The impact of power quality on measurements

Dr. Andrew Roscoe

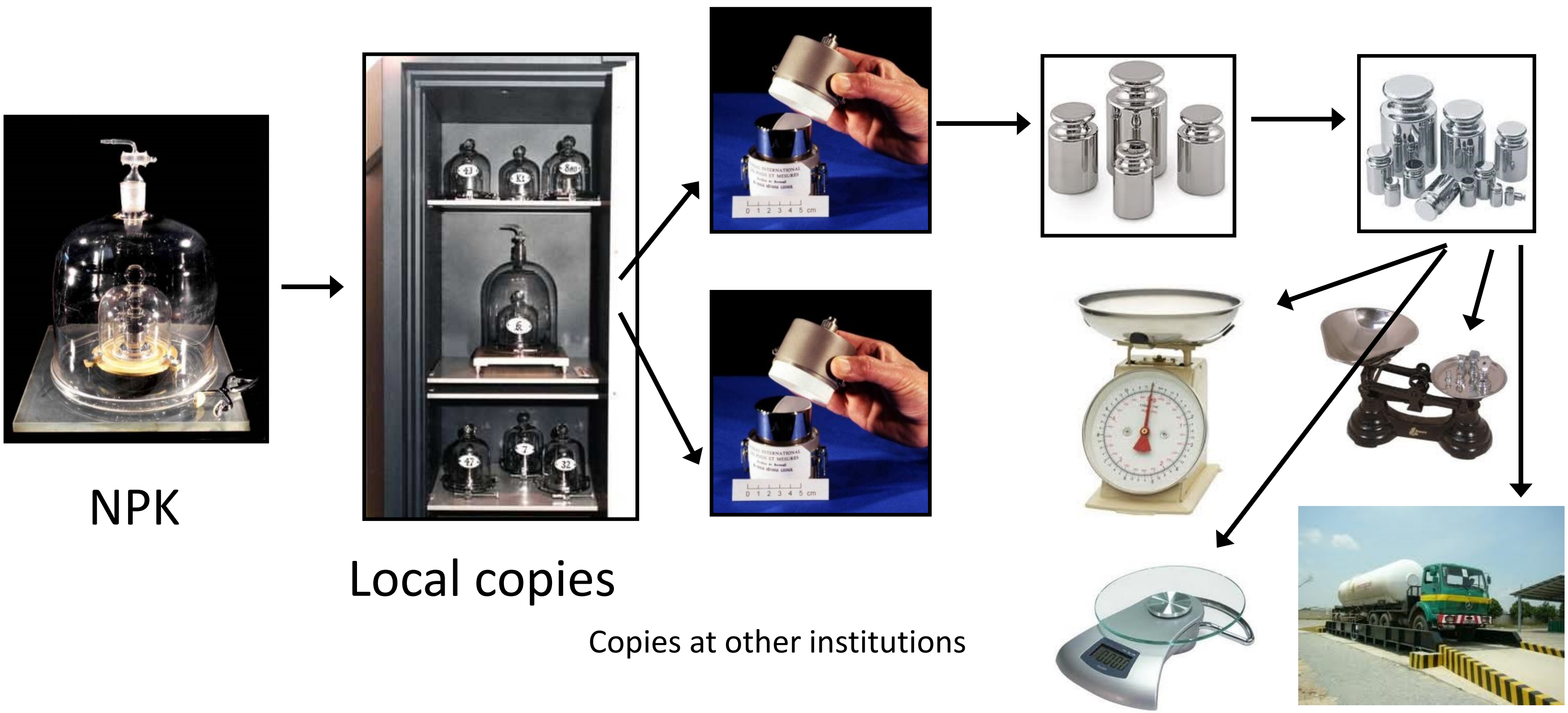
Simple measures : length

Simple measures and accuracy

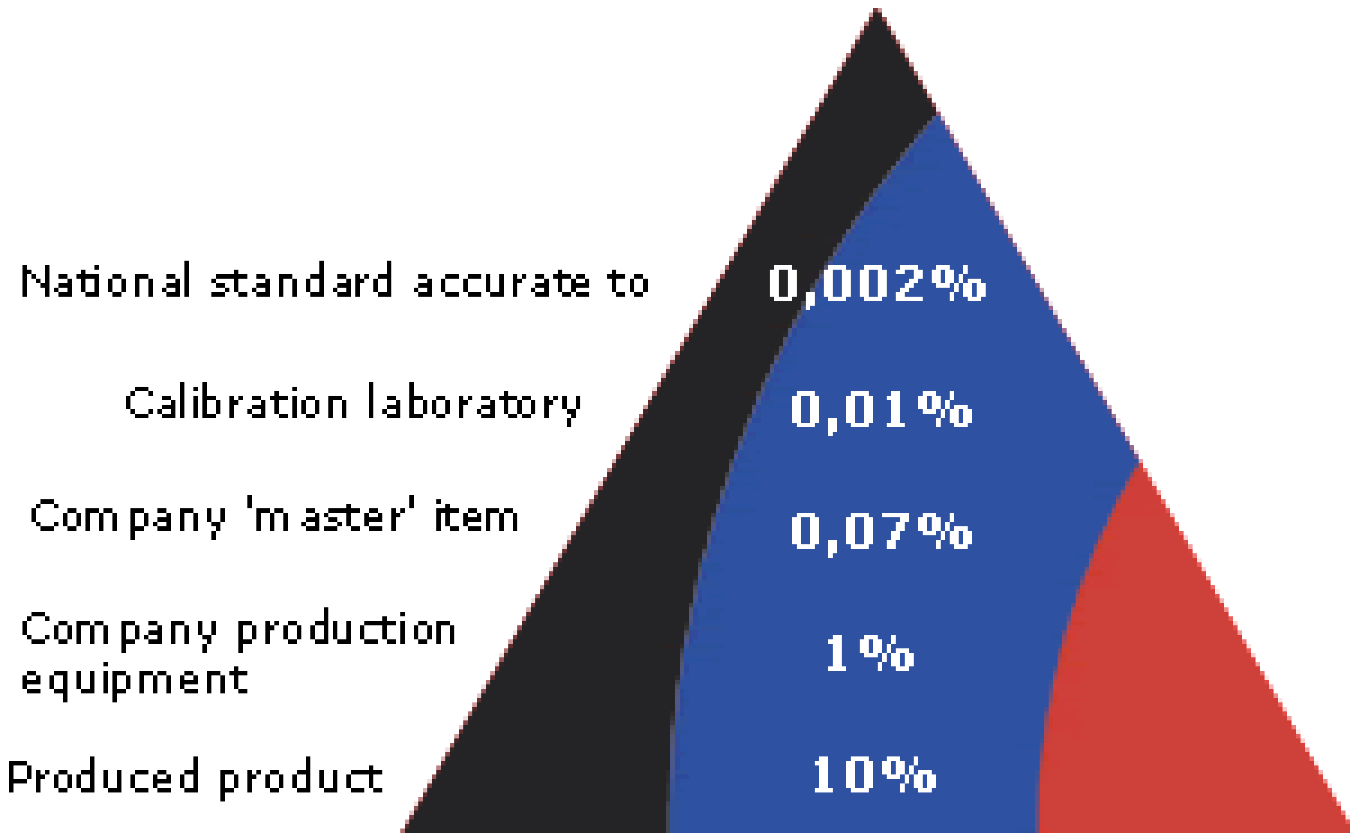
1 inch in 100 feet is about
1 part in 10^3, 0.1%

Transferring standards

- The standard mass (the IPK, International Prototype Kilogram) is kept in France.
- In 1889, 40 copies were made. In the UK, NPL keeps copy #18.
- All the copies can be periodically checked against the IPK
- They are ALL measurably drifting against each other!



Transferring standards and traceability



Example of traceability : Voltage (1)

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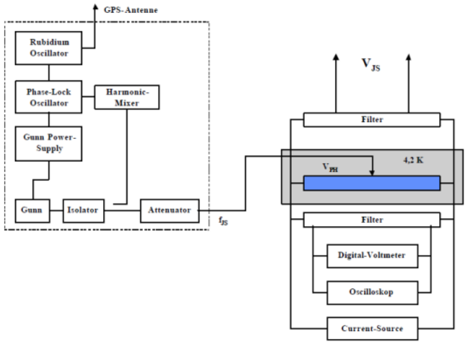
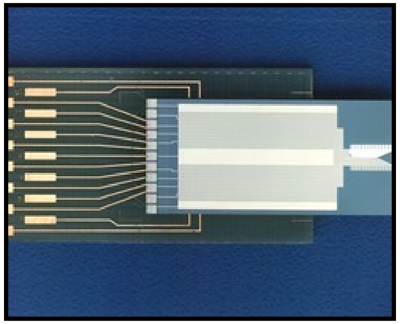




accurate to 1 part in 10^8 (0.01 ppm) using Josephson junctions

Calibration accuracies offered by NPL

Voltage Level	Uncertainty (95 % confidence level)
1.0 V Electronic	0.14 ppm
1.018 V Electronic	0.14 ppm
1.018 V Standard Cell	0.09 ppm
10 V Electronic	0.02 ppm

0.02-0.2 ppm

1-2 ppm
£5000 each

0.01 ppm

Example of traceability : Voltage (2)

Stability

Stability for a given period of time is defined as the output uncertainty minus the calibration uncertainty at the 99% Confidence Level. When the output voltage is characterized by a regression model, stability is given by the following equation:

$$\left| b\left(\frac{P}{365}\right) + 2.65 S_1 \sqrt{\left[\frac{S_{ra}}{S_1}\right]^2 + \left(\frac{1}{n}\right) + \left[\frac{\left(\bar{x} + P - x_1\right)^2}{\Sigma\left(X_j - \bar{x}\right)^2}\right]} \right|$$

where b = slope of regression in ppm/year

S_1 = standard deviation about the regression (SDEV)

S_{ra} = SDEV of data filtered with 7-day moving average filter (MAF)

P = Period of time under consideration in days

$\bar{x}$ = mean time for regession data

n = 180 period (typically 2 meassurements per day)

Xj = jth period

X_1 = time at beginning of data

Each data point for the computation of the regression parameters is the average voltage of 50 readings taken in a 50-second measurement period.

Stability for the 732B outputs at 23 ±1°C is specified as follows:

Output Voltage	Stability (± ppm)		
	30 Days	90 Days	1 Year
10V	0.3	0.8	2.0
1.018V	0.8	NA	NA

Noise at the Output Terminals

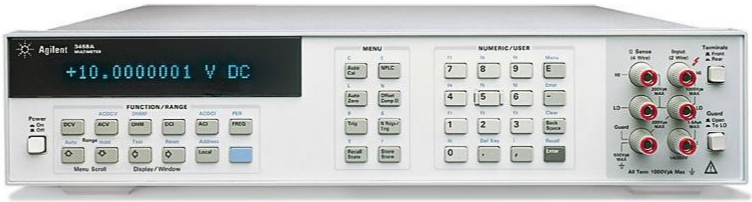
Output noise is specified for both day-to-day observations and for short-term observations. The former is given by the standard deviation of a 90-day regression model. The latter is in terms of its rms value in a bandwidth as follows:

Output Voltage	S_1 (± ppm)	S_{ra} (± ppm)	Noise (0.01 Hz to 10 Hz (± ppm rms)
10V	0.068	0.05	0.06
1.018V	0.1	NA	0.03

Output Current and Limits

Output Voltage	Output Current Limit	Output Impedance
10V	12 mA (Note)	≤ 1 mΩ
1.018V	20 pA	≤ 1 kΩ
Note: Limit output current to ≤ 0.1 mA to realize 72 hour battery operation.		

Example of traceability : Voltage (3)



8-ppm 1 year dcV accuracy, optional 4-ppm
0.05 ppm dcV transfer accuracy

HP/Agilent 3458A, £5600
~10ppm (0.001%)

Agilent DSO1024A
4%, £1500

Agilent 34410A, £850
.0030 % DC2, 0.06% ACV

Agilent 3401A, £300
0.02% DCV ,0.5% ACV

Fluke 115, £150
DCV 0.5% + 2
ACV 1% + 3 (45Hz -500Hz)
2% + 3 (500Hz-1kHz)

DCA 1% + 3
ACA 1.5% + 3
Resistance 0.9% + 1

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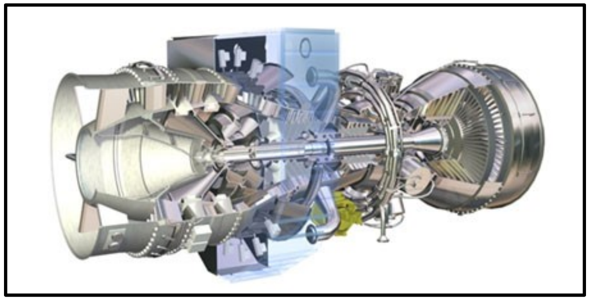
The power system we are used to:

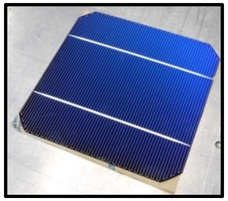
The power system we are moving to:







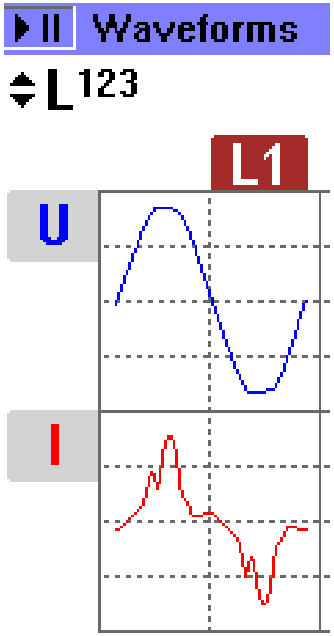





Then add point-point and multi-point HVDC

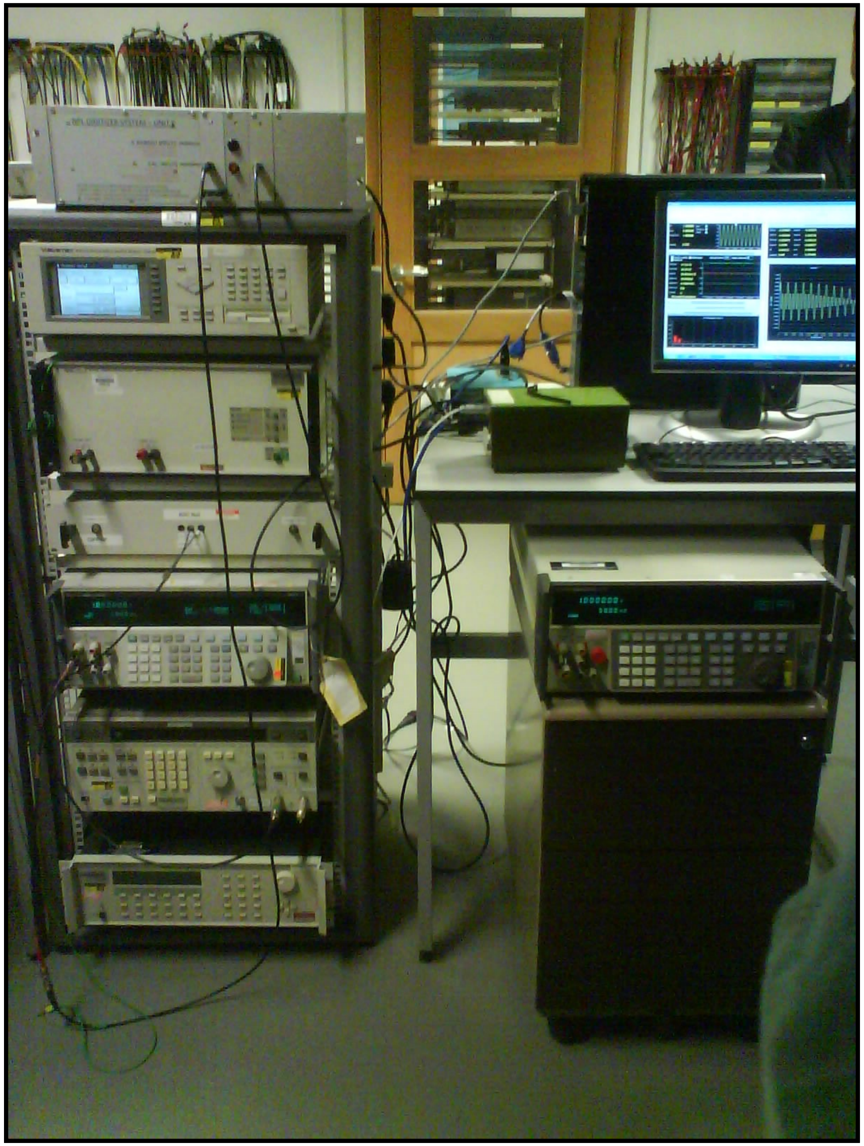
Problems for measurements

- Lower system inertia
  - Frequency is never “nominal”
  - ROCOF levels are rising
- Harmonics
- Inter-harmonics
- Unbalance, Faults
- Inaccessibility, Voltage, Weather
- “Loose” standards

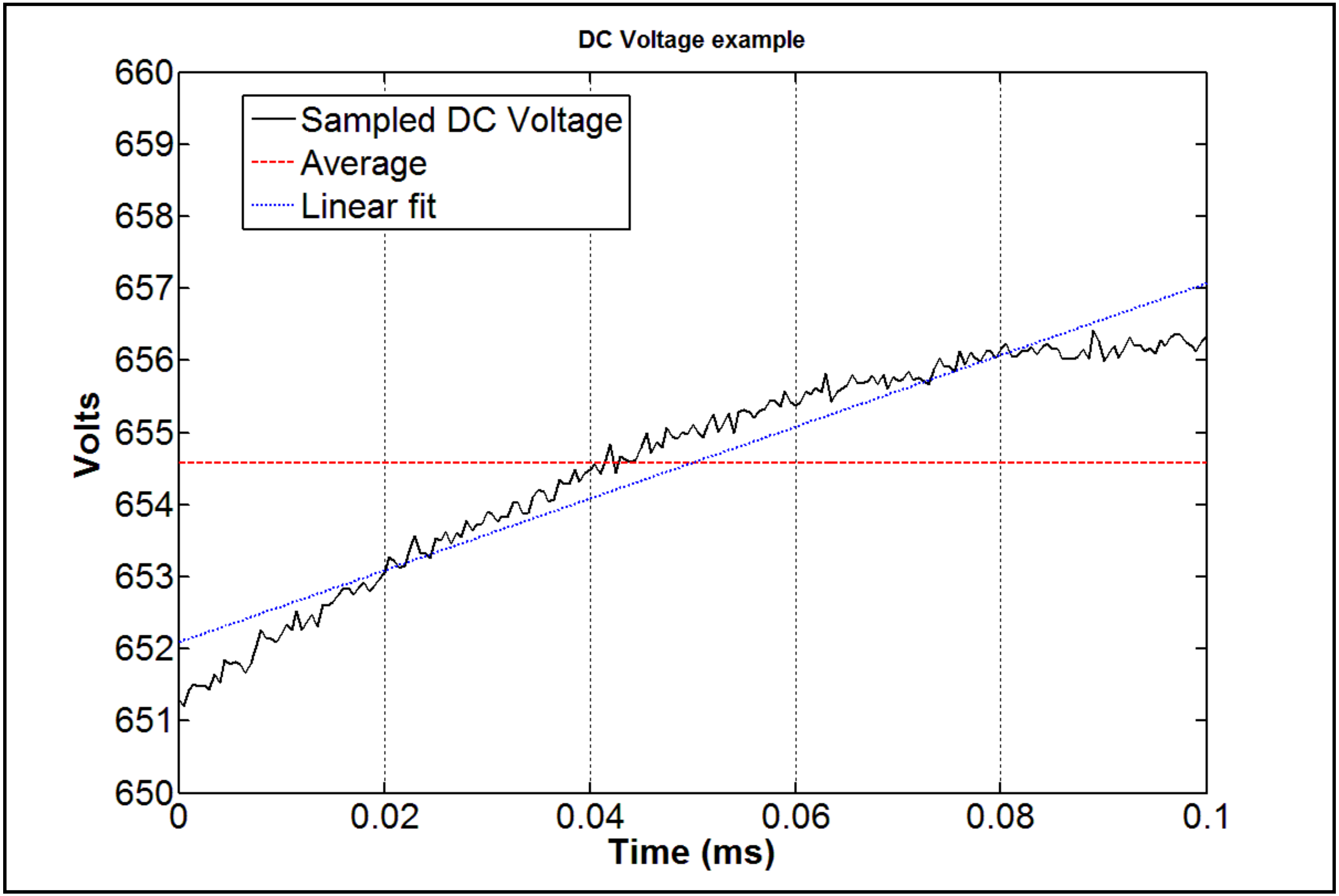


- How do we calibrate?
  - Meters (wideband)
  - Instrumentation
  - On-site? Off-site?
  - How does we ensure robust measurement in “real world” conditions? Can we?

Dynamic harmonic measurement traceability



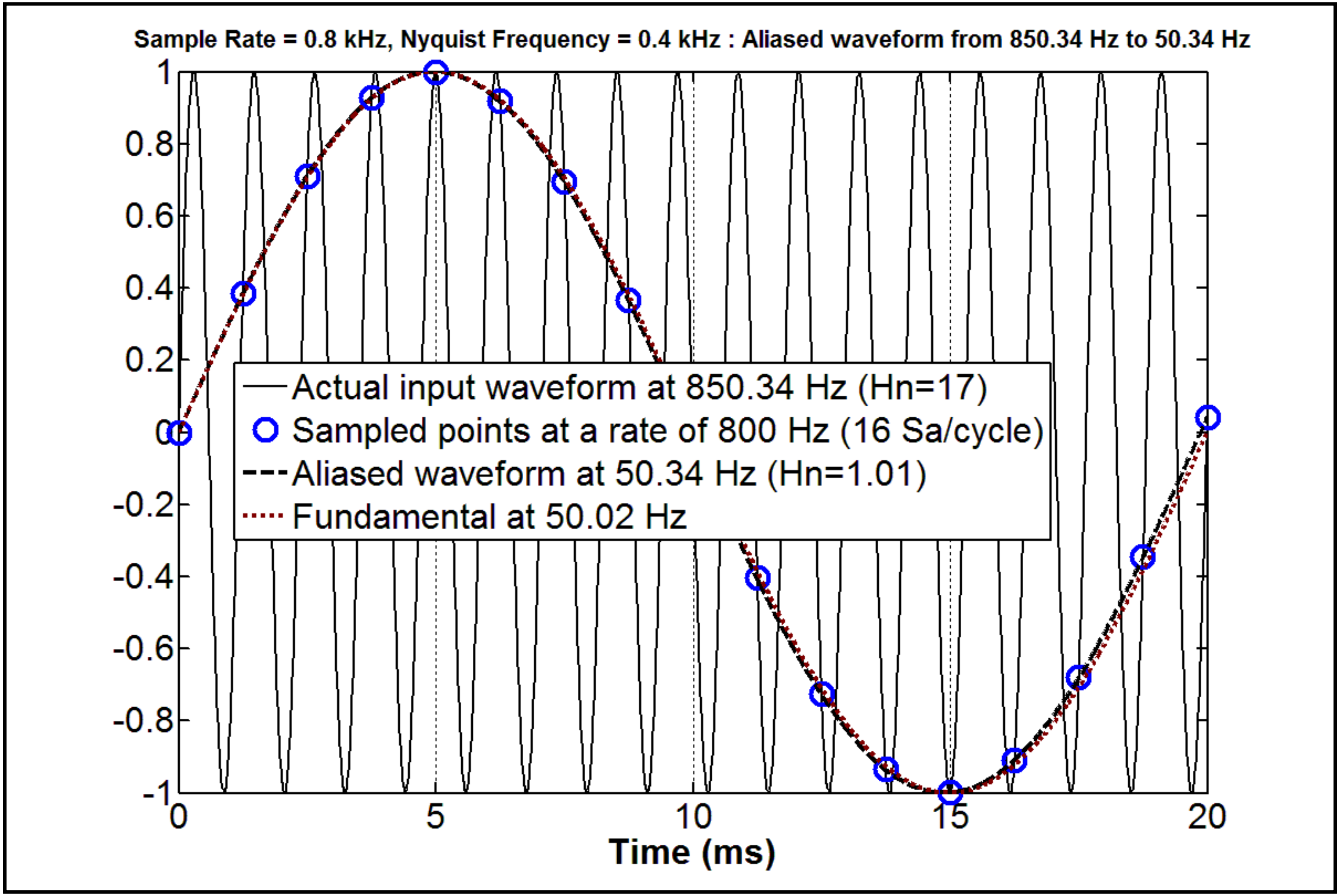
DC is simple ?



DC Voltage example
Sampled DC Voltage
Average
Linear fit
Volts
Time (ms)
660
659
658
657
656
655
654
653
652
651
650
0
0.02
0.04
0.06
0.08
0.1

What’s so hard about AC measurements?

Aliasing



Sample Rate = 0.8 kHz, Nyquist Frequency = 0.4 kHz : Aliased waveform from 850.34 Hz to 50.34 Hz
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
0
5
10
15
20
Time (ms)
Actual input waveform at 850.34 Hz (Hn=17)
Sampled points at a rate of 800 Hz (16 Sa/cycle)
Aliased waveform at 50.34 Hz (Hn=1.01)
Fundamental at 50.02 Hz

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27th August 2013 …

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27 August 2013 Last updated at 13:41

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Power outage in Glasgow after worker hits live cable

The worker was injured after making contact with a live cable on a building site in Allan Glen Place

A worker has been injured after making contact with a live cable at a building site in Glasgow city centre.

Police Scotland said there was a short power outage in the north of the city following the incident at Allen Glen Place at about 12:00 on Tuesday.

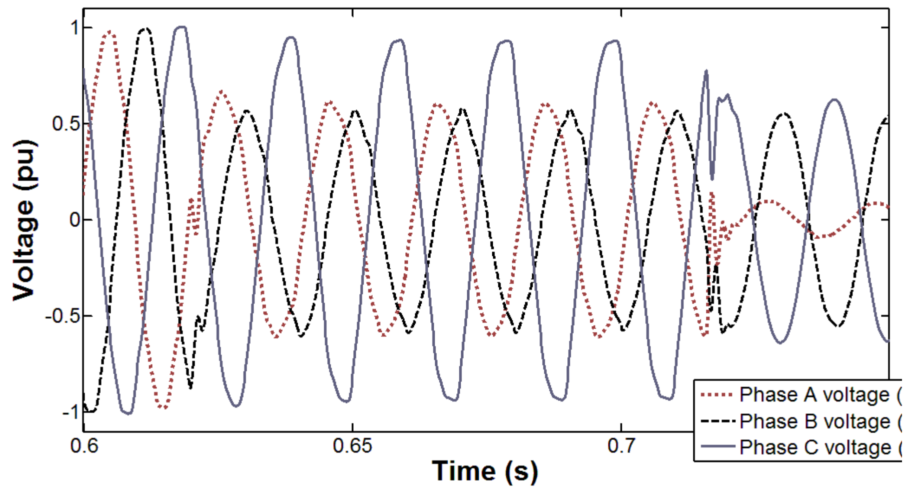
The injured man was taken to nearby Glasgow Royal Infirmary. Details of his condition are not yet known.

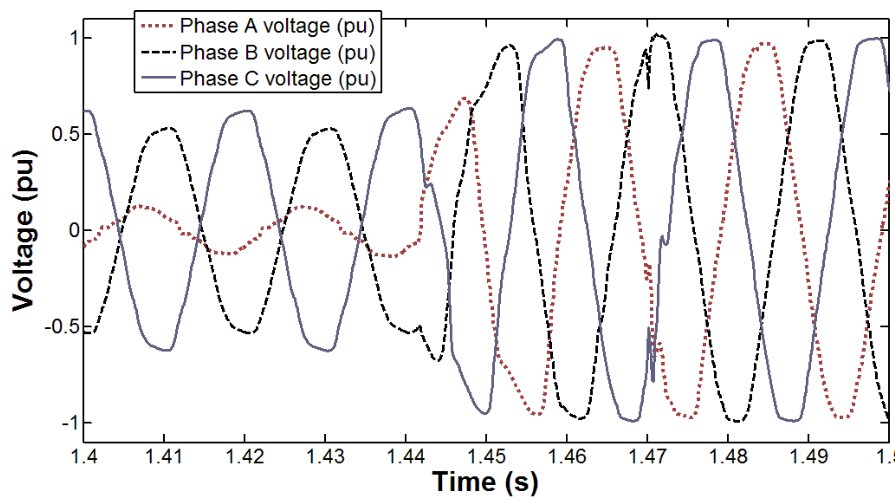
Emergency services remain at the scene. The incident has been reported to the Health and Safety Executive.

Scottish Power officials are also at the scene.

It is understood that people in the area reported hearing a "loud bang and explosion" when the incident occurred.

The power supply was restored a short time later.





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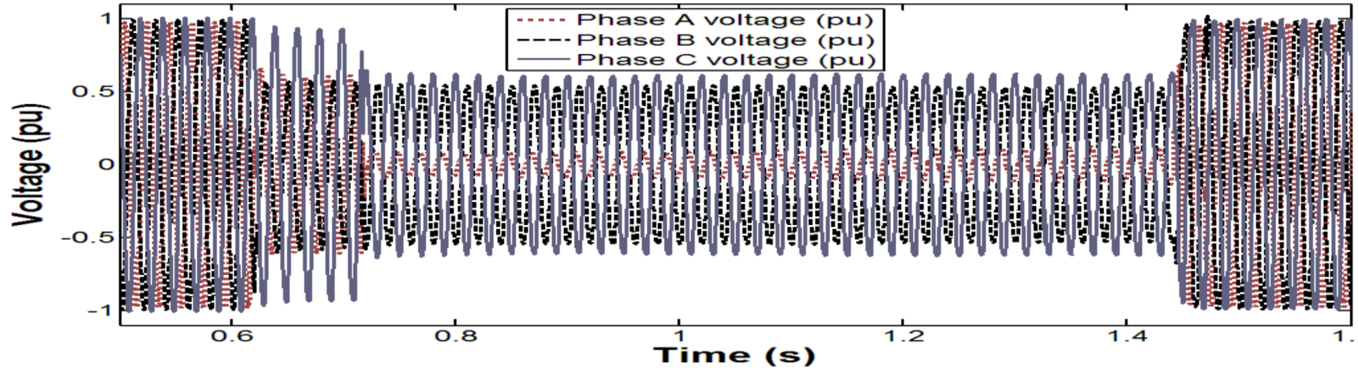
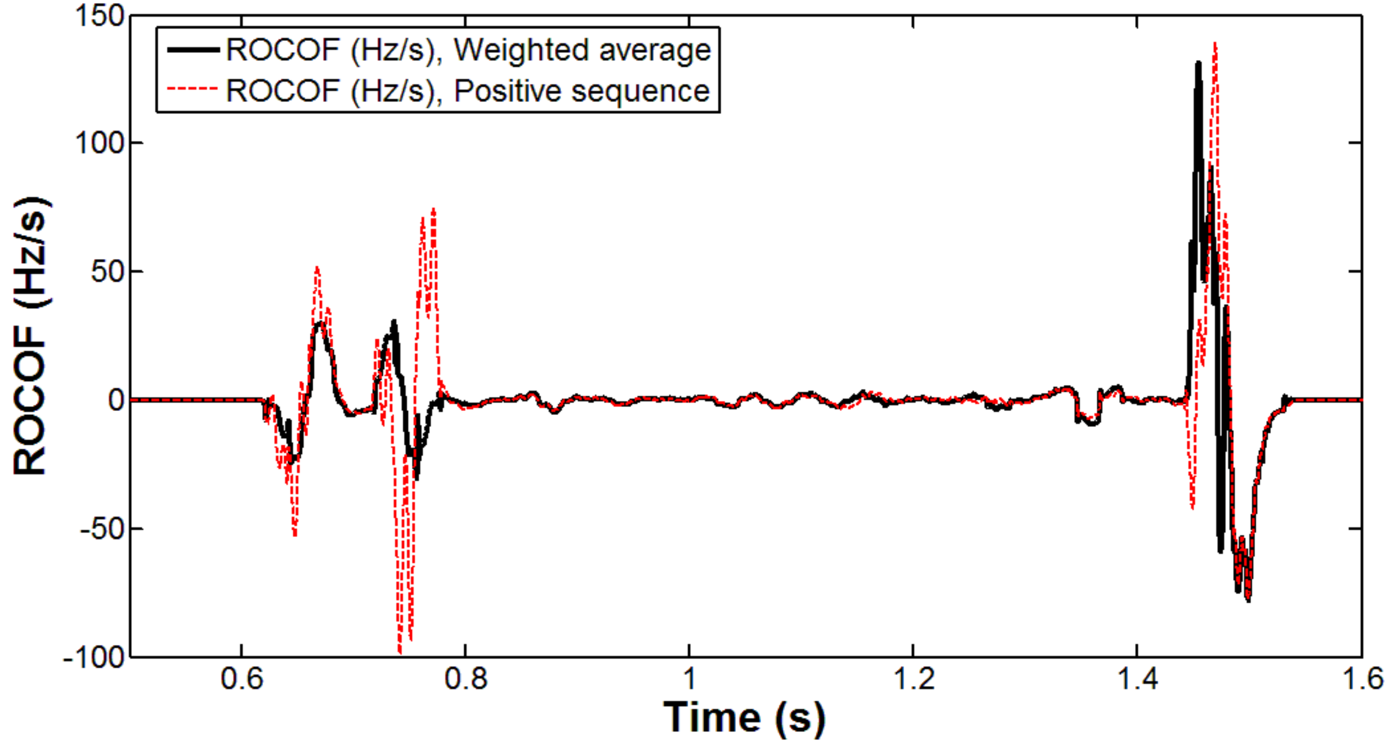




Frequency by zero crossings

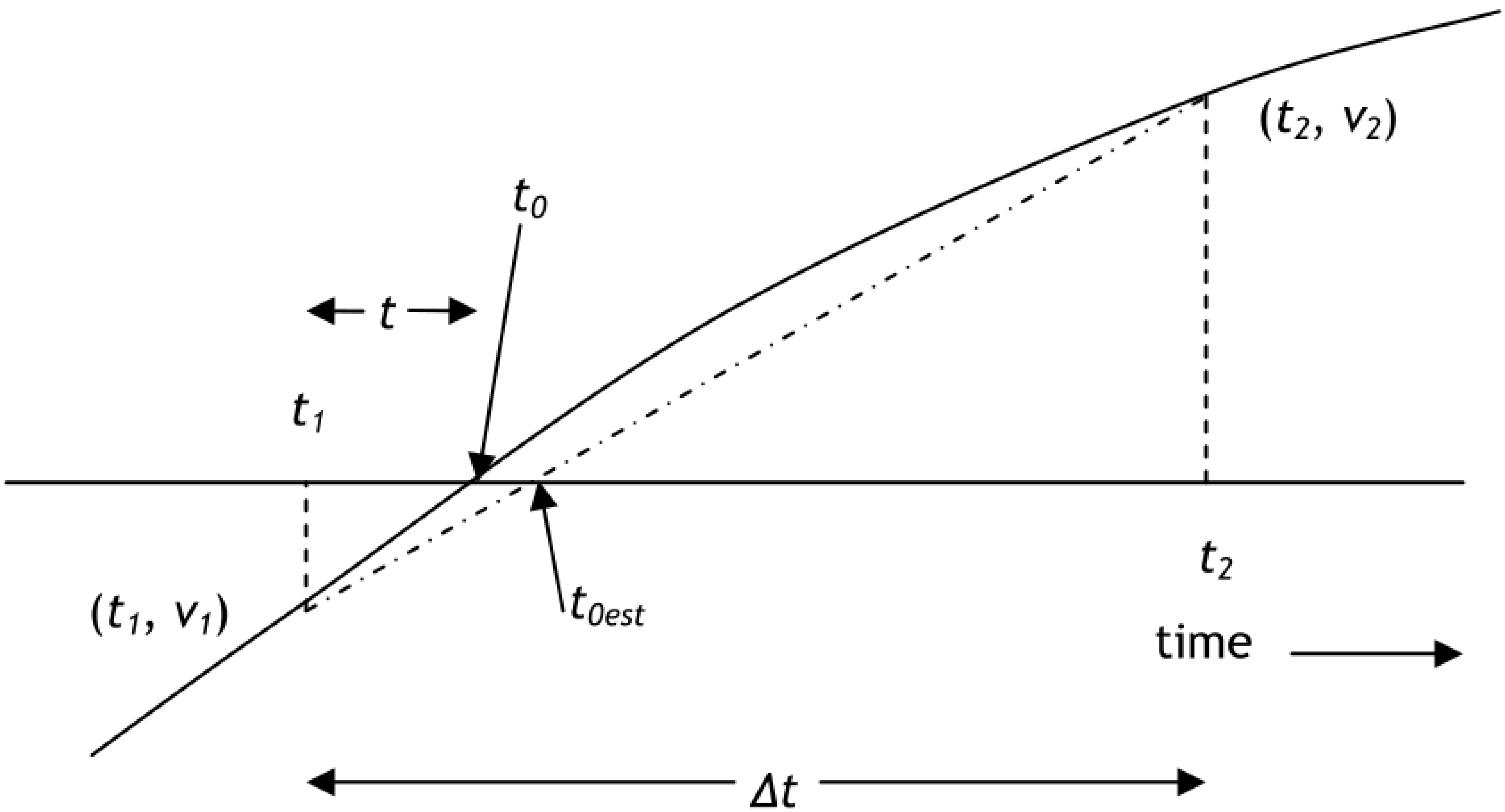
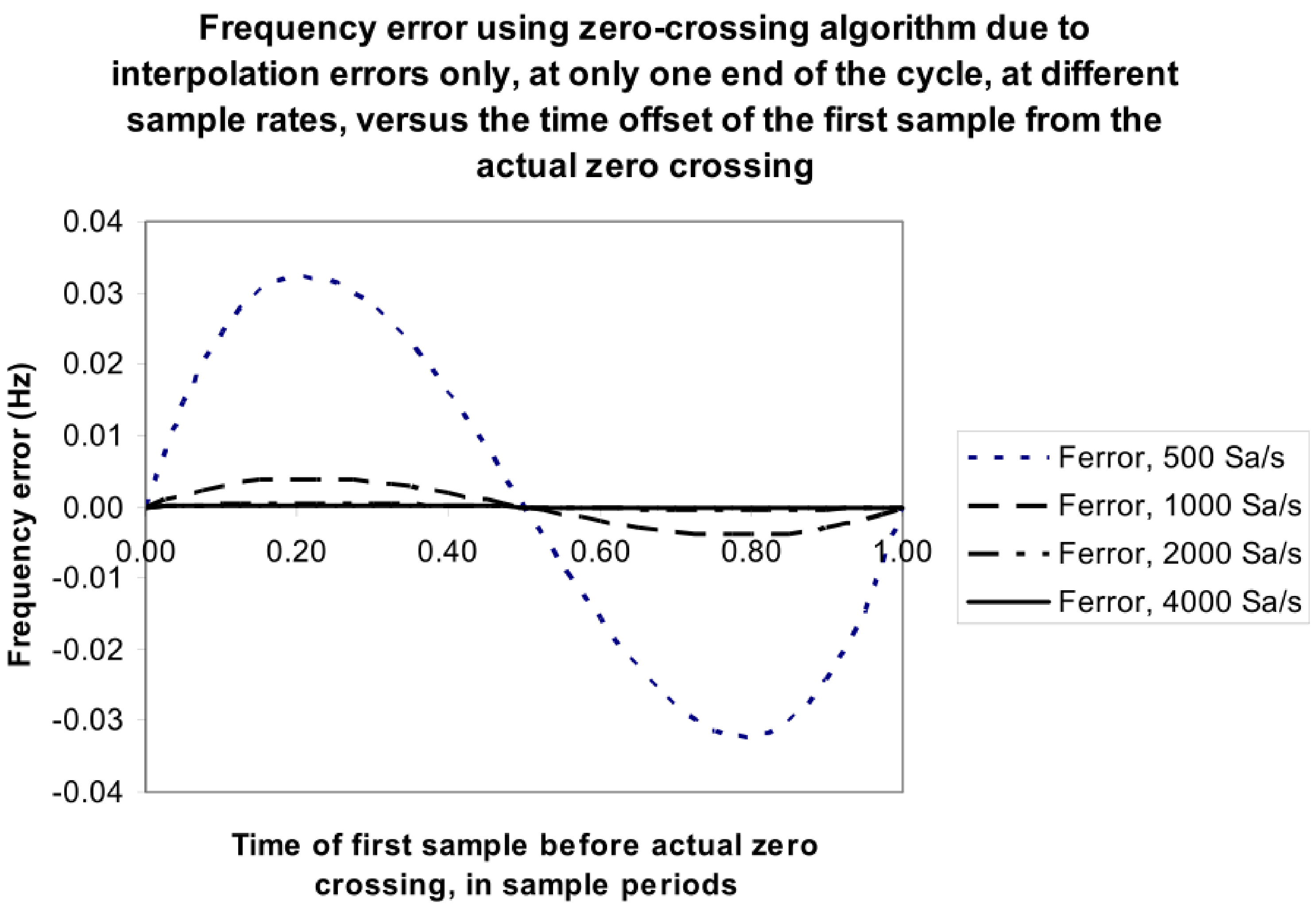
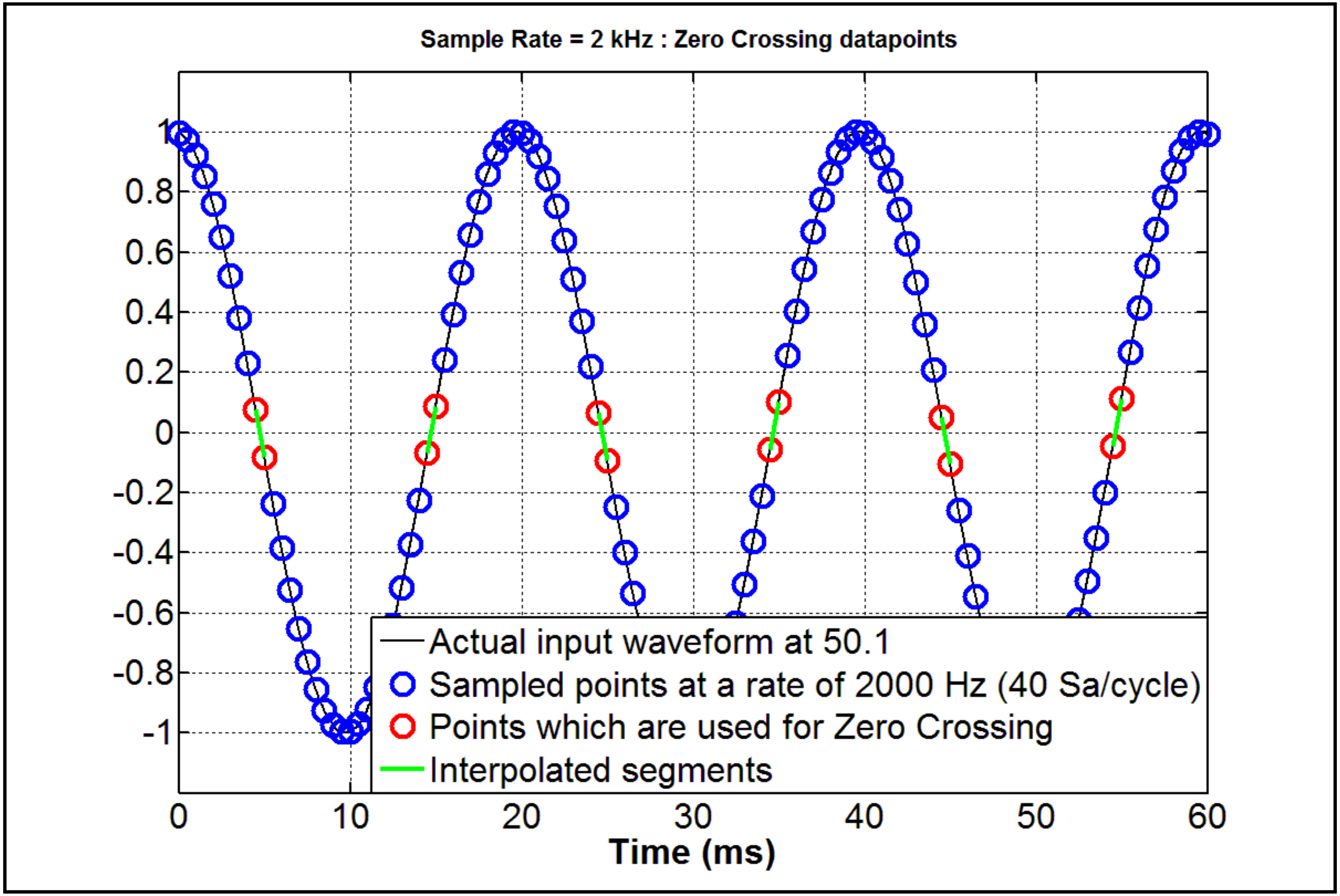


Figure 5-1 : Linear interpolation to estimate the time of a zero crossing

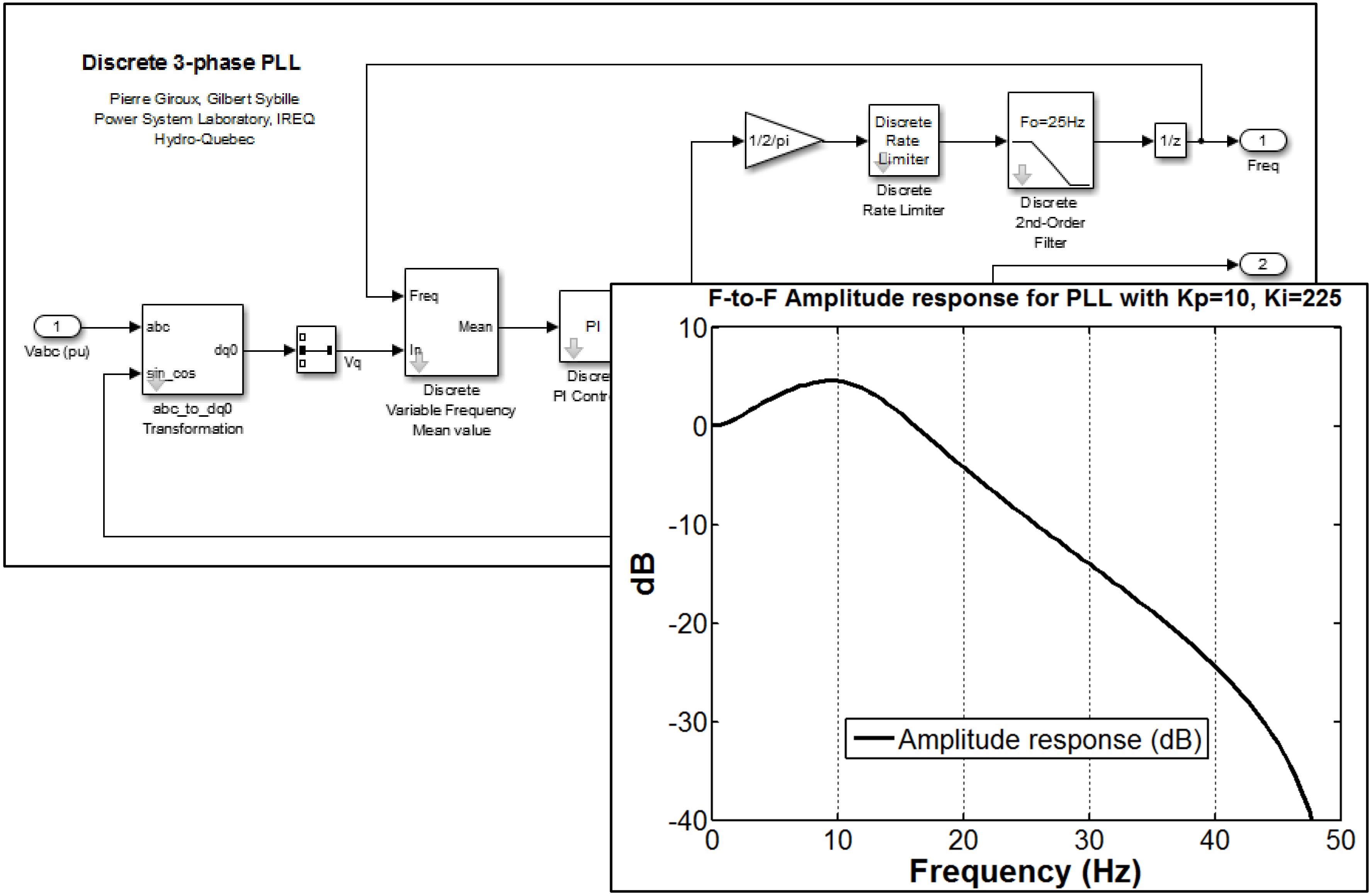
Frequency error using zero crossings



Missing information with zero crossings

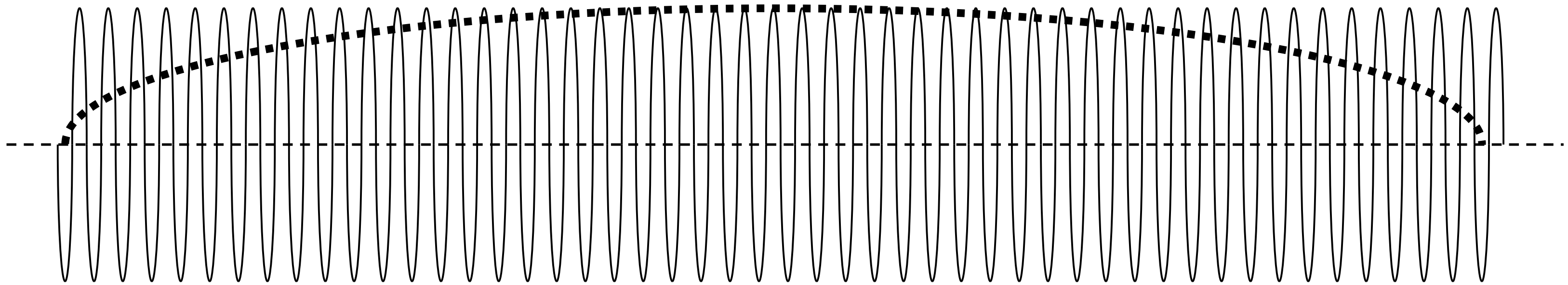


PLLs

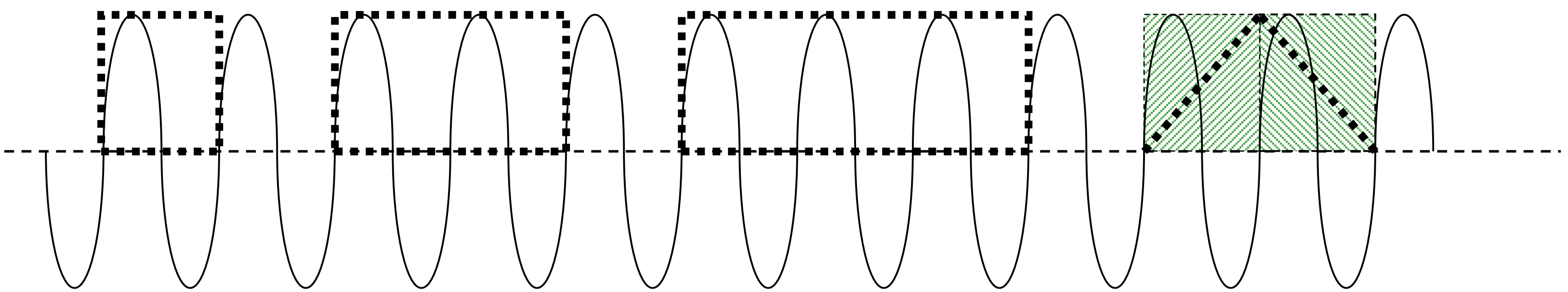

Discrete 3-phase PLL
Pierre Giroux, Gilbert Sybille
Power System Laboratory, IREQ
Hydro-Quebec
1/2/pi
Discrete Rate Limiter
Discrete Rate Limiter
Fo=25Hz
Discrete 2nd-Order Filter
1/z
1
Freq
2
1
Vabc (pu)
abc
dq0
sin_cos
abc_to_dq0 Transformation
Vq
Freq
Mean
In
Discrete Variable Frequency Mean value
PI
F-to-F Amplitude response for PLL with Kp=10, Ki=225
dB
Frequency (Hz)
Amplitude response (dB)
10
0
-10
-20
-30
-40
0
10
20
30
40
50

AC Power system measurements use small numbers of cycles!

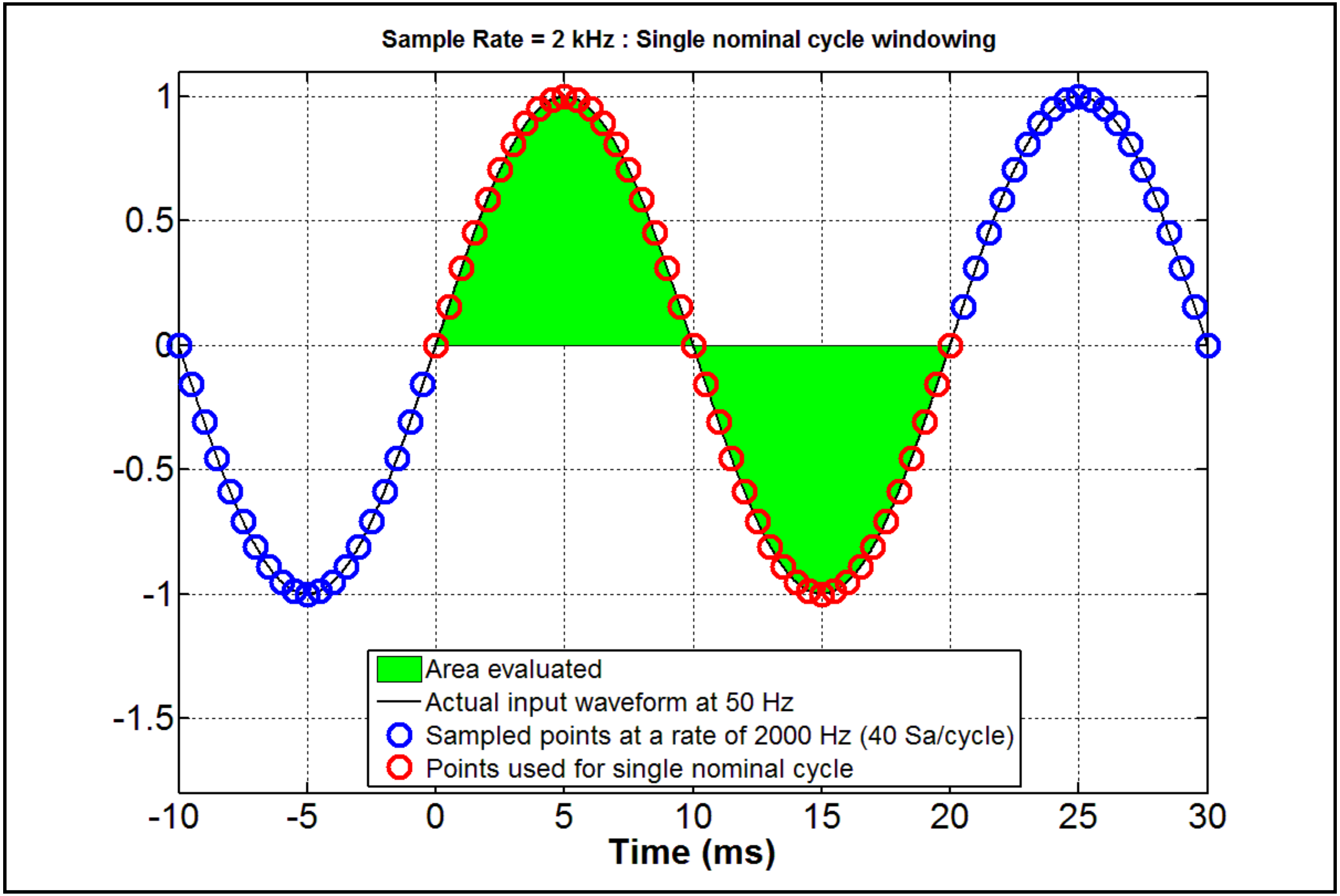
1) Measurement timeframe >> Fundamental period
   - e.g. Radio-frequency measurements



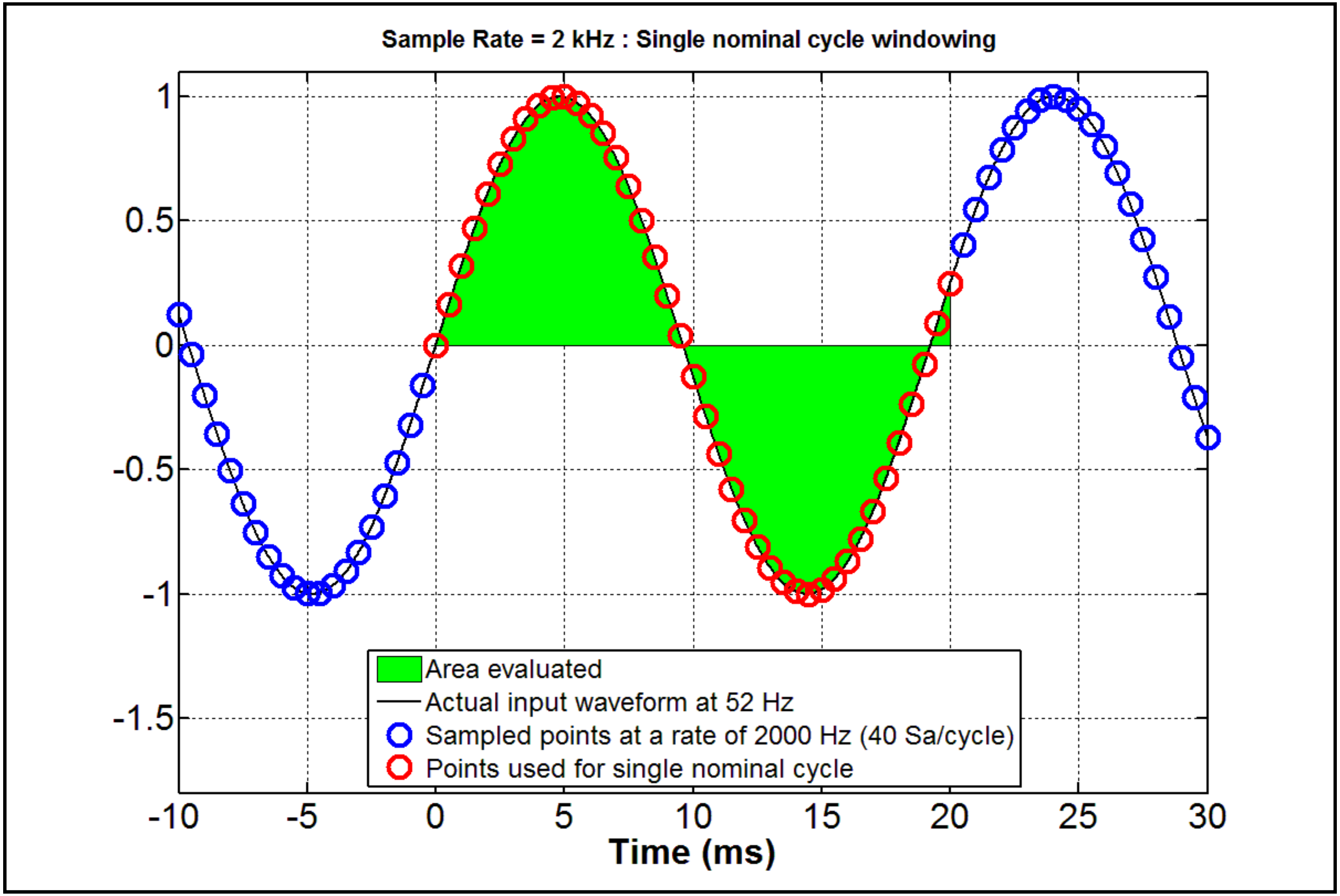
2) Measurement timeframe not >> Fundamental period
   - e.g. Power system measurements over <20 cycles



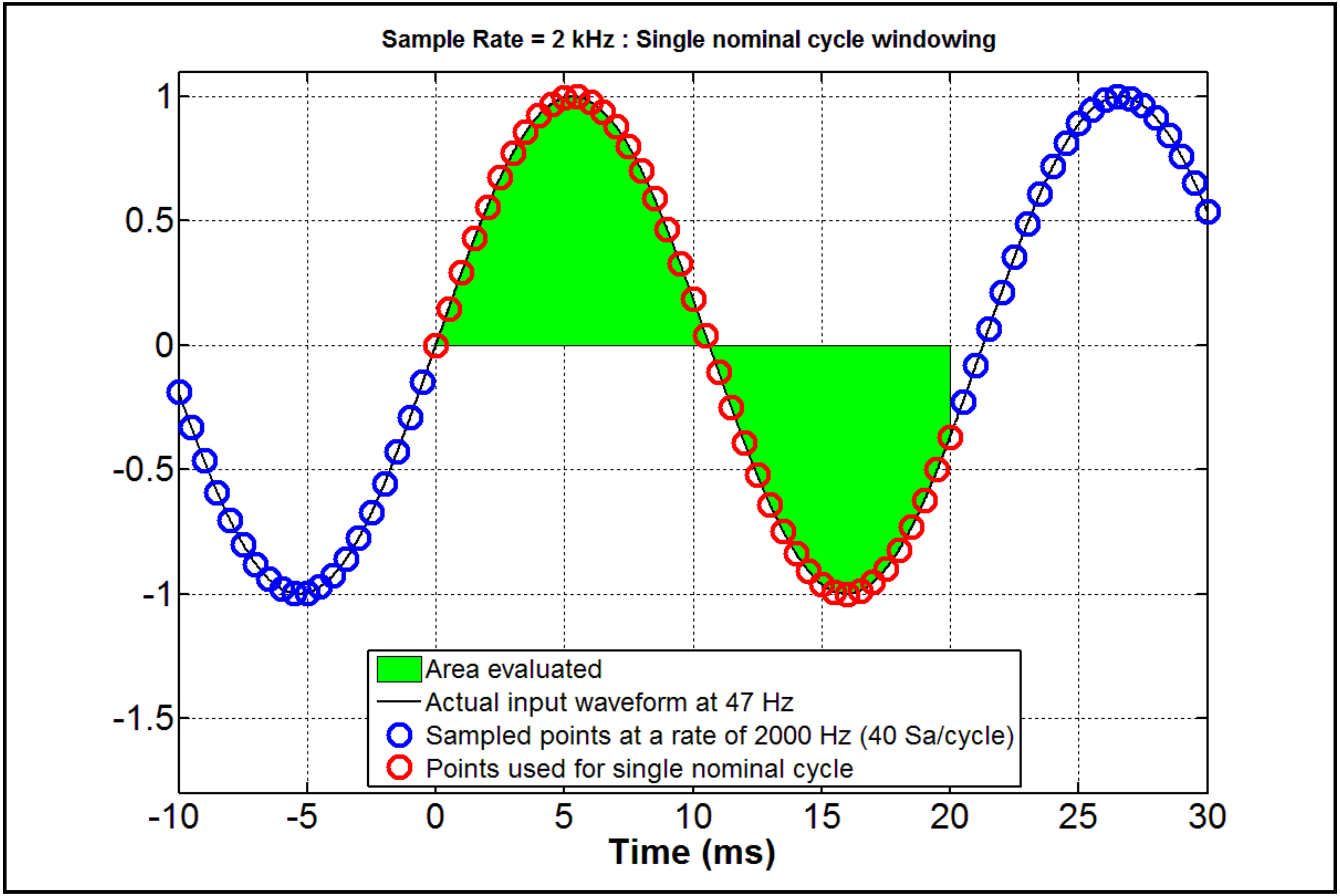
Single-cycle nominal (50Hz) windowing: Signal at nominal 50Hz



Single-cycle nominal (50Hz) windowing: Signal at 52Hz



Single-cycle nominal (50Hz) windowing: Signal at 47Hz

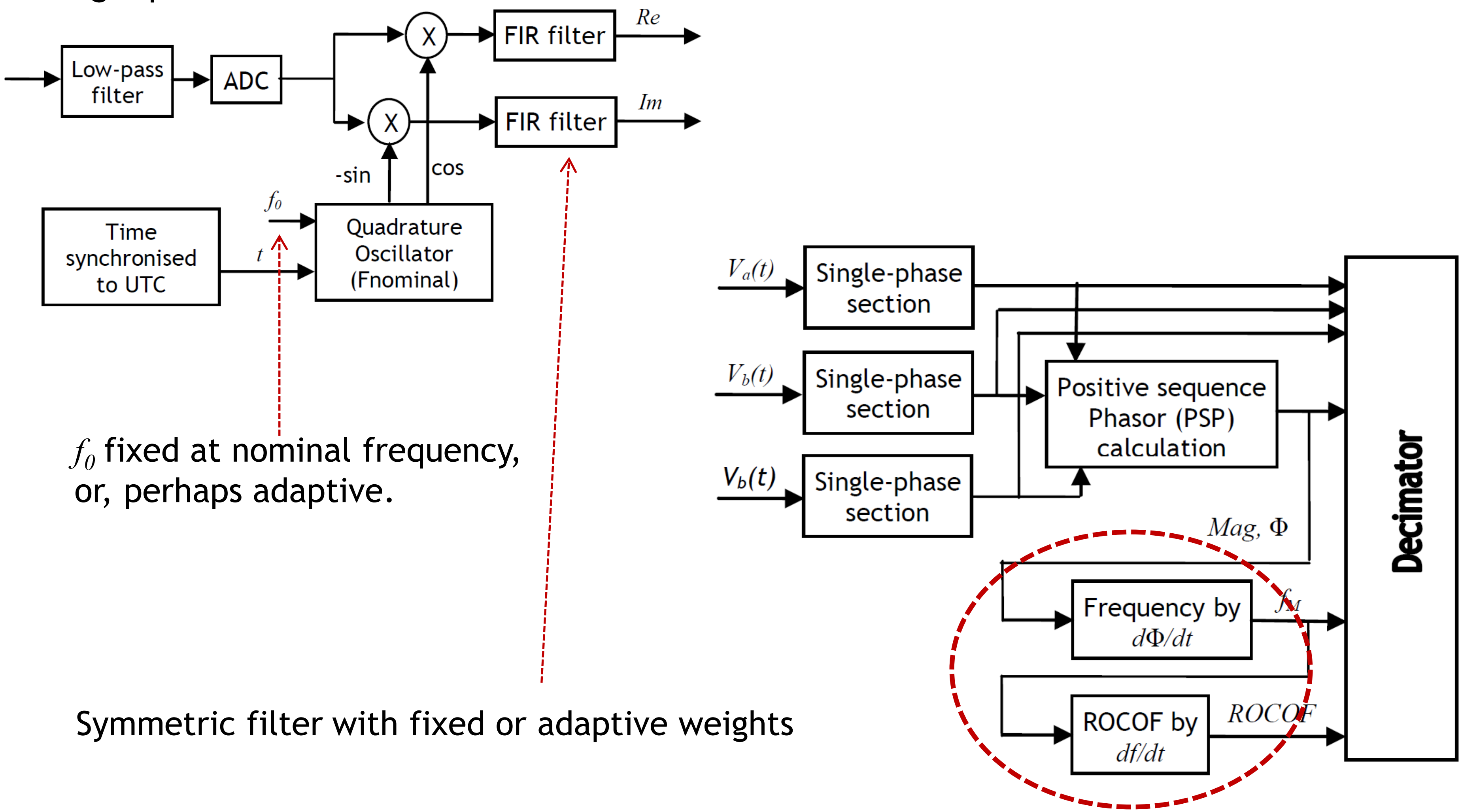


Single-cycle nominal (50Hz) windowing: Signal at 47Hz

[RMS_Example_Animation.mp4]

Fourier-based algorithms:
e.g. the “Reference” algorithm from C37.118.1

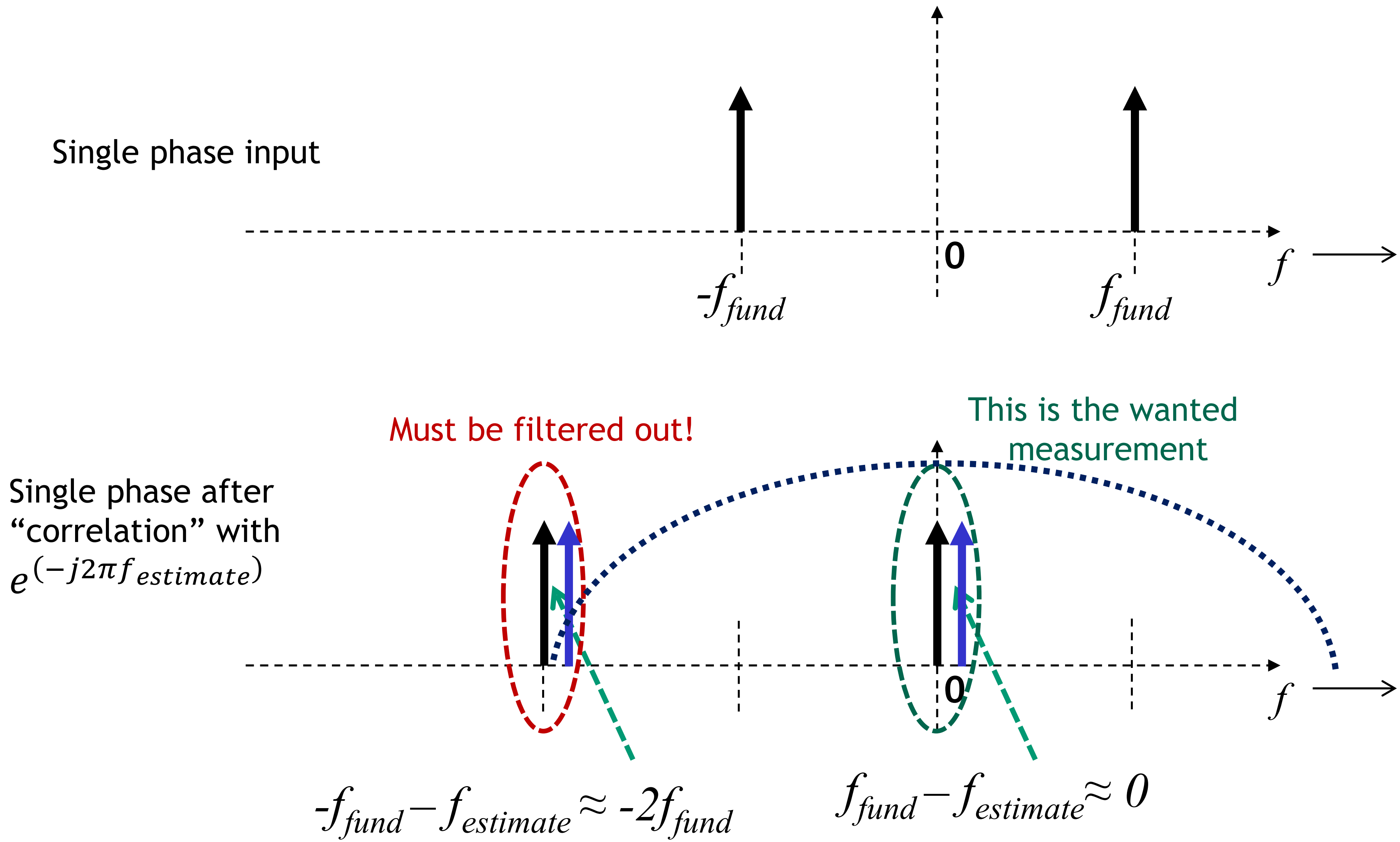
Single-phase section



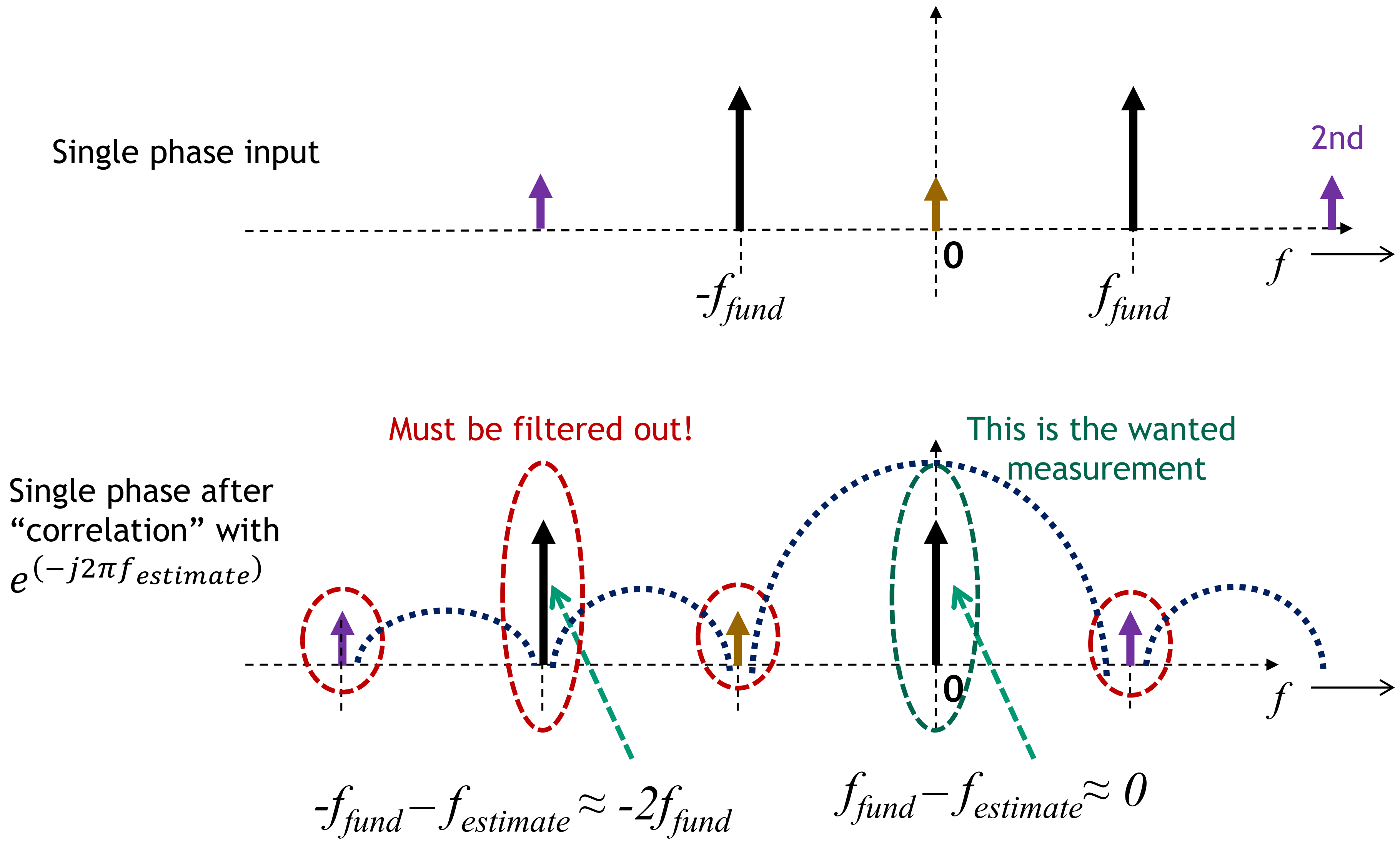
f_0 fixed at nominal frequency, or, perhaps adaptive.

Symmetric filter with fixed or adaptive weights

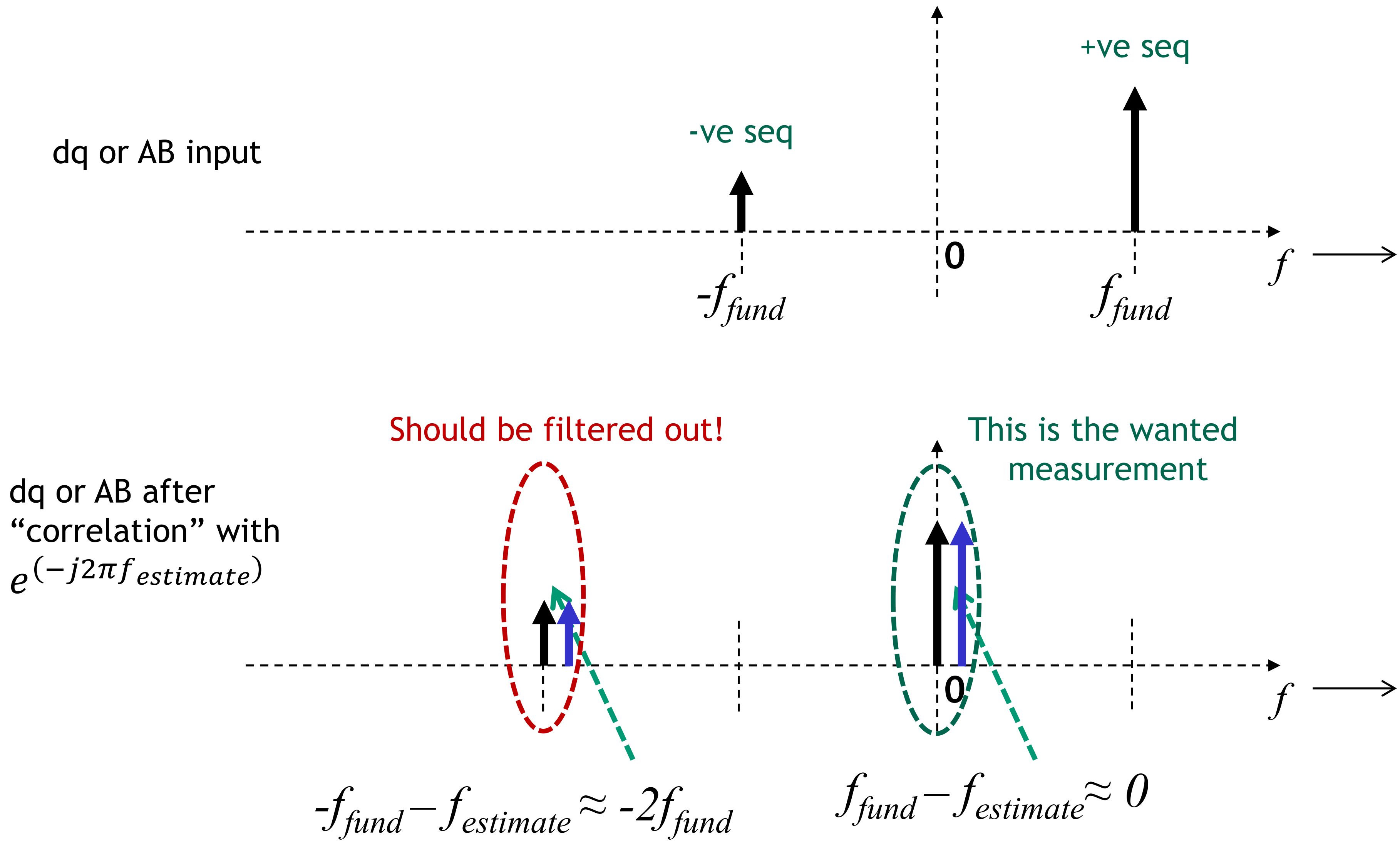
Frequency-translation in Fourier-based methods : Single phase



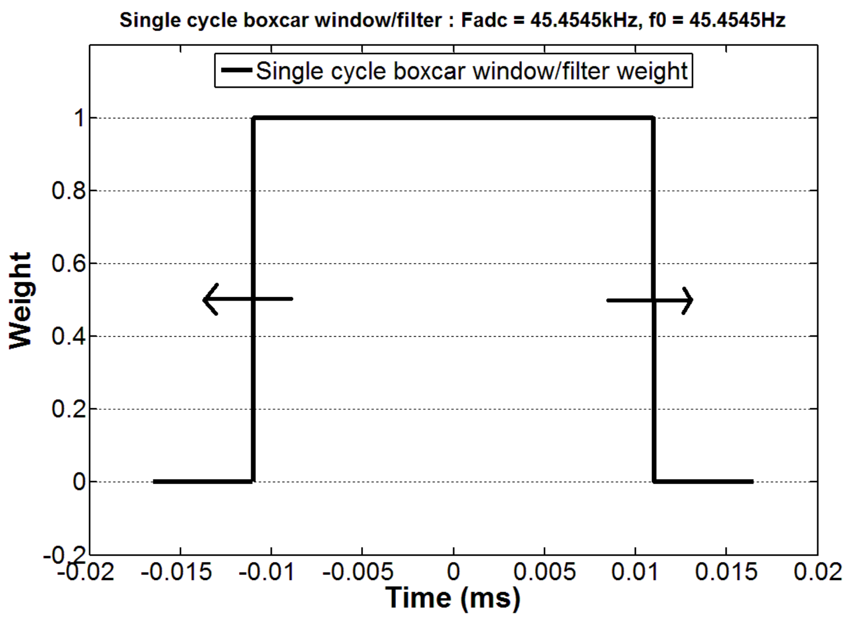
Frequency-translation in Fourier-based methods : Single phase with harmonics

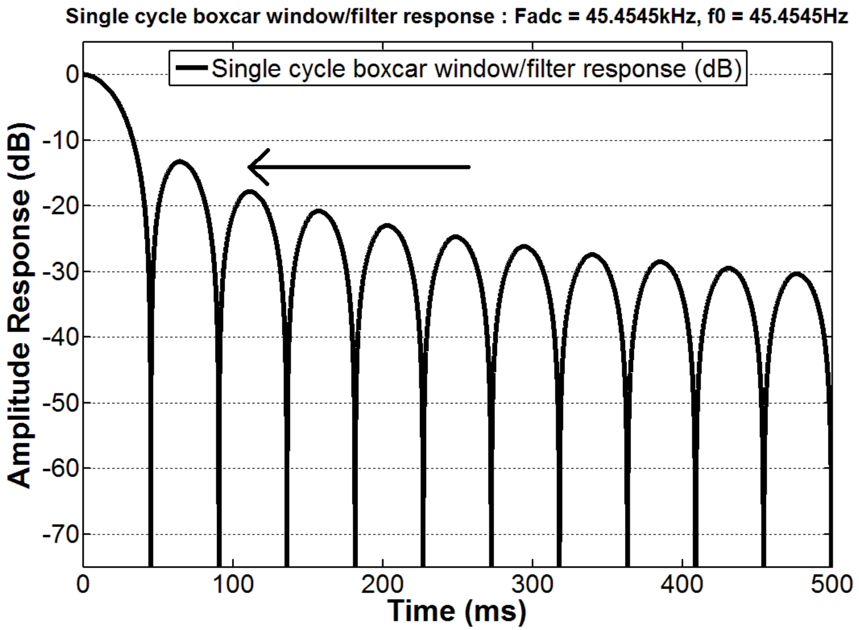


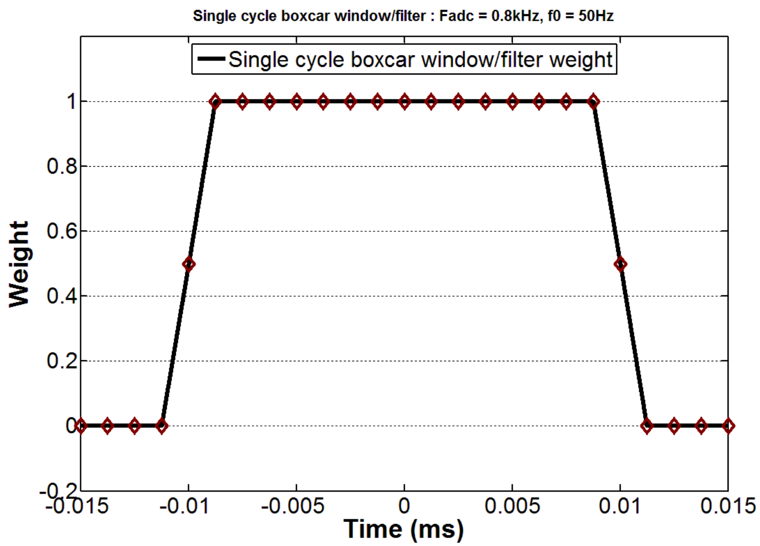
Frequency-translation in Fourier-based methods : Three phase “dq” or “AB”

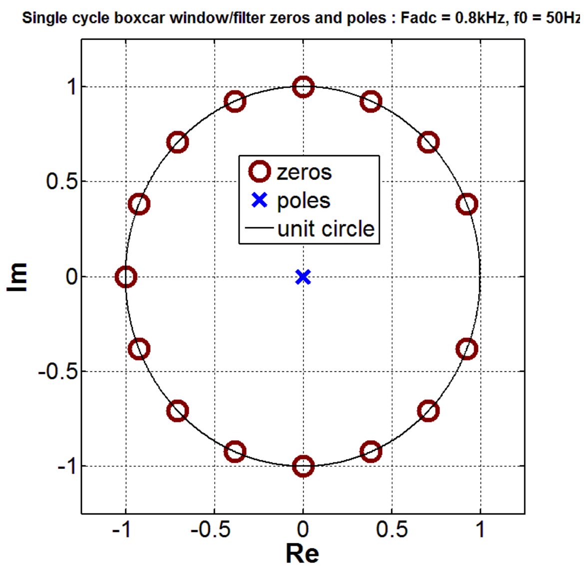


How a single-cycle “boxcar” filter works

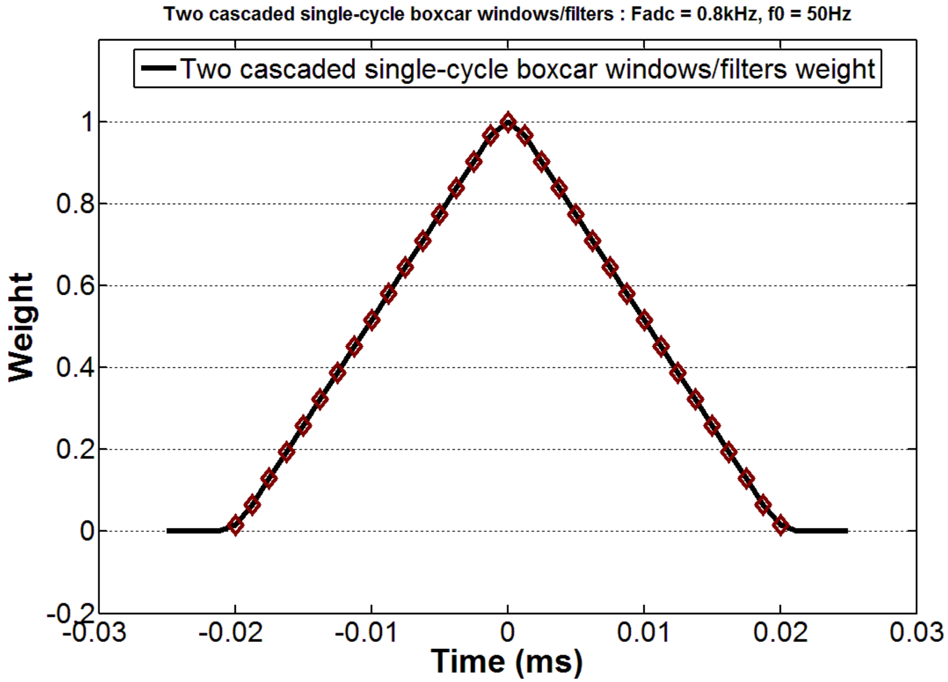


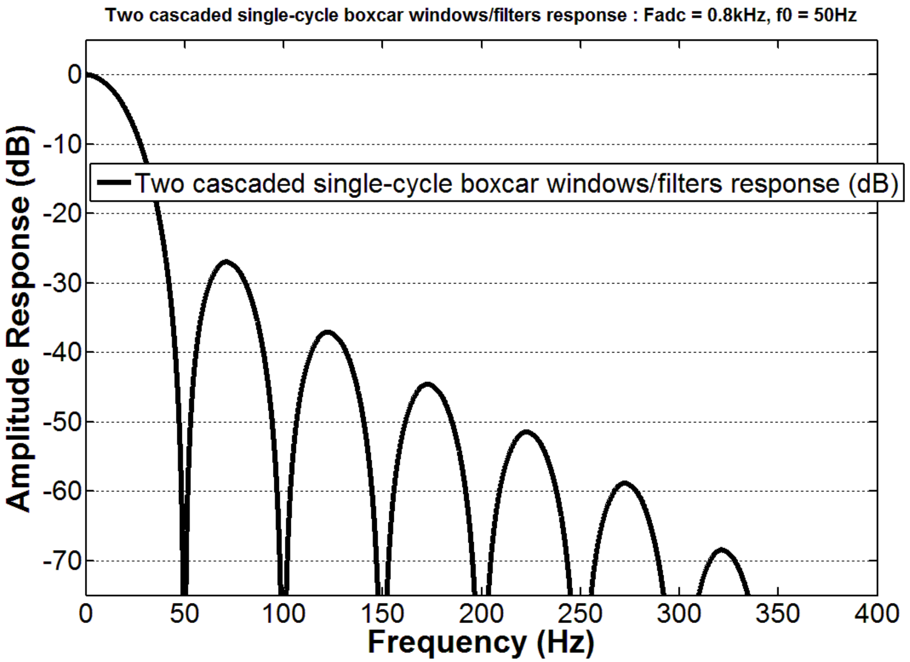




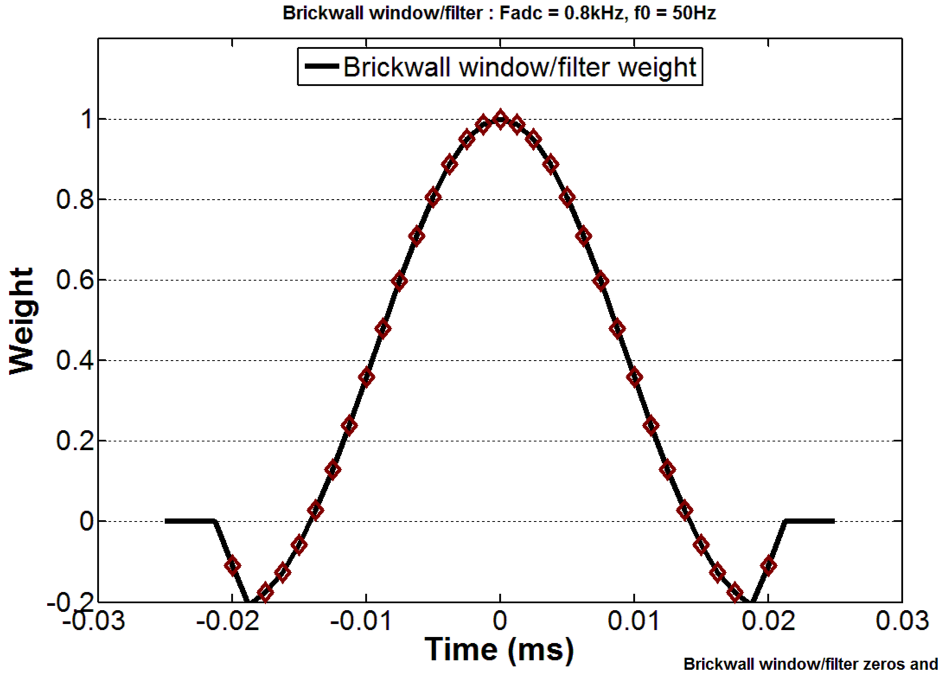


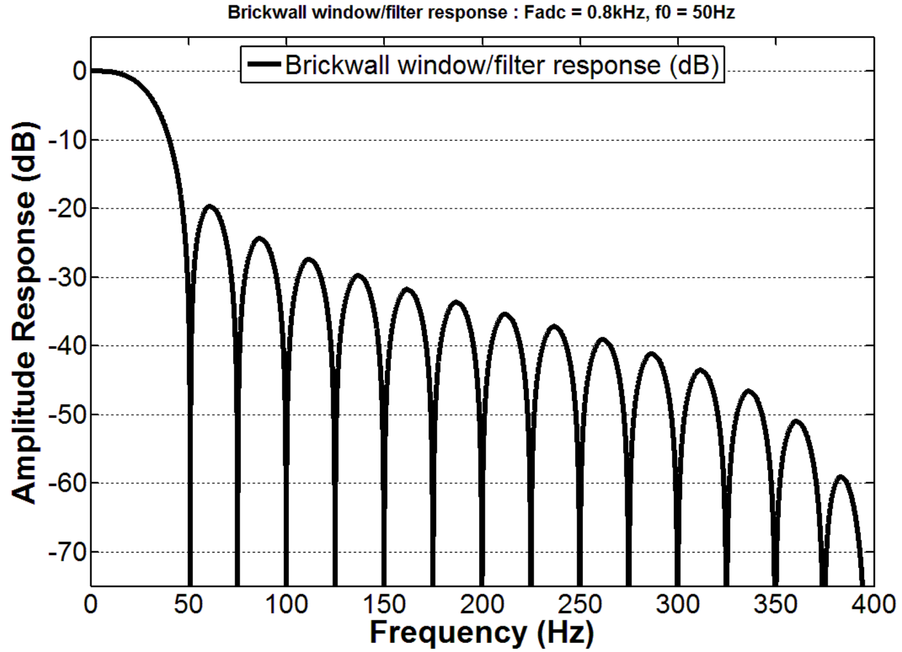
2 cascaded single-cycle boxcars

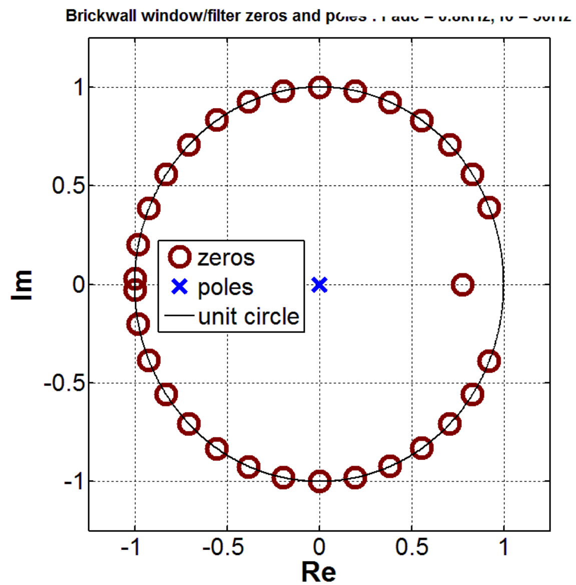




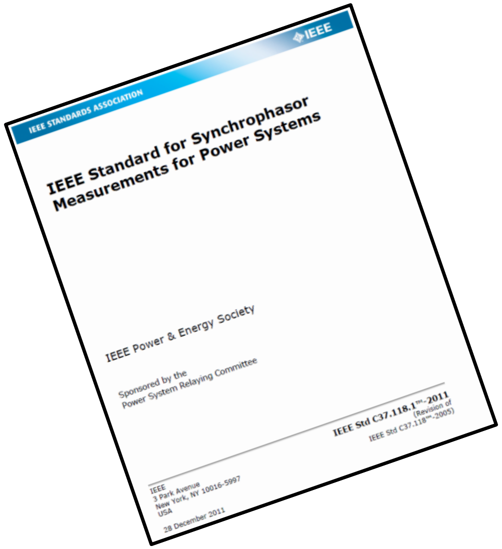
“BrickWall” filters







Case example : Phasor Measurement Units


IEEE STANDARDS ASSOCIATION

IEEE

IEEE Standard for Synchrophasor Measurements for Power Systems

IEEE Power & Energy Society

Sponsored by the
Power System Relaying Committee

IEEE Std C37.118.1™-2011
(Revision of
IEEE Std C37.118™-2005)

IEEE
3 Park Avenue
New York, NY 10016-5997
USA

28 December 2011

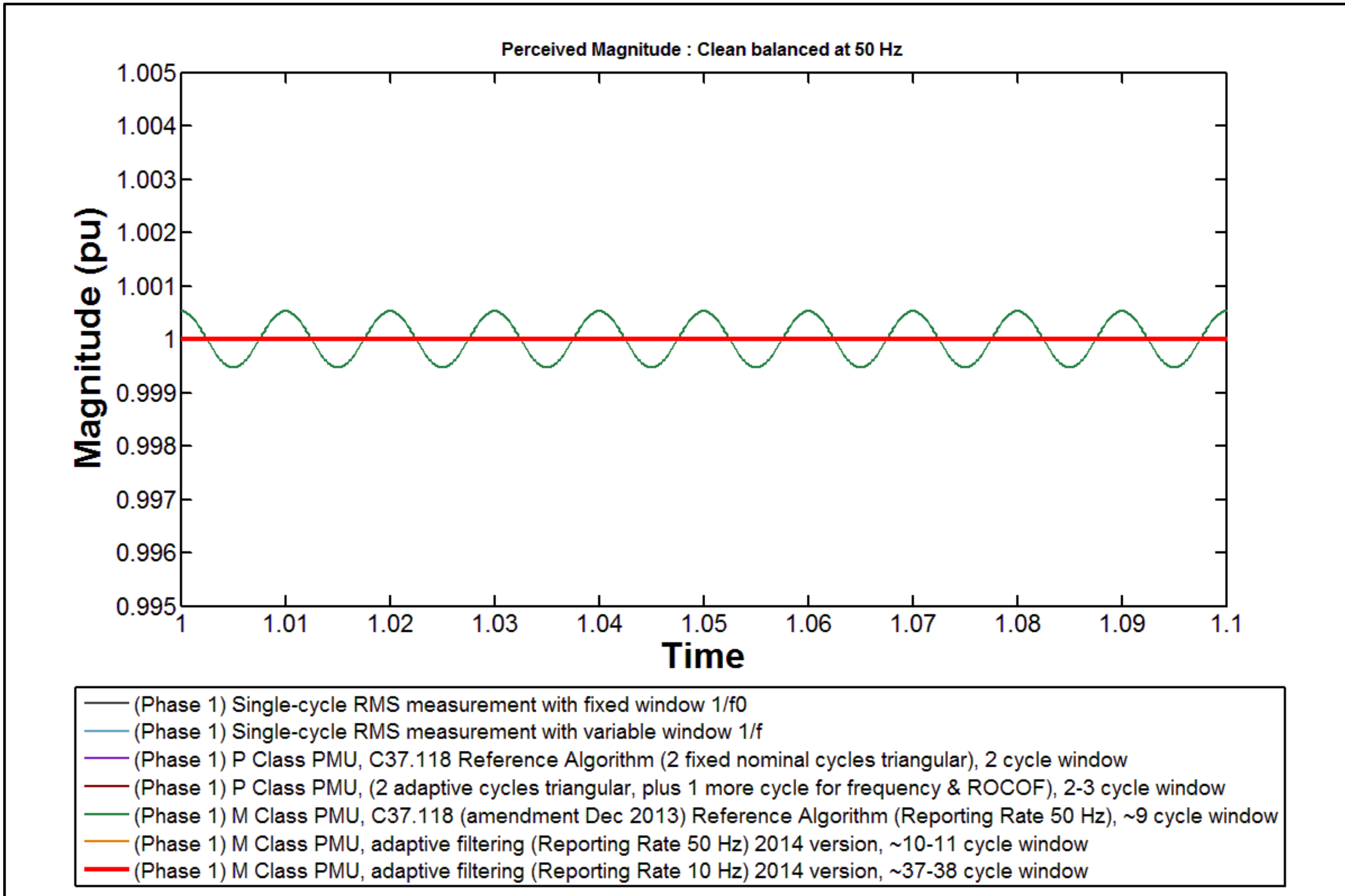
[Arbiter model 1133A]

[SEL 451]

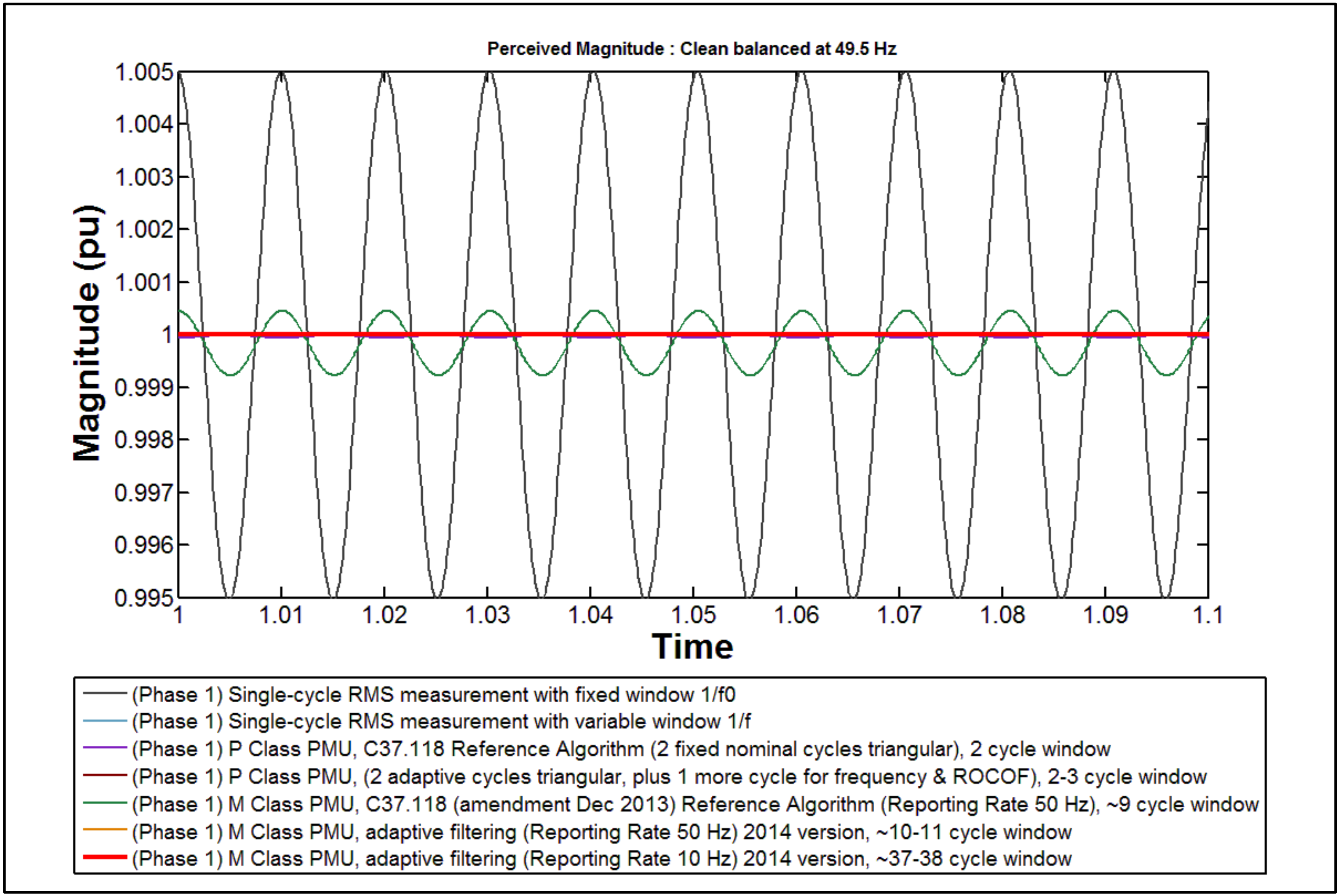
Unbalance,
Interharmonics,
Harmonics,
Frequency ramp

	Max TVE	Max Freq. Error	Max ROCOF Error
	(%)	(Hz)	(Hz/s)
P Basic+	0.35	0.2432	24.596
P TickTock	0.34	0.1706	16.875
M Basic+	0.11	0.0210	2.823
M TickTock	0.05	0.0013	0.167

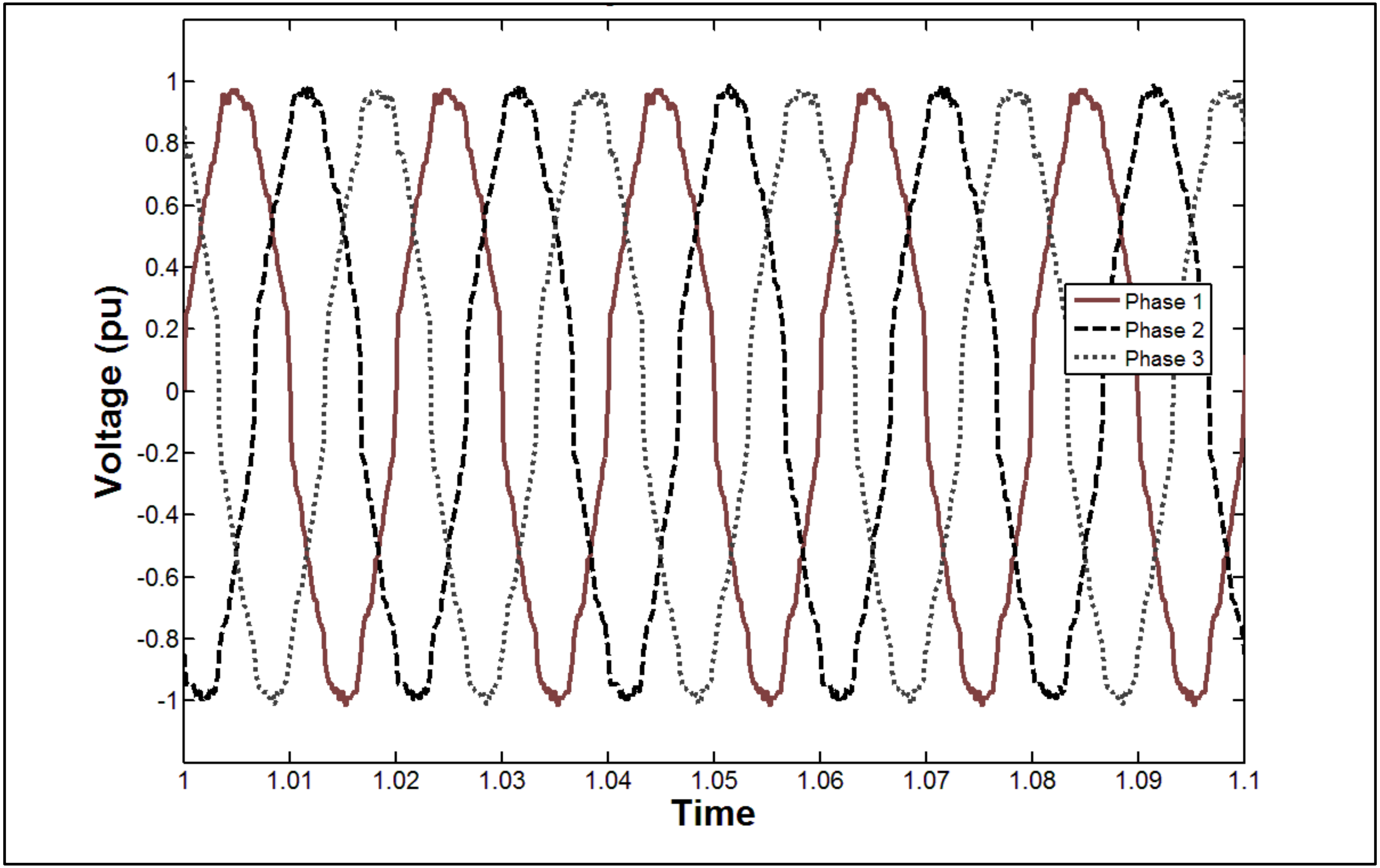
Single-phase RMS and Fundamental Measurement
Clean sinusoids at 50.0 Hz



Single-phase RMS and Fundamental Measurement
Clean sinusoids at 49.5 Hz



Single-phase RMS and Fundamental Measurement EN50160 Harmonics (8% THD) at 50.0 Hz



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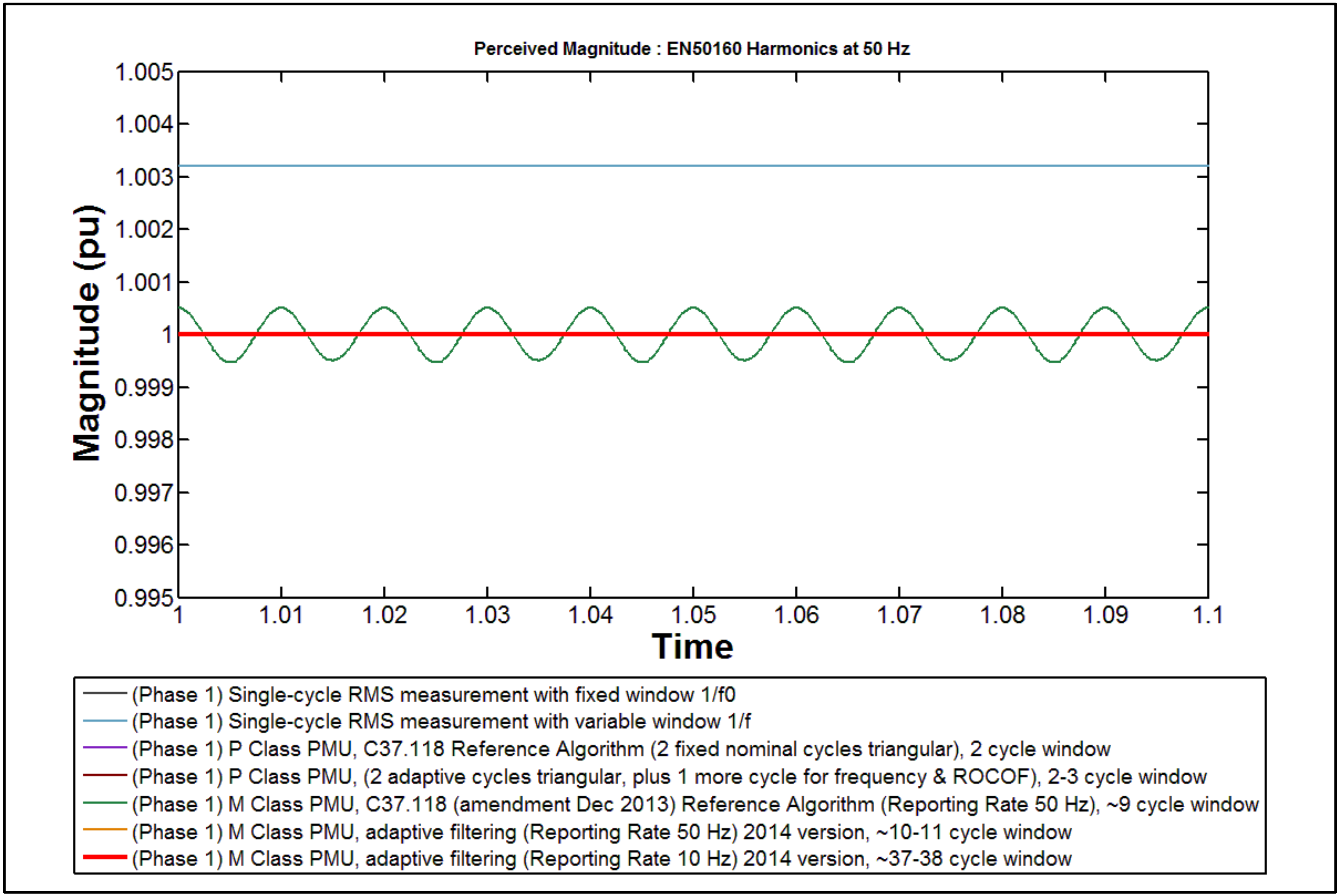
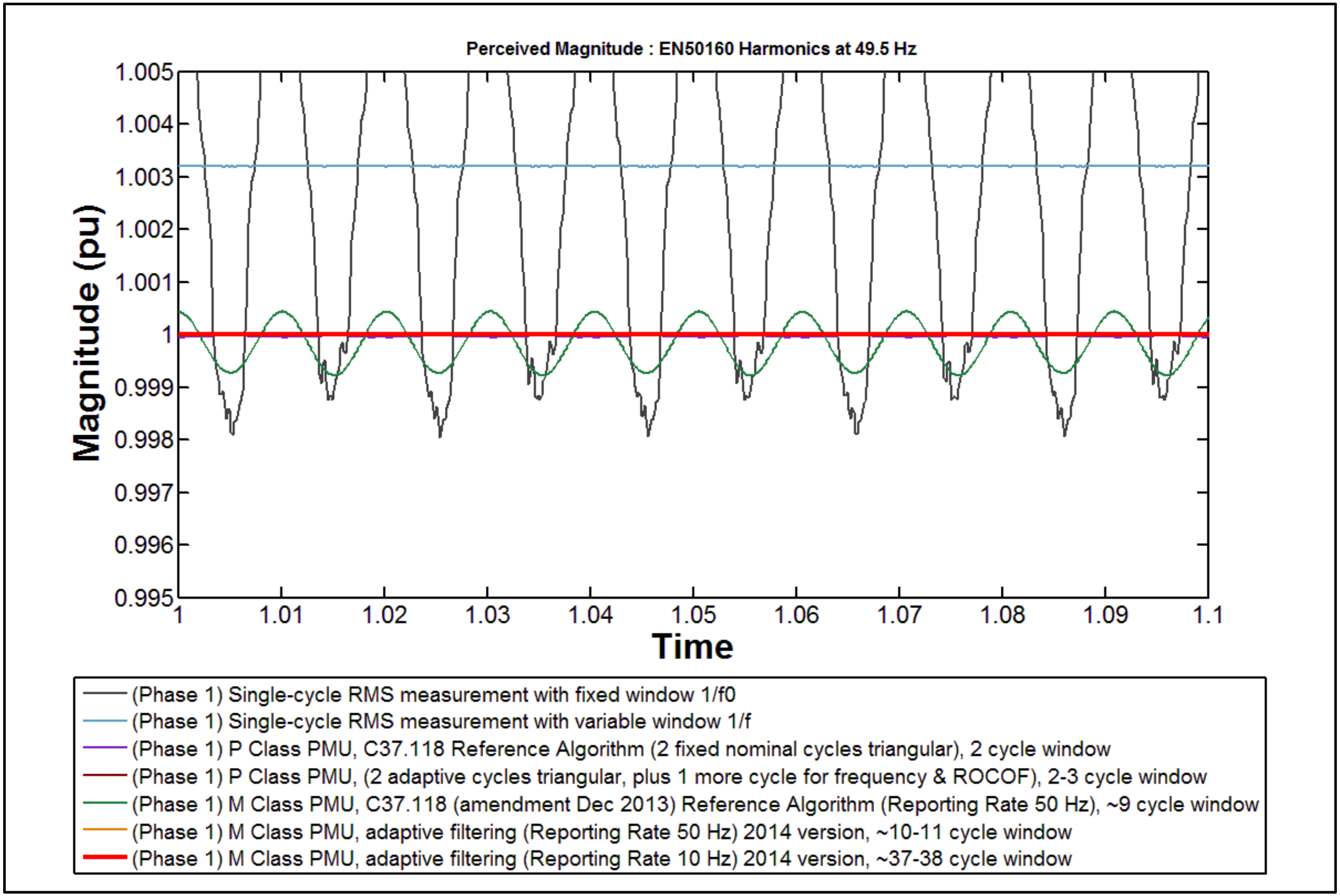
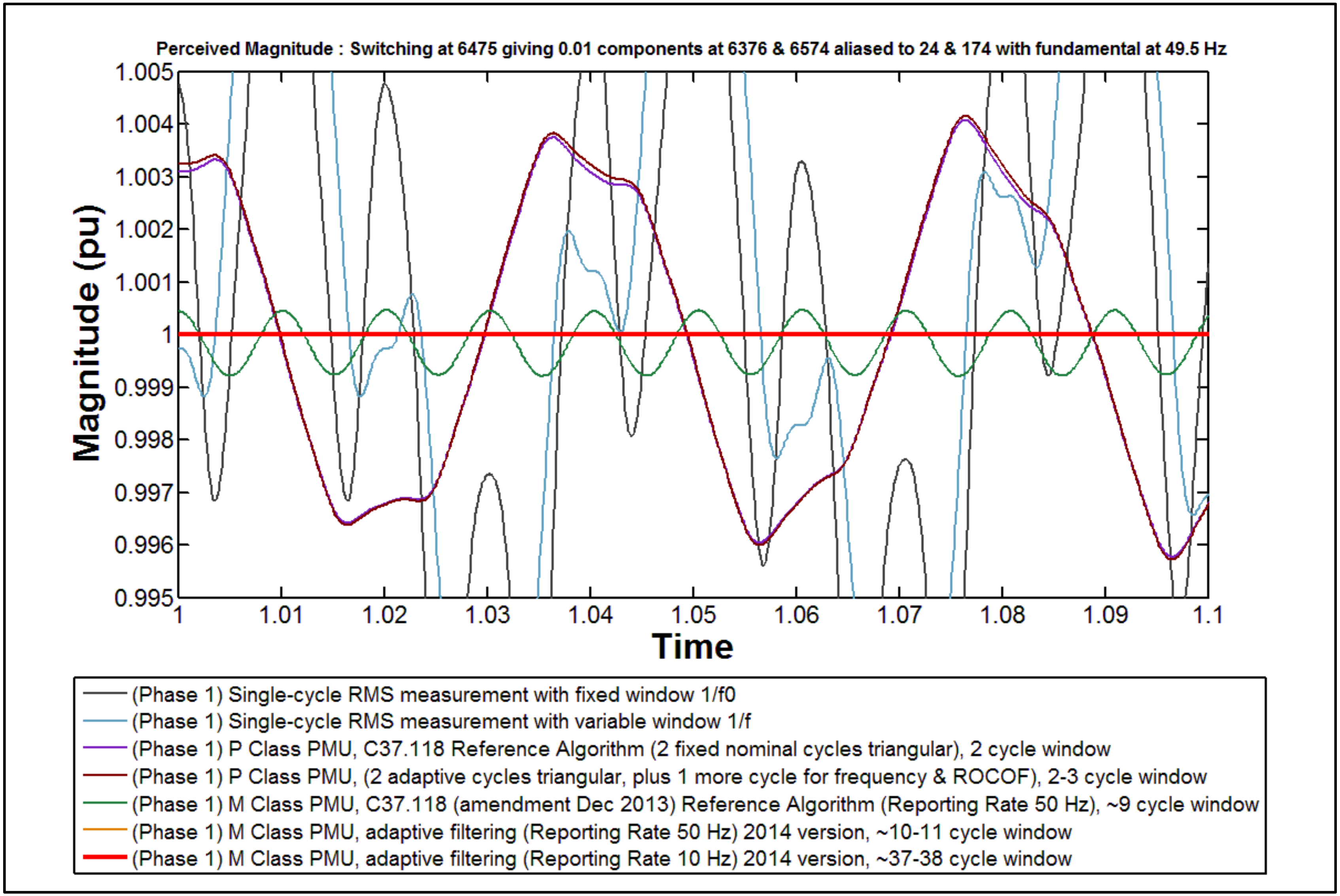


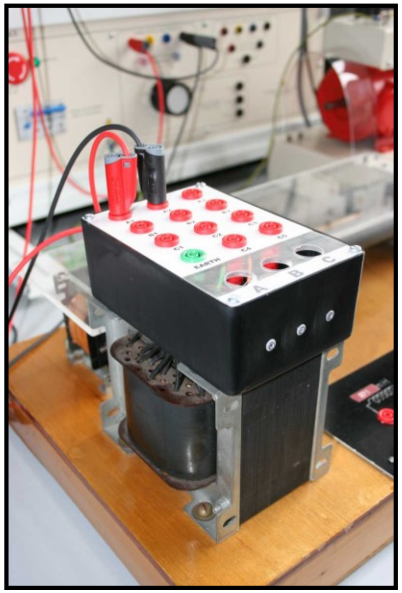
Single-phase RMS and Fundamental Measurement EN50160 Harmonics (8% THD) at 49.5 Hz

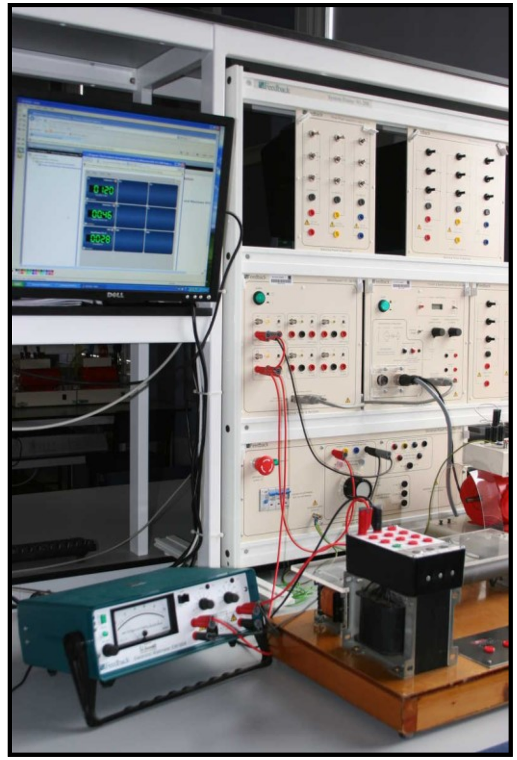


Single-phase RMS and Fundamental Measurement Switching at 6475 Hz, fundamental at 49.5 Hz



Poor measurement algorithms (1)





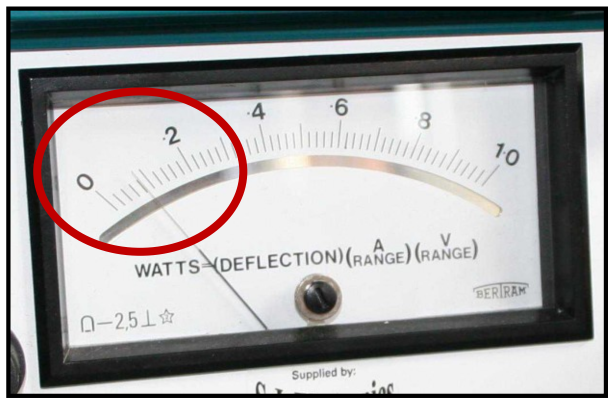
31 Watts ! ?

Measure the power consumption of an open-circuit transformer, using the newest laboratory equipment

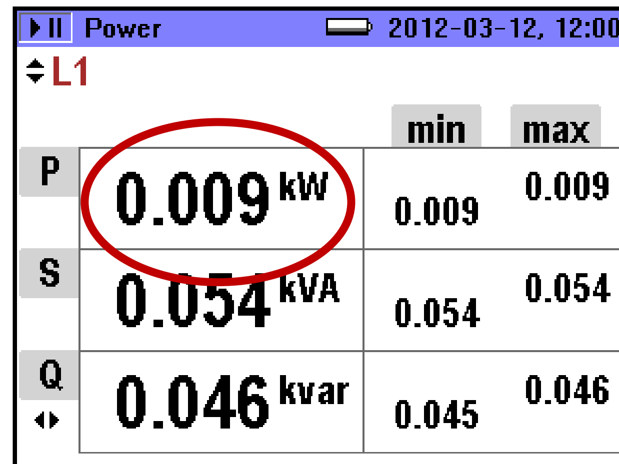
Poor measurement algorithms (2)

Error ~200-300% !!

31 Watts

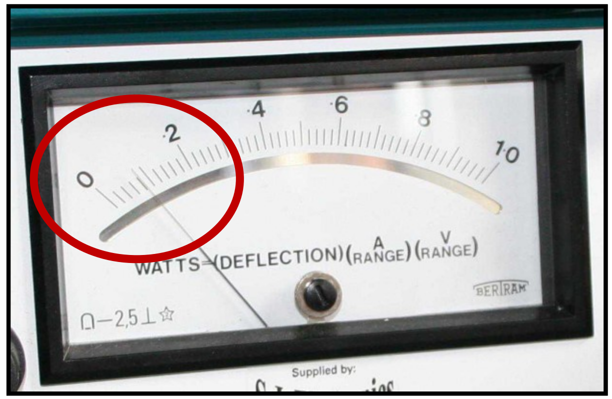


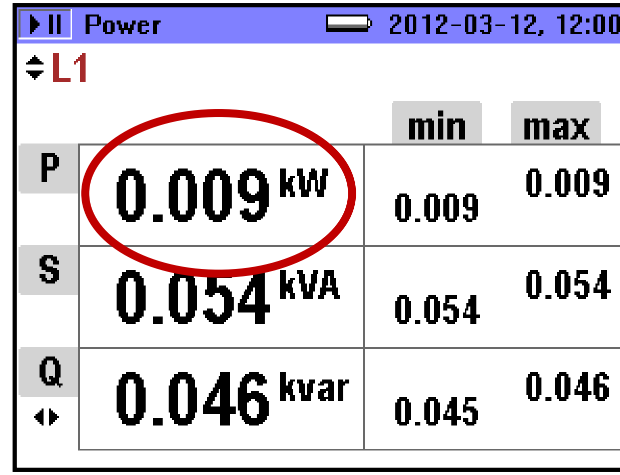
8 Watts

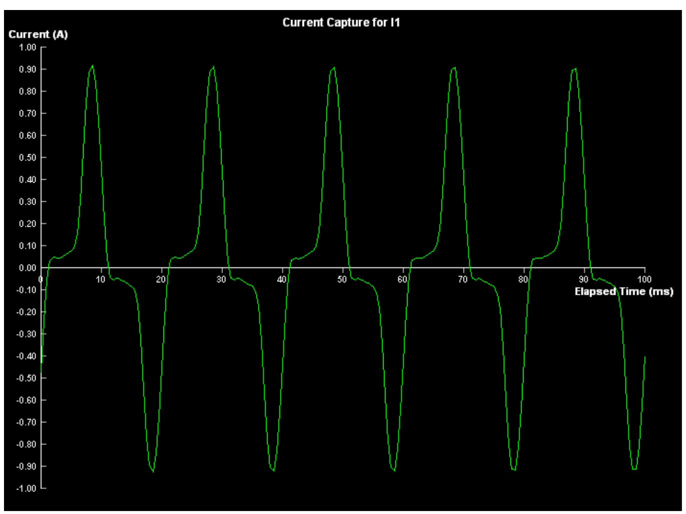


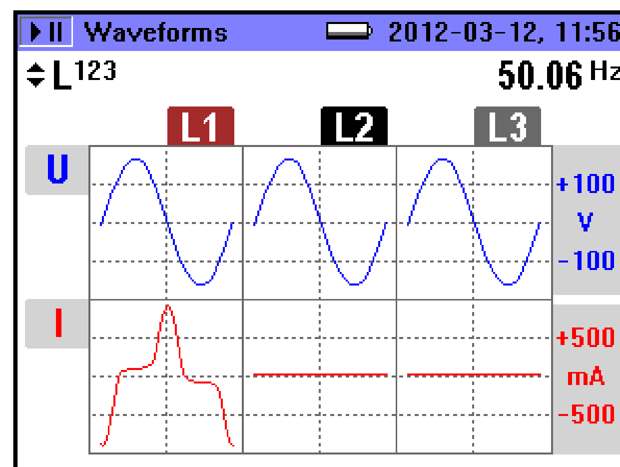
9 Watts

Poor measurement algorithms (3)

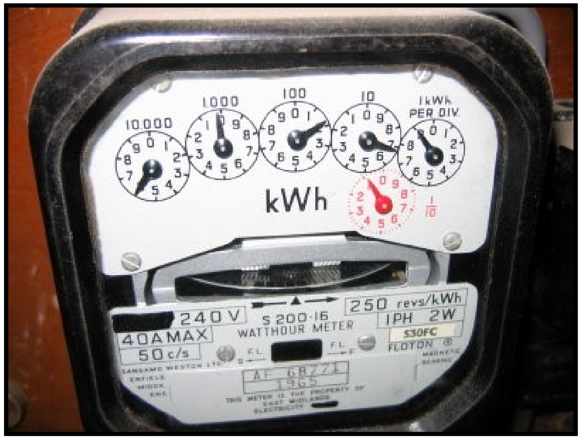


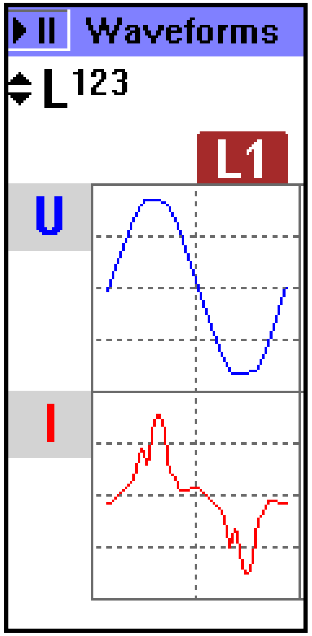






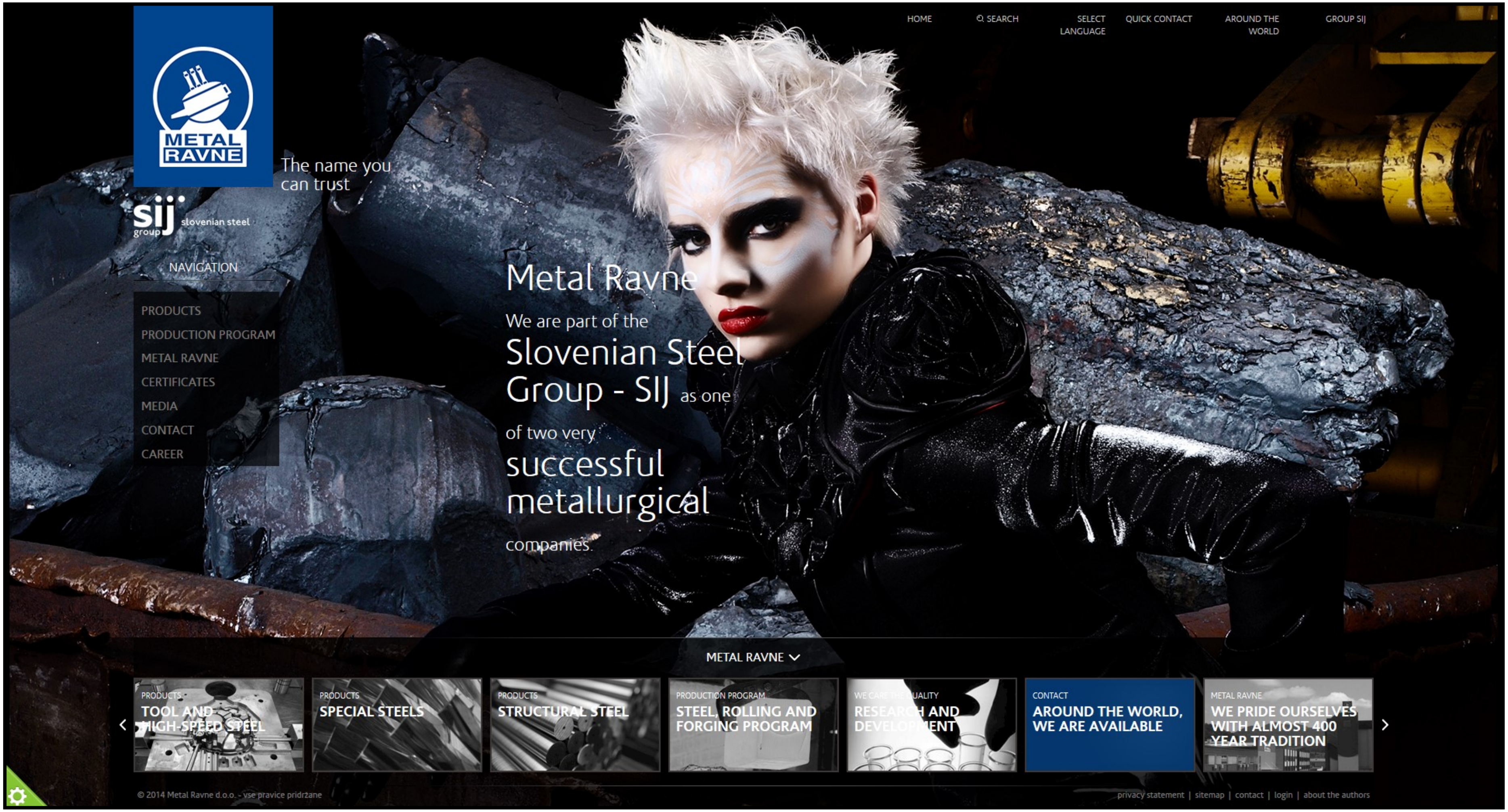
How accurate is your electricity meter?





+2.5% and -3.5% for UK nationally approved meters. *But what about harmonics?!*

Interharmonics and flicker

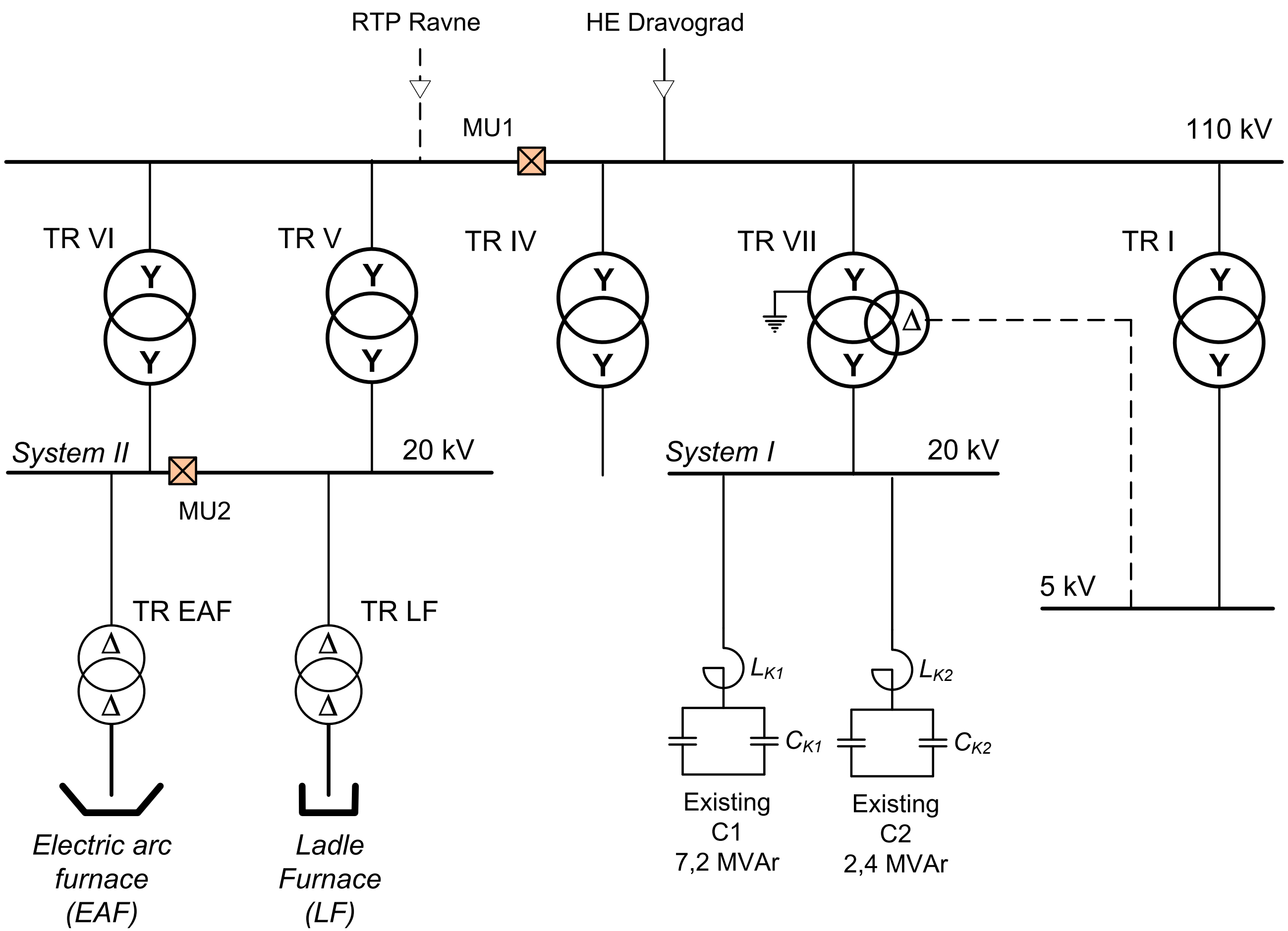


[http://www.metalravne.com/en/]

Electric Arc Furnace

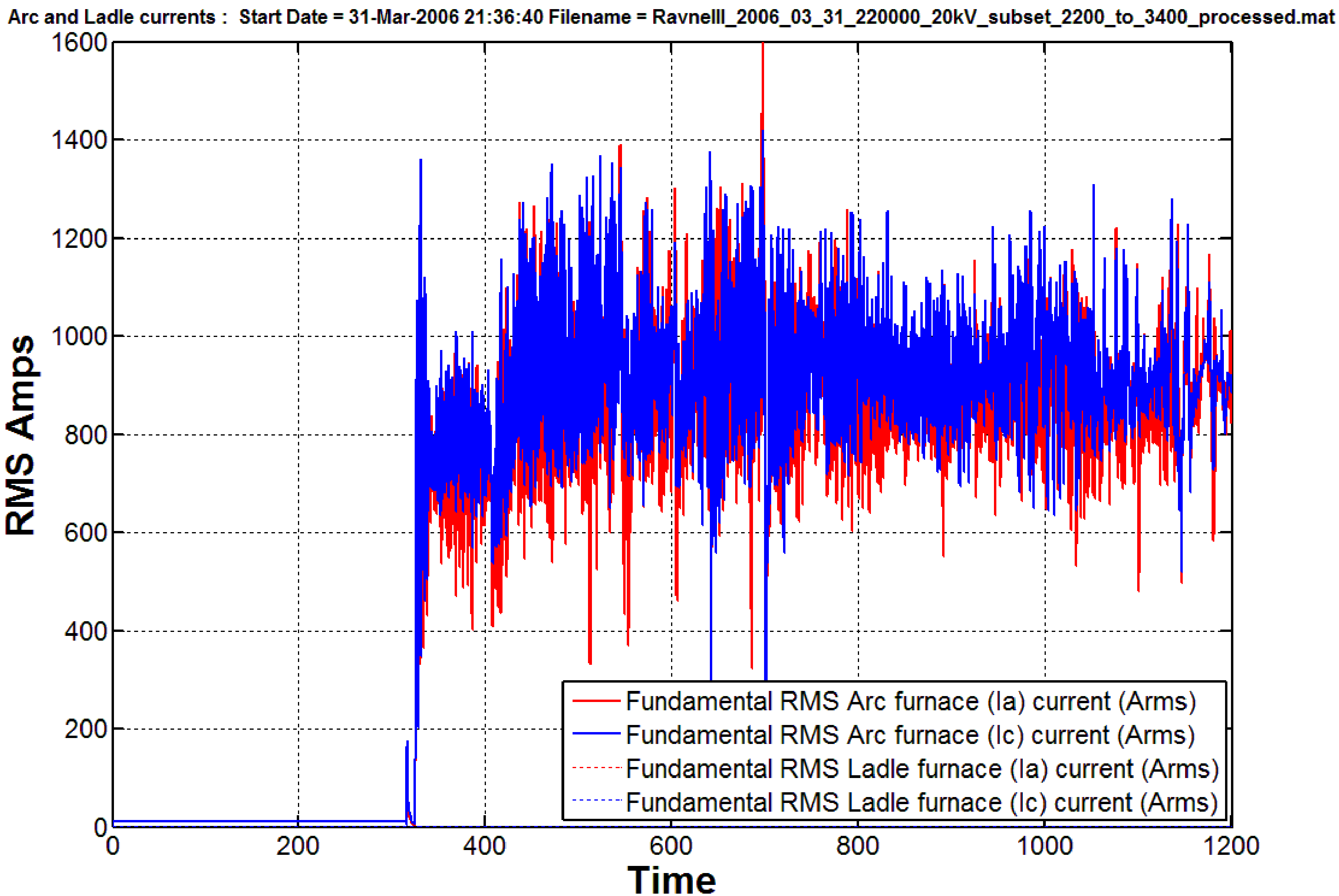
Dataset

- Dataset from 110kV voltage bus (20kV is worse!)

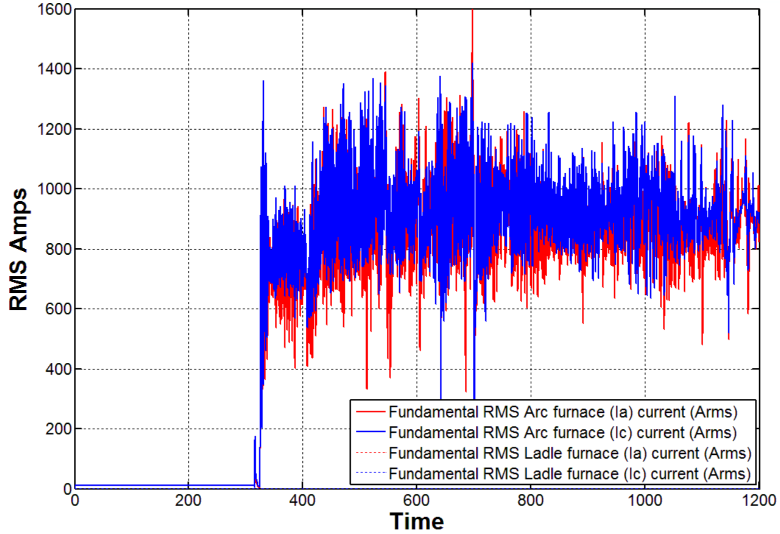


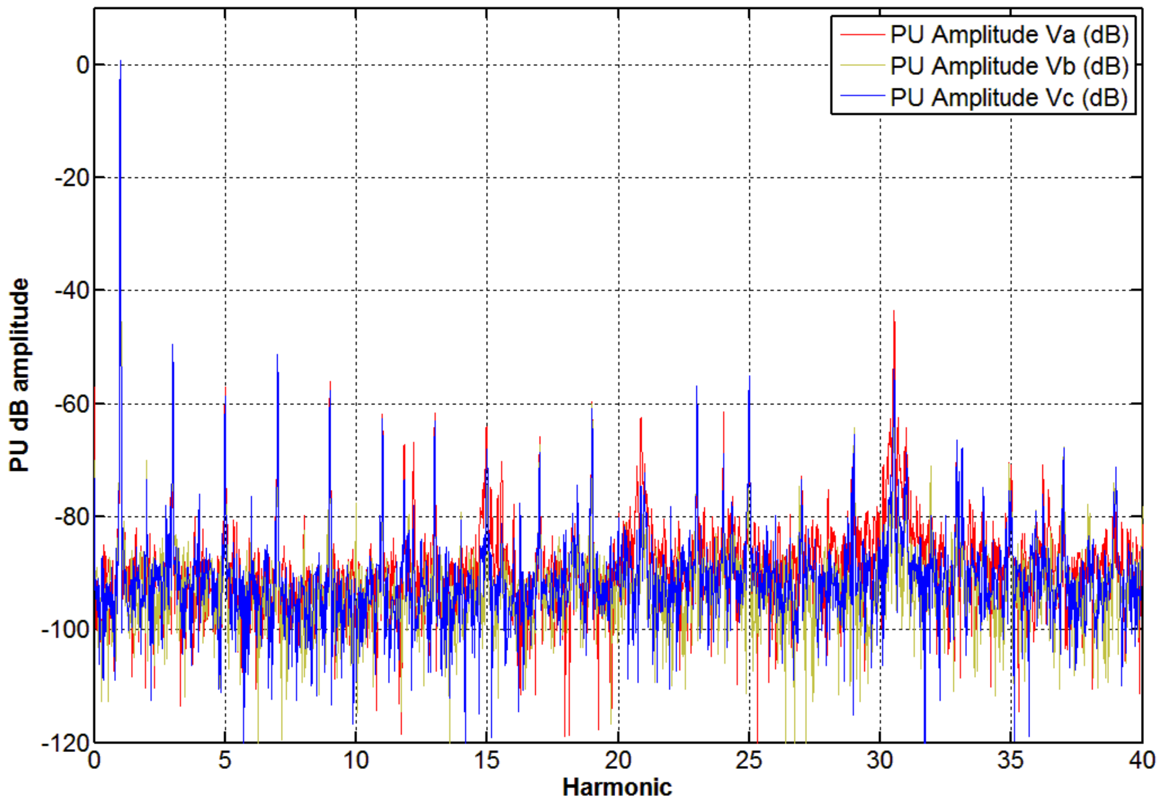
Data courtesy of the University of Ljubljana (Prof. Igor Papič Papič, Igor Igor.Papic@fe.uni-lj.si & Dr. Boštjan Blažič) via Roberto Langella (Roberto Langella roberto.langella@unina2.it) at the 2nd University of Naples

20 minute profile with Arc furnace turn-on (Ladle furnace currents zero)

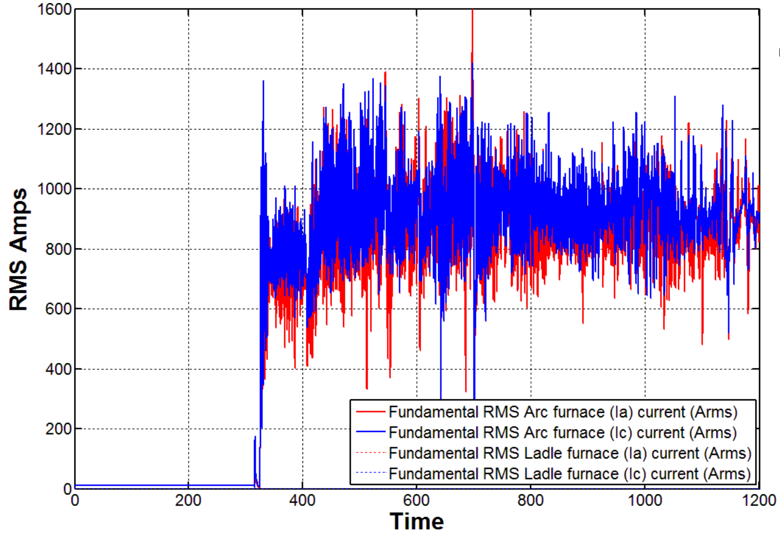


110kV, 10 seconds in

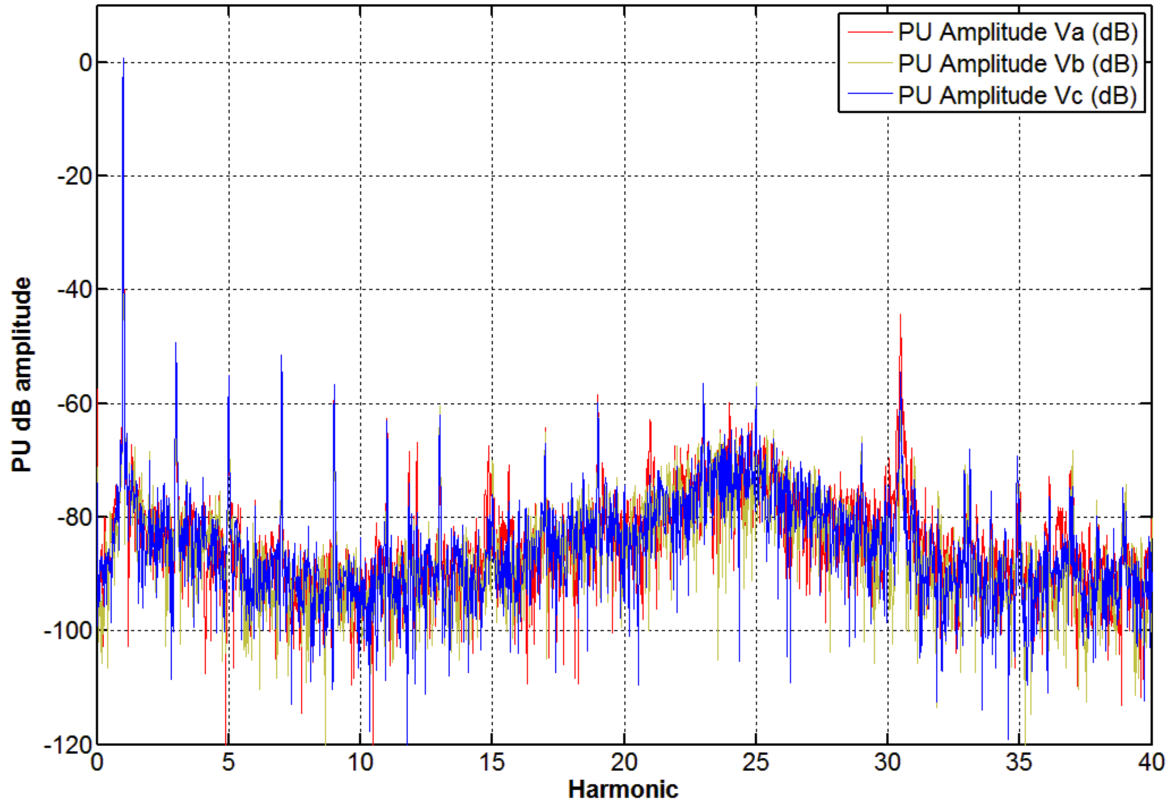




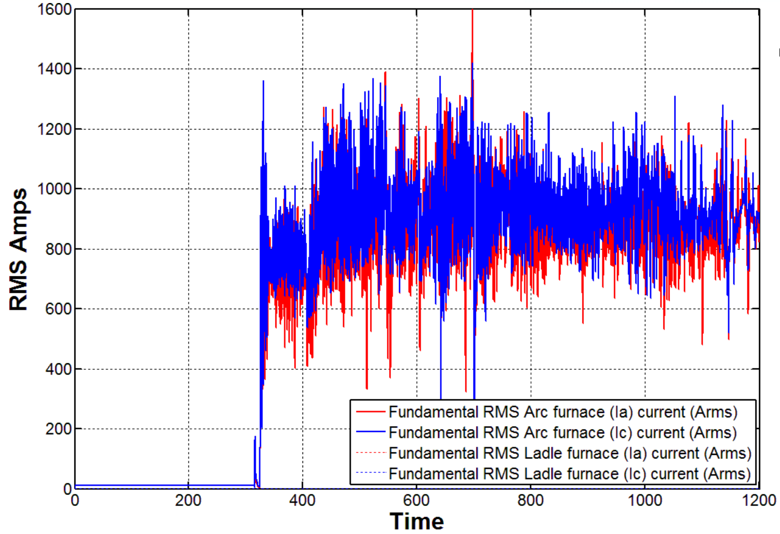
110kV, 100 seconds in



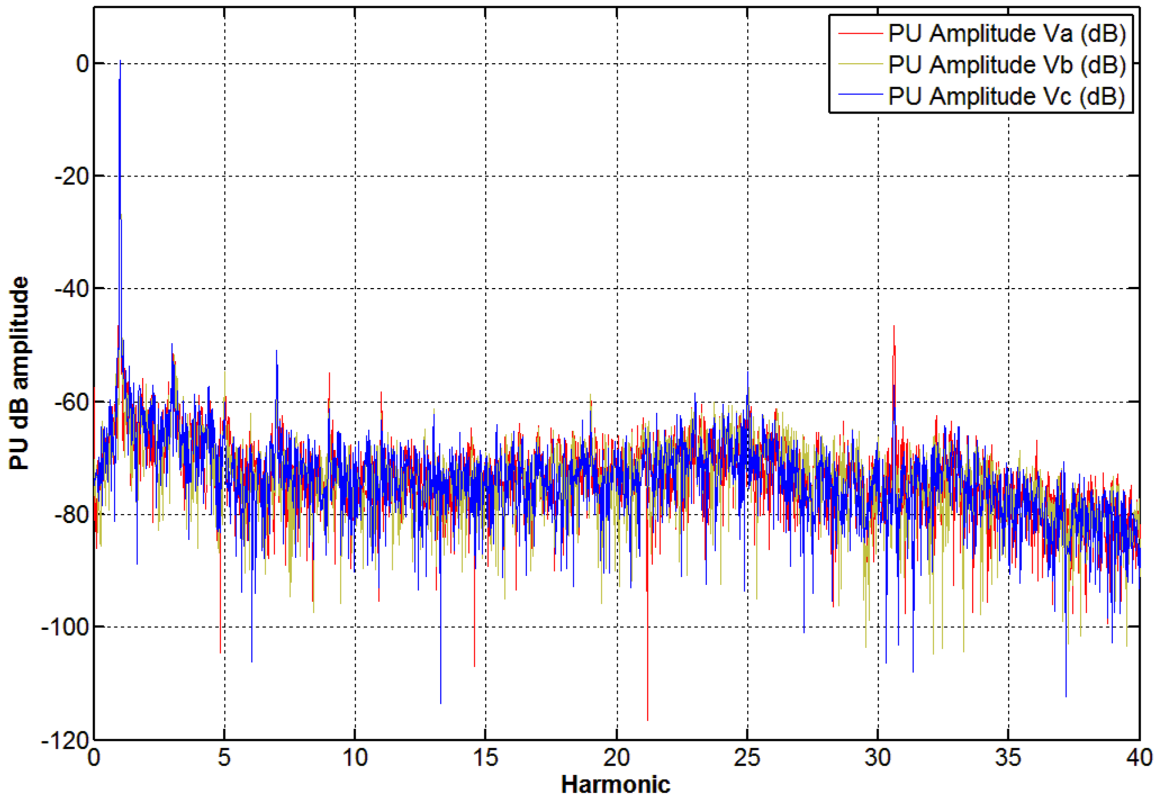
Something turns on at t=42s, but it is not the Arc Furnace or Ladle Furnace on the known 20kV bus!
(110kV quality is comparable to 20kV)



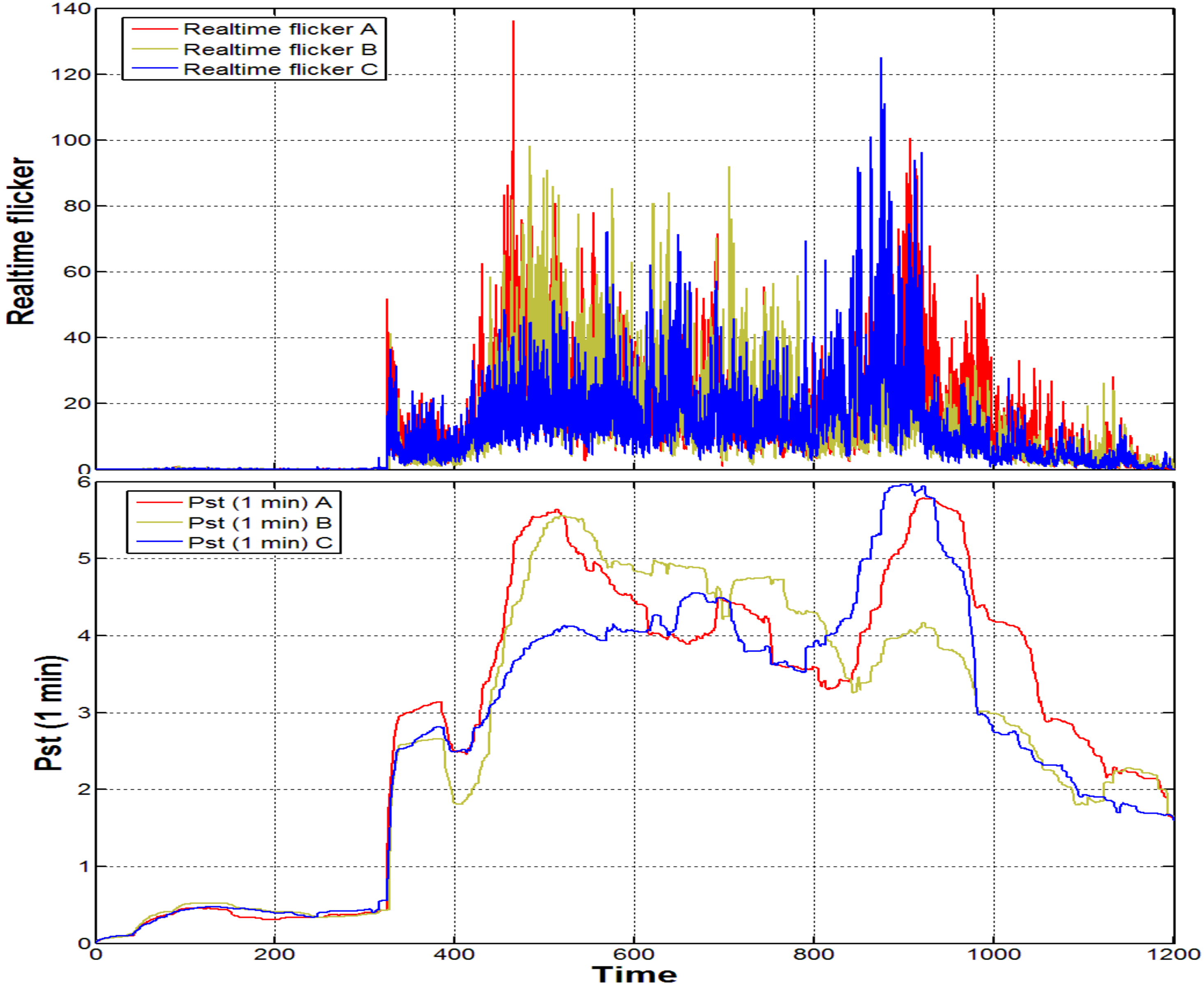
110kV, 500 seconds in



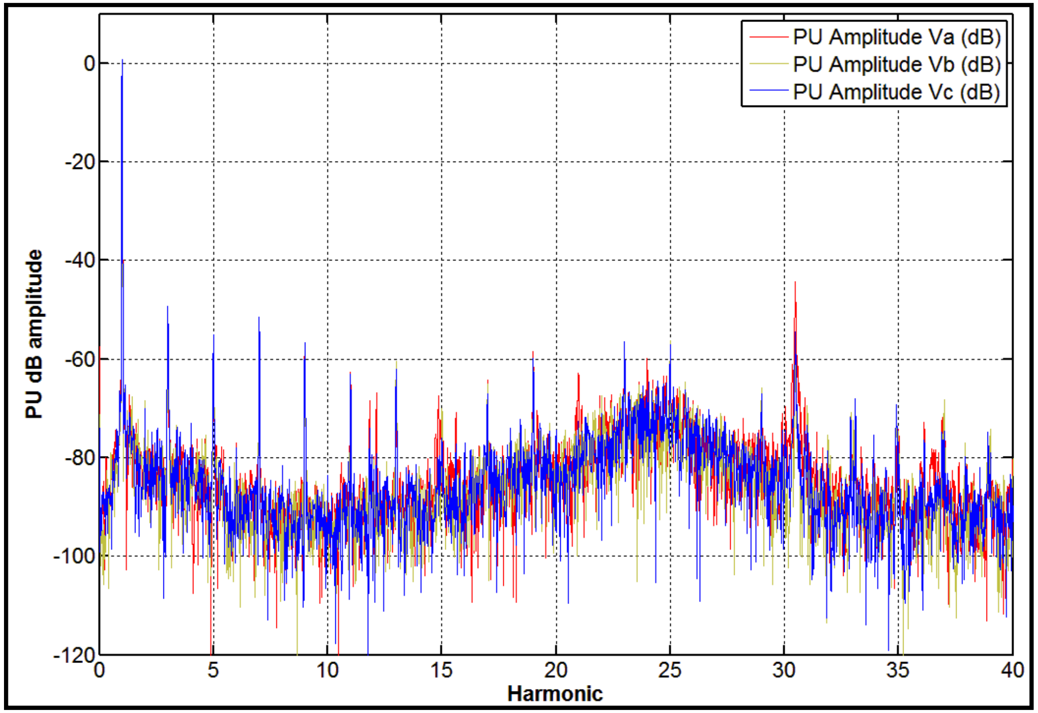
Arc furnace is full on.
(110kV quality is much better than 20kV)



Flicker

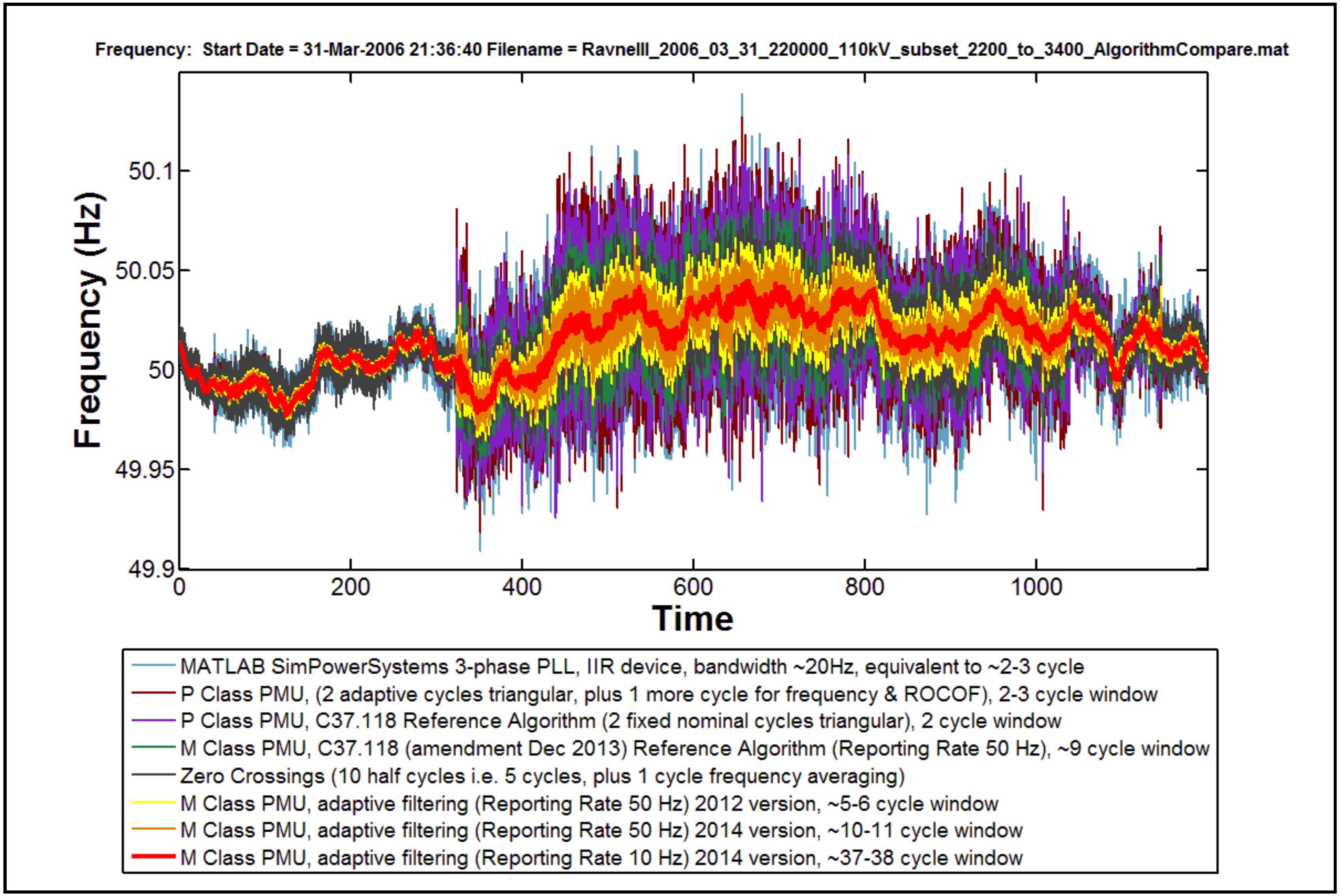

Realtime flicker A
Realtime flicker B
Realtime flicker C
Realtime flicker
140
120
100
80
60
40
20
0
Pst (1 min) A
Pst (1 min) B
Pst (1 min) C
Pst (1 min)
6
5
4
3
2
1
0
0
200
400
600
800
1000
1200
Time

Animation of Steelworks over 20 minutes

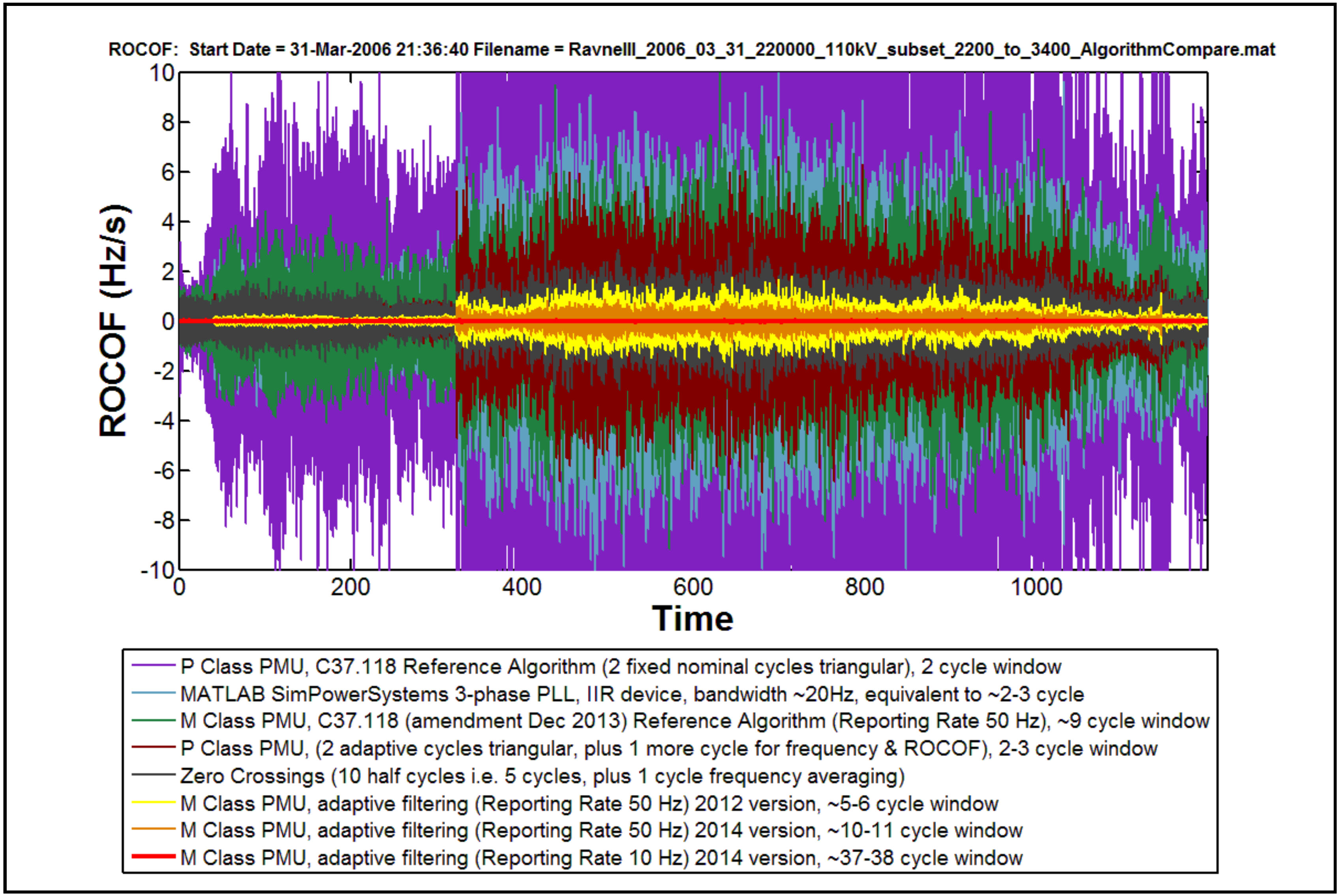


[RavneIII_2006_03_31_220000_110kV_subset_2200_to_3400_harmonic_analysis.mp4]

Frequency from different algorithms: 110kV connection to steelworks



ROCOF from different algorithms: 110kV connection to steelworks



University of Strathclyde

Implications for Control and Billing ?!!

End