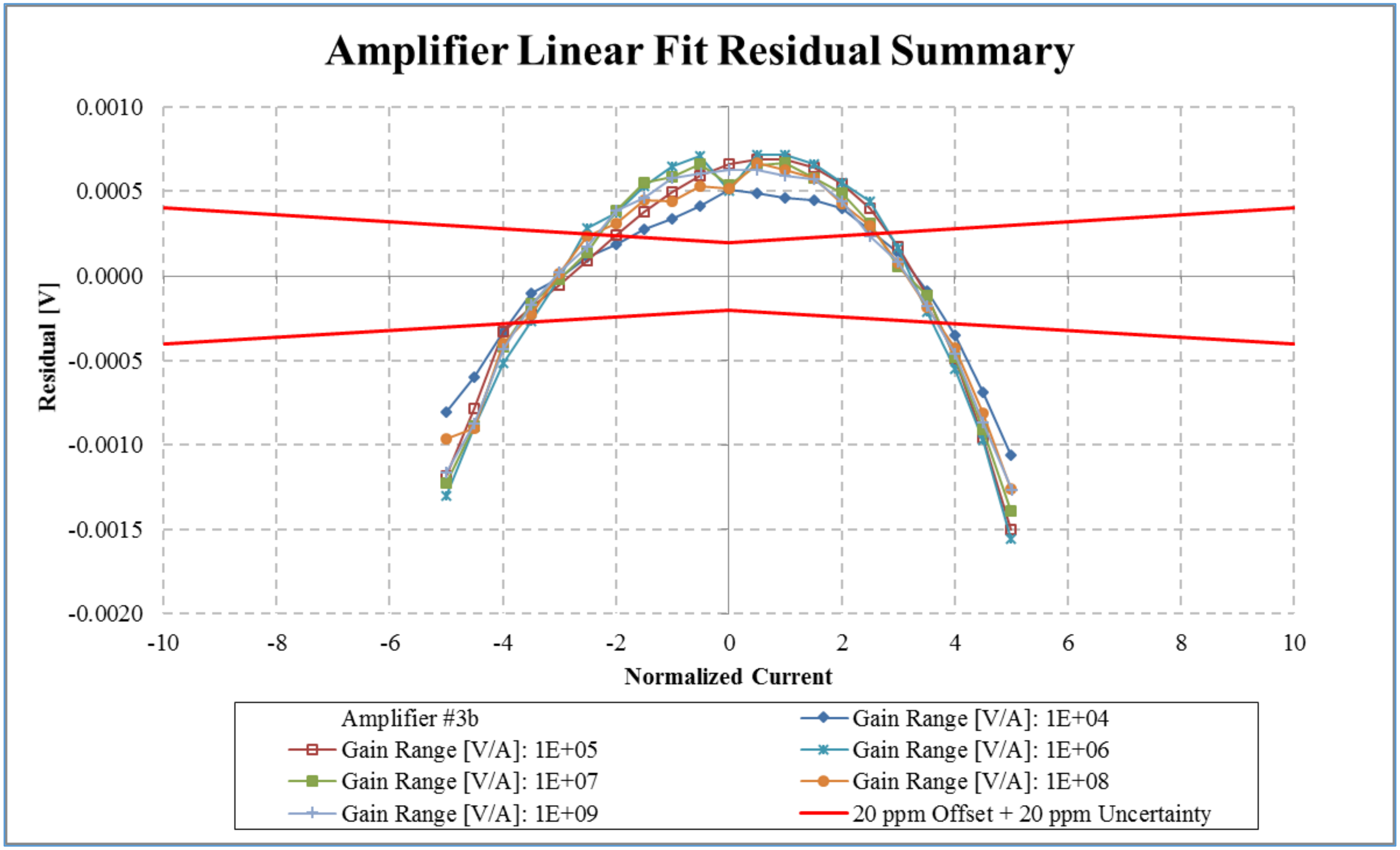
Repeatability

The mean and the standard deviation of 5 measurements at gain 10^7 of Amplifier #3. All amplifiers had similar results.



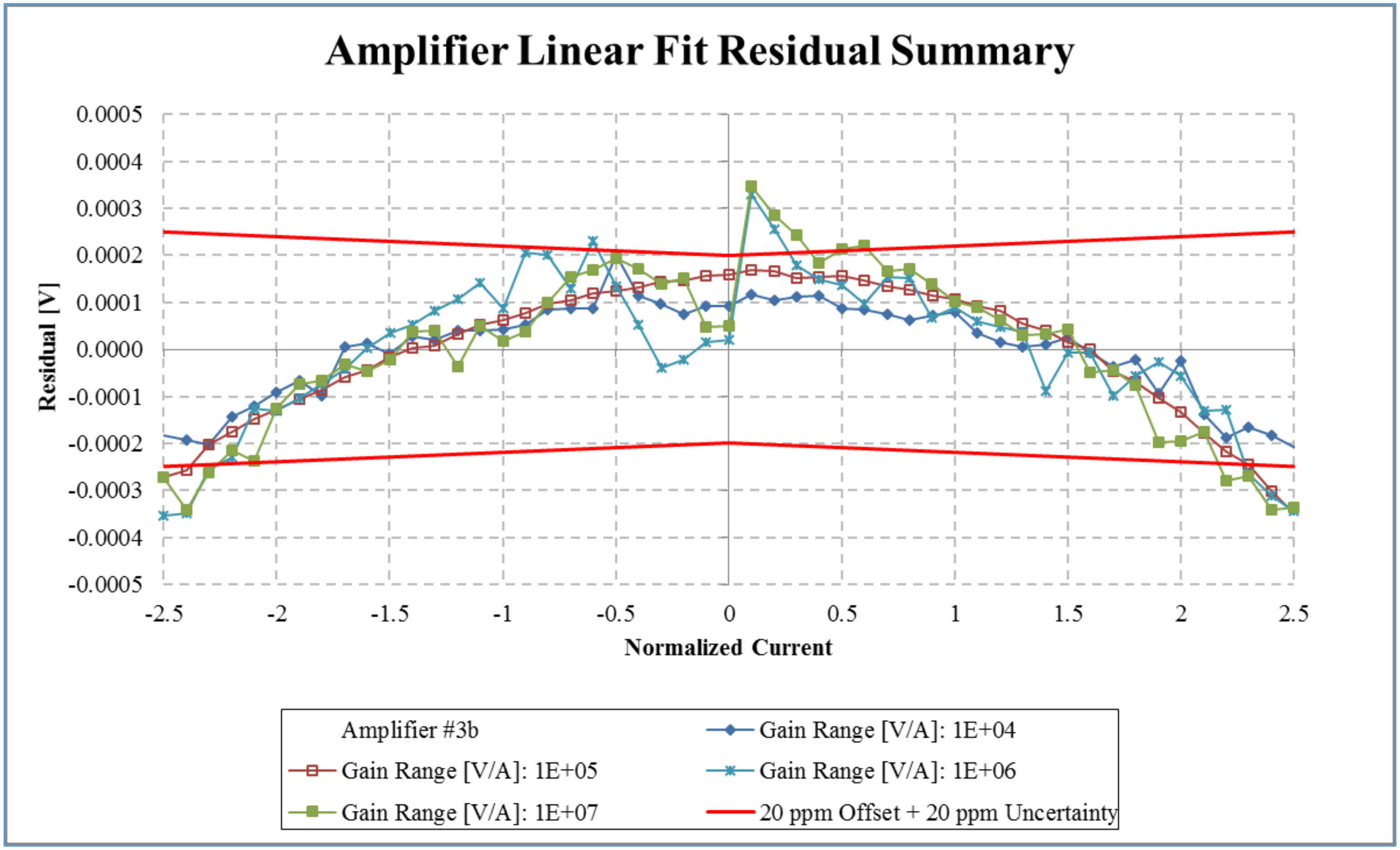
Amplifier #3b Linear Fit Residuals

The straight lines indicate 20x10^{-6} (20 ppm) offset uncertainty with a gain uncertainty of 20 ppm.



Amplifier #3b Linear Fit Residuals: +/- 2.5 V

The straight lines indicate 20x10^{-6} (20 ppm) offset uncertainty with a gain uncertainty of 20 ppm.



Conclusions

- Current-to-voltage preamplifiers have been measured over the output voltages of interest at each gain setting.
- Different preamplifiers have been found to deviate from linear behavior substantially outside the achievable uncertainties.
- The low uncertainties of preamplifier gains can only be realized by measuring over the entire gain range of interest.
- NIST is developing a Special Test service for I-V convertors (i.e., current amplifiers).

References

1. P. Sipila, et al, Calibration of current-to-voltage converters for radiometric applications at picoampere level, in Proceedings of NEWRAD (Davos, Switzerland), edited by J. Grober, pp 17–19, 2005.
2. G. P. Eppeldauer, Traceability of photocurrent measurements to electrical standards, Natl. Inst. Stand. Technol., Tech. Note 1621, 2009.
3. G. P. Eppeldauer, et al, Development of an in situ calibration method for current-to-voltage converters for high-accuracy SI-traceable low dc current measurements, IOP Publishing, Metrologia, Vol. 50, p. 509-517, 2013.

Questions?

NIST Transfer Standard I-V Convertor (i.e., amplifier)