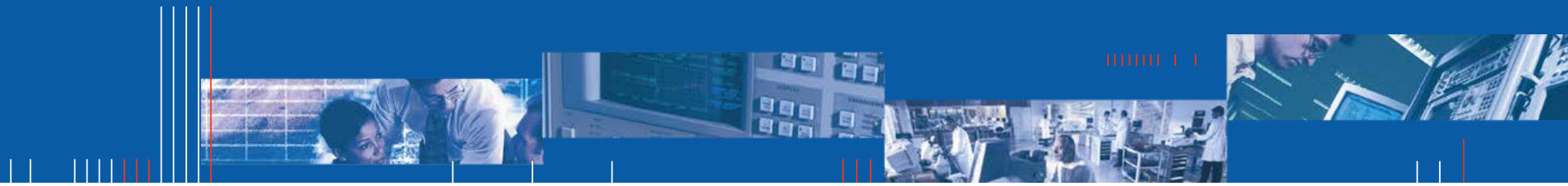

Metrology for Solid State Lighting

Trescal

Measurement of electrical power of SSL lamps over a wide frequency range.

Torsten Lippert

Teddington, April 2013

Outline

- AC power measurement
- Test set-up
- Power measurement of SSL lamps
- Bandwidth requirements/issues

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LED Lamps

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AC Power

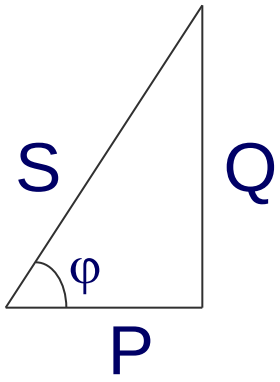
Power (W): $P = V^2/R$

Apparent Power (VA): $S = V^2/Z$

Reactive Power (Var): $Q = V^2/X$

Impedance: $Z = R + iX$

Power Factor: $PF = P/S$



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AC Power

Traditionally at NMI's

Phantom power: seperate voltage and current paths
High resolution DMM for sampling
High precision voltage and current transformers
Low frequency, 50/60Hz
Pure sine wave
Best uncertainty a few ppm

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Developments

- Need for higher frequencies
- Power quality measurements
- Complex signals
- Development of precision voltage dividers and current shunts
- High speed digitizers (up to 10 MSa/s)
- Data analysis software

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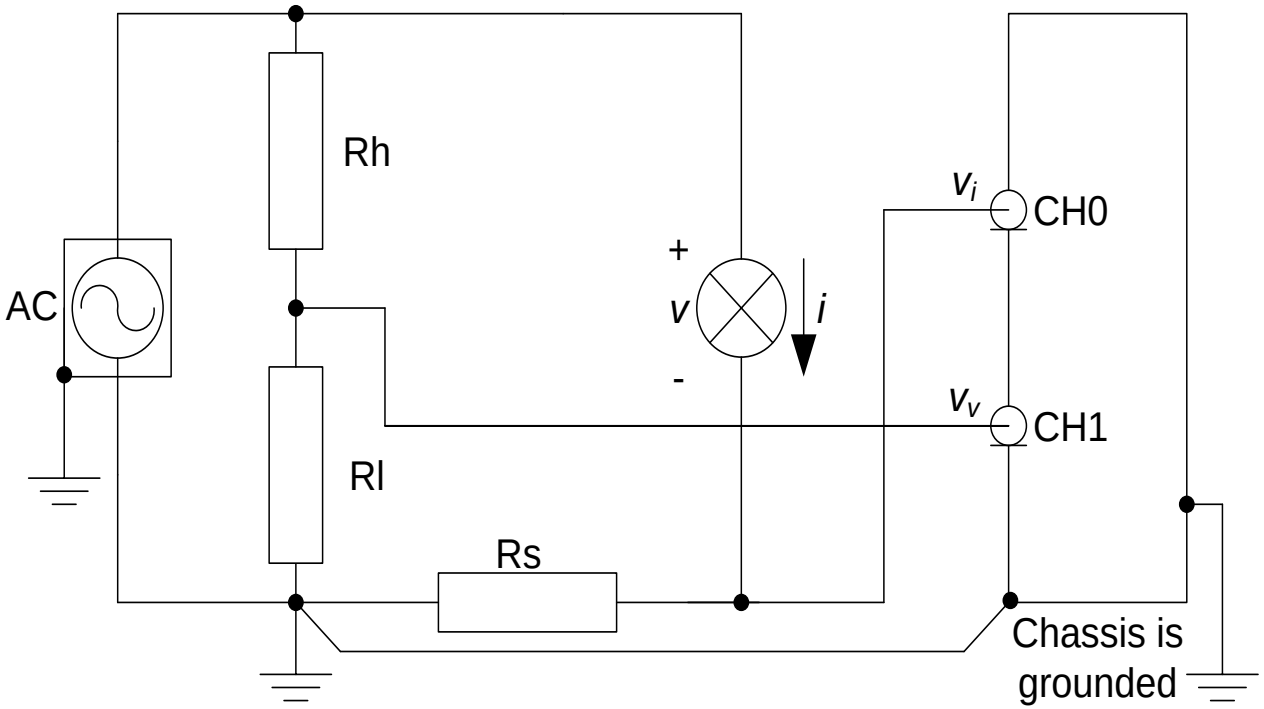
Measurement Set-up, Digitizer

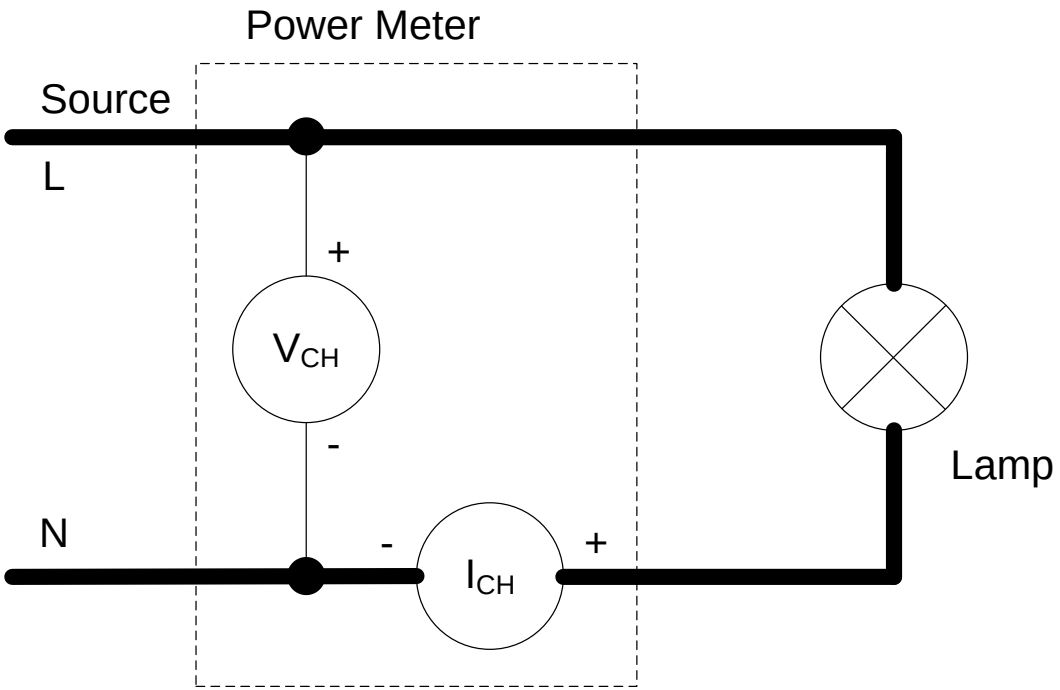


Setup 1

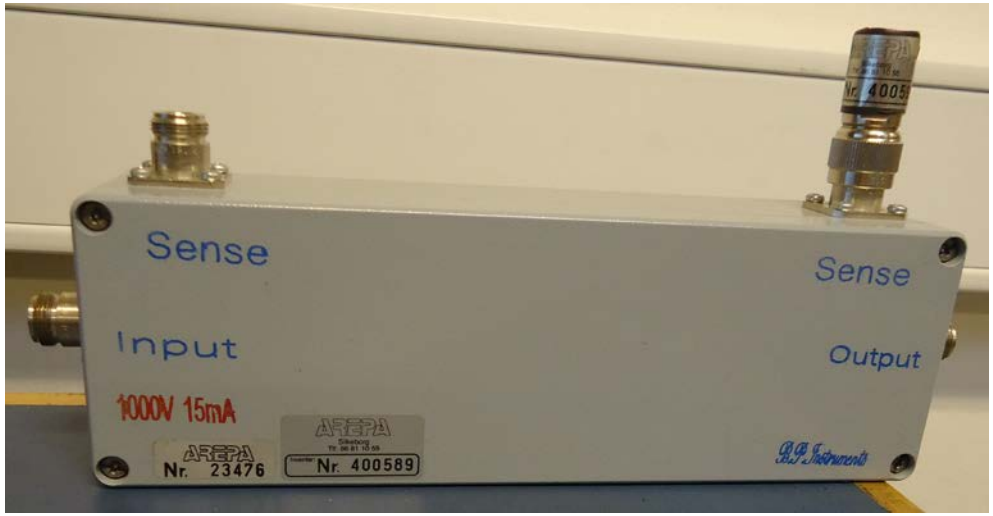
$$i = \frac{v_i}{R_s}$$

$$v = v_v \frac{R_h + R_l}{R_l} - v_i$$

Measurement Set-up, Power Analyzer



Test Set-up



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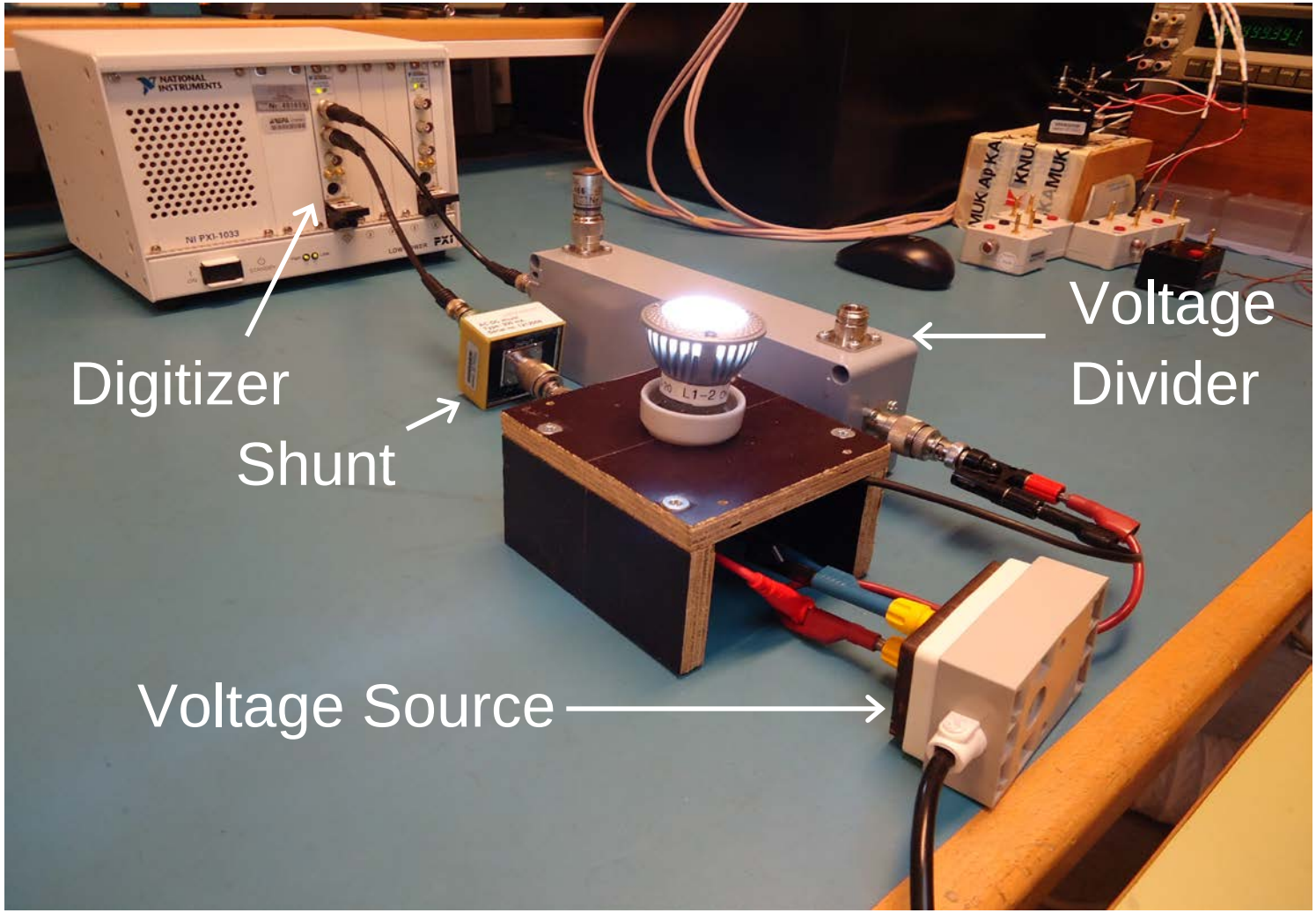
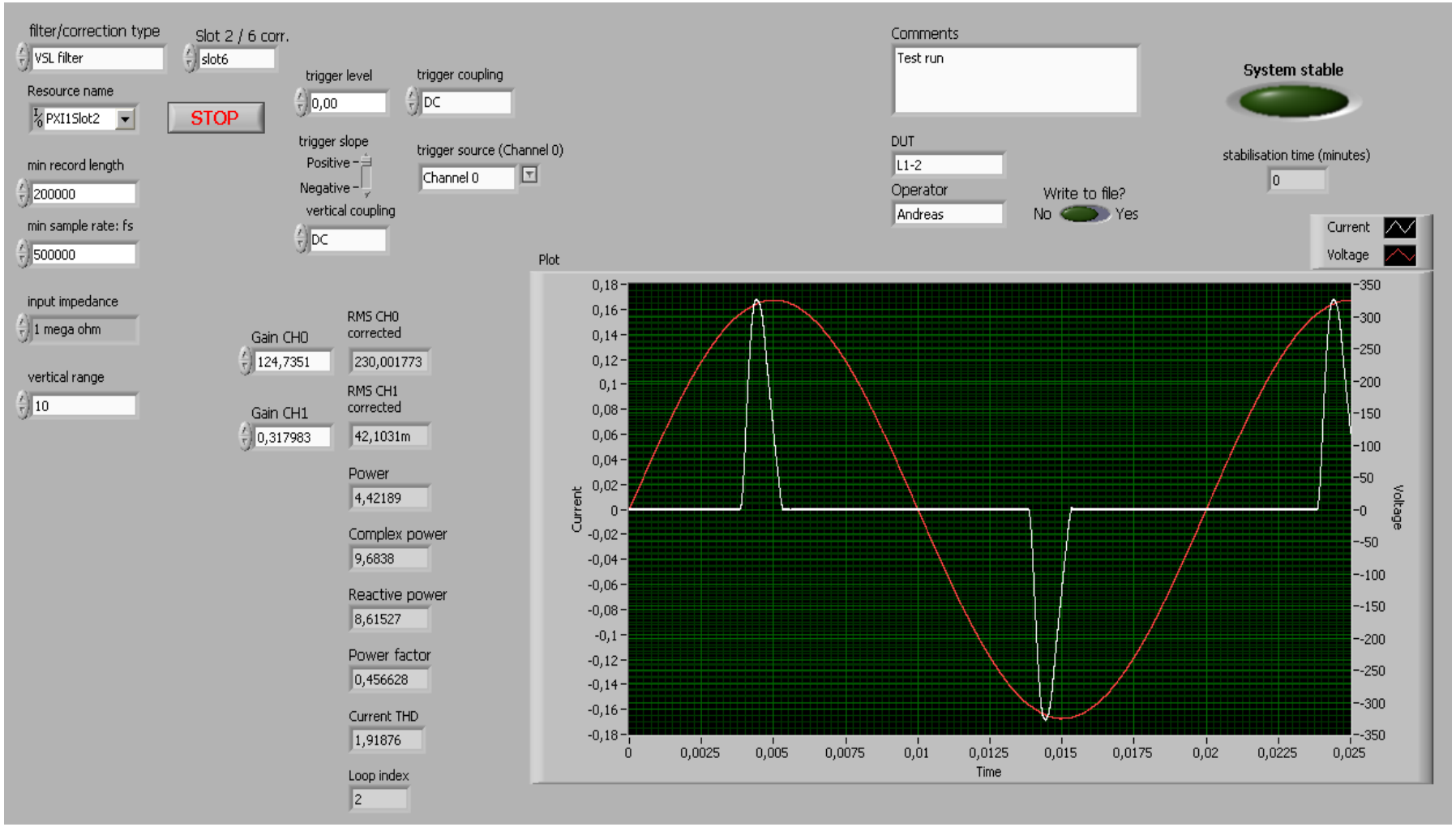
Test Set-up

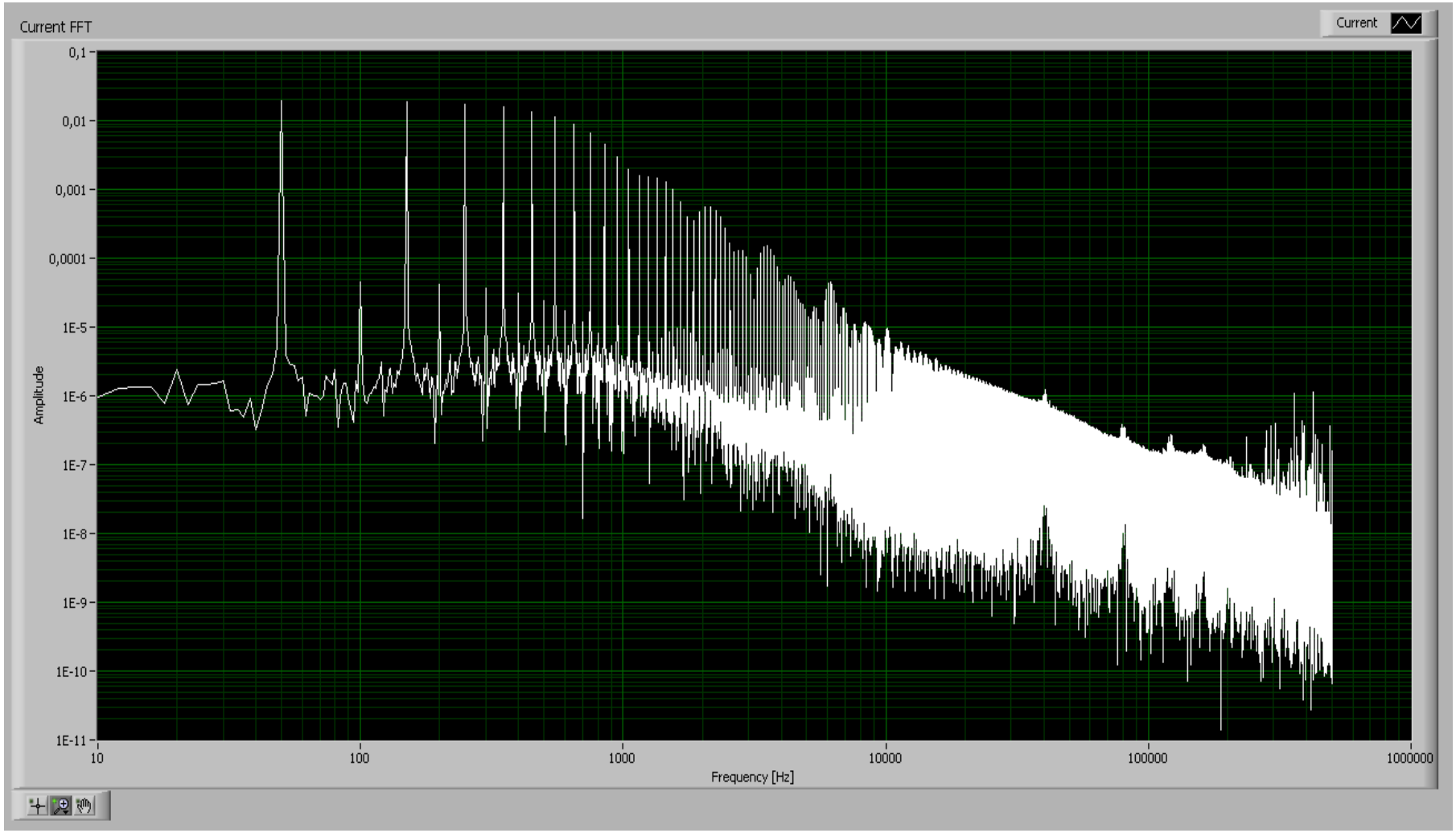


Trescal

Test Set-up


filter/correction type
VSL filter
Slot 2 / 6 corr.
slot6
Resource name
PXI1Slot2
STOP
trigger level
0,00
trigger coupling
DC
trigger slope
Positive
Negative
trigger source (Channel 0)
Channel 0
vertical coupling
DC
min record length
200000
min sample rate: fs
500000
input impedance
1 mega ohm
vertical range
10
Gain CH0
124,7351
Gain CH1
0,317983
RMS CH0 corrected
230,001773
RMS CH1 corrected
42,1031m
Power
4,42189
Complex power
9,6838
Reactive power
8,61527
Power factor
0,456628
Current THD
1,91876
Loop index
2
Comments
Test run
DUT
L1-2
Operator
Andreas
Write to file?
No
Yes
System stable
stabilisation time (minutes)
0
Plot
Current
Voltage
Time

Test Set-up



Trescal

Test Set-up

HARMONIC ANALYZER 12:22:52

Vrange: 300V Arange: 300mA coupling: ac+dc bandwidth: wide

PH1	voltage	current
fundamental	229.61V	19.484mA
harmonic rms	229.61V	44.006mA
THD	0.250%	202.5%
H3	0.095%	96.86%
H3	219.17mV	18.872mA
H3	-089.1°	+025.7°
frequency	50.000Hz	
watts	4.4232W	4.4227W
H3	-1.7382mW	-0.039%
dc watts	7.3674µW	

0:00:07 POWER ANALYZER 12:21:43

Vrange: 300V Arange: 300mA coupling: ac+dc bandwidth: wide

PH1	total	fundamental	
watts	4.4184W	4.4191W	
VA	8.6070VA	4.4696VA	
VAr	7.3864VAr	670.04mVAr	
pf	0.5134	-0.9887	
voltage	229.68V	229.67V	+000.00°
current	37.474mA	19.461mA	+008.62°
frequency	50.000Hz		
H3	231.40µW	0.005%	
dc watts	-6.3005µW		

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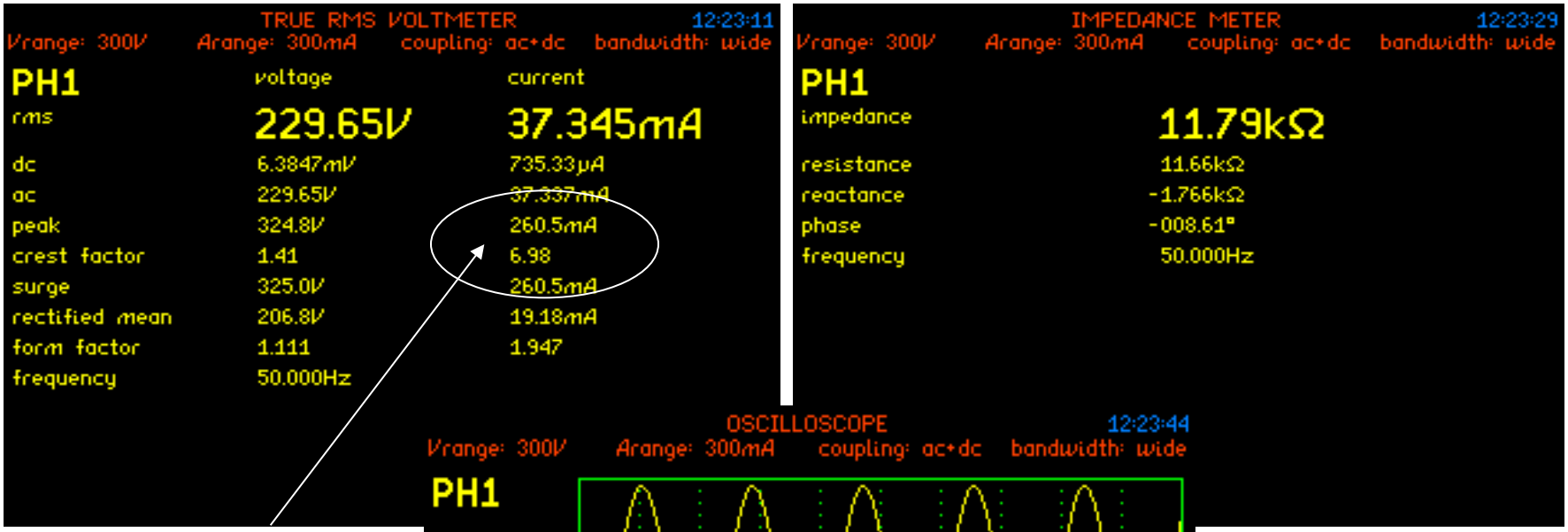
Test Set-up



Peak value

Crest factor

Power Measurement

Power: $$P = \frac{1}{N}\sum_j I_j V_j$$

Voltage: $$V_{rms} = \sqrt{\frac{1}{N}\sum_j V_j^2}$$

Current: $$I_{rms} = \sqrt{\frac{1}{N}\sum_j I_j^2}$$

Apparent Power: $$S = V_{rms} I_{rms}$$

Power Factor: $$PF = P/S$$

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Fourier analysis

$$v(t) = \mathrm{V}_0 + \sum_{m=1}^{m_{Max}} \sqrt{2}\mathrm{V}_m \cos(m\omega t + \theta_m)$$

$$i(t) = \mathrm{I}_0 + \sum_{m=1}^{m_{Max}} \sqrt{2}\mathrm{I}_m \cos(m\omega t + \phi_m)$$

$$P = \mathrm{V}_0\mathrm{I}_0 + \sum_{m=1}^{m_{Max}} \mathrm{V}_m\mathrm{I}_m \cos(\theta_m - \phi_m)$$

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Power Measurement

Amplitude of fundamental & harmonics

Phase between voltage and current components

Check for DC offset & even harmonics

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Power Measurement

Measurement Conditions:

- Ambient condition: 23,0 ± 0,5 °C
- AC Power supply: THD < 0,5%
- Voltage regulated to within ± 0,1% under load
- Stabilization: burn 72 hours after purchasing (>1000 hours)
- At least 30 min to 60 min stabilization prior to measurements readings in 15 min intervals should be within 0,2%
- Operating orientation with lamp upward (base-down)
- The connection between the power supply, shunt and lamps must be kept as short as possible

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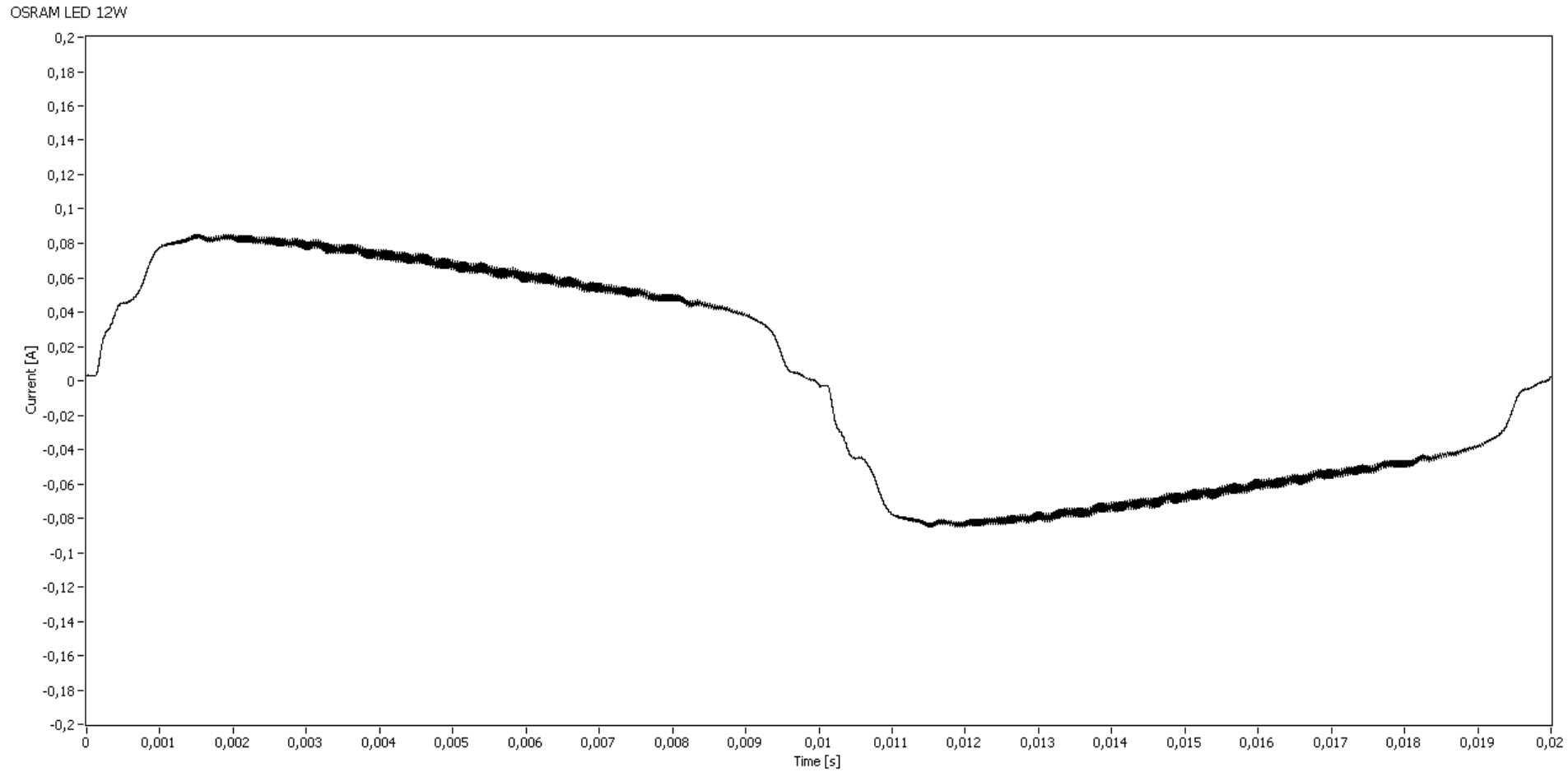
Power Measurement

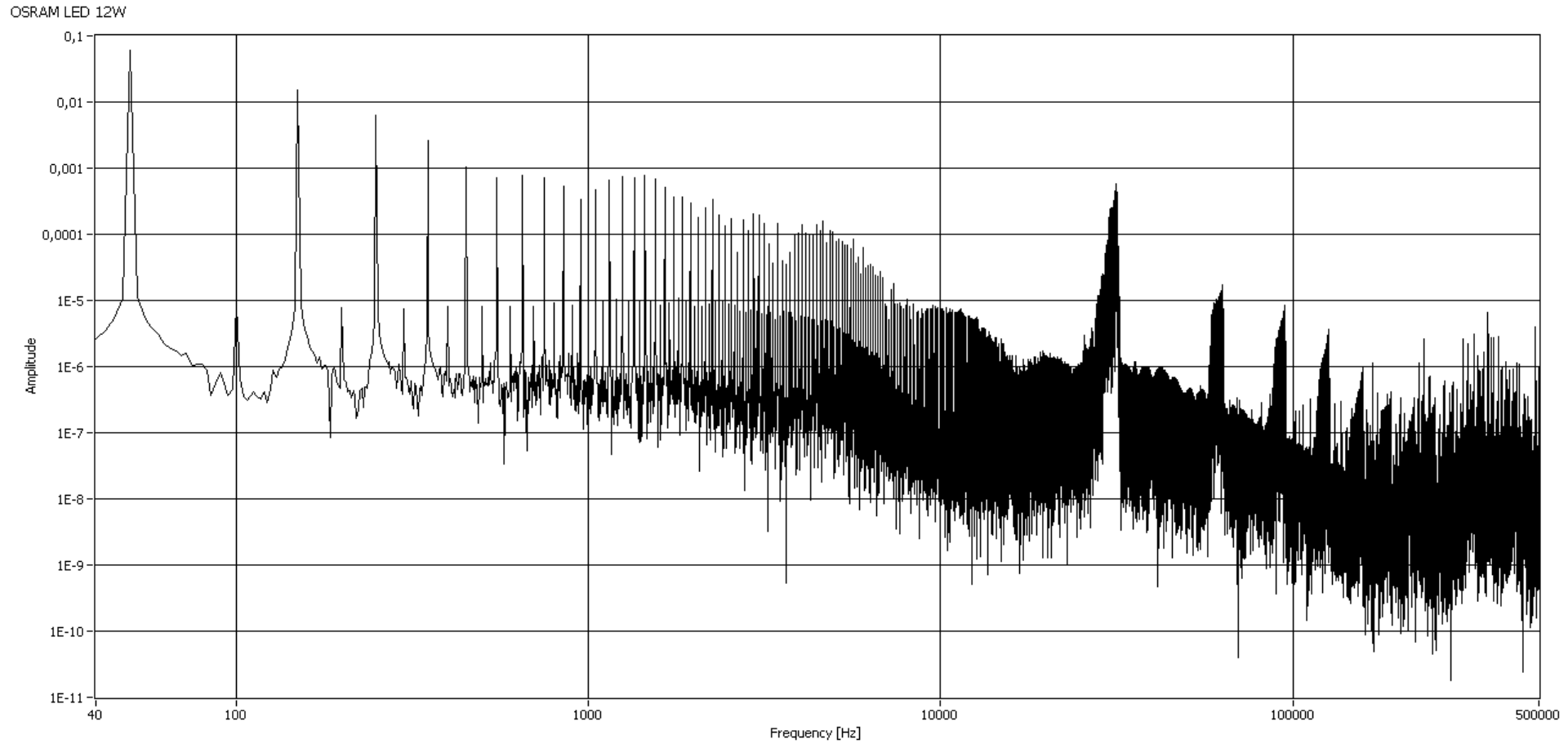
Current waveform (L3)



Trescal

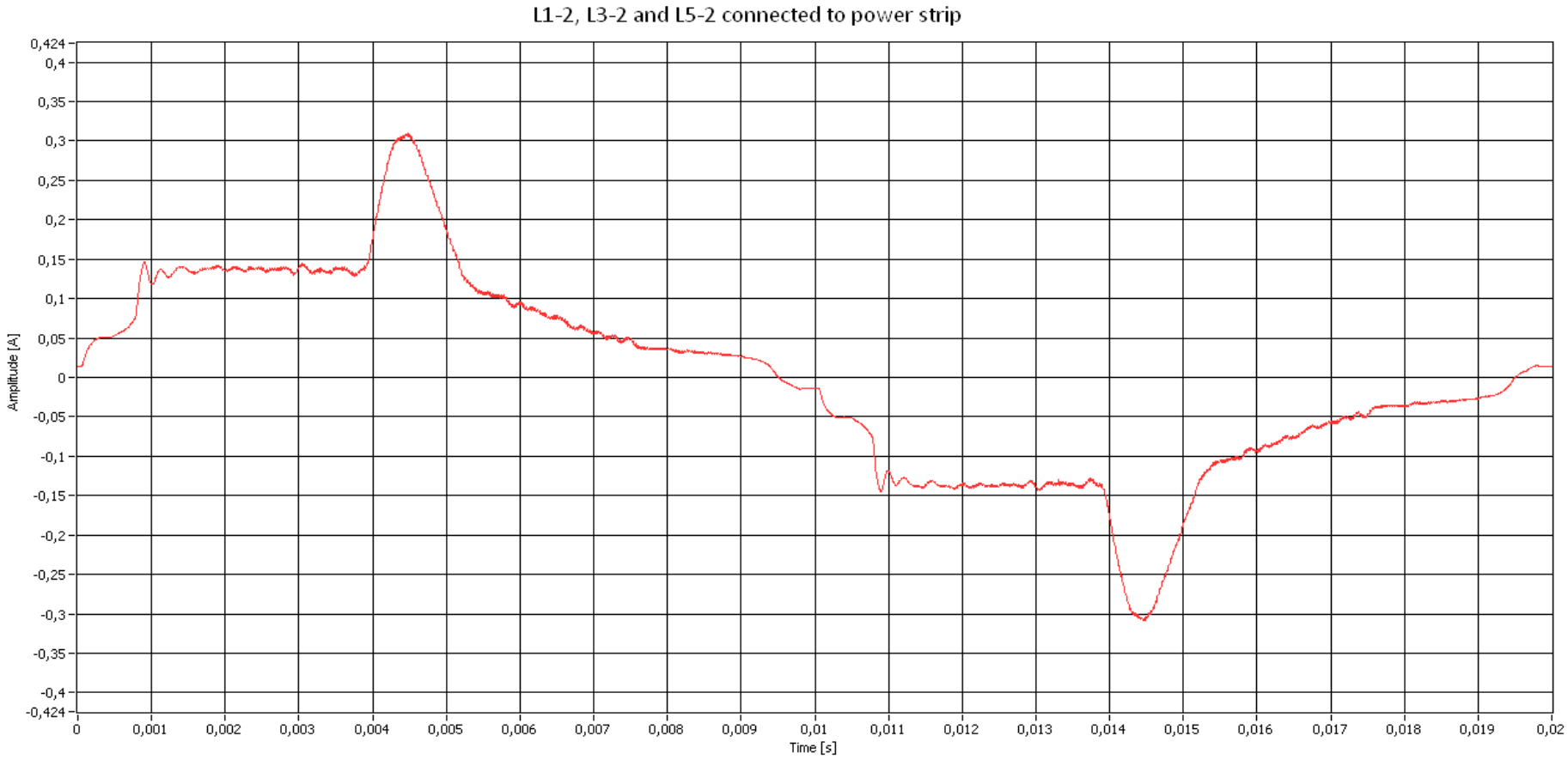
Power Measurement

Current spectrum (L3)



Trescal

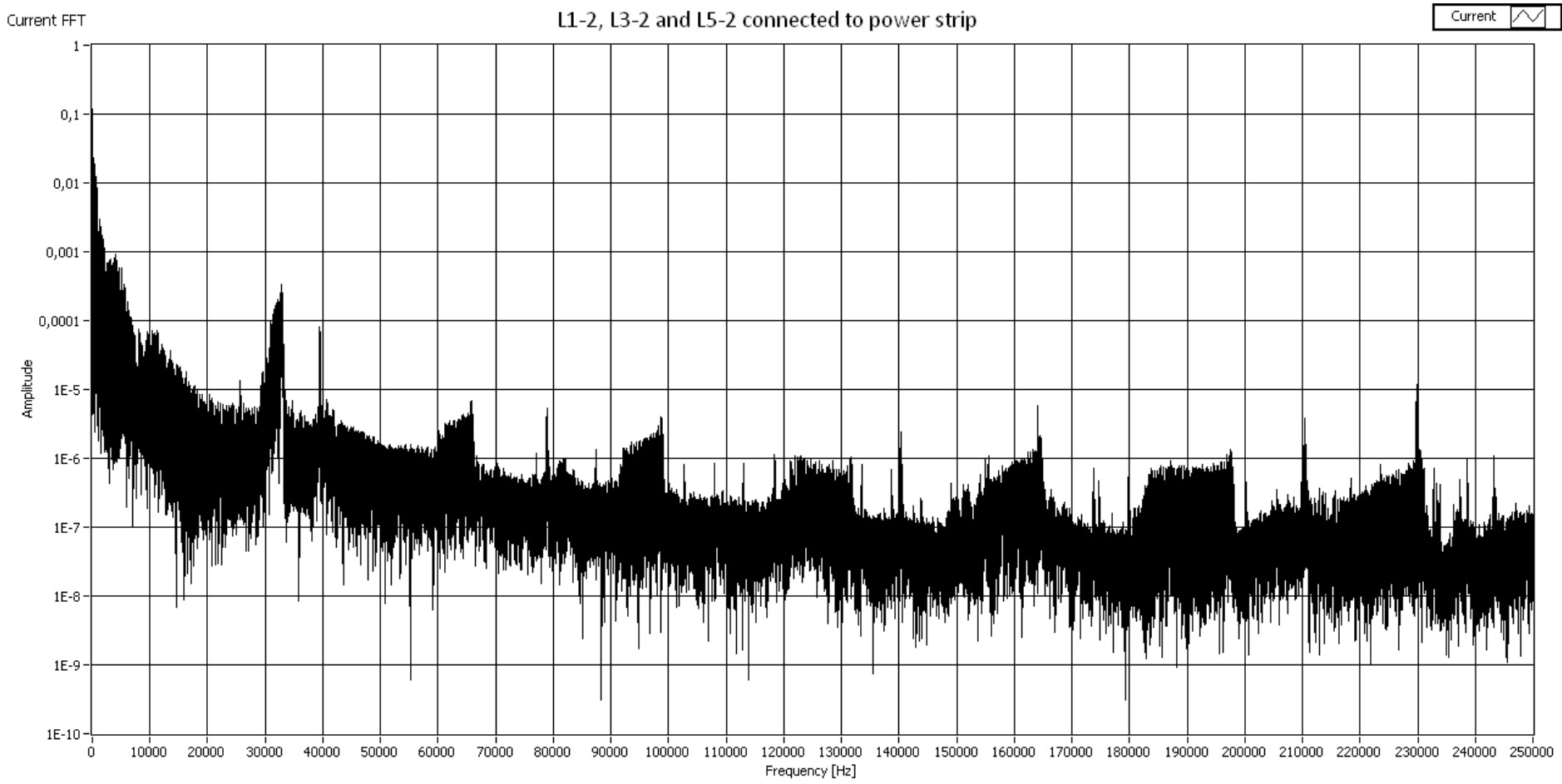
Lamps L1, L3 & L5 connected



Trescal

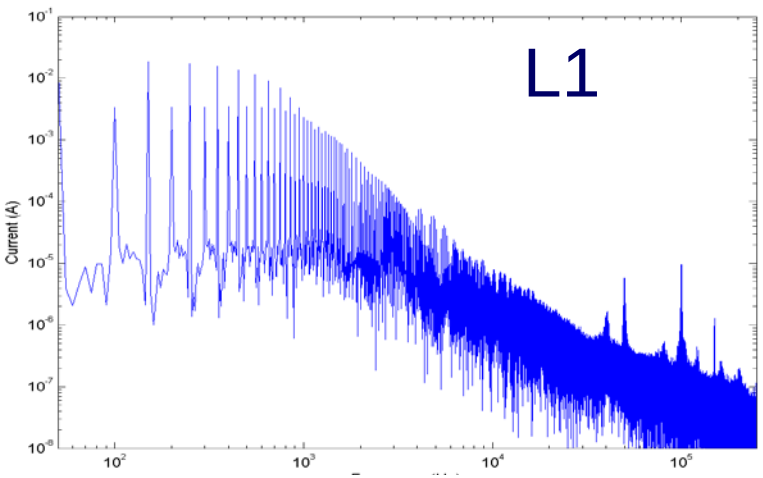
Power Measurement

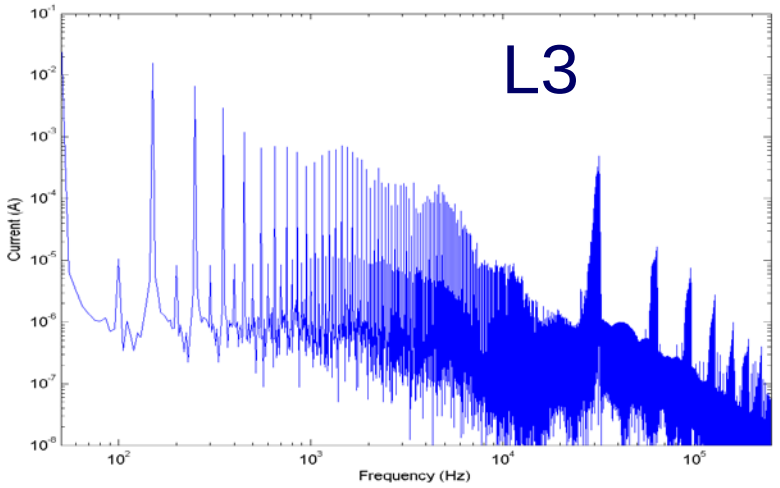
Lamps L1, L3 & L5 connected

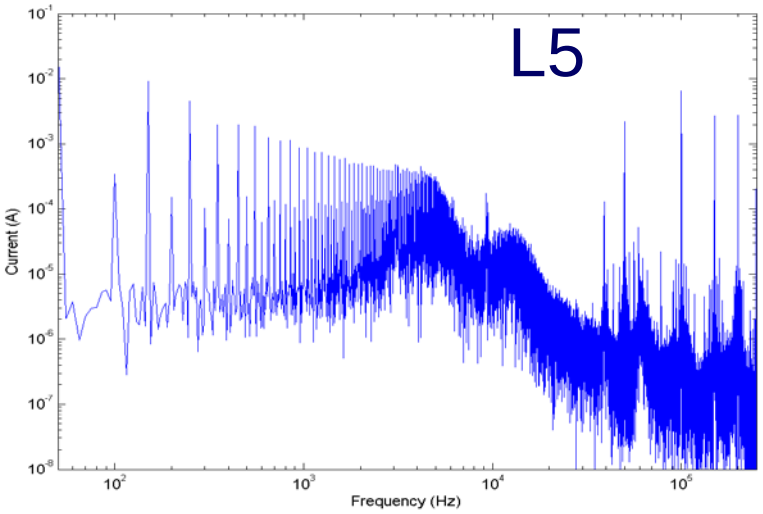


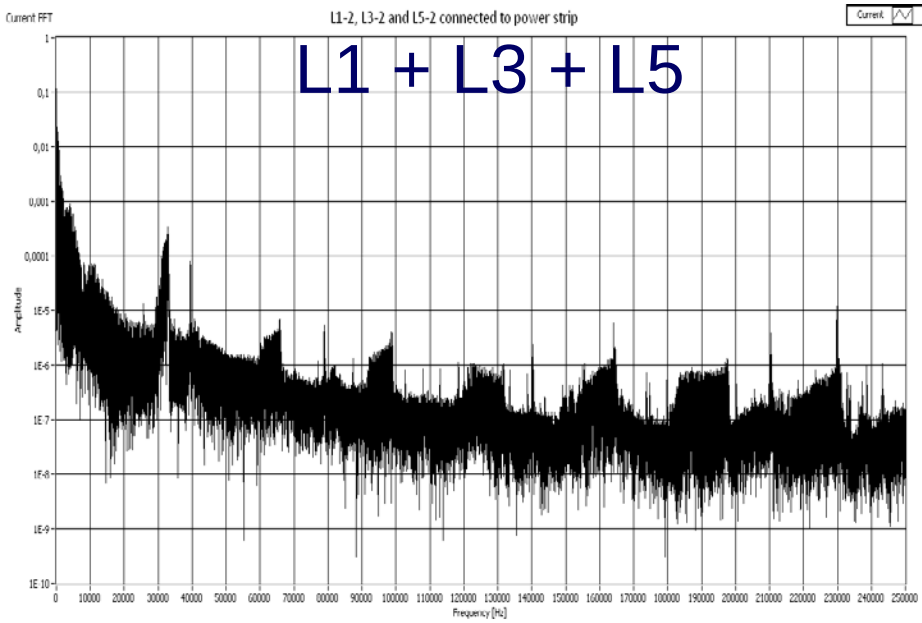
Trescal

Power Measurement









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Power Measurement

Measurement results (230 V, 50 Hz)

	P (W)	S (VA)	PF	Irms (mA)	THD (%)
L1	4,4	9,8	0,45	42,6	196
L3	12,7	13,8	0,92	60,1	31
L5	7,8	9,4	0,83	40,7	30
L1 + L3 + L5	25,3	28,5	0,89	123,8	36
L6	1,4	5,7	0,25	24,9	31

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Bandwidth

Equipment must have wide bandwidth capability:
Current Shunt & Digitizer, Power Analyzer
- at least up to 500 kHz

Equipment must be characterised to high frequency:
- low (known) frequency flatness error
- low (known) phase displacement error

Power Analyzer: Avoid low bandwidth setting or filters

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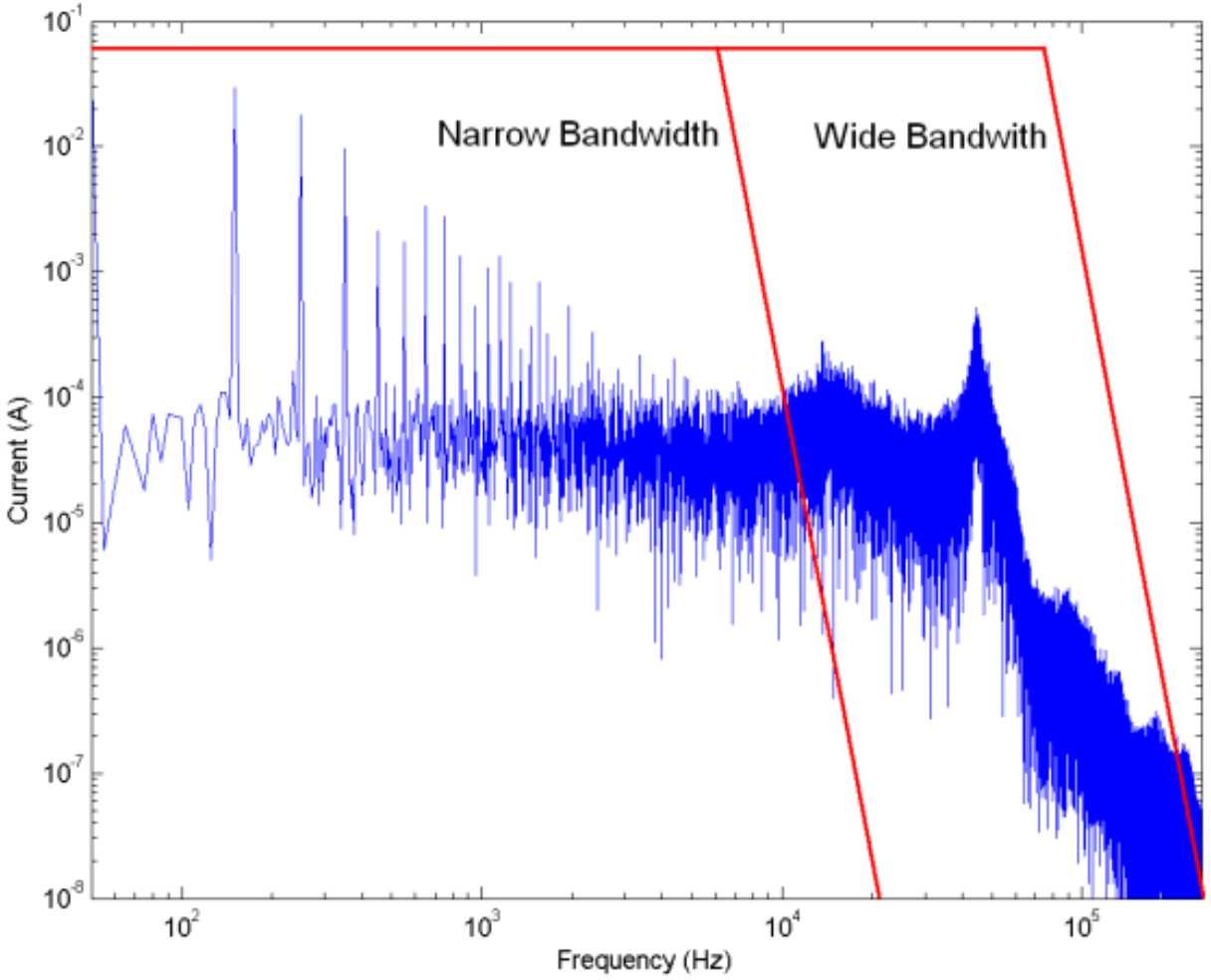
Bandwidth

Bandwidth

Too narrow
~ 0,2%



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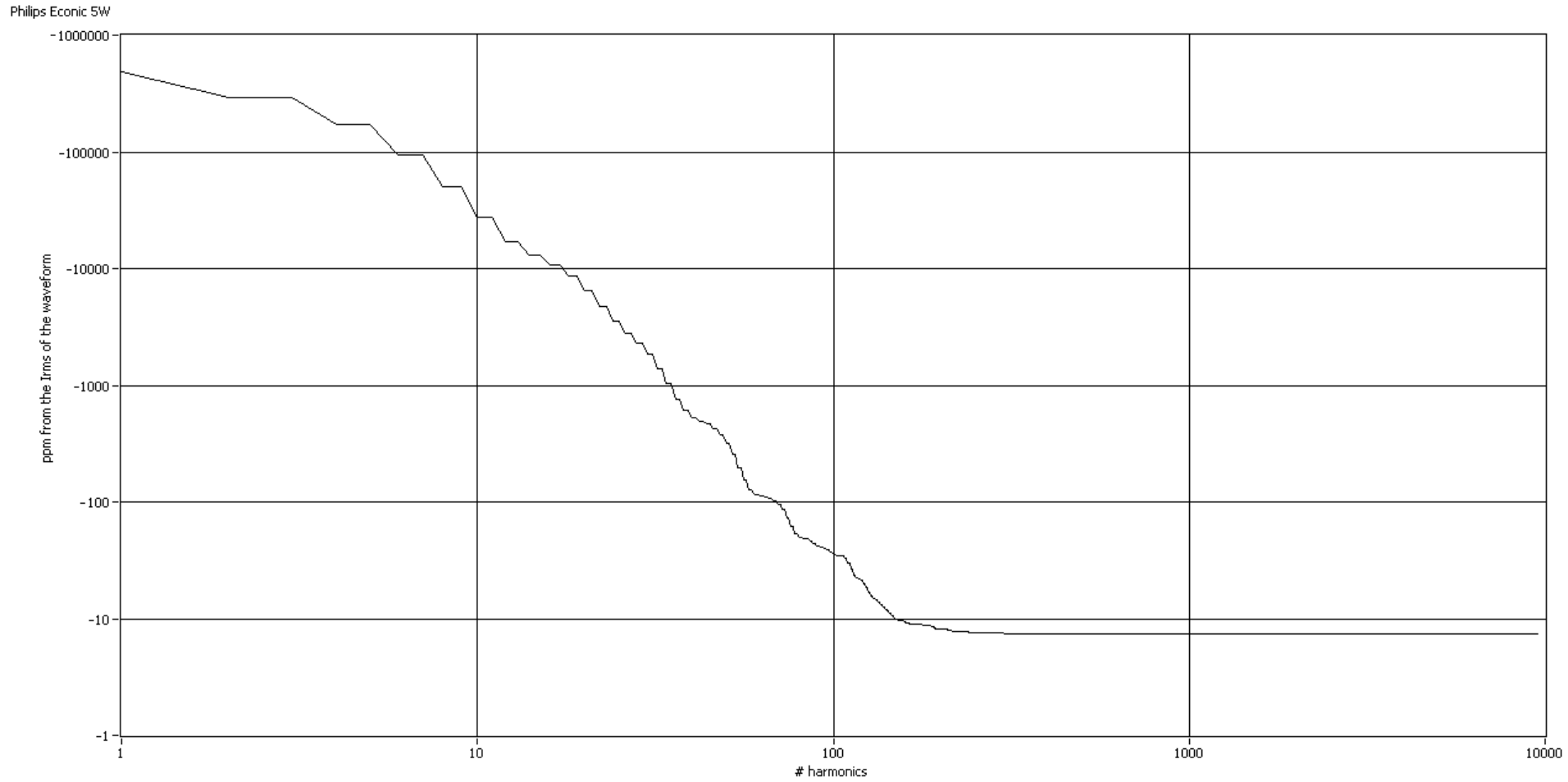
Bandwidth

Difference between Irms and the current calculated from the harmonics as a function of the number of harmonics used in the calculation.



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Acknowledgements

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The research leading to these results has received funding from the Danish Agency for Science Technology and Innovation under the Ministry of Science Technology and Innovation.

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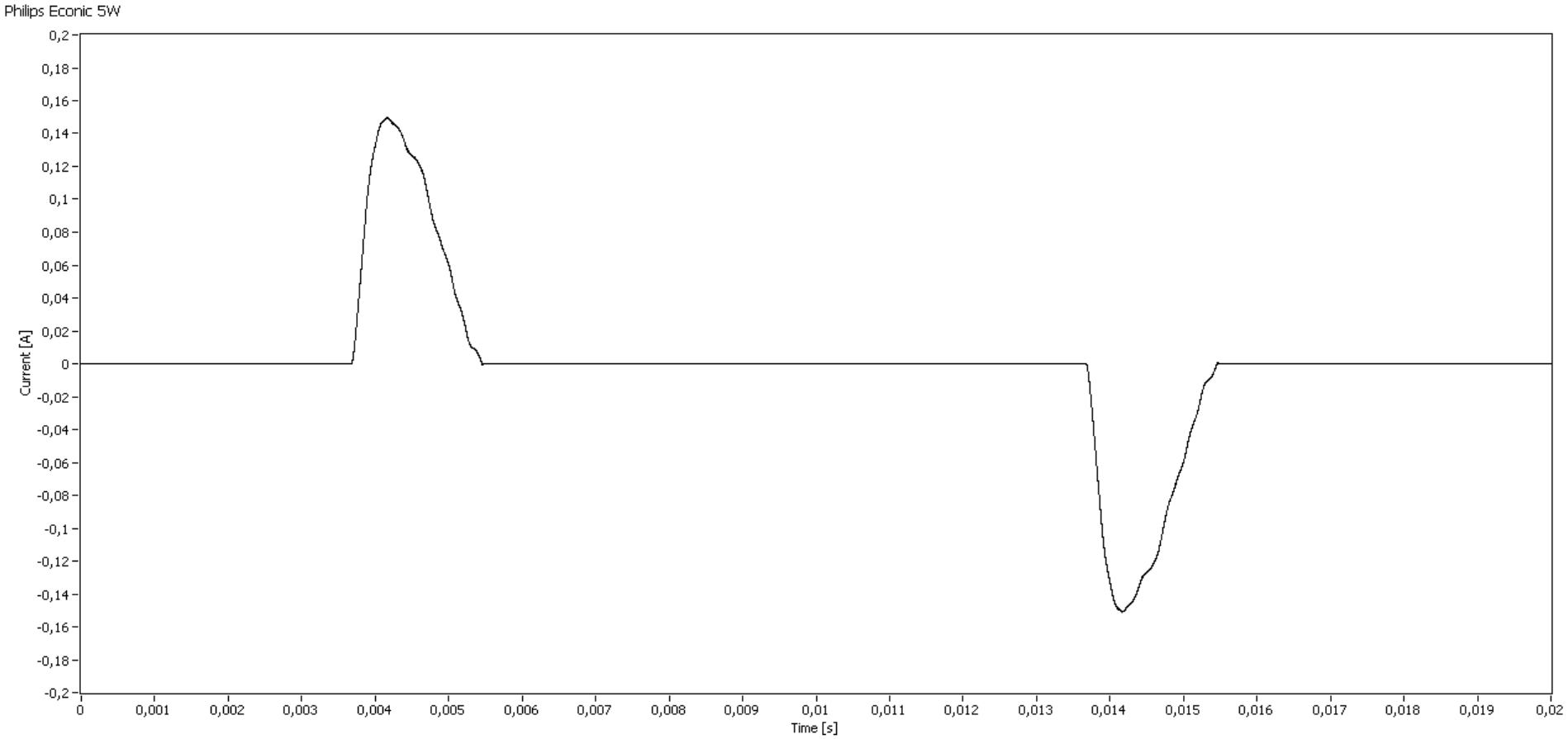
EURAMET
European Association of National Metrology Institutes

EMRP
European Metrology Research Programme
Programme of EURAMET

Extras

Current waveform, Philips Econic, 5 W



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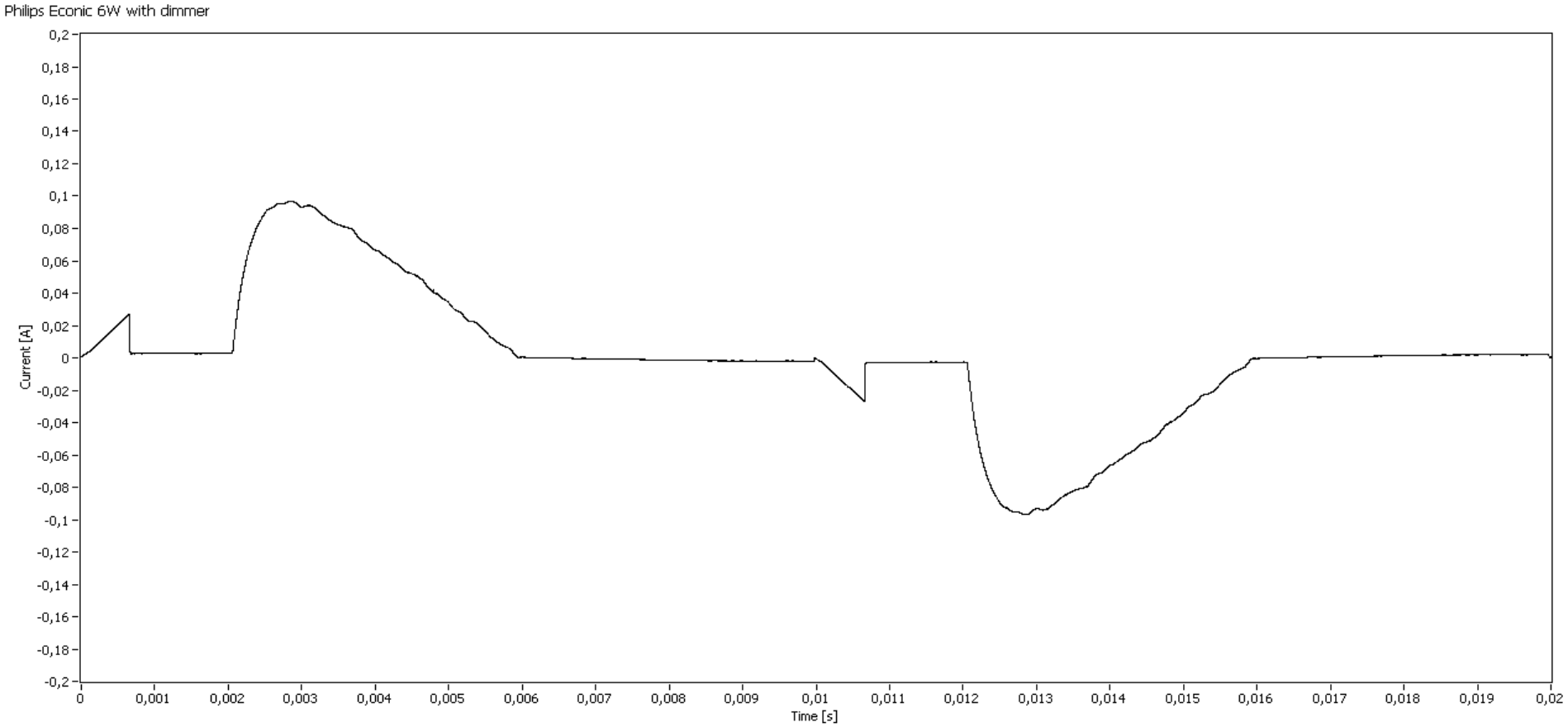
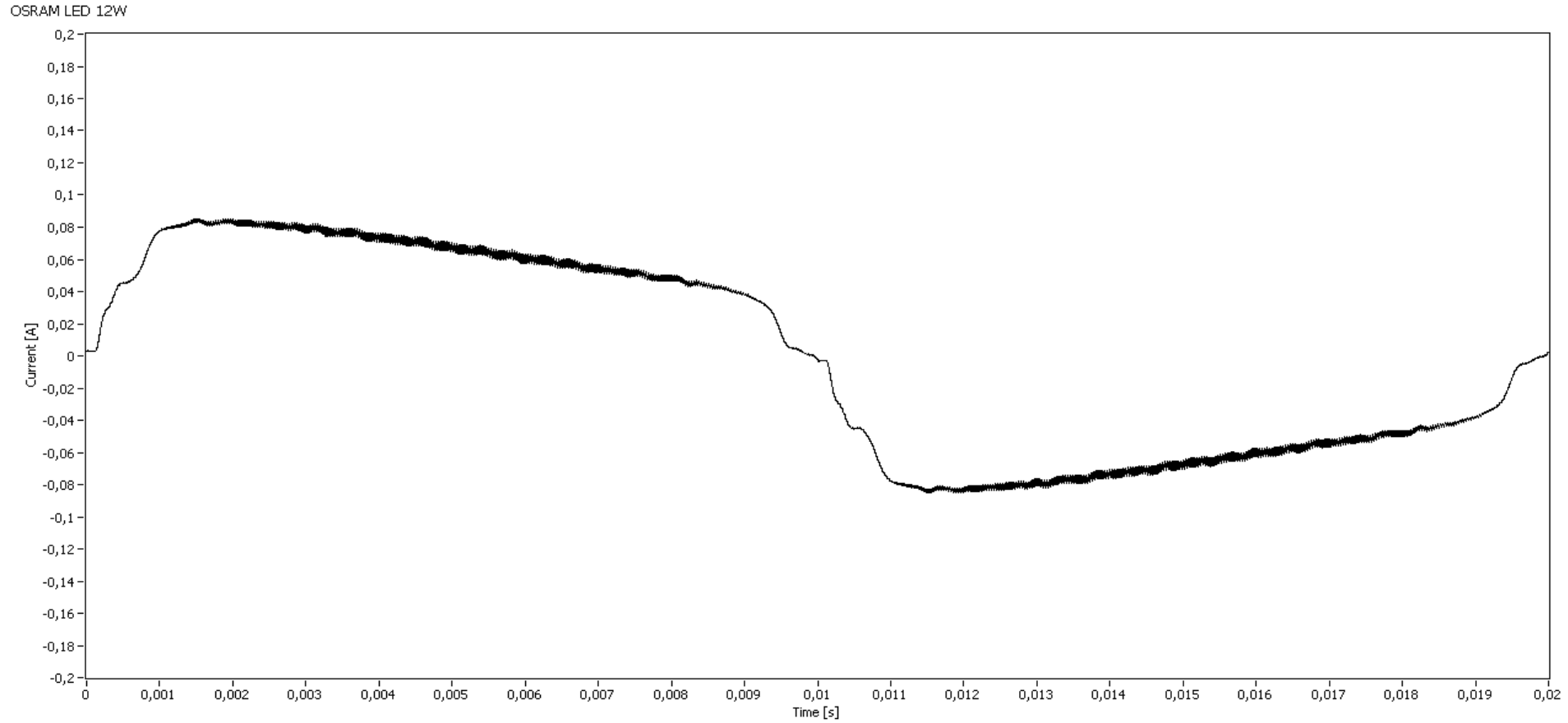
Current waveform, Philips Econic with dimmer, 6 W

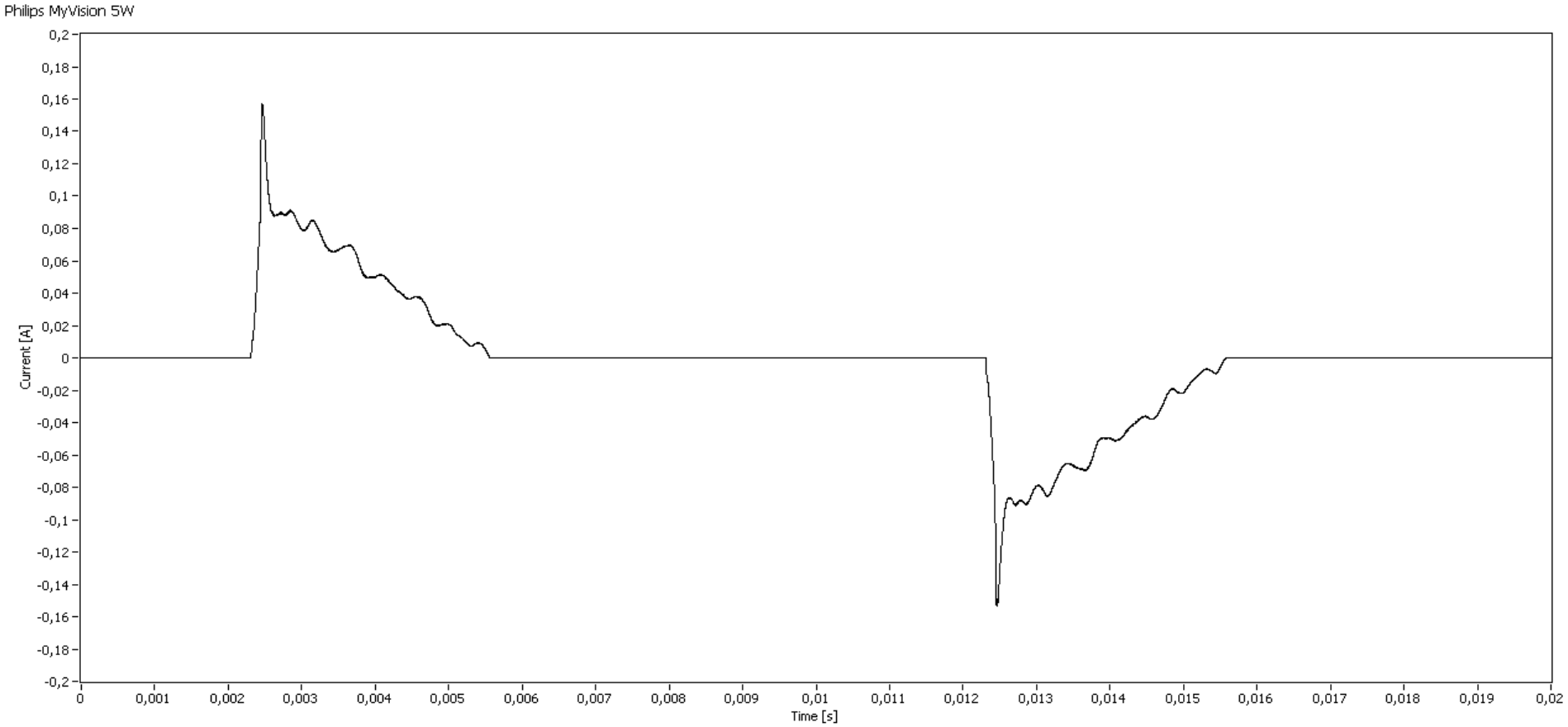


Current waveform, Osram, 12 W

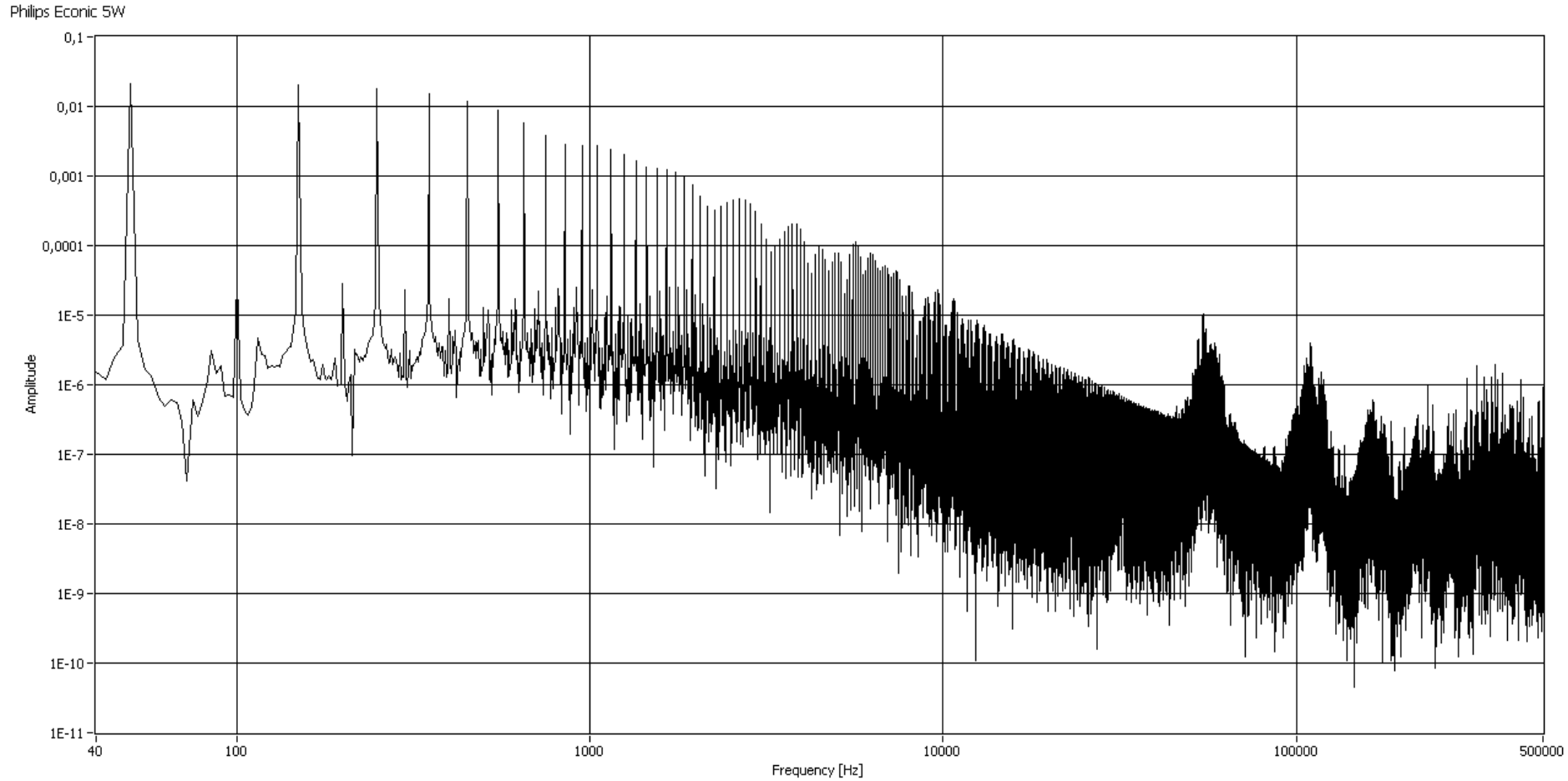


Trescal

Current waveform, Philips MyVision, 5 W

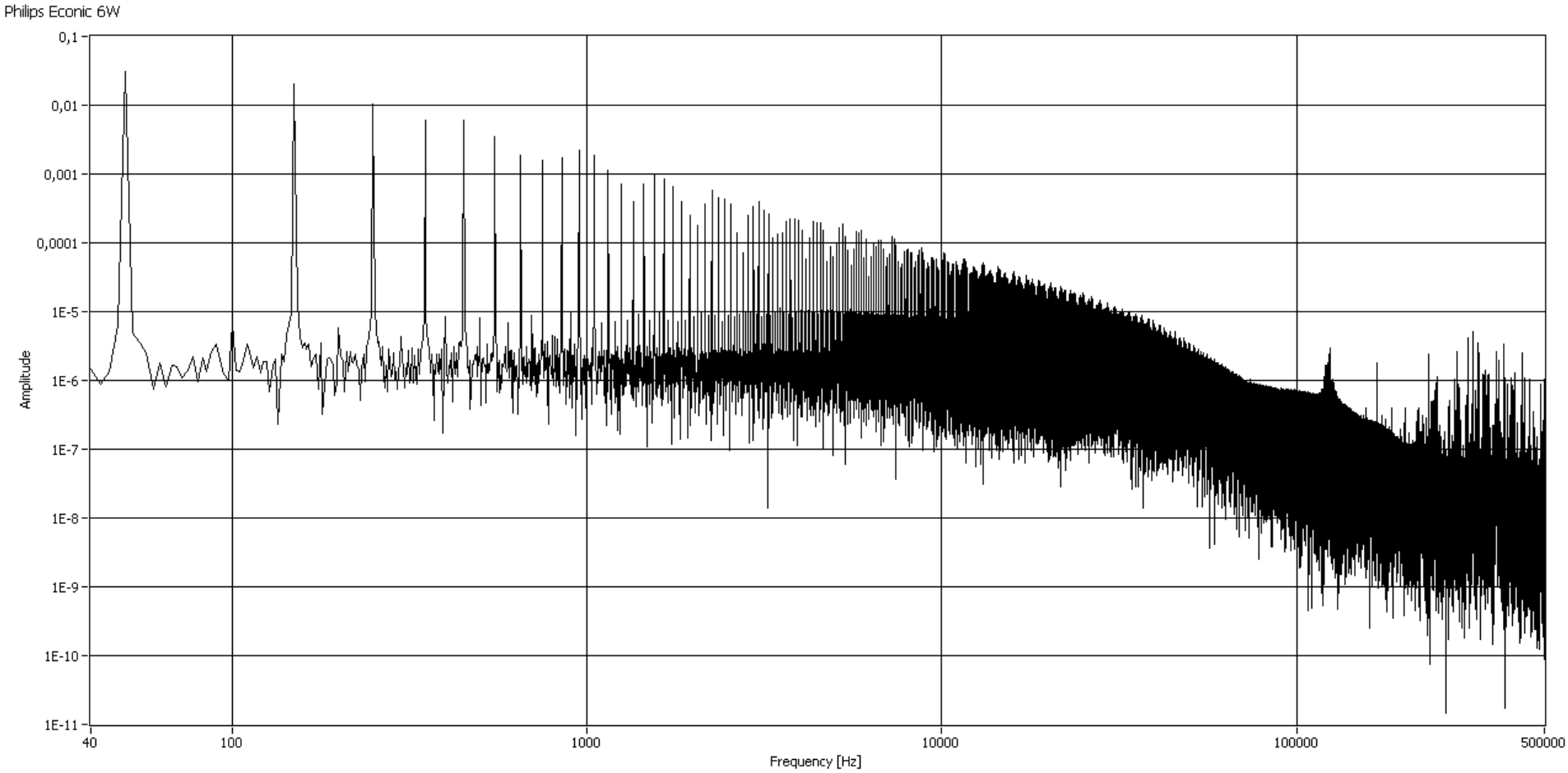


Frequency spectrum (500 kHz), Philips Econic, 5 W



Trescal

Frequency spectrum (500 kHz), Philips Econic, 6 W



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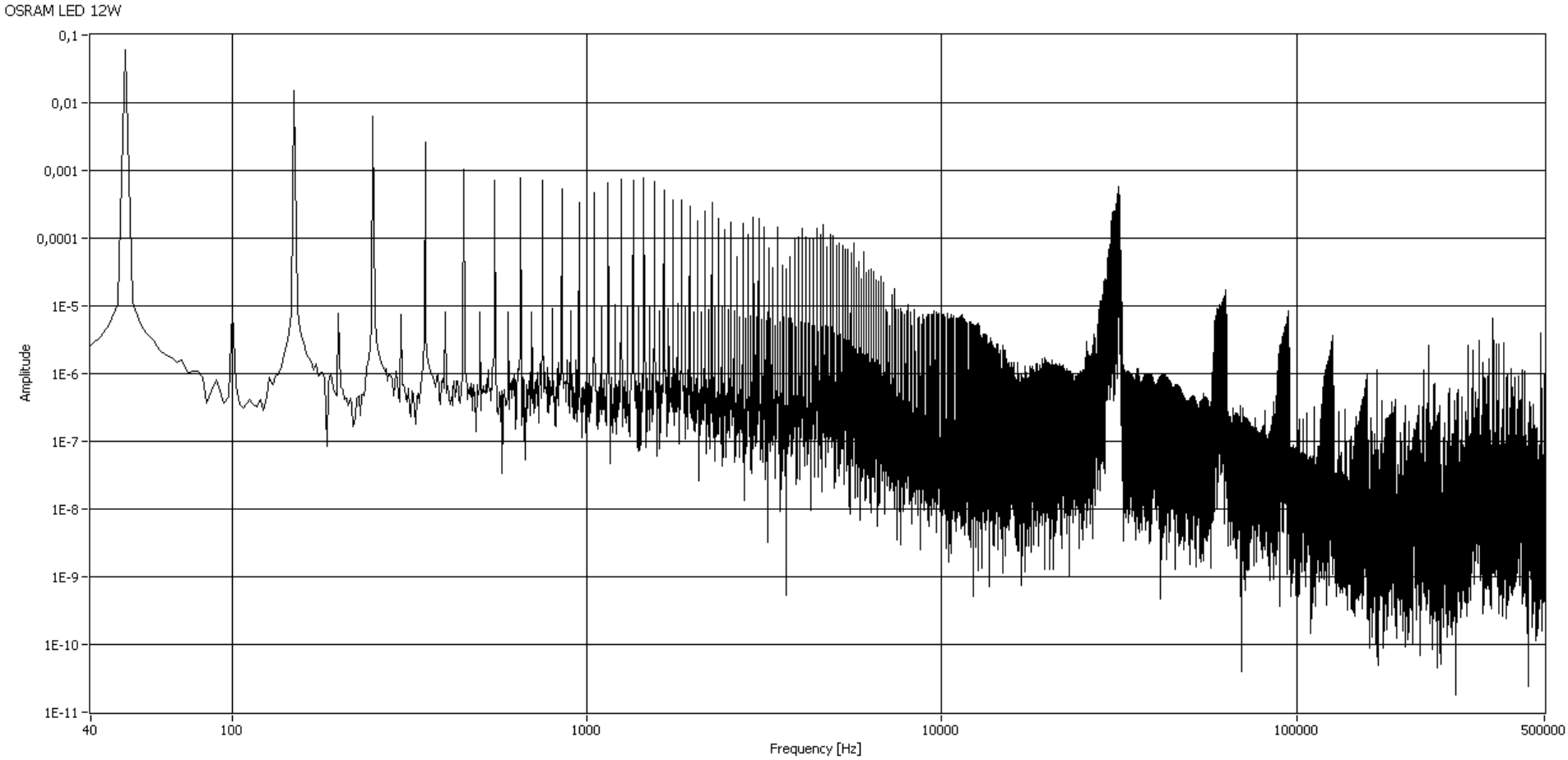
Frequency spectrum (500 kHz), Osram, 12 W



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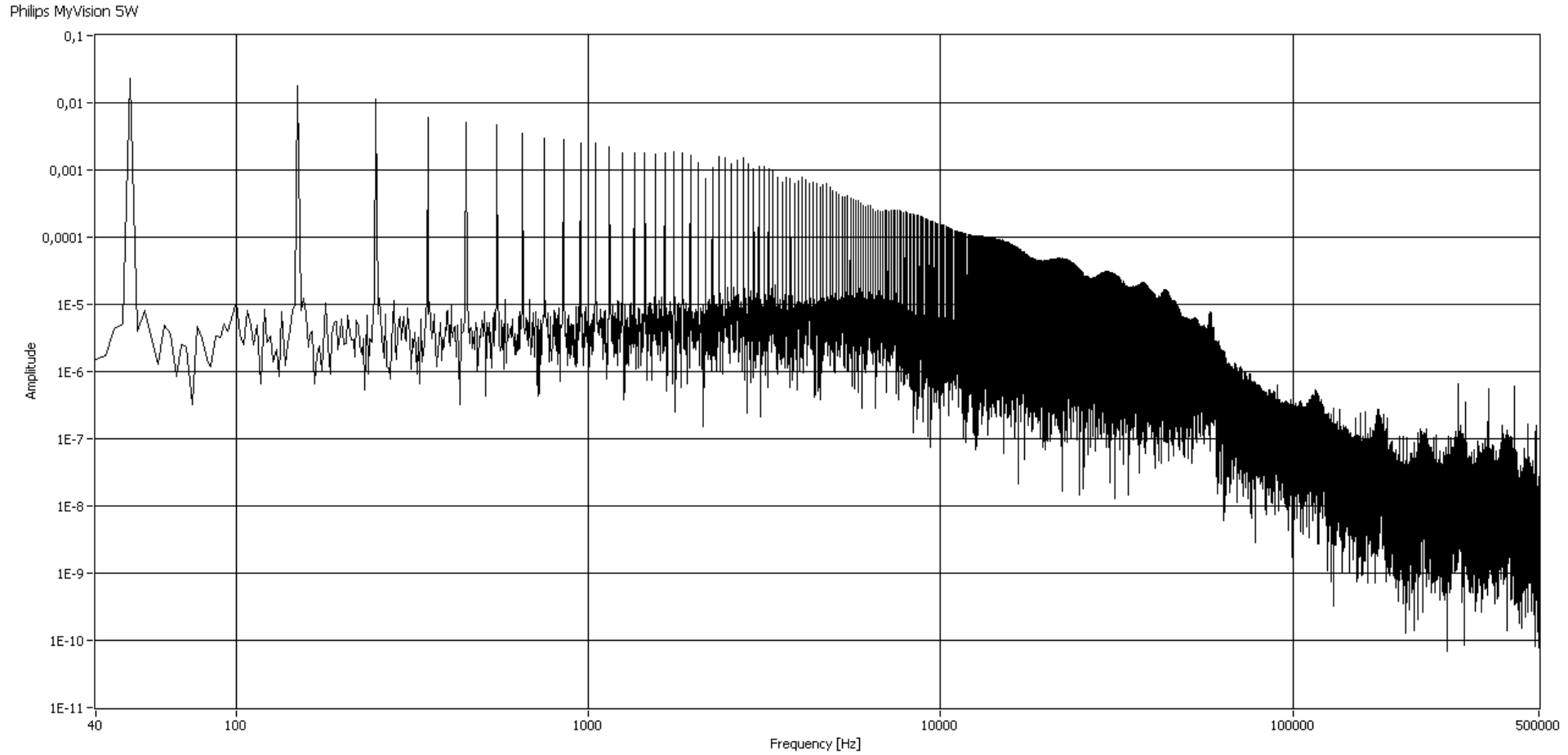
Frequency spectrum (500 kHz), Philips MyVision, 5 W



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