B A T E M I K A
measurement solutions

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Batemika M100

Bridge mA-meter

Evaluation report

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1 Overview

Batemika M100 Bridge mA-meter is a specialised device used for the accurate and reliable measurement of measurement currents of all types of resistance bridges used in thermometry. Accurate determination of the measurement current is essential in order to increase the accuracy of the self-heating correction in SPRT measurements.

Accurate measurement of resistance-bridge measurement currents is not a trivial operation and Bridge mA-meter is designed to simplify this procedure. Any device used for the measurement of bridge currents must satisfy two requirements:

- Introduction of the device in the measurement circuit must generate minimum interference with the bridge operation, which includes noise (readings scatter) performance, drifts in measured resistance and general bridge operation (ability to perform a stable reading).
- Device for the measurement of bridge current must provide sufficient accuracy regardless of the shape of the measurement current. For the requirements of the SPRT primary thermometry and the self-heating correction, the short term accuracy of the ratios of measurement currents is essential.

2 Measurement procedure

Calibration and evaluation of the bridge mA-meter was performed using the indirect measurement method presented in figure 1. Function generator is used to generate DC and AC (sine wave) voltages, which generate an electrical current in the reference resistor and mA-meter. Reference resistor has a nominal value of 2500 ohm and was recalibrated before measurements. The reference voltmeter is used to measure the voltage drop U_V over the reference resistor R_{ref}, which enables us to indirectly determine the electrical current I. The input impedance R_V of the reference voltmeter is also taken into account:

$$I = \frac{U_V}{R} = \frac{U_V}{\dfrac{R_{ref} \cdot R_V}{R_{ref} + R_V}} \tag{1}$$

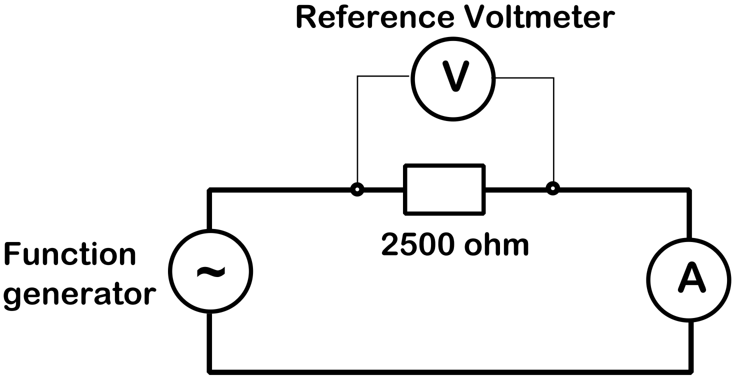

Figure 1: Measurement circuit for the calibration and evaluation of the bridge mA-meter

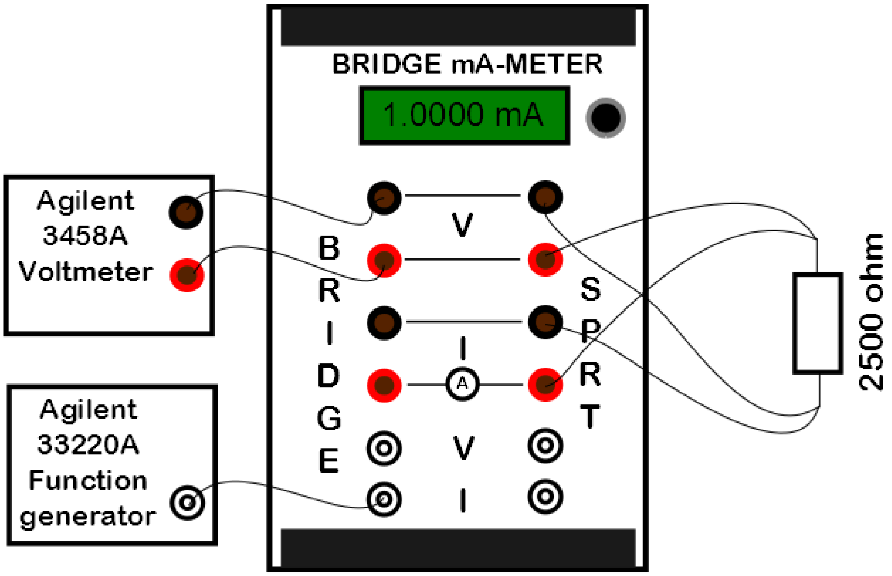

Figure 2: Connection diagram

2.1 Measurement uncertainty

Measurement uncertainty of the calibration and evaluation procedure depends on the accuracy of the reference resistor and reference voltmeter. Accuracy of the function generator does not directly influence the overall measurement uncertainty.

Reference resistor was a Vishay SMR3D foil resistor with nominal resistance of 2500 ohm and nominal temperature coefficient of 2 ppm/°C. Reference resistor was calibrated before and after the measurements and the calibrated value of the resistance was used in measurements. The short-term standard uncertainty of the reference resistance is 5 ppm.

Reference voltmeter was an Agilent 3458A multimeter. DC and AC voltage range of 10 V was used:

- At the 10 V DC range, specified accuracy of the voltmeter is 8 ppm of reading plus 0,05 ppm of range. Input impedance of the voltmeter is higher than 10 GΩ and can be considered negligible.
- At the 10 V AC range (SETACV SYNC setting) at frequency between 1 Hz and 100 Hz, specified accuracy of the voltmeter is 70 ppm of reading plus 40 ppm of range. Input impedance of the voltmeter is 1 MΩ ± 2%. Influence of the voltmeter input resistance was corrected according to equation (1) with residual standard uncertainty of 50 ppm.

Expanded measurement uncertainty (k=2) for DC measurements is 50 ppm.

Expanded measurement uncertainty (k=2) for AC measurements is 400 ppm.

3 Calibration and adjustment

Calibration and adjustment was performed with DC current at a single point of 2 mA. Calibration was performed with both positive and negative polarity of the measurement current and the difference was used to determine the offset calibration constant. Offset calibration constant was set to -5, which is equivalent to -0,156 µA. After adjusting the offset, the measured value of the current at 2 mA DC setpoint was used to determine the gain calibration constant, which was set to 41046, which is equivalent to maximum (peak) current of 4,1046 mA.

The expanded measurement uncertainty (k=2) of the DC calibration and adjustment is 200 ppm and includes the uncertainty of the measurement system used in calibration, the resolution of the calibration constants, the effective resolution of the bridge mA-meter and the short term stability.

The expanded measurement uncertainty (k=2) for AC/DC measurement currents includes also the AC/DC transfer error and is equal to 300 ppm (1,2 µA).

4 Noise and offset

Typical values for the internal noise (no external connections or cables on the bridge mA-meter connectors) is in the range between 0,4 µA and 0,6 µA. The actual measured value (obtained from communication interface) was 0,415 µA.

The results of sampling of zero measurement current are presented in figure 3. Sampling frequency is 50 kHz. Graph has 100000 samples, which is equivalent to 2 seconds.

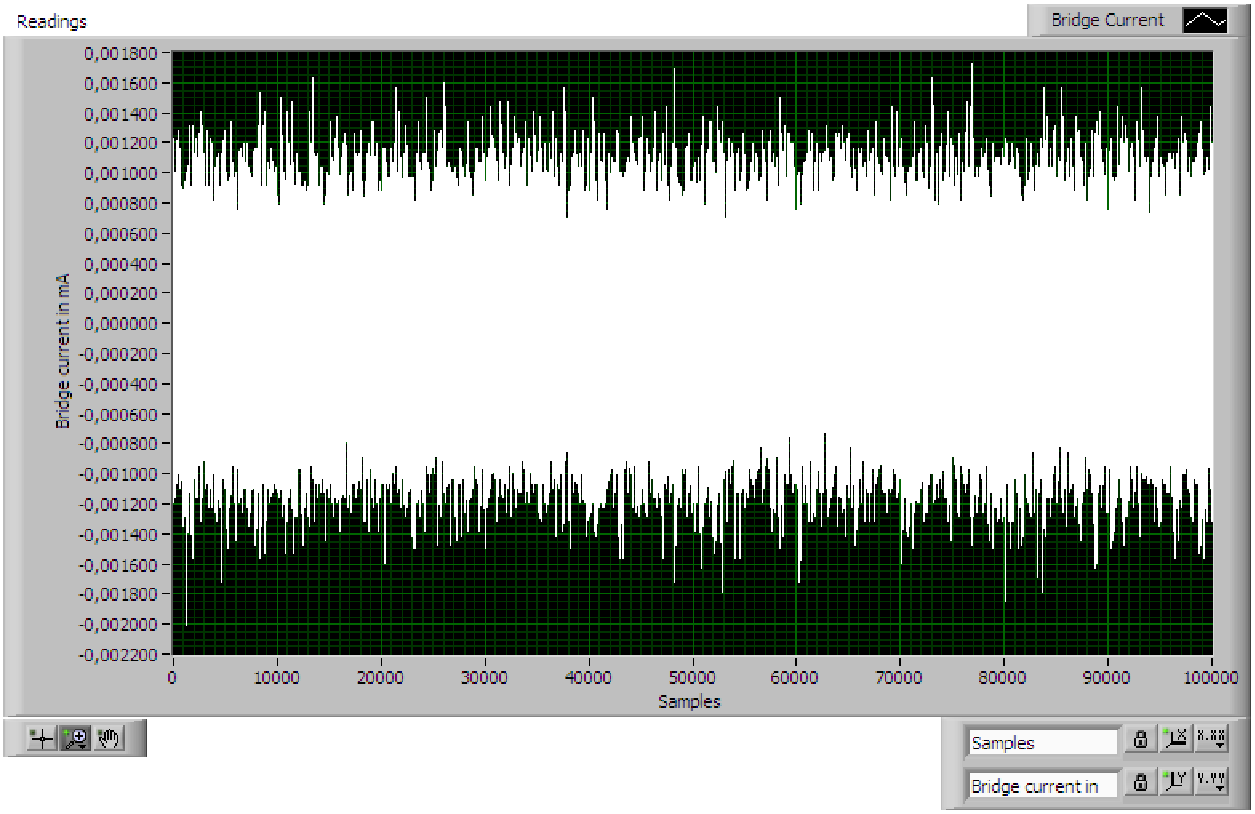

Figure 3: Internal noise with no external connections on the bridge mA-meter

Figure 4 displays the spectrum of the internal noise with no external connections on the bridge mA-meter. Sampling frequency is 50 kHz. Spectrum is the result of 500000 samples (10 seconds). There are no specific components visible within the spectrum.

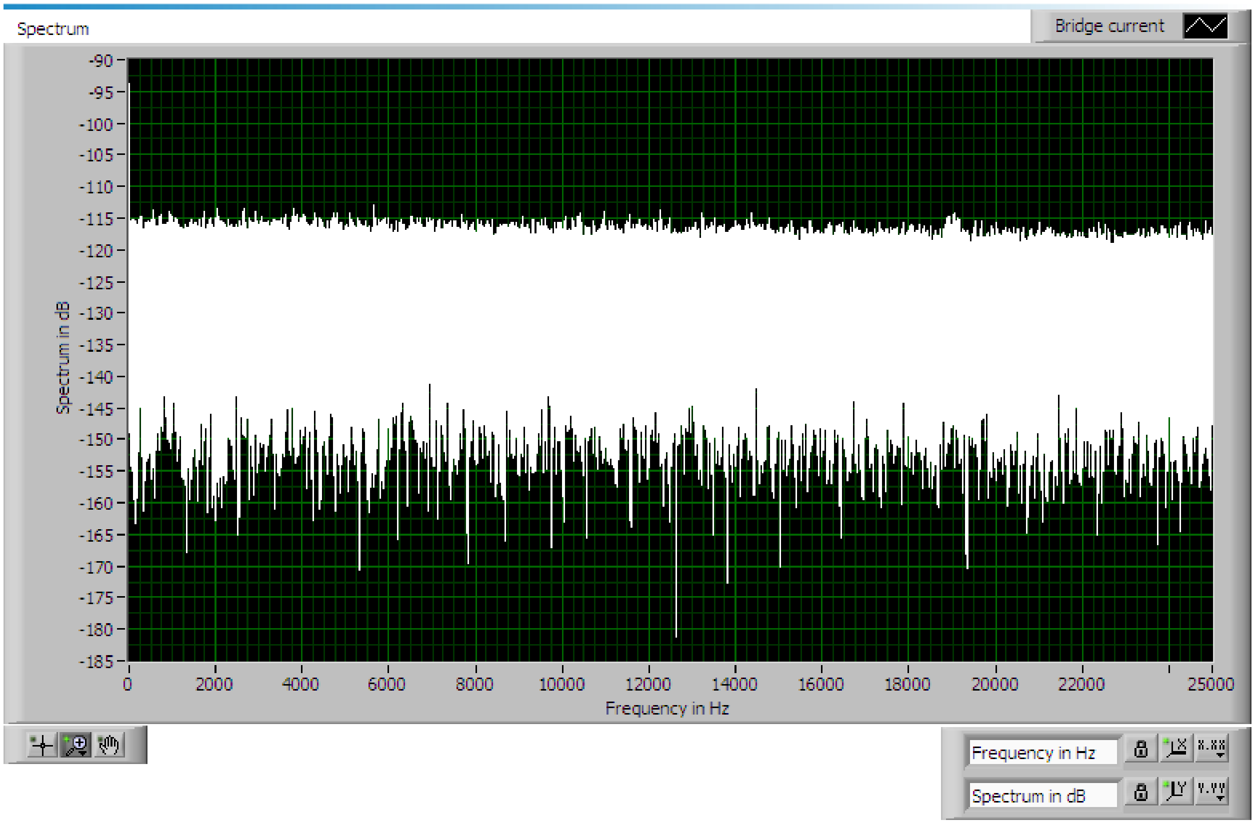

Figure 4: Internal noise spectrum with no external connections on the bridge mA-meter

Offset voltage is defined as the DC voltage with no external signal. Note that after the current is connected to the mA-meter, the offset voltage will stay the same regardless of the shape and magnitude of the measured current.

After offset calibration and adjustment, the remaining offset voltage was -0,024 µA, which is within the 0,031 µA resolution of the offset calibration constant.

Typical values of the offset calibration constant are within ±15, which is equivalent to 0,47 µA. Note that offset voltage may drift depending on the laboratory conditions (primarily temperature), so a readjustment may be required after the installation the laboratory. Adjustment of the offset calibration constant will not affect the gain calibration constant.

5 Harmonic distortion

Spectrum of the 75 Hz sine wave form a function generator is presented in figures 5 and 6. Magnitude of the measurement current is 1 mA RMS. Note that there are a few small components at 9600 Hz and 19200 Hz, which are the result of the radiated EMI from the laboratory environment, however the power associated with these components is practically negligible.

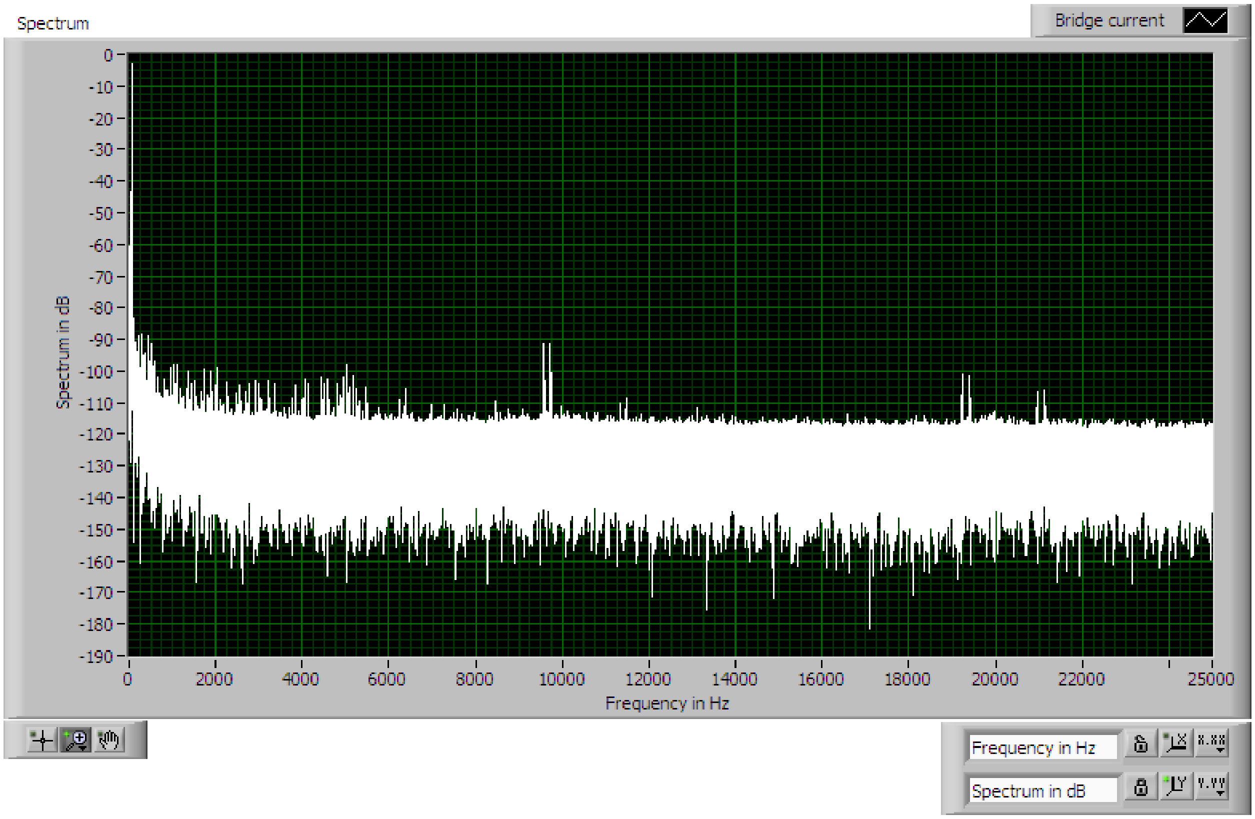

Figure 5: Full spectrum of the 75 Hz sine wave acquired from the function generator

Figure 6 presents the partial spectrum up to 1000 Hz, where higher harmonic components of the 75 Hz signal are visible. Note that all components are well below -80 dB (0,1 µA). Note also that the specified total harmonic distortion of the function generator for this signal is 0,04%, which is already in the same magnitude range.

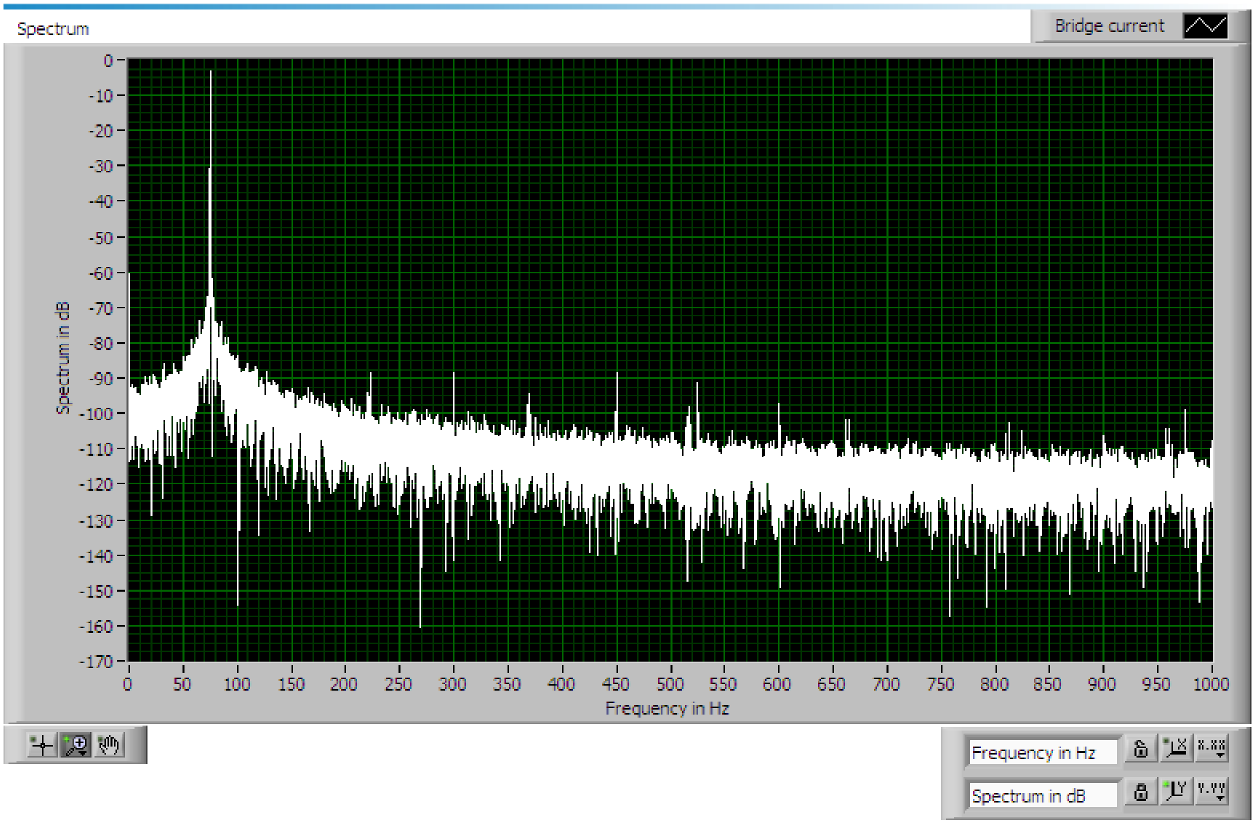

Figure 6: Partial spectrum of the 75 Hz sine wave acquired from the function generator

6 Frequency characteristic

Frequency characteristic was determined for two measurement currents (1mA and 2 mA RMS) and in frequency range from 3 Hz to 10 MHz.

Frequency characteristic was measured using the measurements system in figure 1. The function generator was set to a random frequency within the range under investigation. The instruments were then allowed to fully settle (60 seconds). The measurement software then took 40 readings from the reference voltmeter and bridge mA-meter with 2 seconds sampling period. The average of these 40 readings represents one measurement point on the graphs.

The operating range of the bridge mA-meter is from DC to 100 Hz. The frequency characteristic in the operating range is presented in figures 7 and 8. Result show a slope of the measured current with the frequency in the operating range, however the maximum difference is in the order of 50 ppm.

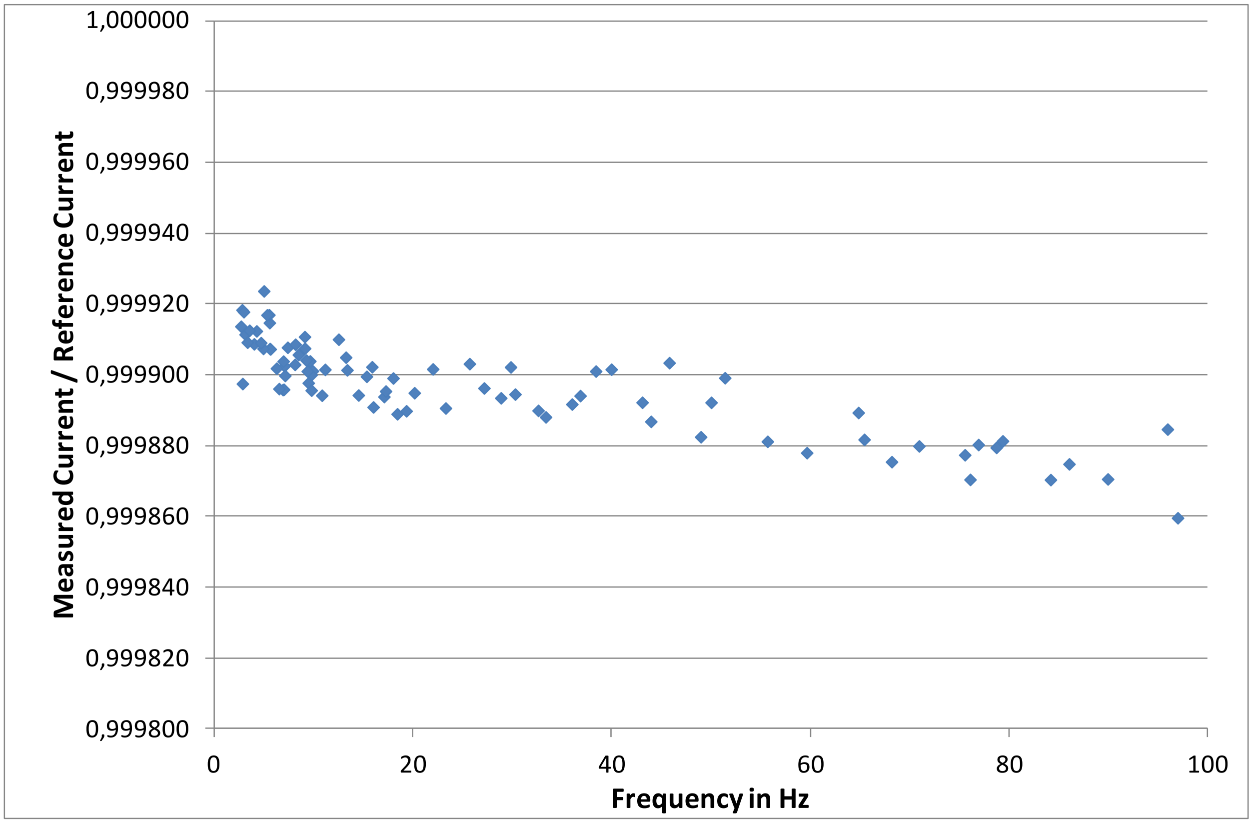

Figure 7: Frequency characteristic in the range from 3 Hz to 100 Hz for 1 mA current

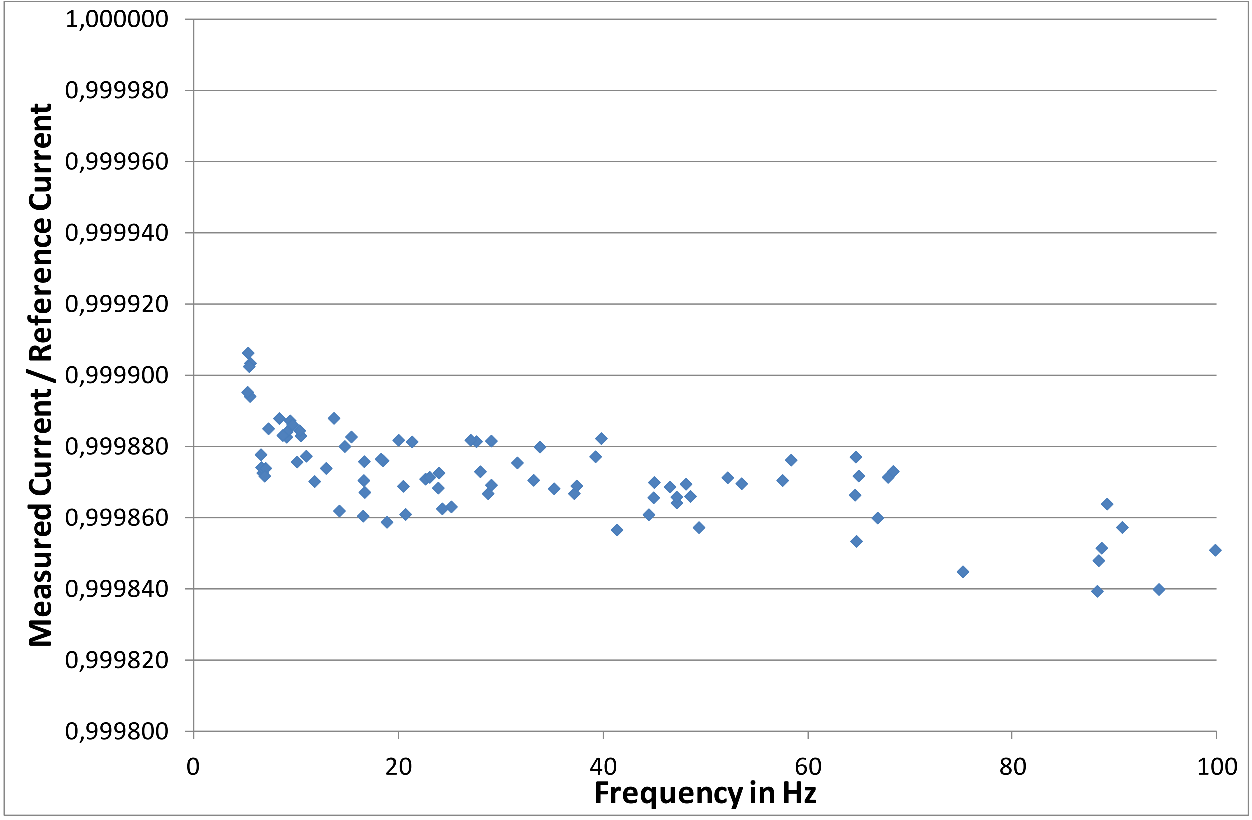

Figure 8: Frequency characteristic in the range from 3 Hz to 100 Hz for 2 mA current

Figures 9 and 10 present the frequency characteristic in the range from 3 Hz to 10 MHz The -3 dB frequency limit is at approximately 15 kHz. Higher frequencies are attenuated.

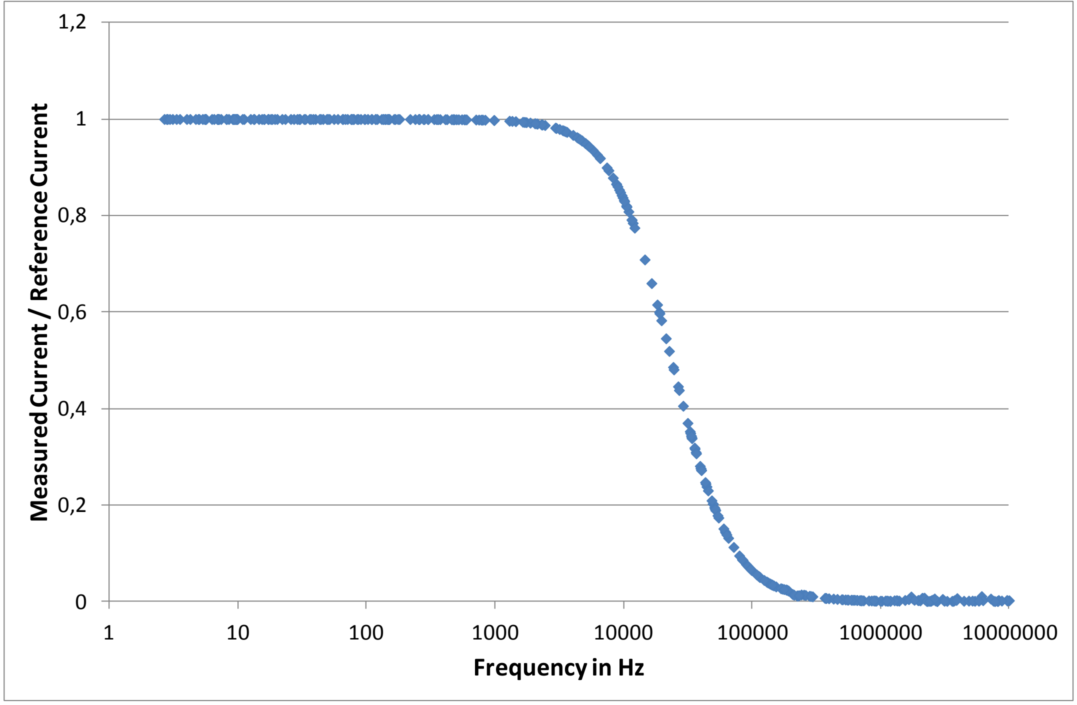

Figure 9: Frequency characteristic in the range from 3 Hz to 10 MHz for 1 mA current

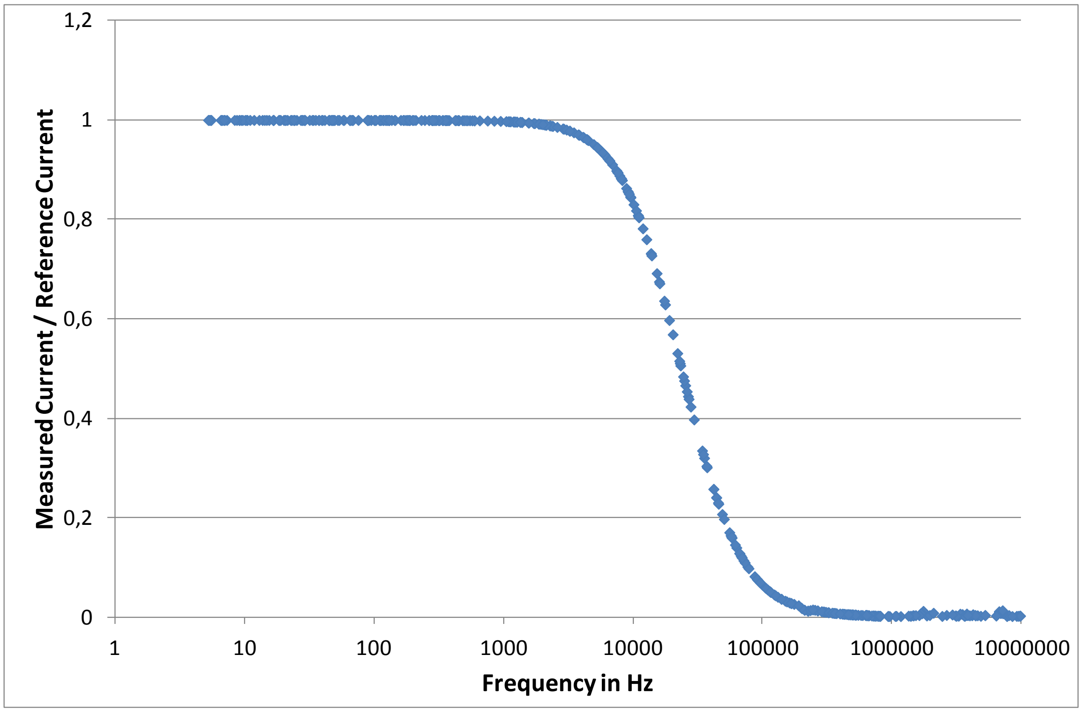

Figure 10: Frequency characteristic in the range from 3 Hz to 10 MHz for 2 mA current

7 Linearity

Linearity was determined at DC, 25 Hz and 75 Hz for currents in the range from 0,2 mA to 2,8 mA.

Measurement procedure was similar as for the frequency characteristics, but here the frequency was fixed and the amplitude was randomly set.

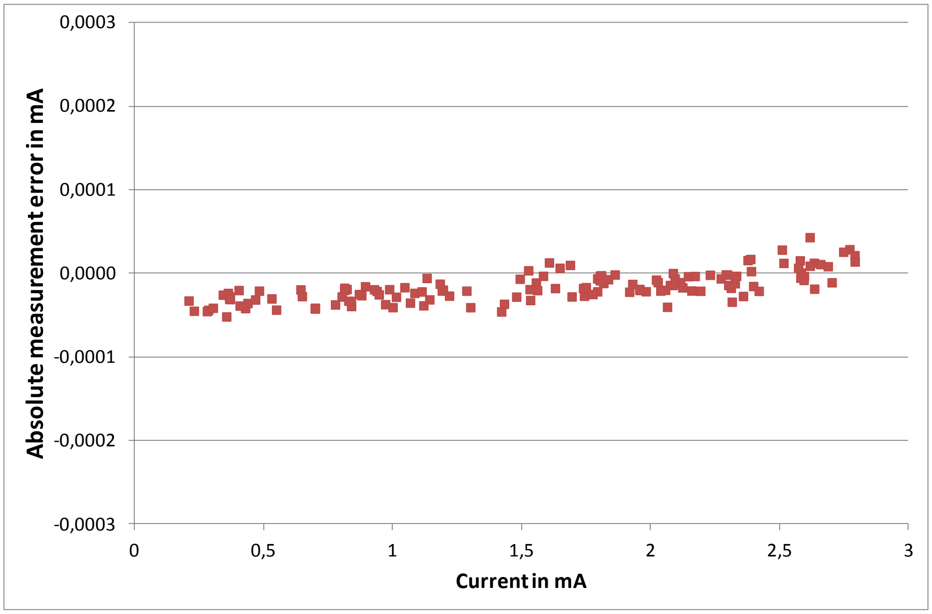

Figure 11: Linearity of the DC measurement current in mA

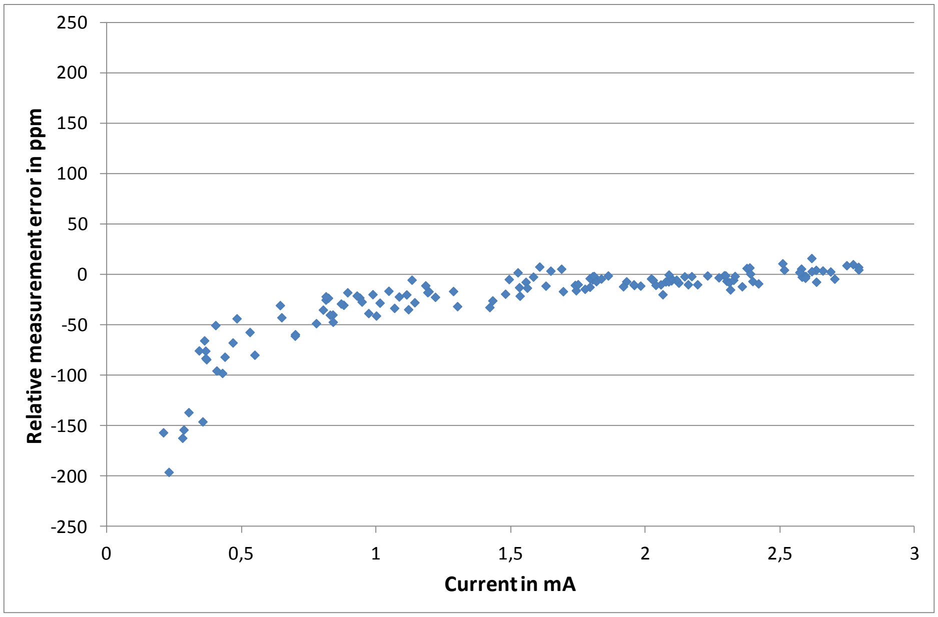

Figure 12: Linearity of the DC measurement current in ppm

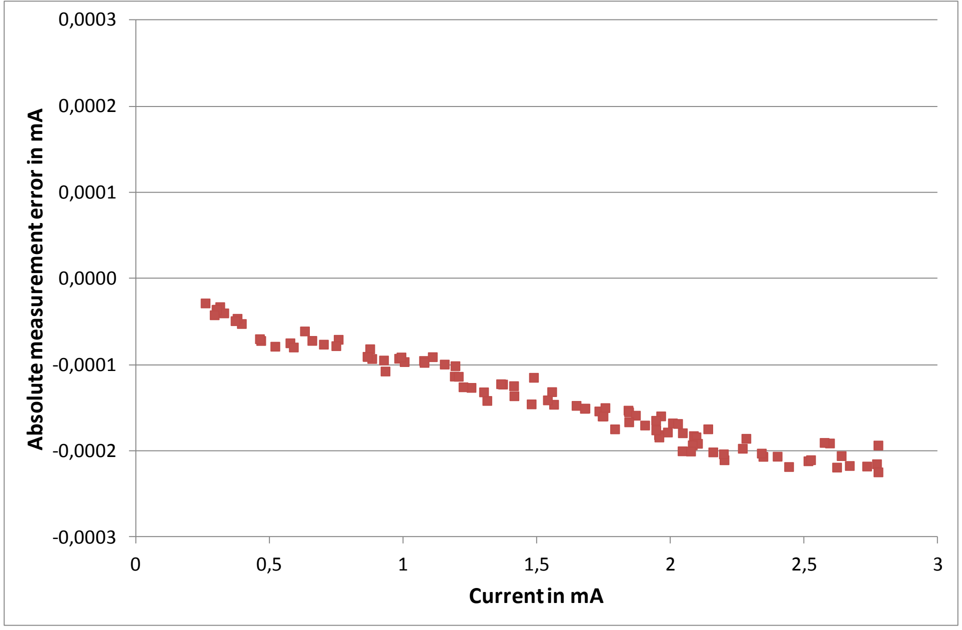

Figure 13: Linearity of the 25 Hz current in mA

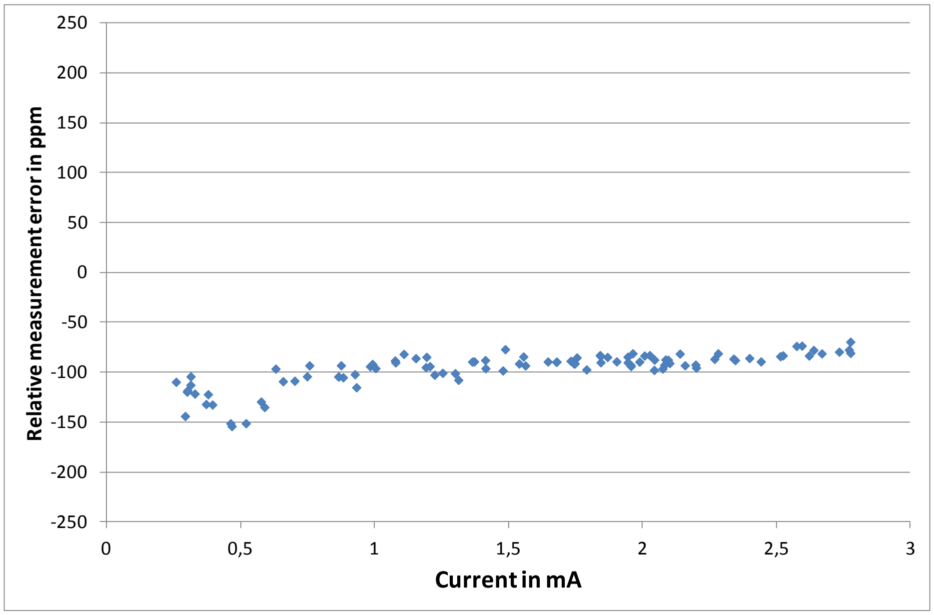

Figure 14: Linearity of the 25 Hz current in ppm

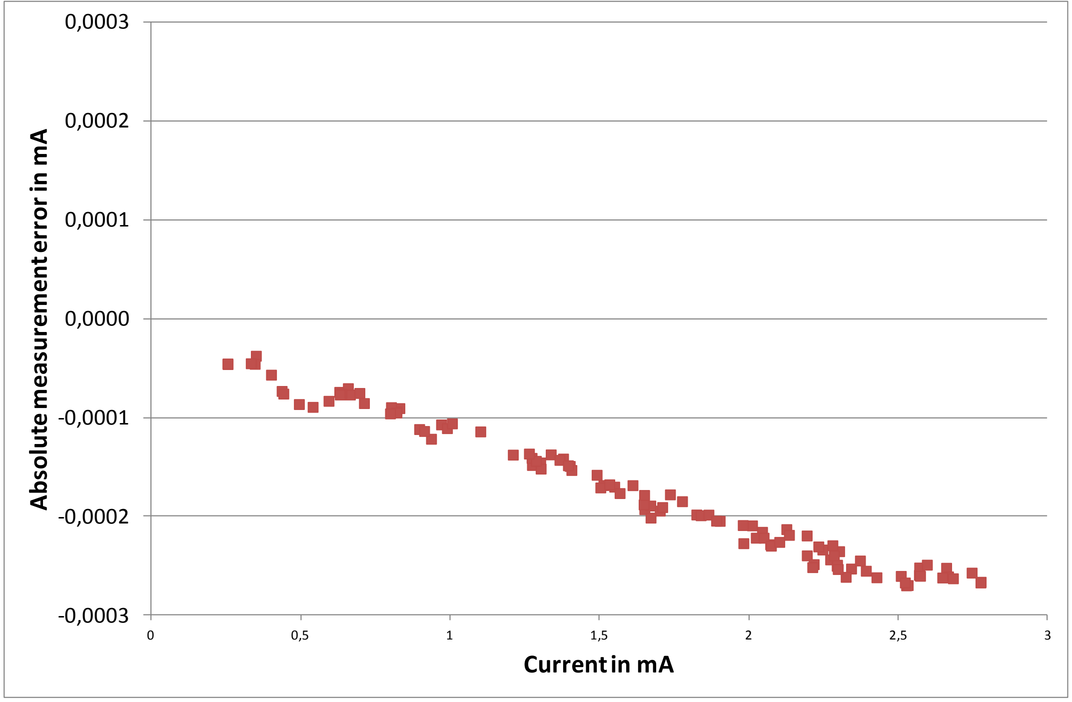

Figure 15: Linearity of the 75 Hz current in mA

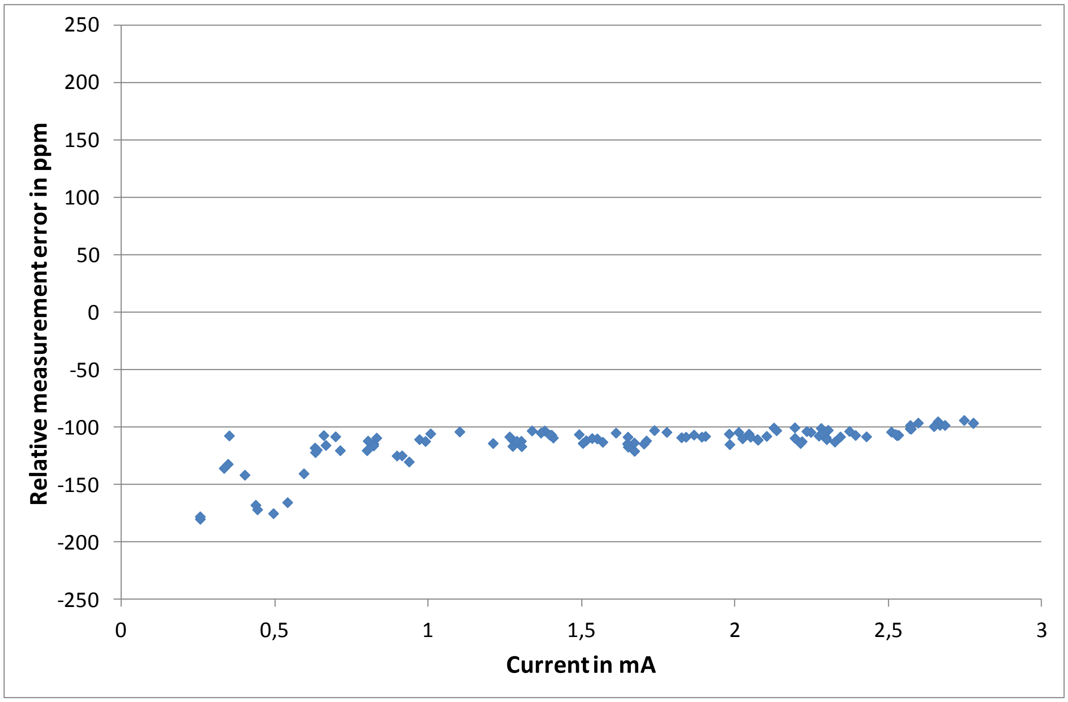

Figure 16: Linearity of the 75 Hz current in ppm

8 Ratio error

Ratio error is defined as the relative error between the ratios of two measured currents. This error is especially important in resistance thermometry, because it directly propagates in the self-heating correction procedure.

$$e = \frac{I_{A1}/I_{A2}}{I_{ref\,1}/I_{ref\,2}} - 1 \tag{2}$$

For the evaluation of the ratio error, data in figures 11 to 16 was reused. Four measured points around 0,5 mA, 1 mA and 2 mA were compared to all other measured points and ratio error was calculated and presented on graphs.

The data on figures 17 to 25 shows that the ratio error increases at small values of measurement current (<1 mA). This is mainly caused by resolution error of bridge mA-meter as well as the reference voltmeter. At DC measurements, offset voltage also can become a significant factor at very low currents.

The maximum ratio error for measurement currents in the range from 0,2 mA to 2,8 mA is 200 ppm.

The ratio error for measurement currents in the reduced range from 1 mA to 2,8 mA is 50 ppm.

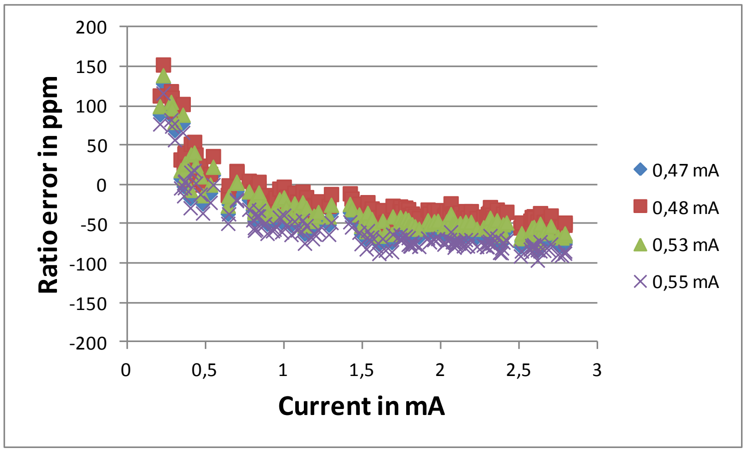

Figure 17: Ratio error for DC 0,5 mA

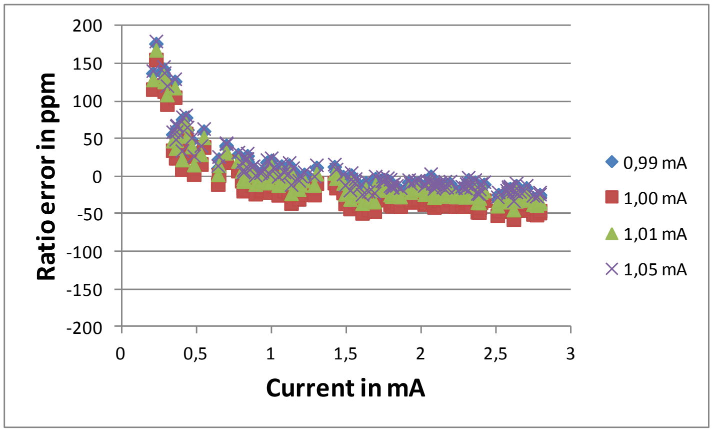

Figure 18: Ratio error for DC 1 mA

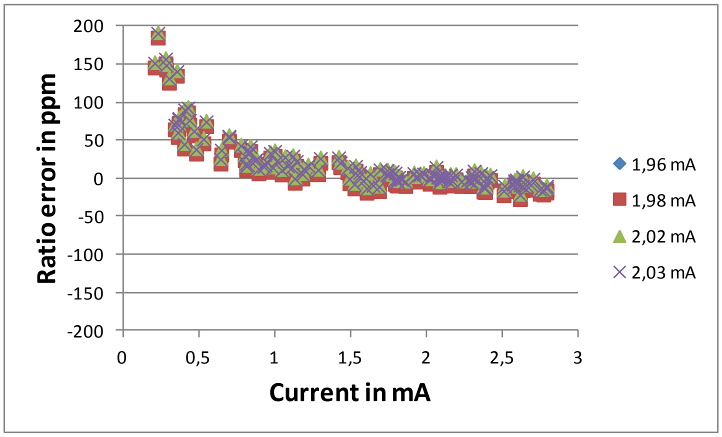

Figure 19: Ratio error for DC 2 mA

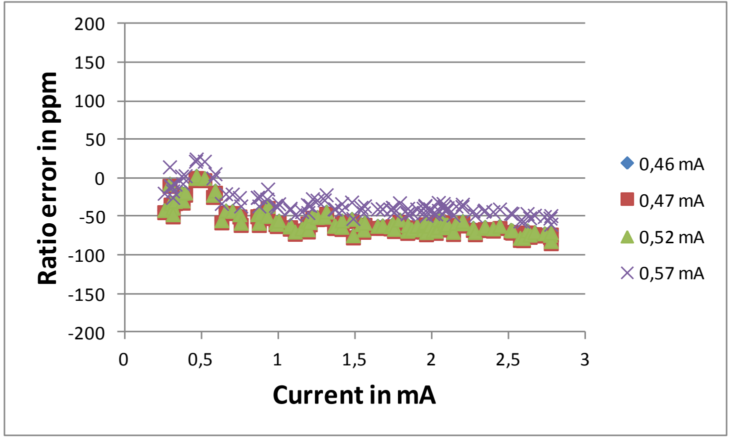

Figure 20: Ratio error for 25 HZ, 0,5 mA

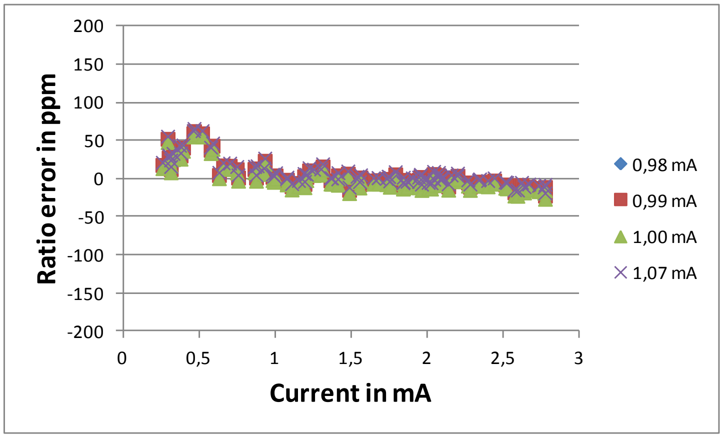

Figure 21: Ratio error for 25 HZ, 1 mA

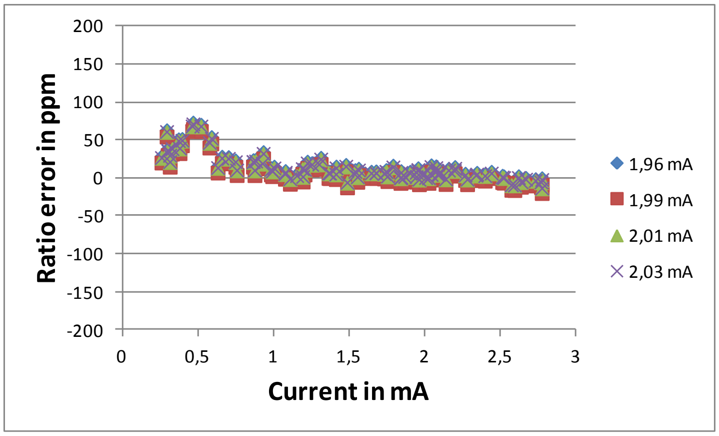

Figure 22: Ratio error for 25 HZ, 2 mA

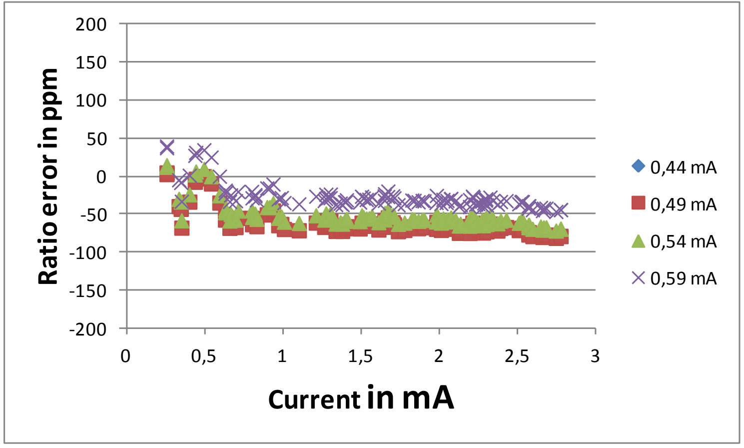

Figure 23: Ratio error for 75 HZ, 0,5 mA

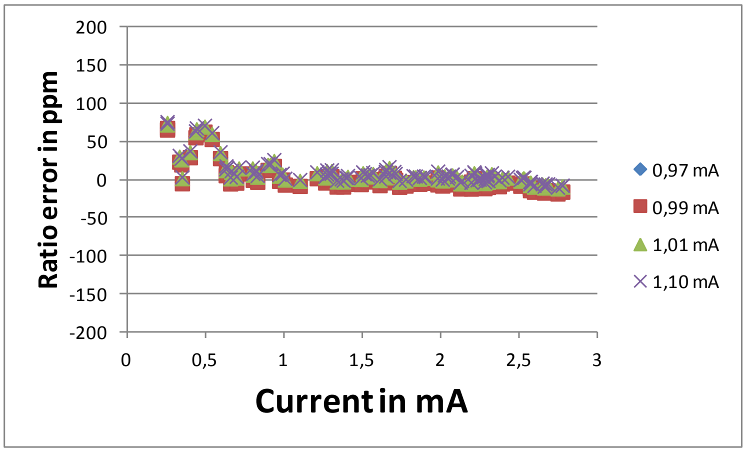

Figure 24: Ratio error for 75 HZ, 1 mA

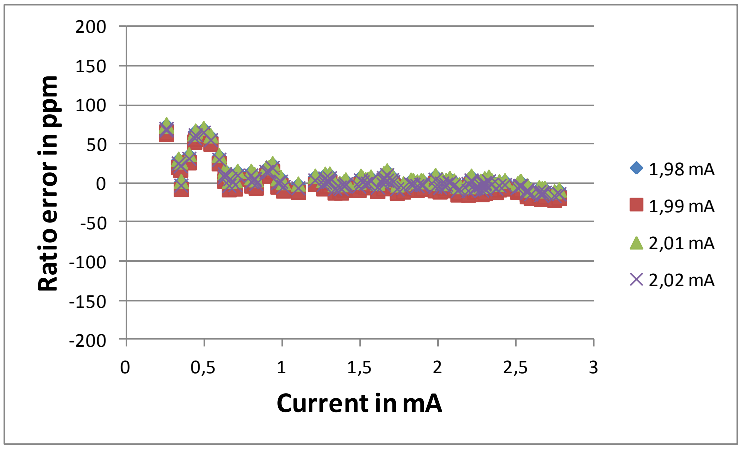

Figure 25: Ratio error for 75 HZ, 2 mA

9 Bridge interference

Batemika M100 Bridge mA-meter is designed with special emphasis on minimum interference with the normal operation of the resistance bridge under investigation. Bridge interference was tested on three different types of resistance bridges:

- ASL F900 is an AC resistance bridge with measurement current with frequency 25 Hz and 75 Hz and sine waveform.
- MI 6010 is a DC resistance bridge with DC current, which reverses polarity approximately every 10 seconds
- Kambic Metrology UT-ONE is a ADC based resistance bridge with DC current, which reverses polarity once per second

9.1 Communication cables

Communication cables can be a significant source of EMI interference and noise. Use of ferrite cores on the communication cables is recommended. Using a snap-in ferrite cores gives also the possibility to determine the optimal configuration for a particular resistance bridge.

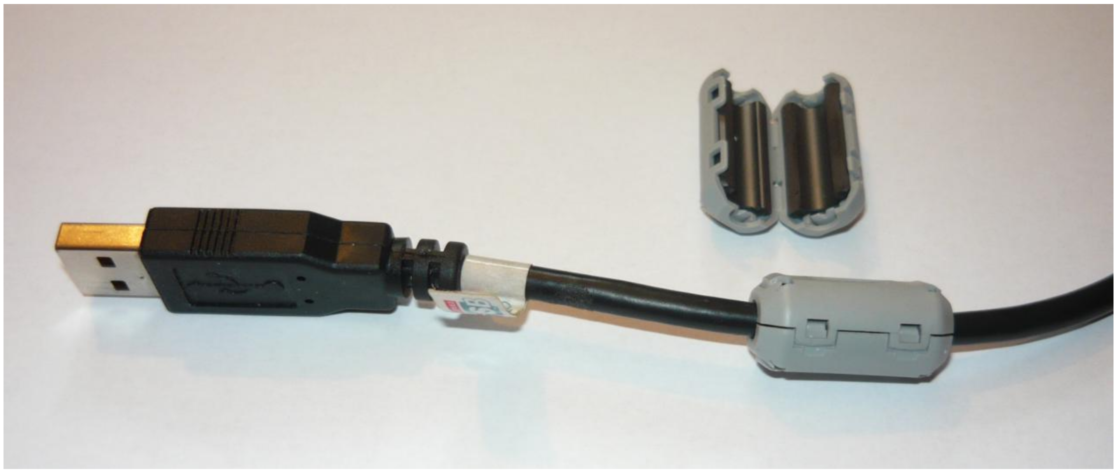

Figure 26: USB cable with snap-in ferrite core

Influence of the unsuitable communication cables is presented in figures 27 and 28. Both figures present the spectrum of the ASL F900 measurement current at 1 mA and 75 Hz settings. Configuration is identical in both cases; the only difference is the communication cable. In the case of figure 27, the USB cable is the recommended hi-speed double-screened cable (1,8 metres) with two ferrite cores. In the case of figure 28, the USB cable is a low-speed single-screened cable (5 metres) with no ferrite cores. The spectrum clearly shows additional EMI components in the measurement current.

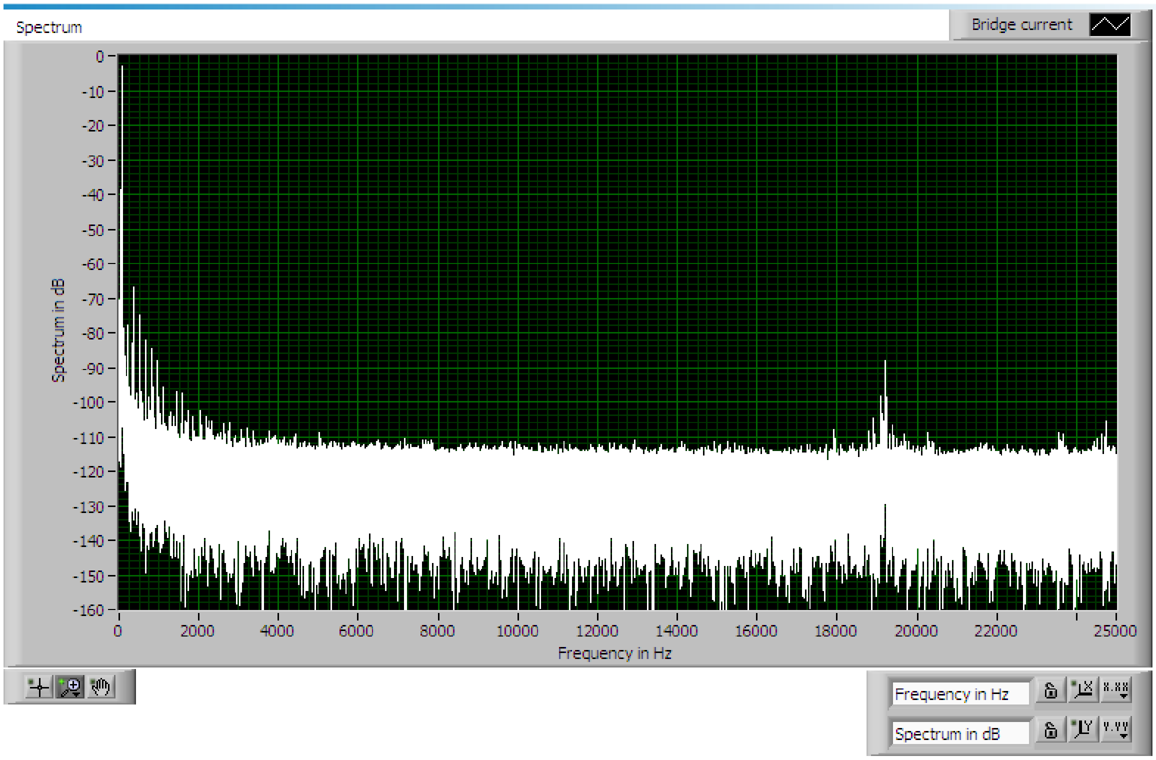

Figure 27: ASL F900 current spectrum with short double-screened USB cable with two ferrite cores

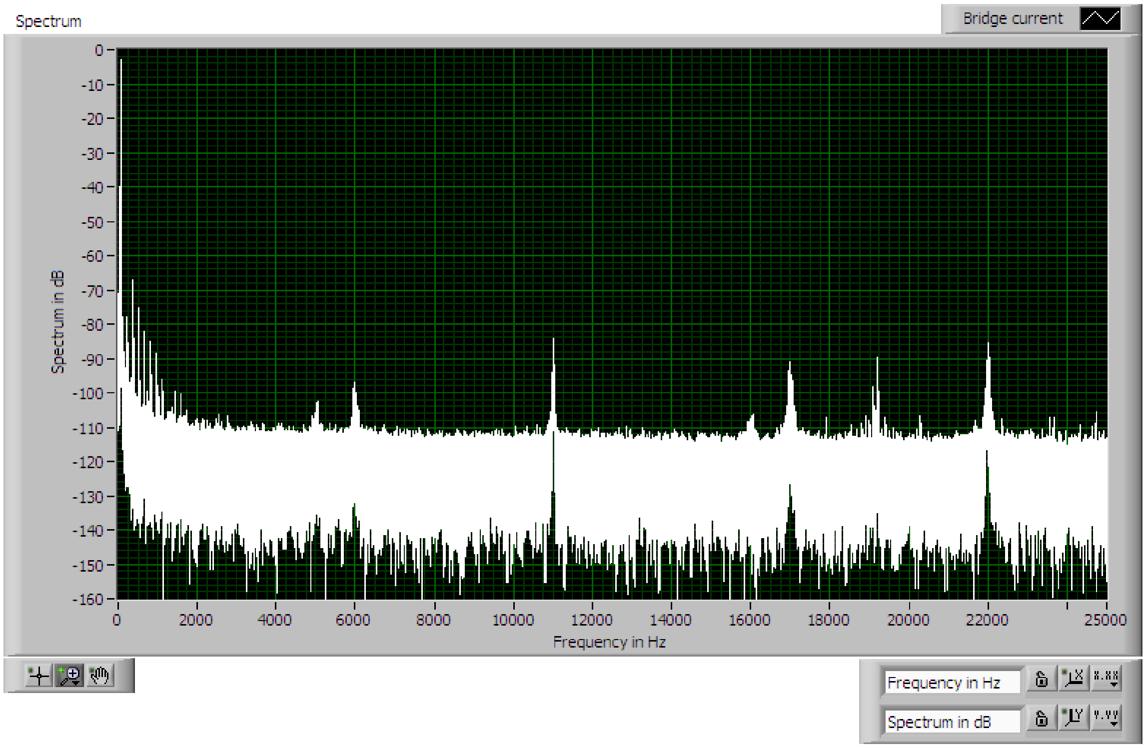

Figure 28: ASL F900 current spectrum with long single-screened USB cable with no ferrite cores

9.2 Noise

Noise or scatter of resistance readings is determined by measuring a large set of readings (100 or more) and calculating their standard deviation. Measurements were performed on a standard resistor and on a SPRT in a triple-point-of-water cell.

After introducing the bridge mA-meter in the measurement system, no change of standard deviation was observed with any of the investigated resistance bridges.

9.3 Resistance change

Resistance change was analysed by measuring the change of resistance with and without the bridge mA-meter in the measurement system.

With MI6010 and UT-ONE the differences were within the normal measurement noise.

With ASL F900, the difference was observable and depends on the particular configuration of the bridge mA-meter. For a 25 Ω reference resistor or a Pt-25 SPRT, the measured resistor change was within ±2 µΩ (20 µK or 0,08 ppm). The value of the resistance change depends on the following parameters:

- Bridge mA-meter is switched on or off
- Bridge mA-meter is grounded via communication interface or dedicated connector
- Ferrite cores for EMI reduction are implemented on SPRT wires
- Bridge mA-meter is connected to low or high lead of the SPRT current wires

Table 1: Results of ASL F900 measurements with various configurations

	Resistance Ω	St. deviation µΩ	Difference µΩ	Configuration
1	25,4344020	1,206	0,00	Reference measurement with passive connection box, ferrite cores on cables
2	25,4343978	0,912	-4,20	M100 measuring, floating, ferrite cores on cables
3	25,4344002	0,978	-1,80	M100 measuring, grounded via USB, ferrite cores on cables
4	25,4344012	0,968	-0,82	M100 switched off, grounded via USB, ferrite cores on cables
5	25,4343979	0,843	-4,16	M100 switched off, floating, ferrite cores on cables
6	25,4343980	0,705	-4,06	M100 switched off, floating, no ferrite cores
7	25,4343979	0,917	-4,14	M100 measuring, floating, no ferrite cores
8	25,4344000	0,959	-2,05	M100 measuring, grounded via USB, no ferrite cores
9	25,4344002	1,026	-1,84	M100 measuring, grounded via GND, no ferrite cores
10	25,4344011	1,003	-0,95	M100 measuring, grounded via GND and USB, no ferrite cores
11	25,4344005	1,358	-1,52	M100 measuring, grounded via USB, no ferrite cores
12	25,4344011	1,08	-0,86	passive connection box, no ferrite cores
13	25,4344014	0,648	-0,63	M100 measuring, grounded via USB, no ferrite cores, BNC cable to bridge
14	25,4343981	0,789	-3,90	M100 measuring, floating, no ferrite cores, BNC cable to bridge
15	25,4344018	0,905	-0,17	passive connection box (original ASL), no ferrite cores, BNC cable to bridge
16	25,4344024	0,876	0,41	passive connection box, no ferrite cores

Table 1 summarizes the results of measurements with the ASL F900 bridge in various configurations. Measurements were performed at 1 mA, 75 Hz and 0,2 Hz bandwidth. SPRT was a metal sheath Pt-25 in triple-point-of-water cell. Each measurement is an average of readings taken over at least 5 minutes. M100 was connected to the bridge with either the Habia shielded twisted-pair cable or dual BNC cable. Results show that the greatest contributing factor is the grounding of the M100 bridge mA-meter. If M100 is not grounded via one of the communication interfaces or the dedicated GND connector (floating configuration), the resulting resistance is approximately 4 μΩ bellow reference measurement with passive connection box. This result is repeatable regardless of any other configuration parameters. For the particular bridge it is therefore recommended to ground the M100 during measurements. With the M100 grounded, the resistance difference is approximately -1 to -2 μΩ.

The standard deviation of readings shows no repeatable dependence on used configuration. Although the values in table 1 vary from 0,6 μΩ to 1,3 μΩ, this variation can be attributed to statistical error due to a relatively small sample size. Repeated measurements with the same configuration were not able reproduce the same values of standard deviation.

9.4 ASL F900 current stability

To evaluate the stability of measurements of bridge measurement current, a set of 15 procedures for self-heating correction was measured over the period of more than 9 hours. Each procedure consists of 60 readings at 1 mA current, 60 readings at 1,4142 mA current and 60 readings at 1 mA. Out of each 60 readings, only the last 30 readings were used for the calculation of average and standard deviation. ASL F900 bridge was set to 75 Hz frequency and 0,2 Hz bandwidth. SPRT was a metal sheath Pt-25 in a triple-point-of water cell.

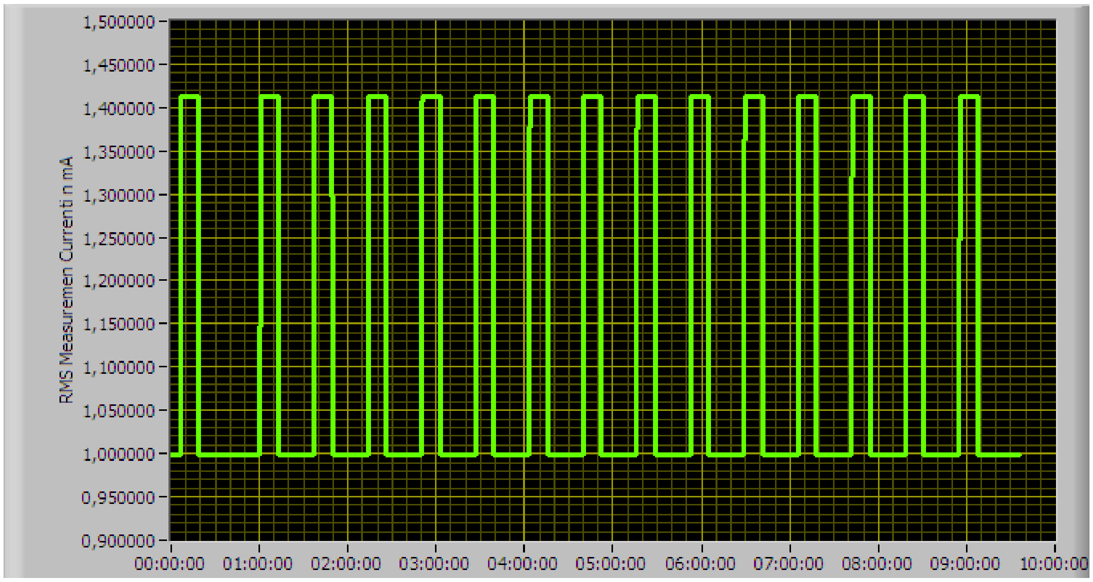

Figure 29: Measurement current for 15 procedures for self-heating correction

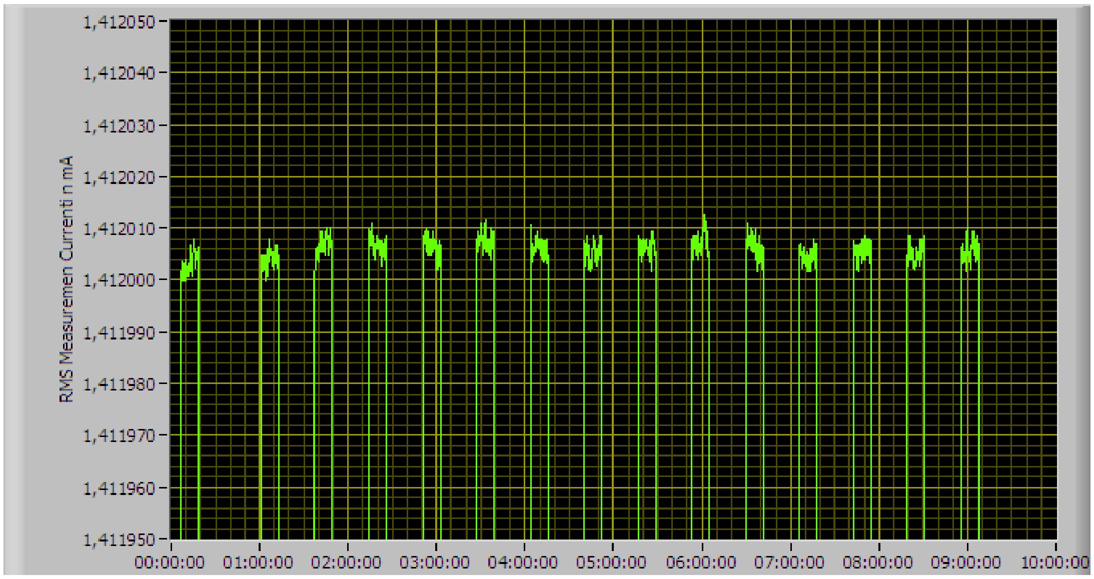

Figure 30: High value (1,4142 mA) of the measurement current

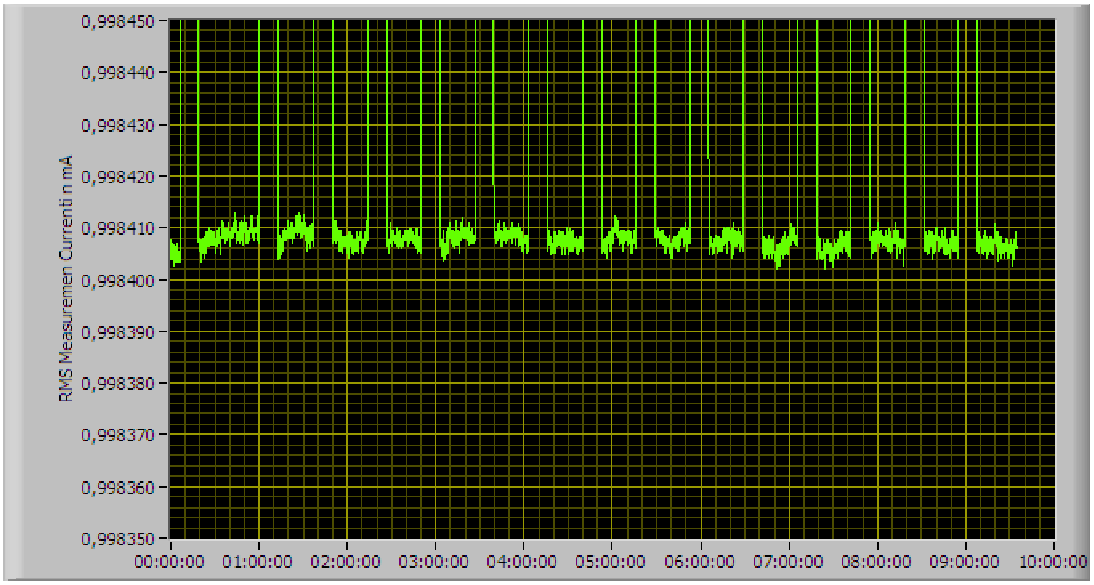

Figure 31: Low value (1 mA) of the measurement current

Results in figures 30 and 31 demonstrate that the measured current is stable within 0,01 µA, which indicates that both the bridge and bridge mA-meter have excellent short-term stability, which has negligible influence on total measurement uncertainty.

10 Conclusions

The results of the evaluation demonstrate that the evaluated bridge mA-meter has an excellent accuracy, which is completely sufficient for the measurement of the bridge current in primary thermometry.

The accuracy of the measurement current is 500 ppm (1,5 µA at low range and 7,5 µA at high range).

The accuracy of the ratio error is 200 ppm (short term accuracy for the same shape of measurement current).

The frequency range of the bridge mA-meter is DC to 100 Hz. Note that the bridge mA-meter has two modes of operation, which must be manually selected in order to get best results for a particular shape and frequency of measurement current.

The -3 dB frequency limit is at approximately 15 kHz. Higher frequencies are attenuated. Note that if the measurement current includes higher frequency components (originating in EMI), they are not measured and may introduce additional heating of the SPRT sensor. Implementation of ferrite cores may attenuate these high frequency currents.

Bridge mA-meter uses the same measurement procedure for measurement of AC and DC currents, and the AC/DC transfer error is within the accuracy specification. The recalibration of the measurement current can therefore be performed for DC current only, which simplifies the procedure and enables better calibration uncertainty.

Bridge mA-meter may be used as fixed component of the measurement system. The influence of the bridge mA-meter on bridge operation and measurement results was evaluated. For the MI 6010 and UT-ONE there was no influence detected within normal measurement noise. For the ASL F900 a decrease of resistance of 1 to 2 µΩ was detected after the installation of bridge mA-meter. If the bridge mA-meter is not grounded via communication interface and/or dedicated GND connector, this difference increases to 4 µΩ.

Note that the observed resistance difference is applicable to the particular resistance bridge and cannot be generalized to all types of resistance bridges and all possible measurement conditions. If bridge mA-meter is to be permanently installed in the system for the measurements of highest accuracy, a short validation (similar to results in table 1) should be performed.