EMRP ENG05 Metrology for Solid State Lighting

D2.1.1 Comparison Report on Measurement of Electrical Quantities of Selected SSL Lamps

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Summary

In task 2.1.1 of SSL project, selected SSL lamps will be measured by three participants (VSL, Trescal, METAS). The measurements results will be compiled into a report. To fulfil the requirements, the main electrical quantities of selected SSL lamps are measured independently and compared during May-August 2012. This report is the output of this task.

In this report, the SSL lamps and the evaluation methods are introduced firstly. Then the topologies and measuring methods are described in detail. The results are given in tables and figures. Finally, conclusions are drawn based on the results.

The results presented in this report are only valid for the selected lamps tested.

Table of contents

List of figures

List of tables

1 Introduction

1.1 Background and objectives

In many aspects, Solid-State Lighting (SSL) has proved itself as the potential alternative of the fluorescent lamps and incandescent lamps, although the products are still in their early stages. To assure market acceptance, metrology technology should provide unambiguous product performance data, which is still missing. As one task of the European joint research project on "Metrology for Solid State Lighting" [1], metrology for traceable electrical power measurement of SSL sources is to be developed.

In WP2, Basic measurement methods for SSL characterization, there is Task 2.1, Electrical properties of SSL source. The task is to determine the best measurement capability in electrical power determination of SSL products. The deliverable 2.1.1 is “Evaluation report on electrical power and power factor measurement of SSL, including device exchange.” This comparison is to fulfill the requirement of the deliverable 2.1.1. It will evaluate the measurement capabilities established by each partner in WP1, The evaluation of the measurement capability for electrical power and the power factor in relation to the harmonic distortion introduced by the SSL product will be used for setting up the guidelines on traceability in WP1.

1.2 Timeline and participants

The protocol is accepted by participants in May 2012. VSL took on the role of pilot for this comparison. There are three participants in this comparison: VSL, METAS and Trescal.

Three groups of 5 lamps, totally 15 lamps were used for the purpose of this comparison. At each measurement, participants measure one group of lamps. Then this group of lamps is shipped to other participants to exchange lamps. The sequence is changed slightly during the comparison because METAS setup is not available for one month. Finally, all these three groups of lamps are measured by all participants.

The actual comparison was done between May and August 2012.

Table 1. Timeline of the comparison

Date				VSL	METAS	Trescal
7-May-12	-	12-May-12	preparing, burning			
14-May-12	-	9-Jun-12	measurement #1	Group1	Group2	Group3
11-Jun-12	-	30-Jun-12	measurement #2	Group3		Group1
9-Jul-12	-	4-Aug-12	measurement #3	Group2	Group1,3	
6-Aug-12	-	20-Aug-12	measurement #4			Group2
20-Aug-12			Start to compile result, report			

The participants reported the measured electrical quantities of each lamp. This report is based on the reported results.

1.3 Travelling EUTs

The travelling EUTs include several pieces of lamps. There are five models of SSL lamps listed below.

Table 2. Models of the lamps used in comparison

	Model	pieces
1	Osram: PARATHOM PAR16 20	3
2	Philips MASTER LED bulb MV	3
3	Osram: Parathom A60	3
4	Osram: Parathom A80	3
5	Osram: Parathom A40FR	3

To clearly identify the EUTs, the following methods of annotations are used, for instance,

L2-1: refers the unit in group1, which is of the lamp type Philips MASTER LED bulb MV, with “L2-1” marked on the lamp base and the package box.

L4: refers all three lamps of the lamp type Osram: Parathom A80.

All lamps are grouped into 3 groups for easy circulation.

Table 3. Lamps grouping in comparison

Group 1	L1-1	L2-1	L3-1	L4-1	L5-1
Group 2	L1-2	L2-2	L3-2	L4-2	L5-2
Group 3	L1-3	L2-3	L3-3	L4-3	L5-3

1.4 Comparison protocol

1.4.1 Electrical quantities to be measured and compared:

The following formulas are used to calculate the main electrical quantities of SSL product, include active power P, RMS value of voltage V_{rms} and current I_{rms}, apparent power S , power factor PF and Total harmonic distortion THD:

$$P = \frac{1}{2}\sum_i \Re(V_m(f_i)\cdot I_m(f_i)) \text{ or } P = \sqrt{\frac{1}{N}\sum_j I_j V_j} \qquad (1)$$

$$V_{rms} = \sqrt{\frac{1}{2}\sum_i |V_m(f_i)|^2} \text{ or } V_{rms} = \sqrt{\frac{1}{N}\sum_j V_j^2} \tag{2}$$

$$I_{rms} = \sqrt{\frac{1}{2}\sum_i |I_m(f_i)|^2} \text{ or } I_{rms} = \sqrt{\frac{1}{N}\sum_j I_j^2} \tag{3}$$

$$S = V_{rms} I_{rms} \tag{4}$$

$$PF = P/S \tag{5}$$

$$THD = \frac{1}{I_1}\sqrt{\sum_{m=2}^{m_{Max}} I_m^2} \tag{6}$$

1.4.2 The time domain waveform and harmonic contents

For each lamp, the participants provide two files containing time domain waveform and harmonic contents.

In the waveform file, both current and voltage waveforms are recorded. The length is 10 complete periods with sampling rate of 500 kSa/s.

In the harmonics contents file, the harmonic magnitude and the phase of voltage and current are stored. They are calculated using the current and voltage waveforms lasting for 0.2 second. In the file, the frequency points start from DC to 250 kHz with 5 Hz frequency resolution.

These files are not used for comparison directly, but provide more details of the measurements done.

1.4.3 Ambient conditions

The ambient temperature in which measurements are being taken shall be maintained at 23 ± 0.5 °C, measured at a point not more than 1m from the SSL product and at the same height as the SSL product.

1.4.4 AC power supply

The AC power supply, while operating the SSL product, shall have a sinusoidal voltage wave shape at 50 Hz such that the RMS summation of all harmonic components does not exceed 0.5% of the fundamental component (THD<0.5%) during operation of the test item.

1.4.5 Voltage regulation

The voltage of an AC power supply (RMS voltage) applied to the device under test shall be regulated to within ±0.1% under load.

1.4.6 Stabilization of SSL product

After purchasing, before the first measurement, each lamp will be burned for 3 days to let the lamp stable. In each measurement, before collecting data, the lamp shall be operated long enough until reaching stabilization and temperature equilibrium. The time required for stabilization depends on the type of SSL products. The stabilization time typically ranges from 30 min to 2 or more hours. It can be judged that stability is reached when the variation the electrical power over a period of 30 min is less than 0.2%. The stabilization time used for the lamp shall be reported.

1.4.7 Operating orientation

The lamps shall be evaluated in the operating orientation with lamp upward (lamp base in the bottom), the light emission may not be blocked.

1.4.8 Electrical setting

The lamps product under test shall be operated at 230V 50Hz.

1.4.9 Inter-connection

The connection between the power supply, transducer and lamps must be kept as short as possible to get better agreement in measurement condition.

There is a standard [2], specifying procedures for measuring total luminous flux, electrical power, luminous efficacy, and chromaticity of SSL luminaries and replacement lamp products, where the part of electrical measurement follows the standards of previous kinds of lighting products.

The above comparison protocols are based on [2], but with more stringent requirements to minimize the influence of test facilities.

1.5 Measurement techniques

For SSL products, to achieve better efficiency and lower losses, higher switching frequencies are used. As a consequence, the SSL current signal is rich in high harmonic components far beyond 2 kHz, which is the classic upper frequency bound of harmonics. Therefore, to achieve the best measurement capability in electrical quantities, the sampling frequency should be several hundred kHz.

In all three participants, the reference meters are based on a fully characterized digitizer, a wideband current shunt and a wideband voltage divider. The ac power supplier provides a stable and clean 50Hz 230V pure sinusoidal wave.

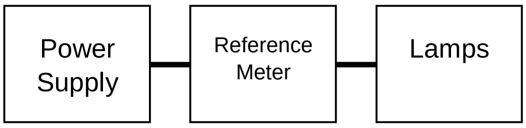
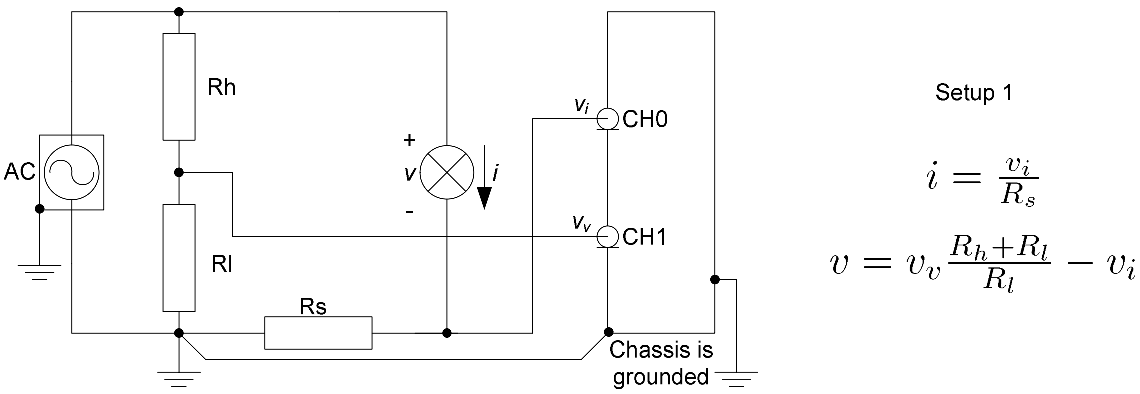
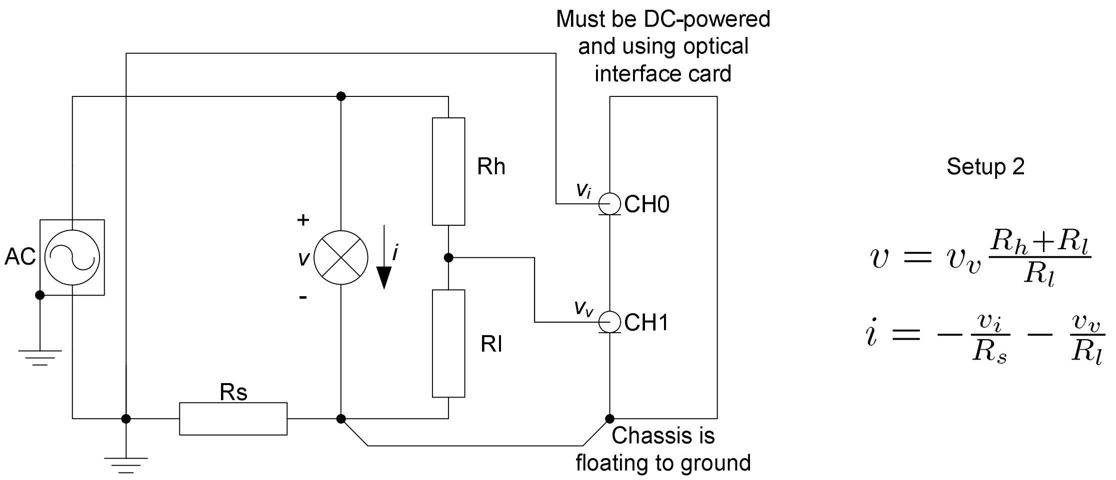


Figure 1. General diagram of the measurement setup

There are two wiring methods of the reference meter.



(a) Setup1



(b) Setup2

Figure 2. Two wiring methods of reference meter

In this comparison, the setup1 is used in all three participants. This wiring method is relatively simple and the digitizer is not necessary to be floating to ground.

1.6 Outline of the report

In the following parts of the report, first the properties of variant lamps used in the test are listed. After that, the measured electrical quantities are compared with tables and figures. The last part concludes with the discussion.

2 Various lamps used in measurements

In this part, the lamps used in measurements are listed below.

2.1 Lamp L1

Figure 3 below illustrates the actual current waveform of the lamp L1 measured by three labs. This lamp is using passive rectifier with few high frequency components but relatively low power factor and high distortion.

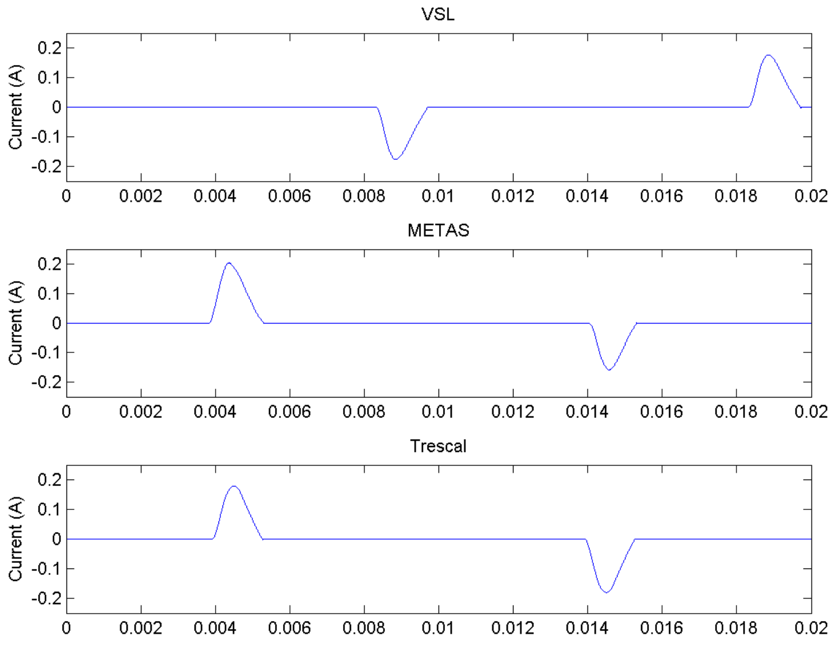


Figure 3. The current waveform of the L1 measured by three labs

The power consumed is 4.36W when powered from 230V. The PF (Power factor) is 0.442, and the THD (Total harmonic distortion) is around 199.8%.

2.2 Lamp L2

Figure 4 below illustrates the actual current waveform of the lamp L2 measured by three labs. This lamp is using active rectifier with rich high frequency components but relatively high power factor and low distortion.

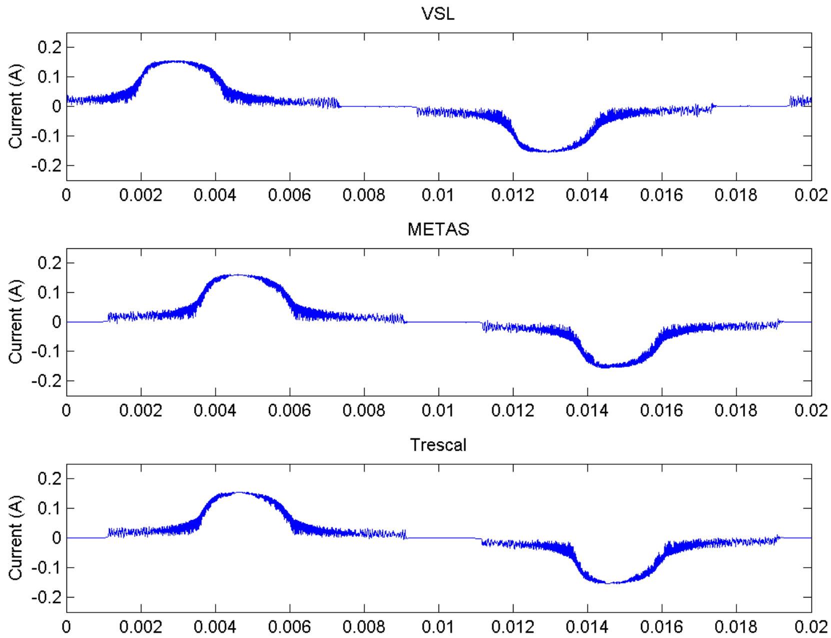


Figure 4. The current waveform of the L2 measured by three labs

The power consumed is 12.73W when powered from 230V. The PF (Power factor) is 0.823, and the THD (Total harmonic distortion) is around 67.5%.

2.3 Lamp L3

Figure 5 below illustrates the actual current waveform of the lamp L3 measured by three labs. This lamp includes passive rectifier and passive power factor correction circuit. The high frequency components are low. The power factor is relatively high and the distortion is relatively low.

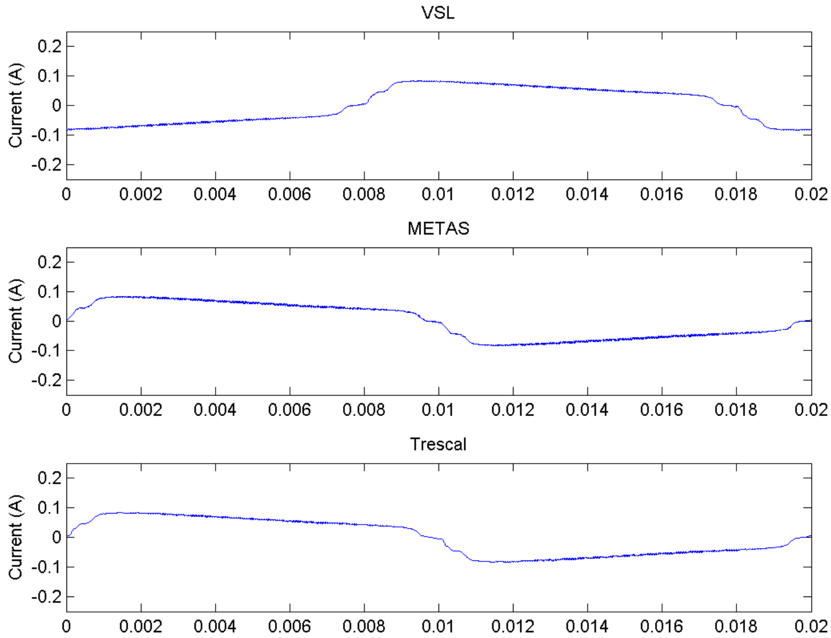


Figure 5. The current waveform of the L3 measured by three labs

The power consumed is 12.61W when powered from 230V. The PF (Power factor) is 0.923, and the THD (Total harmonic distortion) is around 30.7%.

2.4 Lamp L4

Figure 6 below illustrates the actual current waveform of the lamp L4 measured by three labs. This lamp includes passive rectifier and passive power factor correction circuit. The high frequency components are low. The power factor is relatively high and the distortion is relatively low.

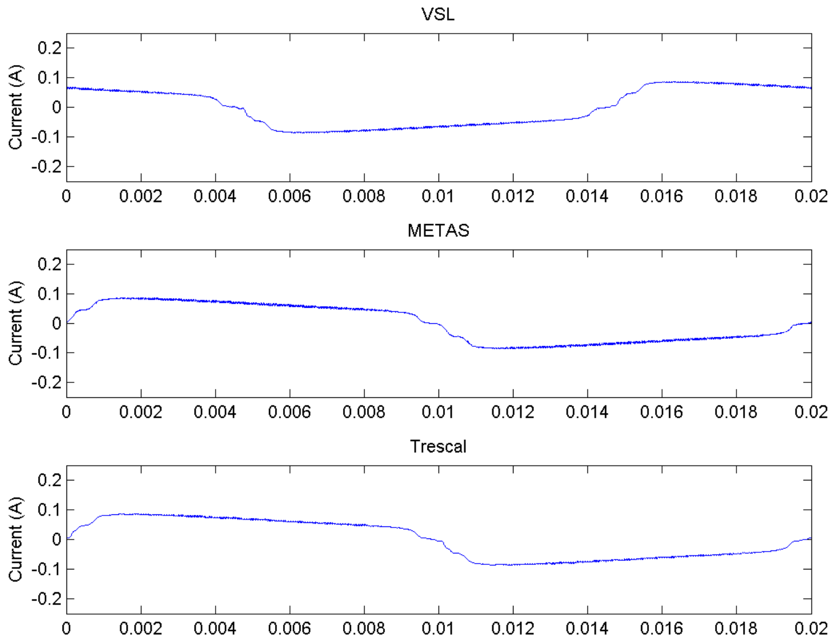


Figure 6. The current waveform of the L4 measured by three labs

The power consumed is 13.50W when powered from 230V. The PF (Power factor) is 0.935, and the THD (Total harmonic distortion) is around 28.7%.

2.5 Lamp L5

Figure 7 below illustrates the actual current waveform of the lamp L5 measured by three labs. This lamp includes passive rectifier and passive power factor correction circuit. The high frequency components are low. The power factor is relatively high and the distortion is relatively low.

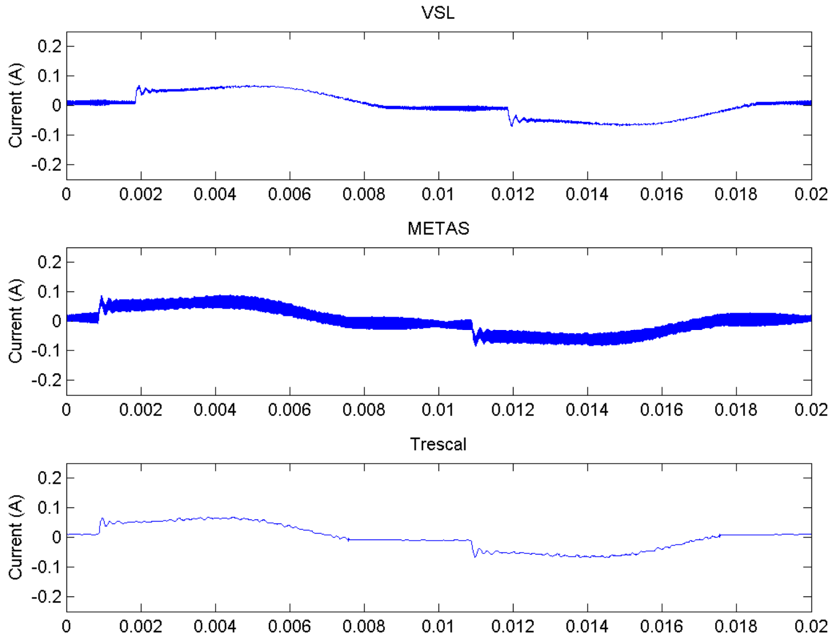


Figure 7. The current waveform of the L5 measured by three labs

The power consumed is 7.90W when powered from 230V. The PF (Power factor) is 0.823, and the THD (Total harmonic distortion) is around 33.6%.

3 Measurement results

In this part, the measured electrical quantities are compared with tables and figures. The uncertainties of the electrical quantities are also provided.

In I_{rms} measured by METAS, significant dc and even harmonic components are found. The data is corrected using the data from harmonic components file provided by METAS.

3.1 Power measurement results

Table 4. Power measurement results

	Trescal	Uncertainty (*k*=1)	METAS	Uncertainty (*k*=1)	VSL	Uncertainty (*k*=1)
L1-1	4.279	0.009	4.297	0.007	4.284	0.002
L1-2	4.406	0.003	4.419	0.007	4.398	0.002
L1-3	4.390	0.024	4.403	0.007	4.396	0.002
L2-1	12.687	0.027	12.805	0.030	12.709	0.006
L2-2	12.540	0.010	12.656	0.030	12.546	0.006
L2-3	12.934	0.070	12.880	0.030	12.782	0.006
L3-1	12.605	0.027	12.551	0.020	12.584	0.006
L3-2	12.769	0.010	12.702	0.021	12.765	0.006
L3-3	12.485	0.068	12.497	0.020	12.539	0.006
L4-1	13.603	0.029	13.517	0.013	13.581	0.007
L4-2	13.634	0.011	13.573	0.013	13.620	0.007
L4-3	13.374	0.073	13.279	0.013	13.345	0.007
L5-1	7.940	0.017	7.962	0.017	7.949	0.004
L5-2	7.826	0.006	7.841	0.017	7.806	0.004
L5-3	7.895	0.043	7.946	0.017	7.931	0.004

3.2 V_{rms} measurement results

Table 5. V_{rms} measurement results

	Trescal	Uncertainty (*k*=1)	METAS	Uncertainty (*k*=1)	VSL	Uncertainty (*k*=1)
L1-1	229.180	0.061	230.096	0.085	230.050	0.053
L1-2	230.247	0.061	230.020	0.085	230.034	0.053
L1-3	230.060	0.061	230.058	0.085	230.036	0.053
L2-1	229.885	0.061	230.081	0.085	230.025	0.053
L2-2	230.212	0.061	229.960	0.084	230.061	0.053
L2-3	230.090	0.061	230.024	0.084	230.014	0.053
L3-1	229.977	0.061	230.093	0.085	230.022	0.053
L3-2	229.962	0.061	229.960	0.085	230.017	0.053
L3-3	229.920	0.061	230.029	0.085	230.017	0.053
L4-1	229.978	0.061	230.097	0.085	230.002	0.053
L4-2	229.945	0.061	229.970	0.085	229.998	0.053
L4-3	230.070	0.061	230.034	0.085	229.996	0.053
L5-1	229.872	0.061	230.095	0.085	230.089	0.053
L5-2	230.239	0.061	230.030	0.085	229.998	0.053
L5-3	230.100	0.061	230.079	0.085	230.065	0.053

3.3 I_{rms} measurement results

Table 6. I_{rms} measurement results

	Trescal	Uncertainty (*k*=1)	METAS	Uncertainty (*k*=1)	VSL	Uncertainty (*k*=1)
L1-1	0.04261	0.00009	0.04140	0.00004	0.04199	0.00003
L1-2	0.04331	0.00003	0.04226	0.00004	0.04270	0.00003
L1-3	0.04282	0.00023	0.04218	0.00004	0.04260	0.00003
L2-1	0.06667	0.00014	0.06762	0.00025	0.06693	0.00143
L2-2	0.06648	0.00005	0.06767	0.00025	0.06670	0.00142
L2-3	0.06774	0.00037	0.06785	0.00025	0.06710	0.00143
L3-1	0.05938	0.00013	0.05921	0.00010	0.05932	0.00025
L3-2	0.06011	0.00004	0.05989	0.00010	0.06010	0.00026
L3-3	0.05878	0.00032	0.05890	0.00010	0.05900	0.00025
L4-1	0.06329	0.00014	0.06298	0.00004	0.06321	0.00026
L4-2	0.06332	0.00005	0.06314	0.00004	0.06330	0.00026
L4-3	0.06210	0.00034	0.06177	0.00004	0.06200	0.00026
L5-1	0.04149	0.00009	0.04305	0.00102	0.04152	0.00121
L5-2	0.04076	0.00003	0.04237	0.00101	0.04080	0.00119
L5-3	0.04116	0.00022	0.04288	0.00102	0.04140	0.00121

3.4 PF measurement results

Table 7. PF measurement results

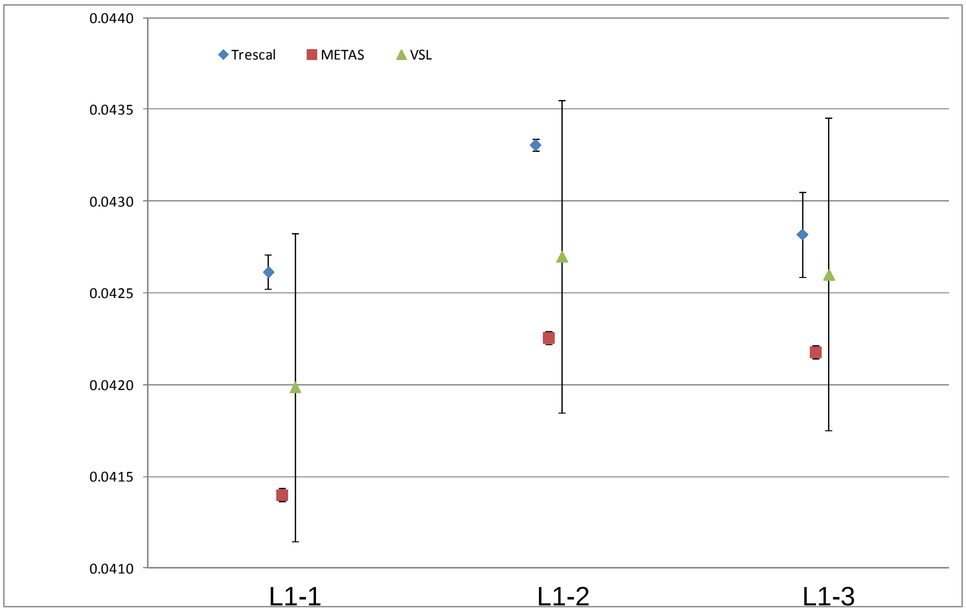
	Trescal	METAS	VSL
L1-1	0.4381	0.4358	0.4435
L1-2	0.4419	0.4410	0.4477
L1-3	0.4460	0.4392	0.4480
L2-1	0.8278	0.8218	0.8254
L2-2	0.8194	0.8120	0.8171
L2-3	0.8300	0.8241	0.8283
L3-1	0.9230	0.9213	0.9223
L3-2	0.9238	0.9220	0.9233
L3-3	0.9240	0.9223	0.9234
L4-1	0.9346	0.9327	0.9341
L4-2	0.9364	0.9350	0.9360
L4-3	0.9360	0.9345	0.9359
L5-1	0.8325	0.8036	0.8322
L5-2	0.8339	0.8040	0.8323
L5-3	0.8340	0.8053	0.8327

3.5 THD measurement results

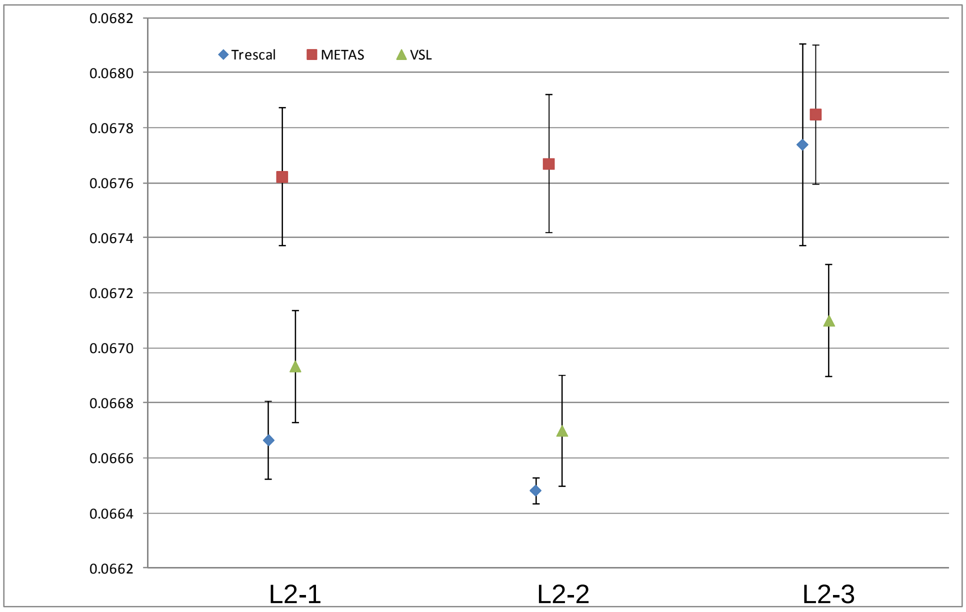
Table 8. THD measurement results

	Trescal	METAS	VSL
L1-1	202.64	203.59	199.21
L1-2	200.22	200.46	196.61
L1-3	198.02	201.33	196.41
L2-1	65.87	67.30	67.68
L2-2	68.05	70.01	69.86
L2-3	65.37	66.77	66.97
L3-1	30.53	30.81	30.72
L3-2	30.41	30.71	30.56
L3-3	30.65	30.97	30.83
L4-1	28.83	29.18	29.00
L4-2	28.23	28.61	28.41
L4-3	28.51	28.82	28.65
L5-1	30.05	40.84	30.41
L5-2	29.78	40.71	30.13
L5-3	29.95	40.69	30.28

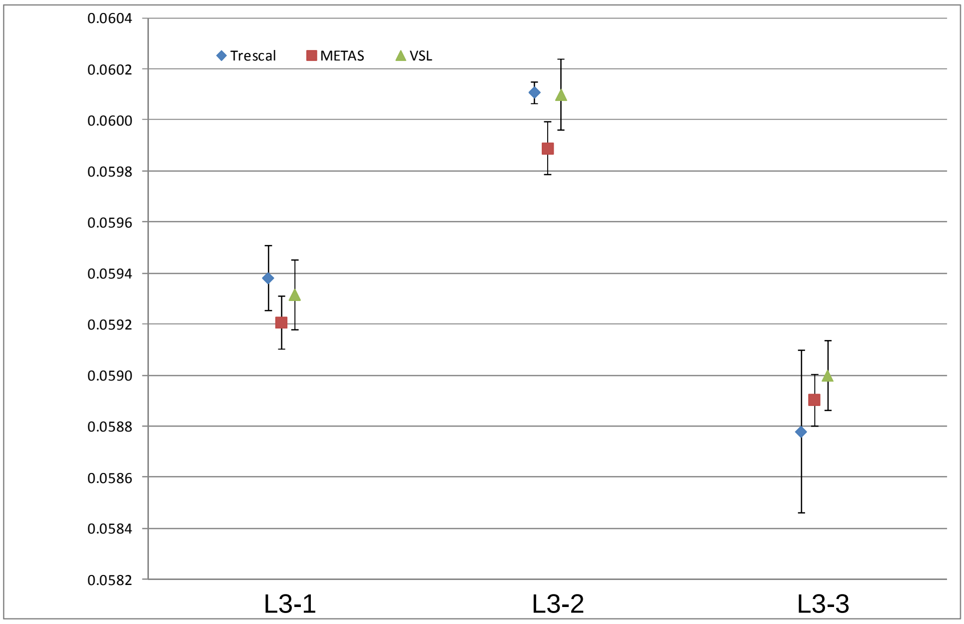
The measurement results are also compared using figures. For each model of lamps, there are three units under test. There exist slight differences between units caused by components and manufacturing. In each figure, three units of the same model are compared. Three clusters in the figure from the left to the right represent the Lx-1, Lx-2 and Lx-3 units with the same model of Lx. In each cluster in the figure, three measurement results from three labs are compared.



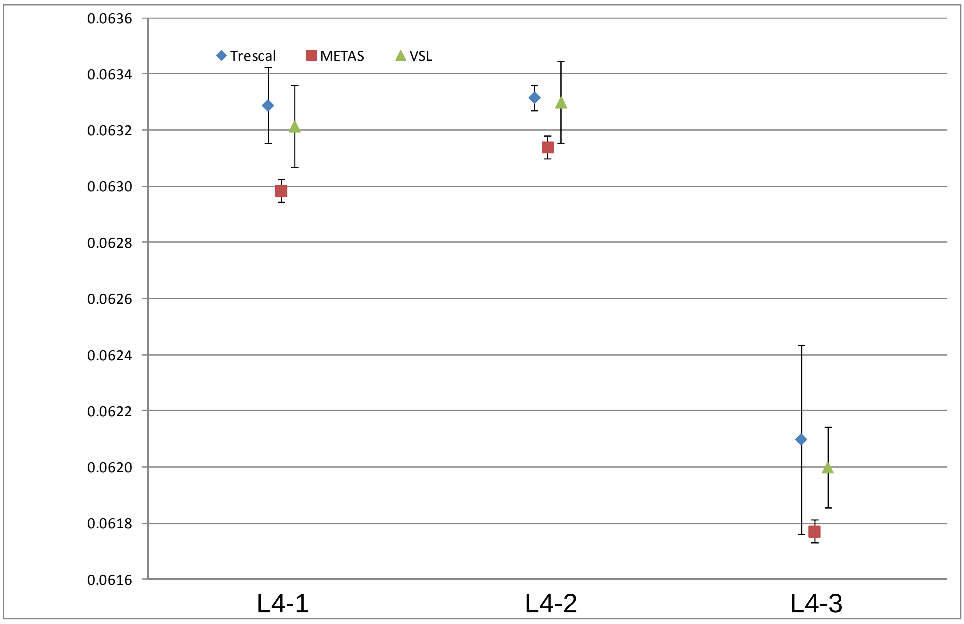
(a) measured I_{rms} of L1



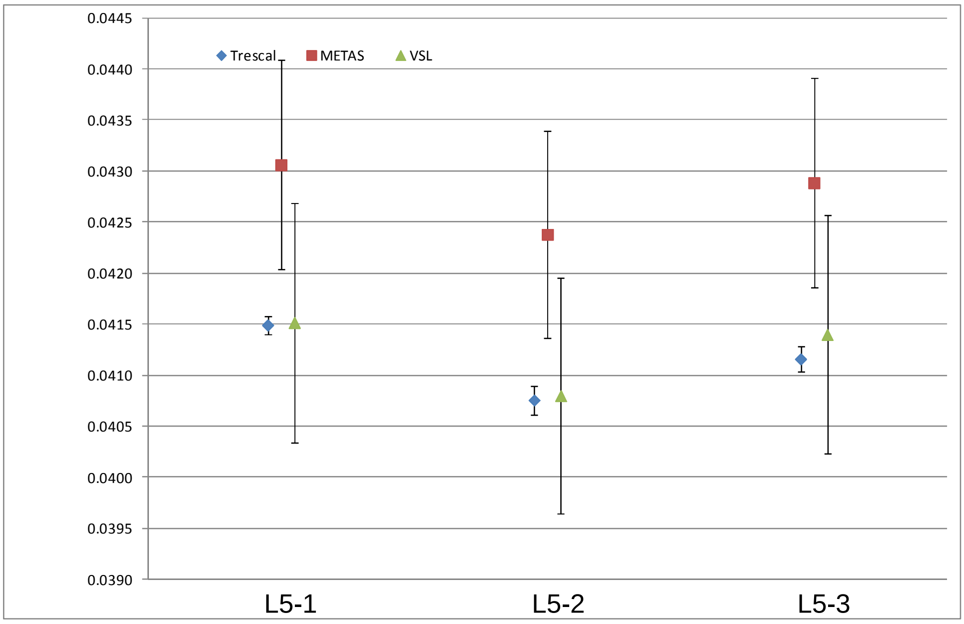
(b) measured I_{rms} of L2



(c) measured I_{rms} of L3

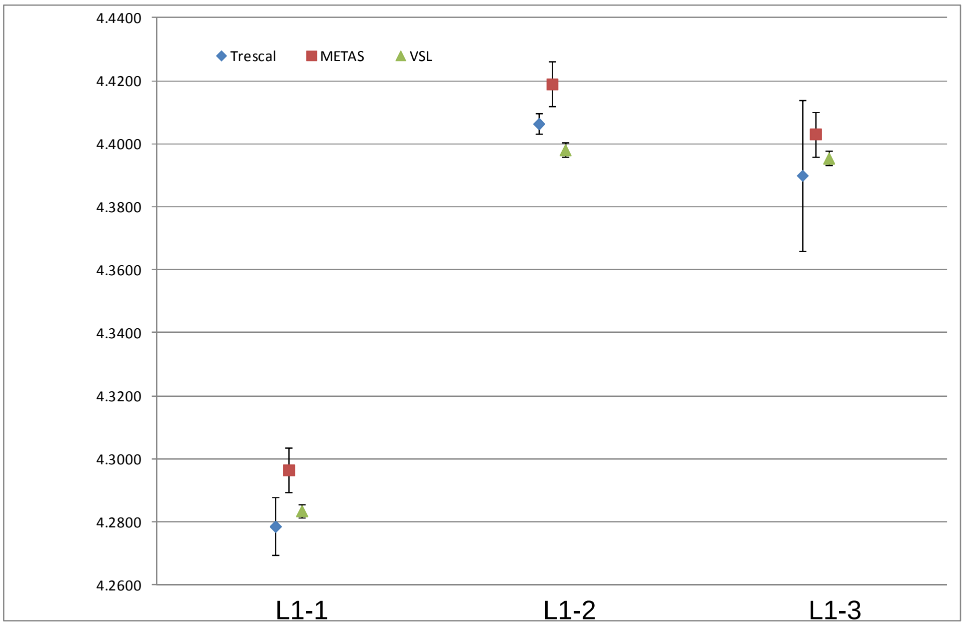


(d) measured I_{rms} of L4

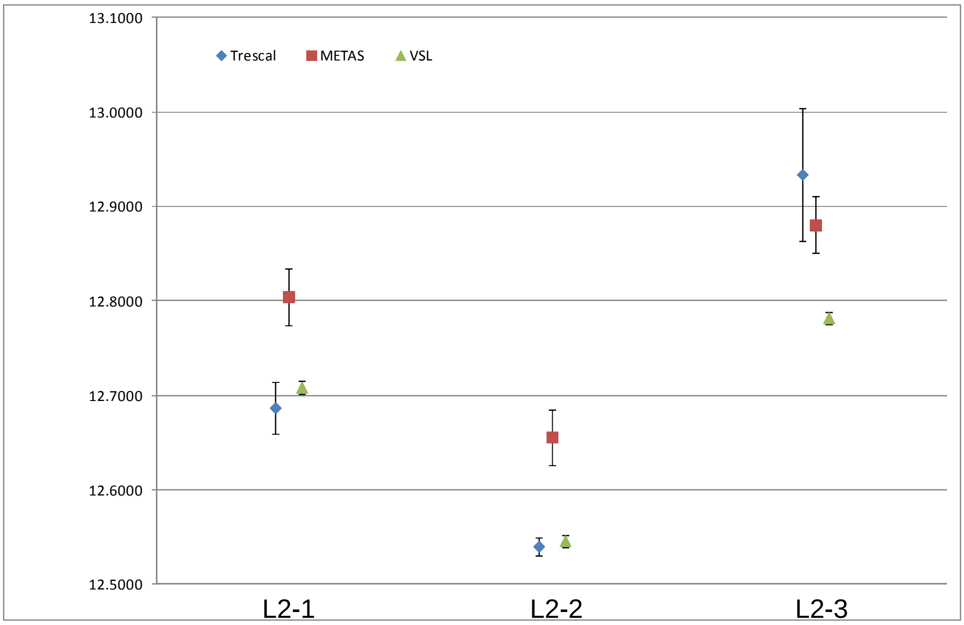


(e) measured I_{rms} of L5

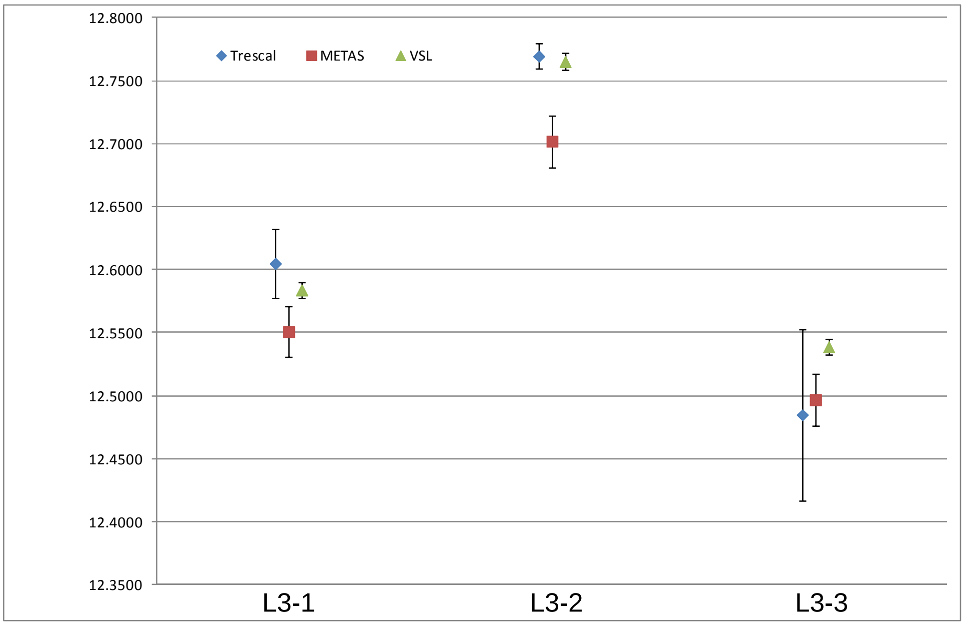
Figure 8. Measurements and combined uncertainties of I_{rms}



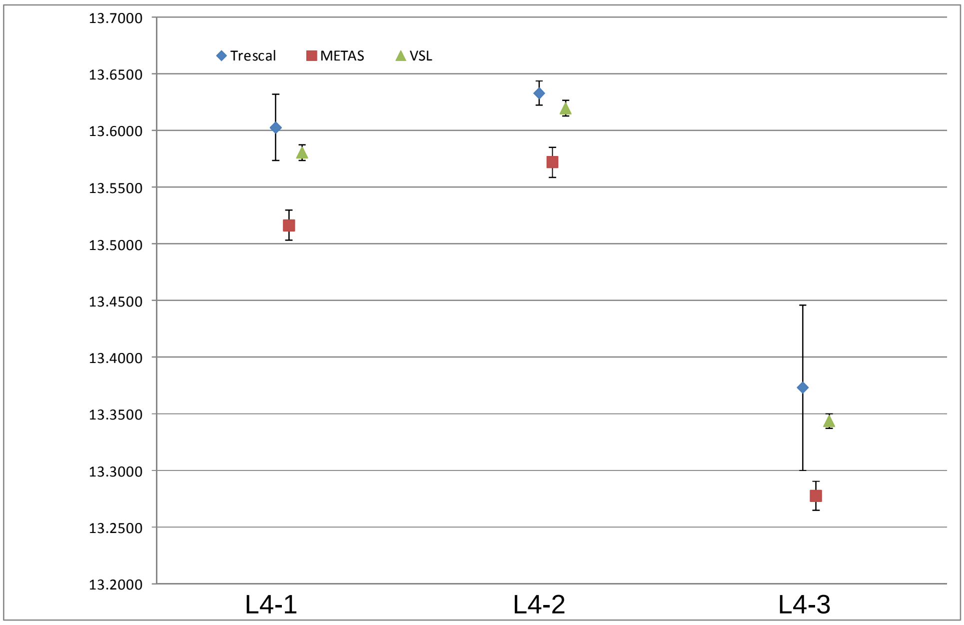
(a) measured power of of L1



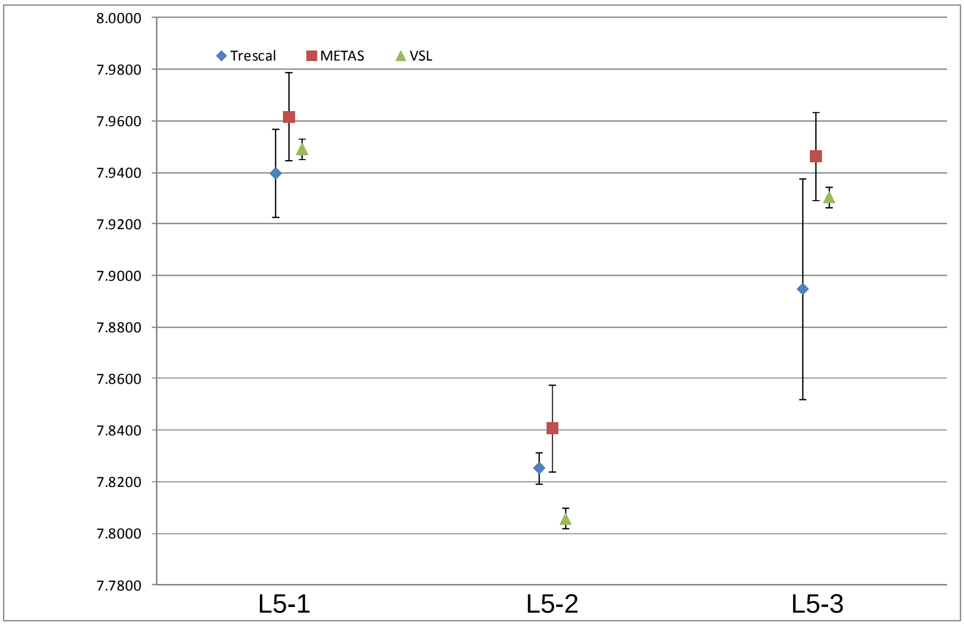
(b) measured power of L2



(c) measured power of L3



(d) measured power of L4



(e) measured power of L5

Figure 9. Measurements and combined uncertainties of power

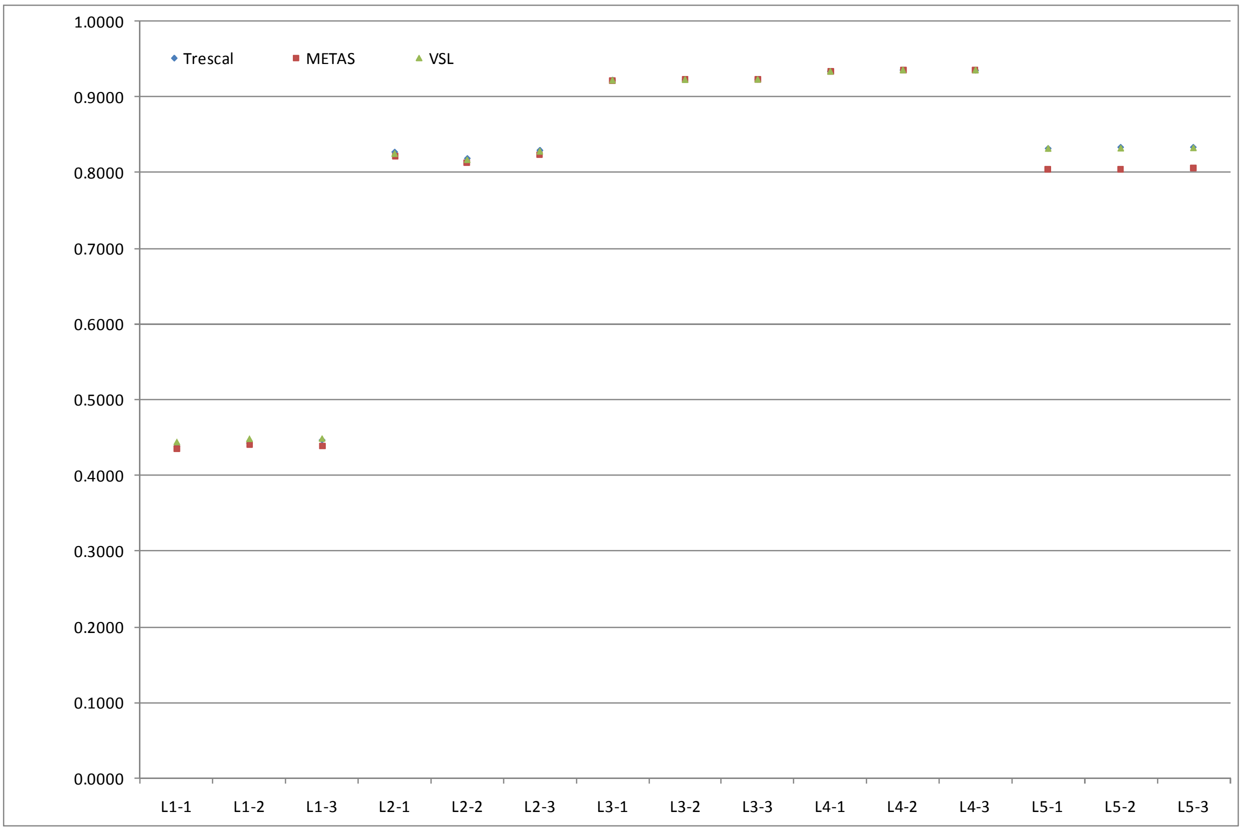


Figure 10. Measurements of power factor

In the next two figures, the comparison is done using relative deviation from the mean (one mean for each lamp model). The y-axis is the relative deviation and the x-axis is the lamp model. It gives a better overview of the whole result.

It becomes clear that the reproducibility between different lamps of the same model is not better than 2% for power measurement, and is not better than 3% for I_{rms} measurement.

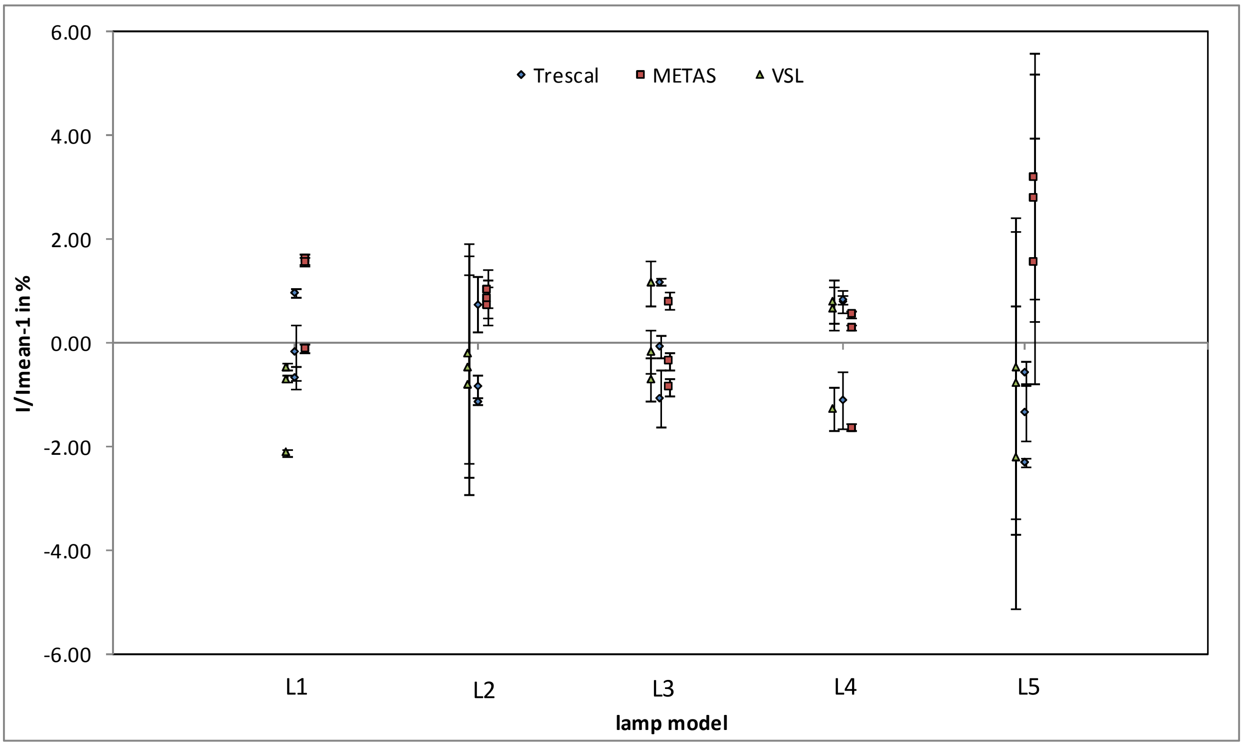


Figure 11. The comparison of relative deviations of the measured I_{rms}

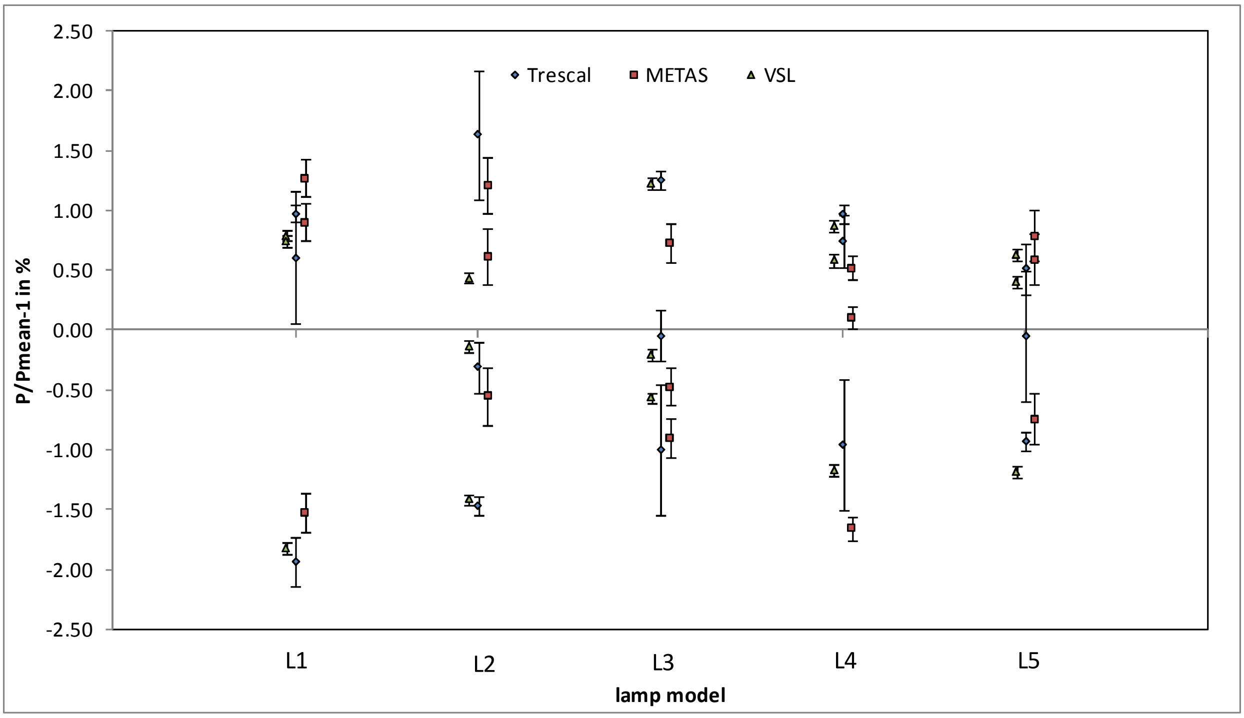


Figure 12. The comparison of relative deviations of the measured power

4 Discussion and conclusion

Based on the measurement results, we have the following conclusions:

1. Generally, the uncertainty of power measurement can be within 0.6% for EUTs like SSL lamps. For I_{rms} measurement, the uncertainties are high for some special lamps, as high as 3%.
2. The large uncertainty of I_{rms} measurement has three reasons. The first reason is that the measurement has larger uncertainty in higher frequency range. That is due to the characteristic of the digitizer and the transducers. If the EUT has rich harmonics in high frequency range, the total uncertainty increases. The second reason is that the EUT includes not only the lamps in high frequency. The cable, the power supply, the connections are also parts of EUT which are variant in different setups. For some special EUTs, resonance occurs which becomes predominant source of uncertainty. The third reason is that the transducers (mainly the current shunt) can change the current waveform of the EUT. This is a significant uncertainty source for some lamps with large peaks in current waveform, for instance, L1 in this comparison.
3. The comparisons are done with the same lamps circulated around laboratories. The difference of the power measured using different samples of the same model can be as high as 2%. The difference of the I_{rms} measured using different samples of the same model can be as high as 3%.
4. The uncertainty calculation results obtained by the participated laboratories are the first try, which never appear in literature. For SSL products, with rich high frequency harmonics, the uncertainty calculations of electrical parameters need completely new approaches. Further experiences and discussions are needed.

References

[1] Metrology for Solid State Lighting [Online]. Available: http://www.m4ssl.npl.co.uk/

[2] Approved Method: Electrical and Photometric Measurements of Solid-State Lighting Products, IES LM-79-08, 2008.

Appendix A. The devices used in the comparison

Table 9. The devices of VSL used in the comparison

Devices	Model	S/N
Power supply	Pacific Power Source, 108-AMX-UPC12 1	665_06766
Digitizer N	I PXI-5922	
Current shunt	3Ω JV Current shunt	
Voltage divider	SP Digital sampling wattmeter voltage divider VD2	VD2-0605

Table 10. The devices of METAS used in the comparison

Devices	Model	S/N
Power supply	Chroma 61501 + NI PXI-4461	615010000923 + 0x13EB769
Digitizer N	I PXI-5922 0	xF175CA
Current shunt	Fluke A40B	989158645
Voltage divider	Home-made	

Table 11. The devices of Trescal used in the comparison

Devices	Model	S/N
Power supply	Takasago, LTD. Japan, model AA1000F	3030598012
Digitizer N	I PXI-5922	
Current shunt	Fluke shunt, model A40, 2Ω	3965005
Voltage divider	B. P. Instruments 1000V 15mA voltage divider	

Appendix B. Uncertainty budgets

B.1 VSL uncertainty budgets

The uncertainty analysis of I_{rms} is not an easy task. The I_{rms} is correlated to all HF components. It is divided into three groups: LF (70-2000Hz); HF(2000 - 20 kHz) and VHF(above 20 kHz). The uncertainty in each range is calculated independently, and then combined. The uncertainty is also relevant to the proportion of the components. For L2, with rich harmonics, the uncertainty is high. For L5, because the possible of resonance, the uncertainty of the VHF (above 20 kHz) components is extremely high, therefore, the total uncertainty is also high. For L1, because of its low power factor and large peaks in current waveform, the current shunt has significant influence to the current waveform. Because the current shunt is different in each lab, the uncertainty of the LF (50 - 2 kHz) components is relatively high.

For power measurement, because the high frequency voltage components are negligible, only LF (70-2000Hz) part of harmonic are useful to contribute the result of power. The uncertainty is based on the uncertainty of voltage, current and phase measurements.

Uncertainty of V_{rms}

Source	Type	Value (mV/V)	Distribution	k-factor	Sen.-Coef.	Std. Unc. (mV/V)
Digitizer (Ch 1)	B	35	normal	1	1	35.0
Calibration, voltage divider	B	200	normal	1	1	200.0
Input impedance of digitizer	B	20	normal	1	1	20.0
Stability after varm-up	B	34	normal	1	1	34.0
Repeatability	A	100	normal	1	1	100.0
				Combined uncertainty:		230

Uncertainty of I_{rms}

L1-x						
Source	**Type**	**Value (mA/A)**	**Distribution**	**k-factor**	**Sen.-Coef.**	**Std. Unc. (mA/A)**
Components (50-2kHz)						
Digitizer (Ch 0)	B	35	normal	1	1	35.0
Calibration, Shunt	B	6	normal	1	1	6.0
Shunt AC-DC	B	2	normal	1	1	2.0
Input impedance of digitizer	B	2	normal	1	1	2.0

Stability after varm-up	B	400	normal	1	1	400.0
Distortion by transducer	B	2.00E+04	normal	1	1	20000.0
Repeatability	A	200	normal	1	1	200.0
				Combined uncertainty:		20005
Components (2kHz-20kHz)						
Digitizer (Ch 0)	B	35	normal	1	1	35.0
Calibration, Shunt	B	6	normal	1	1	6.0
Shunt AC-DC	B	2	normal	1	1	2.0
Input impedance of digitizer	B	20	normal	1	1	20.0
Stability after varm-up	B	400	normal	1	1	400.0
High frequency effect	B	2.00E+04	normal	1	1	20000.0
Repeatability	A	200	normal	1	1	200.0
				Combined uncertainty:		20005
Components (above 20kHz)						
Digitizer (Ch 0)	B	180	normal	1	1	180.0
Calibration, Shunt	B	6	normal	1	1	6.0
Shunt AC-DC	B	35	normal	1	1	35.0
Input impedance of digitizer	B	200	normal	1	1	200.0
Stability after varm-up	B	400	normal	1	1	400.0
High frequency effect	B	2.00E+05	normal	1	1	200000.0
Repeatability	A	200	normal	1	1	200.0
				Combined uncertainty:		200001
Components (50-2kHz)	20005				99.97%	19992
Components (2kHz-20kHz)	20005				2.56%	13
Components (above 20kHz)	200001				0.10%	0
				Combined uncertainty:		19992

L2-x

Source	**Type**	**Value (mA/A)**	**Distribution**	**k-factor**	**Sen.-Coef.**	**Std. Unc. (mA/A)**
Components (50-2kHz)						
Digitizer (Ch 0)	B	35	normal	1	1	35.0

Calibration, Shunt	B	6	normal	1	1	6.0
Shunt AC-DC	B	2	normal	1	1	2.0
Input impedance of digitizer	B	1064	normal	1	1	1064.0
Stability after varm-up	B	400	normal	1	1	400.0
Distortion by transducer	B	2.00E+03	normal	1	1	2000.0
Repeatability	A	200	normal	1	1	200.0
				Combined uncertainty:		2309
Components (2kHz-20kHz)						
Digitizer (Ch 0)	B	35	normal	1	1	35.0
Calibration, Shunt	B	6	normal	1	1	6.0
Shunt AC-DC	B	2	normal	1	1	2.0
Input impedance of digitizer	B	20	normal	1	1	20.0
Stability after varm-up	B	400	normal	1	1	400.0
High frequency effect	B	2.00E+04	normal	1	1	20000.0
Repeatability	A	200	normal	1	1	200.0
				Combined uncertainty:		20005
Components (above 20kHz)						
Digitizer (Ch 0)	B	180	normal	1	1	180.0
Calibration, Shunt	B	6	normal	1	1	6.0
Shunt AC-DC	B	35	normal	1	1	35.0
Input impedance of digitizer	B	200	normal	1	1	200.0
Stability after varm-up	B	400	normal	1	1	400.0
High frequency effect	B	2.00E+05	normal	1	1	200000.0
Repeatability	A	200	normal	1	1	200.0
				Combined uncertainty:		200001
Components (50-2kHz)	2309				99.34%	2279
Components (2kHz-20kHz)	20005				5.63%	63
Components (above 20kHz)	200001				9.99%	1995
				Combined uncertainty:		3029

L3-x

Source	Type	Value (mA/A)	Distribution	k-factor	Sen.-Coef.	Std. Unc. (mA/A)
Components (50-2kHz)						
Digitizer (Ch 0)	B	35	normal	1	1	35.0
Calibration, Shunt	B	6	normal	1	1	6.0
Shunt AC-DC	B	2	normal	1	1	2.0
Input impedance of digitizer	B	1064	normal	1	1	1064.0
Stability after varm-up	B	400	normal	1	1	400.0
Distortion by transducer	B	2.00E+03	normal	1	1	2000.0
Repeatability	A	200	normal	1	1	200.0
				Combined uncertainty:		2309
Components (2kHz-20kHz)						
Digitizer (Ch 0)	B	35	normal	1	1	35.0
Calibration, Shunt	B	6	normal	1	1	6.0
Shunt AC-DC	B	2	normal	1	1	2.0
Input impedance of digitizer	B	20	normal	1	1	20.0
Stability after varm-up	B	400	normal	1	1	400.0
High frequency effect	B	2.00E+04	normal	1	1	20000.0
Repeatability	A	200	normal	1	1	200.0
				Combined uncertainty:		20005
Components (above 20kHz)						
Digitizer (Ch 0)	B	180	normal	1	1	180.0
Calibration, Shunt	B	6	normal	1	1	6.0
Shunt AC-DC	B	35	normal	1	1	35.0
Input impedance of digitizer	B	200	normal	1	1	200.0
Stability after varm-up	B	400	normal	1	1	400.0
High frequency effect	B	2.00E+05	normal	1	1	200000.0
Repeatability	A	200	normal	1	1	200.0
				Combined uncertainty:		200001
Components (50-2kHz)	2309				99.97%	2308
Components (2kHz-20kHz)	20005				1.22%	3
Components (above 20kHz)	200001				1.98%	78

				Combined uncertainty:		2310

L4-x						
Source	**Type**	**Value (mA/A)**	**Distribution**	**k-factor**	**Sen.-Coef.**	**Std. Unc. (mA/A)**
Components (50-2kHz)						
Digitizer (Ch 0)	B	35	normal	1	1	35.0
Calibration, Shunt	B	6	normal	1	1	6.0
Shunt AC-DC	B	2	normal	1	1	2.0
Input impedance of digitizer	B	1064	normal	1	1	1064.0
Stability after varm-up	B	400	normal	1	1	400.0
Distortion by transducer	B	2.00E+03	normal	1	1	2000.0
Repeatability	A	200	normal	1	1	200.0
				Combined uncertainty:		2309
Components (2kHz-20kHz)						
Digitizer (Ch 0)	B	35	normal	1	1	35.0
Calibration, Shunt	B	6	normal	1	1	6.0
Shunt AC-DC	B	2	normal	1	1	2.0
Input impedance of digitizer	B	20	normal	1	1	20.0
Stability after varm-up	B	400	normal	1	1	400.0
High frequency effect	B	2.00E+04	normal	1	1	20000.0
Repeatability	A	200	normal	1	1	200.0
				Combined uncertainty:		20005
Components (above 20kHz)						
Digitizer (Ch 0)	B	180	normal	1	1	180.0
Calibration, Shunt	B	6	normal	1	1	6.0
Shunt AC-DC	B	35	normal	1	1	35.0
Input impedance of digitizer	B	200	normal	1	1	200.0
Stability after varm-up	B	400	normal	1	1	400.0
High frequency effect	B	2.00E+05	normal	1	1	200000.0
Repeatability	A	200	normal	1	1	200.0
				Combined uncertainty:		200001

Components (50-2kHz)	2309				99.97%	2308
Components (2kHz-20kHz)	20005				1.21%	3
Components (above 20kHz)	200001				1.92%	74
				Combined uncertainty:		2309

L5-x						
Source	**Type**	**Value (mA/A)**	**Distribution**	**k-factor**	**Sen.-Coef.**	**Std. Unc. (mA/A)**
Components (50-2kHz)						
Digitizer (Ch 0)	B	35	normal	1	1	35.0
Calibration, Shunt	B	6	normal	1	1	6.0
Shunt AC-DC	B	2	normal	1	1	2.0
Input impedance of digitizer	B	1064	normal	1	1	1064.0
Stability after varm-up	B	400	normal	1	1	400.0
Distortion by transducer	B	2.00E+03	normal	1	1	2000.0
Repeatability	A	200	normal	1	1	200.0
				Combined uncertainty:		2309
Components (2kHz-20kHz)						
Digitizer (Ch 0)	B	35	normal	1	1	35.0
Calibration, Shunt	B	6	normal	1	1	6.0
Shunt AC-DC	B	2	normal	1	1	2.0
Input impedance of digitizer	B	20	normal	1	1	20.0
Stability after varm-up	B	400	normal	1	1	400.0
High frequency effect	B	2.00E+04	normal	1	1	20000.0
Repeatability	A	200	normal	1	1	200.0
				Combined uncertainty:		20005
Components (above 20kHz)						
Digitizer (Ch 0)	B	180	normal	1	1	180.0
Calibration, Shunt	B	6	normal	1	1	6.0
Shunt AC-DC	B	35	normal	1	1	35.0
Input impedance of digitizer	B	200	normal	1	1	200.0
Stability after varm-up	B	400	normal	1	1	400.0

High frequency effect	B	1.50E+06	normal	1	1	1500000.0
Repeatability	A	200	normal	1	1	200.0
				Combined uncertainty:		1500000
Components (50-2kHz)	2309				97.97%	2217
Components (2kHz-20kHz)	20005				6.98%	97
Components (above 20kHz)	1500000				13.70%	28160
				Combined uncertainty:		28247

Uncertainty of P

Source	**Type**	**Value (mW/VA)**	**Distribution**	**k-factor**	**Sen.-Coef.**	**Std. Unc. (mW/VA)**
Digitizer (Ch 1)	B	35	normal	1	1	35.0
Calibration, voltage divider	B	200	normal	1	1	200.0
Input impedance of digitizer	B	20	normal	1	1	20.0
Stability after varm-up	B	34	normal	1	1	34.0
Repeatability	A	100	normal	1	1	100.0
				Combined uncertainty:		230
Components (50-2kHz)						
Digitizer (Ch 0)	B	35	normal	1	1	35.0
Calibration, Shunt	B	6	normal	1	1	6.0
Shunt AC-DC	B	2	normal	1	1	2.0
Input impedance of digitizer	B	53	normal	1	1	53.0
Stability after varm-up	B	400	normal	1	1	400.0
Resonance effect	B	0	normal	1	1	0.0
Repeatability	A	200	normal	1	1	200.0
				Combined uncertainty:		452
Components (Voltage)	B	230	normal	1	1	229.7
Components (Current)	B	452	normal	1	1	451.7
Components (Phase)	B	10	normal	1	1	10.0
				Combined uncertainty:		507

B.2 METAS uncertainty budgets

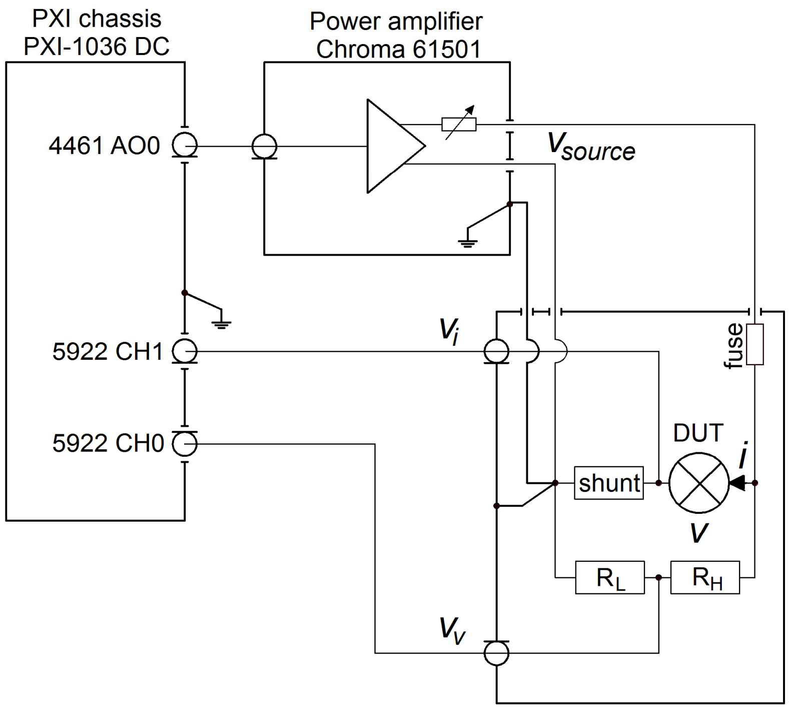


Figure 13. Schematic of the measuring setup at METAS

V=V_v (1+g_v) 1/(r_nom (1+ε_r))-V_i (1+g_i)

I=V_i (1+g_i) ((1+δ_(ac-dc)))/(R_nom (1+ε_R))

g_v: gain error of the CH0 of the 5922 board

g_i: gain error of the CH1 of the 5922 board

ε_r: error on the voltage ratio of the voltage divider ε_R: error on the DC resistance of the shunt A40

δ_(ac-dc): ac-dc- difference of the shunt A40

U-Budget L1-x: V_{rms}

Quantity	Standard uncertainty	unit	Probability distribution	Method of evaluation	Sensitivity coefficient	Relative uncertainty in uF/F	Degrees of freedom
X_i	$u(x_i)$			(A, B)	c_i	$c_i*u(x_i)$	n_i
Digitizer gain CH0	300	µV/V	Box	B	1	0.017	50
Digitizer gain CH1	200	µΩ/Ω	Box	A & B	1	0.012	50
Ratio error of the voltage divider	500	µV/V	Box	B	1	0.029	50
Effect of source resistance	0.2	Ω	Box	B	0.04	0.005	5
Effect of source inductance	100	µH	Box	B	0.00	0.000	5
Standard deviation	100	µV/V	Normal	A	1	0.010	20

Combined standard uncertainty	u_c	0.037	%
Effective degree of freedom	n_i	116	
Expanded uncertainty (p=95%)	***U***	**0.07**	**%**

U-Budget L1-x: I_{rms}

Quantity	Standard uncertainty	unit	Probability distribution	Method of evaluation	Sensitivity coefficient	Relative uncertainty in uF/F	Degrees of freedom
X_i	$u(x_i)$			(A, B)	c_i	$c_i*u(x_i)$	n_i
Digitizer gain CH1	300	µV/V	Box	B	1	0.017	50

Shunt DC resistance	170	μΩ/Ω	Box	A & B	1	0.010	50
Shunt ac/dc difference	100	μA/A	Box	B	1	0.006	50
Effect of source resistance	0.2	Ω	Box	B	0.57	0.066	5
Effect of source inductance	100	μH	Box	B	0.49	0.028	5
Standard deviation	100	μA/A	Normal	A	1	0.010	20

Combined standard uncertainty	u_c	0.075	%
Effective degree of freedom	n_i	8	
Expanded uncertainty (p=95%)	***U***	**0.17**	**%**

U-Budget L1-x: P

Quantity	Standard uncertainty	unit	Probability distribution	Method of evaluation	Sensitivity coefficient	Relative uncertainty in uF/F	Degrees of freedom
X_i	$u(x_i)$			(A, B)	c_i	c_i*$u(x_i)$	n_i
Digitizer gain CH1	300	μV/V	Box	B	1	0.017	50
Digitizer gain CH1	300	μΩ/Ω	Box	A & B	1	0.017	50
Ratio error of the voltage divider	200	μΩ/Ω	Box	A & B	1	0.012	50
Shunt DC resistance	200	μΩ/Ω	Box	A & B	1	0.012	50
Shunt ac/dc difference	50	μA/A	Box	B	1	0.003	50
Effect of source resistance	0.2	Ω	Box	B	1.05	0.121	5
Effect of source inductance	100	μH	Box	B	0.10	0.006	5
Standard deviation	100	μW/W	Normal	A	1	0.010	20

Combined standard uncertainty	u_c	0.125	%
Effective degree of freedom	n_i	6	
Expanded uncertainty (p=95%)	***U***	**0.32**	**%**

U-Budget L2-x: V_{rms}

Quantity	Standard uncertainty	unit	Probability distribution	Method of evaluation	Sensitivity coefficient	Relative uncertainty in uF/F	Degrees of freedom
X_i	$u(x_i)$			(A, B)	c_i	$c_i*u(x_i)$	n_i
Digitizer gain CH0	300	µV/V	Box	B	1	0.017	50
Digitizer gain CH1	200	µΩ/Ω	Box	A & B	1	0.012	50
Ratio error of the voltage divider	500	µV/V	Box	B	1	0.029	50
Effect of source resistance	0.2	Ω	Box	B	0.02	0.002	5
Effect of source inductance	100	µH	Box	B	0.03	0.002	5
Standard deviation	100	µV/V	Normal	A	1	0.010	20

Combined standard uncertainty	u_c	0.037	%
Effective degree of freedom	n_i	114	
Expanded uncertainty (p=95%)	***U***	**0.07**	**%**

U-Budget L2-x: I_{rms}

Quantity	Standard uncertainty	unit	Probability distribution	Method of evaluation	Sensitivity coefficient	Relative uncertainty in uF/F	Degrees of freedom
X_i	$u(x_i)$			(A, B)	c_i	$c_i*u(x_i)$	n_i
Digitizer gain CH1	300	µV/V	Box	B	1	0.017	50

Shunt DC resistance	170	µΩ/Ω	Box	A & B	1	0.010	50
Shunt ac/dc difference	100	µA/A	Box	B	1	0.006	50
Effect of source resistance	0.2	Ω	Box	B	2.43	0.281	5
Effect of source inductance	100	µH	Box	B	1.09	0.063	5
Standard deviation	100	µA/A	Normal	A	1	0.010	20

Combined standard uncertainty	u_c	0.288	%
Effective degree of freedom	n_i	6	
Expanded uncertainty (p=95%)	***U***	**0.74**	**%**

U-Budget L2-x: P

Quantity	Standard uncertainty	unit	Probability distribution	Method of evaluation	Sensitivity coefficient	Relative uncertainty in uF/F	Degrees of freedom
X_i	$u(x_i)$			(A, B)	c_i	c_i*$u(x_i)$	n_i
Digitizer gain CH1	300	µV/V	Box	B	1	0.017	50
Digitizer gain CH1	300	µΩ/Ω	Box	A & B	1	0.017	50
Ratio error of the voltage divider	200	µΩ/Ω	Box	A & B	1	0.012	50
Shunt DC resistance	200	µΩ/Ω	Box	A & B	1	0.012	50
Shunt ac/dc difference	50	µA/A	Box	B	1	0.003	50
Effect of source resistance	0.2	Ω	Box	B	1.53	0.177	5
Effect of source inductance	100	µH	Box	B	0.49	0.028	5
Standard deviation	100	µW/W	Normal	A	1	0.010	20

Combined standard uncertainty	u_c	0.182 %
Effective degree of freedom	n_i	6
Expanded uncertainty (p=95%)	***U***	**0.47 %**

U-Budget L3-x: V_{rms}

Quantity	Standard uncertainty	unit	Probability distribution	Method of evaluation	Sensitivity coefficient	Relative uncertainty in uF/F	Degrees of freedom
X_i	$u(x_i)$			(A, B)	c_i	c_i*$u(x_i)$	n_i
Digitizer gain CH0	300	µV/V	Box	B	1	0.017	50
Digitizer gain CH1	200	µΩ/Ω	Box	A & B	1	0.012	50
Ratio error of the voltage divider	500	µV/V	Box	B	1	0.029	50
Effect of source resistance	0.2	Ω	Box	B	0.03	0.003	5
Effect of source inductance	100	µH	Box	B	0.04	0.002	5
Standard deviation	100	µV/V	Normal	A	1	0.010	20

Combined standard uncertainty	u_c	0.037 %
Effective degree of freedom	n_i	116
Expanded uncertainty (p=95%)	***U***	**0.07 %**

U-Budget L3-x: I_{rms}

Quantity	Standard uncertainty	unit	Probability distribution	Method of evaluation	Sensitivity coefficient	Relative uncertainty in uF/F	Degrees of freedom
X_i	$u(x_i)$			(A, B)	c_i	c_i*$u(x_i)$	n_i
Digitizer gain CH1	300	µV/V	Box	B	1	0.017	50

Shunt DC resistance	170	µΩ/Ω	Box	A & B	1	0.010	50
Shunt ac/dc difference	100	µA/A	Box	B	1	0.006	50
Effect of source resistance	0.2	Ω	Box	B	1.14	0.132	5
Effect of source inductance	100	µH	Box	B	0.16	0.009	5
Standard deviation	100	µA/A	Normal	A	1	0.010	20

Combined standard uncertainty	u_c	0.134	%
Effective degree of freedom	n_i	5	
Expanded uncertainty (p=95%)	***U***	**0.34**	**%**

U-Budget L3-x: P

Quantity	Standard uncertainty	unit	Probability distribution	Method of evaluation	Sensitivity coefficient	Relative uncertainty in uF/F	Degrees of freedom
X_i	$u(x_i)$			(A, B)	c_i	c_i*$u(x_i)$	n_i
Digitizer gain CH1	300	µV/V	Box	B	1	0.017	50
Digitizer gain CH1	300	µΩ/Ω	Box	A & B	1	0.017	50
Ratio error of the voltage divider	200	µΩ/Ω	Box	A & B	1	0.012	50
Shunt DC resistance	200	µΩ/Ω	Box	A & B	1	0.012	50
Shunt ac/dc difference	50	µA/A	Box	B	1	0.003	50
Effect of source resistance	0.2	Ω	Box	B	1.06	0.122	5
Effect of source inductance	100	µH	Box	B	0.17	0.010	5
Standard deviation	100	µW/W	Normal	A	1	0.010	20

Combined standard uncertainty	u_c	0.127 %
Effective degree of freedom	n_i	6
Expanded uncertainty (p=95%)	***U***	**0.33 %**

U-Budget L4-x: V_{rms}

Quantity	Standard uncertainty	unit	Probability distribution	Method of evaluation	Sensitivity coefficient	Relative uncertainty in uF/F	Degrees of freedom
X_i	$u(x_i)$			(A, B)	c_i	$c_i*u(x_i)$	n_i
Digitizer gain CH0	300	µV/V	Box	B	1	0.017	50
Digitizer gain CH1	200	µΩ/Ω	Box	A & B	1	0.012	50
Ratio error of the voltage divider	500	µV/V	Box	B	1	0.029	50
Effect of source resistance	0.2	Ω	Box	B	0.02	0.002	5
Effect of source inductance	100	µH	Box	B	0.05	0.003	5
Standard deviation	100	µV/V	Normal	A	1	0.010	20

Combined standard uncertainty	u_c	0.037 %
Effective degree of freedom	n_i	115
Expanded uncertainty (p=95%)	***U***	**0.07 %**

U-Budget L4-x: I_{rms}

Quantity	Standard uncertainty	unit	Probability distribution	Method of evaluation	Sensitivity coefficient	Relative uncertainty in uF/F	Degrees of freedom
X_i	$u(x_i)$			(A, B)	c_i	$c_i*u(x_i)$	n_i
Digitizer gain CH1	300	µV/V	Box	B	1	0.017	50

Shunt DC resistance	170	µΩ/Ω	Box	A & B	1	0.010	50
Shunt ac/dc difference	100	µA/A	Box	B	1	0.006	50
Effect of source resistance	0.2	Ω	Box	B	0.42	0.048	5
Effect of source inductance	100	µH	Box	B	0.29	0.017	5
Standard deviation	100	µA/A	Normal	A	1	0.010	20
	Combined standard uncertainty				u_c	0.056	%
	Effective degree of freedom				n_i	9	
	Expanded uncertainty (p=95%)				***U***	**0.13**	**%**

U-Budget L4-x: P

Quantity	Standard uncertainty	unit	Probability distribution	Method of evaluation	Sensitivity coefficient	Relative uncertainty in uF/F	Degrees of freedom
X_i	$u(x_i)$			(A, B)	c_i	c_i*$u(x_i)$	n_i
Digitizer gain CH1	300	µV/V	Box	B	1	0.017	50
Digitizer gain CH1	300	µΩ/Ω	Box	A & B	1	0.017	50
Ratio error of the voltage divider	200	µΩ/Ω	Box	A & B	1	0.012	50
Shunt DC resistance	200	µΩ/Ω	Box	A & B	1	0.012	50
Shunt ac/dc difference	50	µA/A	Box	B	1	0.003	50
Effect of source resistance	0.2	Ω	Box	B	0.65	0.075	5
Effect of source inductance	100	µH	Box	B	0.36	0.021	5
Standard deviation	100	µW/W	Normal	A	1	0.010	20

Combined standard uncertainty	u_c	0.084 %
Effective degree of freedom	n_i	8
Expanded uncertainty (p=95%)	***U***	**0.20 %**

U-Budget L5-x: V_{rms}

Quantity	Standard uncertainty	unit	Probability distribution	Method of evaluation	Sensitivity coefficient	Relative uncertainty in uF/F	Degrees of freedom
X_i	$u(x_i)$			(A, B)	c_i	$c_i*u(x_i)$	n_i
Digitizer gain CH0	300	µV/V	Box	B	1	0.017	50
Digitizer gain CH1	200	µΩ/Ω	Box	A & B	1	0.012	50
Ratio error of the voltage divider	500	µV/V	Box	B	1	0.029	50
Effect of source resistance	0.2	Ω	Box	B	0.03	0.003	5
Effect of source inductance	100	µH	Box	B	0.02	0.001	5
Standard deviation	100	µV/V	Normal	A	1	0.010	20

Combined standard uncertainty	u_c	0.037 %
Effective degree of freedom	n_i	115
Expanded uncertainty (p=95%)	***U***	**0.07 %**

U-Budget L5-x: I_{rms}

Quantity	Standard uncertainty	unit	Probability distribution	Method of evaluation	Sensitivity coefficient	Relative uncertainty in uF/F	Degrees of freedom
X_i	$u(x_i)$			(A, B)	c_i	$c_i*u(x_i)$	n_i
Digitizer gain CH1	300	µV/V	Box	B	1	0.017	50

Shunt DC resistance	170	µΩ/Ω	Box	A & B	1	0.010	50
Shunt ac/dc difference	100	µA/A	Box	B	1	0.006	50
Effect of source resistance	0.2	Ω	Box	B	1.07	0.124	5
Effect of source inductance	100	µH	Box	B	32.00	1.848	5
Standard deviation	100	µA/A	Normal	A	1	0.010	20

Combined standard uncertainty	u_c	1.852	%
Effective degree of freedom	n_i	5	
Expanded uncertainty (p=95%)	***U***	**4.76**	**%**

U-Budget L5-x: P

Quantity	Standard uncertainty	unit	Probability distribution	Method of evaluation	Sensitivity coefficient	Relative uncertainty in uF/F	Degrees of freedom
X_i	$u(x_i)$			(A, B)	c_i	$c_i*u(x_i)$	n_i
Digitizer gain CH1	300	µV/V	Box	B	1	0.017	50
Digitizer gain CH1	300	µΩ/Ω	Box	A & B	1	0.017	50
Ratio error of the voltage divider	200	µΩ/Ω	Box	A & B	1	0.012	50
Shunt DC resistance	200	µΩ/Ω	Box	A & B	1	0.012	50
Shunt ac/dc difference	50	µA/A	Box	B	1	0.003	50
Effect of source resistance	0.2	Ω	Box	B	1.42	0.164	5
Effect of source inductance	100	µH	Box	B	0.02	0.001	5
Standard deviation	100	µW/W	Normal	A	1	0.010	20

Combined standard uncertainty	u_c	0.167	%
Effective degree of freedom	n_i	5	
Expanded uncertainty (p=95%)	***U***	**0.43**	**%**

B.3 Trescal uncertainty budgets

Uncertainty of V_{rms}

Source	Type	Value (mV/V)	Distribution	k-factor	Sen.-Coef.	Std. Unc. (mV/V)
Digitizer (Ch 0)	B	34	Gaussian	1	1	34.0
Calibration, voltage divider	B	135	Gaussian	1	1	135.0
Stability after varm-up	B	150	Uniform	1.732	1	86.6
Repeatability	A	210	Gaussian	1	1	210.0
				Combined uncertainty:		266

Uncertainty of I_{rms}

Lamp Group 1, (L1-1, L2-1, L3-1, L4-1, L5-1)						
Source	**Type**	**Value (mA/A)**	**Distribution**	**k-factor**	**Sen.-Coef.**	**Std. Unc. (mA/A)**
Digitizer (Ch 1)	B	170	Gaussian	1	1	170.0
Calibration, current shunt	B	100	Gaussian	1	1	100.0
Wideband characteristic, shunt	B	200	Uniform	1.732	1	115.5
Source impedance	B	500	Uniform	1.732	1	288.7
Stability after varm-up	B	250	Uniform	1.732	1	144.3
Repeatability, Group 1	A	2100	Gaussian	1	1	2100.0
				Combined uncertainty:		2137

Lamp Group 2, (L1-2, L2-2, L3-2, L4-2, L5-2)

Source	Type	Value (mA/A)	Distribution	k-factor	Sen.-Coef.	Std. Unc. (mA/A)
Digitizer (Ch 1)	B	170	Gaussian	1	1	170.0
Calibration, current shunt	B	100	Gaussian	1	1	100.0
Wideband characteristic, shunt	B	200	Uniform	1.732	1	115.5
Source impedance	B	500	Uniform	1.732	1	288.7
Stability after varm-up	B	250	Uniform	1.732	1	144.3
Repeatability, Group 2	A	600	Gaussian	1	1	600.0
				Combined uncertainty:		719

Lamp Group 3, (L1-3, L2-3, L3-3, L4-3, L5-3)						
Source	**Type**	**Value (mA/A)**	**Distribution**	**k-factor**	**Sen.-Coef.**	**Std. Unc. (mA/A)**
Digitizer (Ch 1)	B	170	Gaussian	1	1	170.0
Calibration, current shunt	B	100	Gaussian	1	1	100.0
Wideband characteristic, shunt	B	200	Uniform	1.732	1	115.5
Source impedance	B	500	Uniform	1.732	1	288.7
Stability after varm-up	B	250	Uniform	1.732	1	144.3
Repeatability, Group 3	A	5410	Gaussian	1	1	5410.0
				Combined uncertainty:		5424

Uncertainty of P

Lamp Group 1, (L1-1, L2-1, L3-1, L4-1, L5-1)						
Source	**Type**	**Value (mW/VA)**	**Distribution**	**k-factor**	**Sen.-Coef.**	**Std. Unc. (mW/VA)**
Voltage:						
Digitizer (Ch 0)	B	34	Gaussian	1	1	34.0
Calibration, voltage divider	B	135	Gaussian	1	1	135.0
Voltage divider, phase	B	80	Uniform	1.732	1	46.2

Repeatability	A	210	Gaussian	1	1	210.0
Current:						
Digitizer (Ch 1)	B	170	Gaussian	1	1	170.0
Calibration, current shunt	B	100	Gaussian	1	1	100.0
Wideband characteristic, shunt	B	200	Uniform	1.732	1	115.5
Current shunt, phase	B	80	Uniform	1.732	1	46.2
Source impedance	B	500	Uniform	1.732	1	288.7
Repeatability	A	2100	Gaussian	1	1	2100.0
Digitizer, phase	B	2	Gaussian	1	1	2.0
Power, stability after varm-up	B	300	Uniform	1.732	1	173.2
				Combined uncertainty:		2157

Lamp Group 2, (L1-2, L2-2, L3-2, L4-2, L5-2)						
Source	**Type**	**Value (mW/VA)**	**Distribution**	**k-factor**	**Sen.-Coef.**	**Std. Unc. (mW/VA)**
Voltage:						
Digitizer (Ch 0)	B	34	Gaussian	1	1	34.0
Calibration, voltage divider	B	135	Gaussian	1	1	135.0
Voltage divider, phase	B	80	Uniform	1.732	1	46.2
Repeatability	A	210	Gaussian	1	1	210.0
Current:						
Digitizer (Ch 1)	B	170	Gaussian	1	1	170.0
Calibration, current shunt	B	100	Gaussian	1	1	100.0
Wideband characteristic, shunt	B	200	Uniform	1.732	1	115.5
Current shunt, phase	B	80	Uniform	1.732	1	46.2
Source impedance	B	500	Uniform	1.732	1	288.7
Repeatability	A	600	Gaussian	1	1	600.0

Digitizer, phase	B	2	Gaussian	1	1	2.0
Power, stability after varm-up	B	300	Uniform	1.732	1	173.2
				Combined uncertainty:		777

Lamp Group 3, (L1-3, L2-3, L3-3, L4-3, L5-3)						
Source	**Type**	**Value (mW/VA)**	**Distribution**	**k-factor**	**Sen.-Coef.**	**Std. Unc. (mW/VA)**
Voltage:						
Digitizer (Ch 0)	B	34	Gaussian	1	1	34.0
Calibration, voltage divider	B	135	Gaussian	1	1	135.0
Voltage divider, phase	B	80	Uniform	1.732	1	46.2
Repeatability	A	210	Gaussian	1	1	210.0
Current:						
Digitizer (Ch 1)	B	170	Gaussian	1	1	170.0
Calibration, current shunt	B	100	Gaussian	1	1	100.0
Wideband characteristic, shunt	B	200	Uniform	1.732	1	115.5
Current shunt, phase	B	80	Uniform	1.732	1	46.2
Source impedance	B	500	Uniform	1.732	1	288.7
Repeatability	A	5410	Gaussian	1	1	5410.0
Digitizer, phase	B	2	Gaussian	1	1	2.0
Power, stability after varm-up	B	300	Uniform	1.732	1	173.2
				Combined uncertainty:		5432