TWM/TPQA and Algorithms

Traceability Routes for Electrical Power Quality Measurement

27. – 28. May 2019

ČMI, Brno

Presenter: Stanislav Mašláň, Czech Metrology Institute

Traceability Routes for Electrical Power Quality Measurement

EMPIR Research Potential project

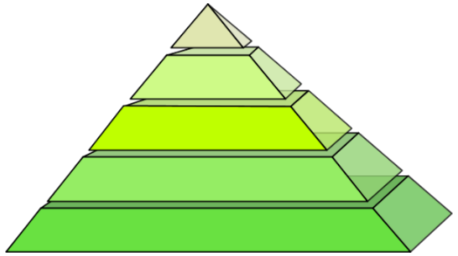
Project code: 15RPT04 TracePQM

Running time: June 2016 to May 2019

Consortium: 13 Partners + 1 RMG
  7 already **developed** capability
  2 in process of development
  2 intend to develop
  Potential to **knowledge transfer**

Coordinator:
  Věra Nováková Zachovalová

Why Power Quality (PQ)?



Power Distribution Grid

- Many small "green" sources with **fluctuating power** in the grid
- Non-linear loads (appliances) - **distortion**
- Damage of highly sensitive electronic equipment
- In worst case risk of **blackouts**

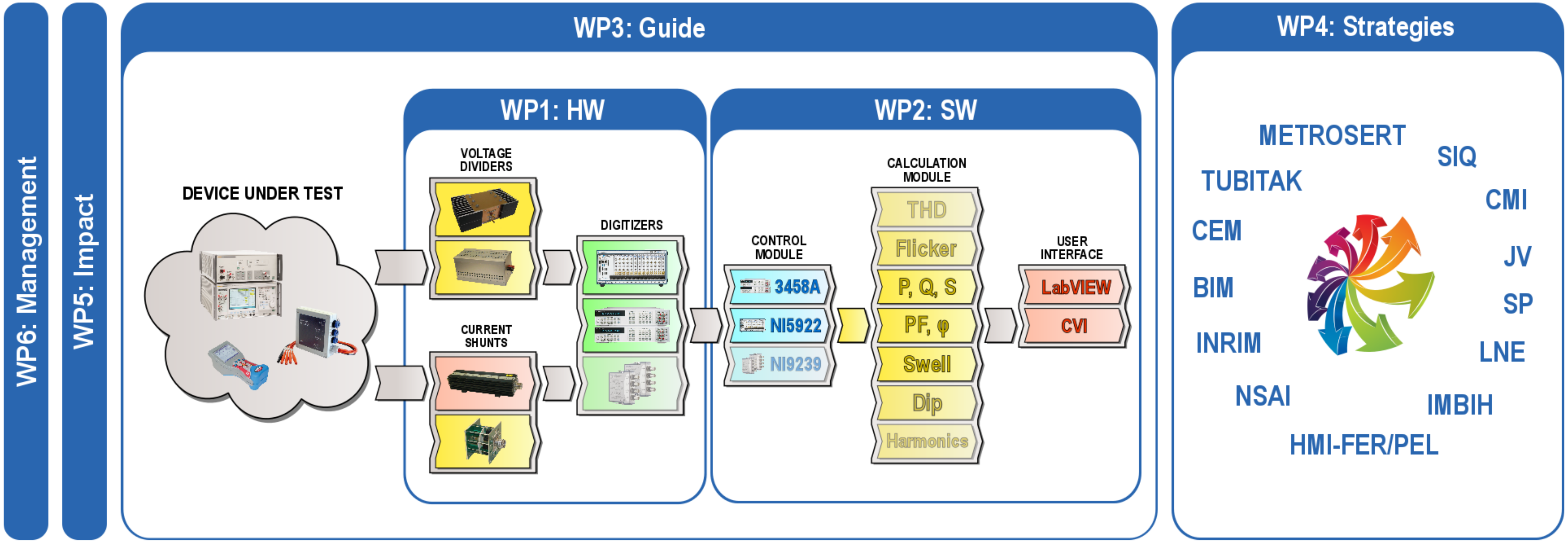
Power Quality Monitoring

- Large number of diverse parameters
  (harmonics, flicker, dips, swells, ...)
- IEC 61000-4-30, IEC 62586-2, IEC 61000-4-15, IEC 61000-4-7
- Wide range of measuring instrumentation

SI Traceability of PQ measurements is imperative to ensure comparability of results
BUT
Difficult to obtain traceability for all PQ parameters

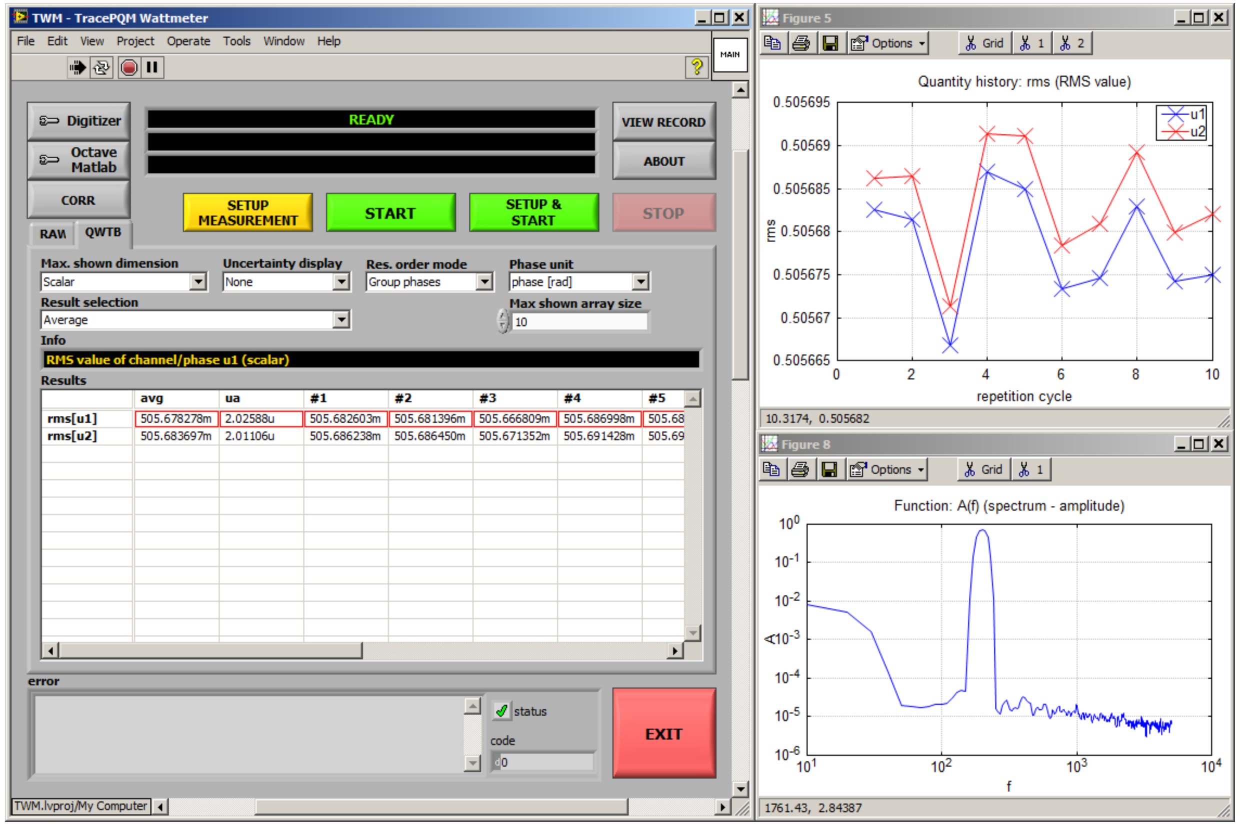
Project structure

Overall goal: To **develop** and **validate** an **open**, **modular** and well **documented metrology grade system** for sampled power and PQ parameters measurements, which can be easily established at all NMIs and other interested parties.



Open software tools - TWM

- Digitize voltage/current waveforms using:
  - Keysight 3458A DMMs
  - NI PXI 5922 wideband digitizers (niScope compatible)
  - SoundCard (testing purposes)
  - Future: Oscilloscopes, QuADC quantum digitizer, …
- Any number of digitizer channels
- Save waveform data in unified format
- Load correction for each component of setup
- Execute selected algorithm on waveform data to obtain desired power or PQ parameter(s)
- Display result as table or graph
- Export results
- Archive data and results for future processing



- Written in LabVIEW + Matlab/Octave
- Full open source: https://github.com/smaslan/TWM

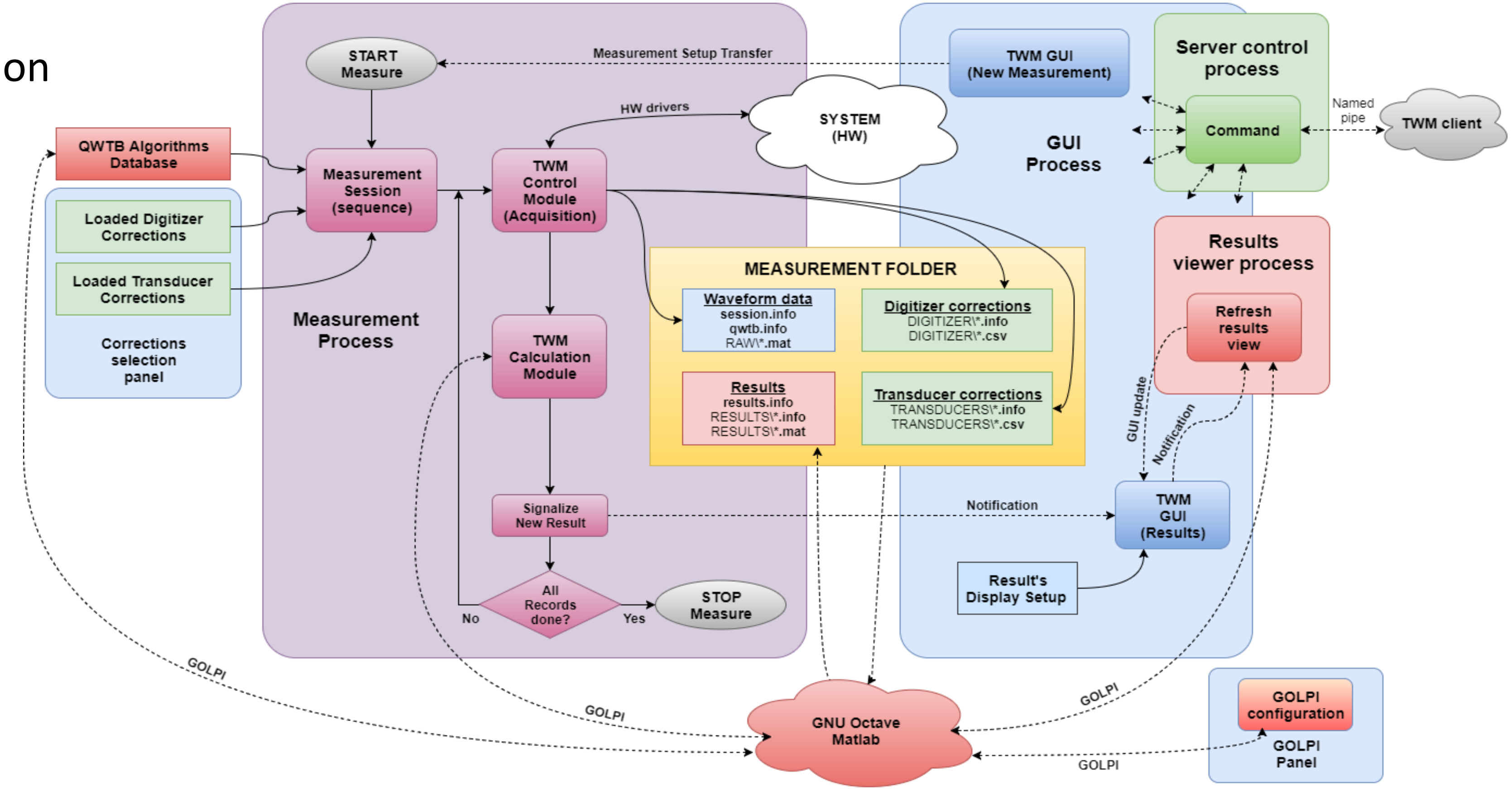
TWM Concept

Two components:

- Control module in LabVIEW
- Processing in Matlab/Octave
- Interlinked to single application using GOLPI

Both can operate standalone:

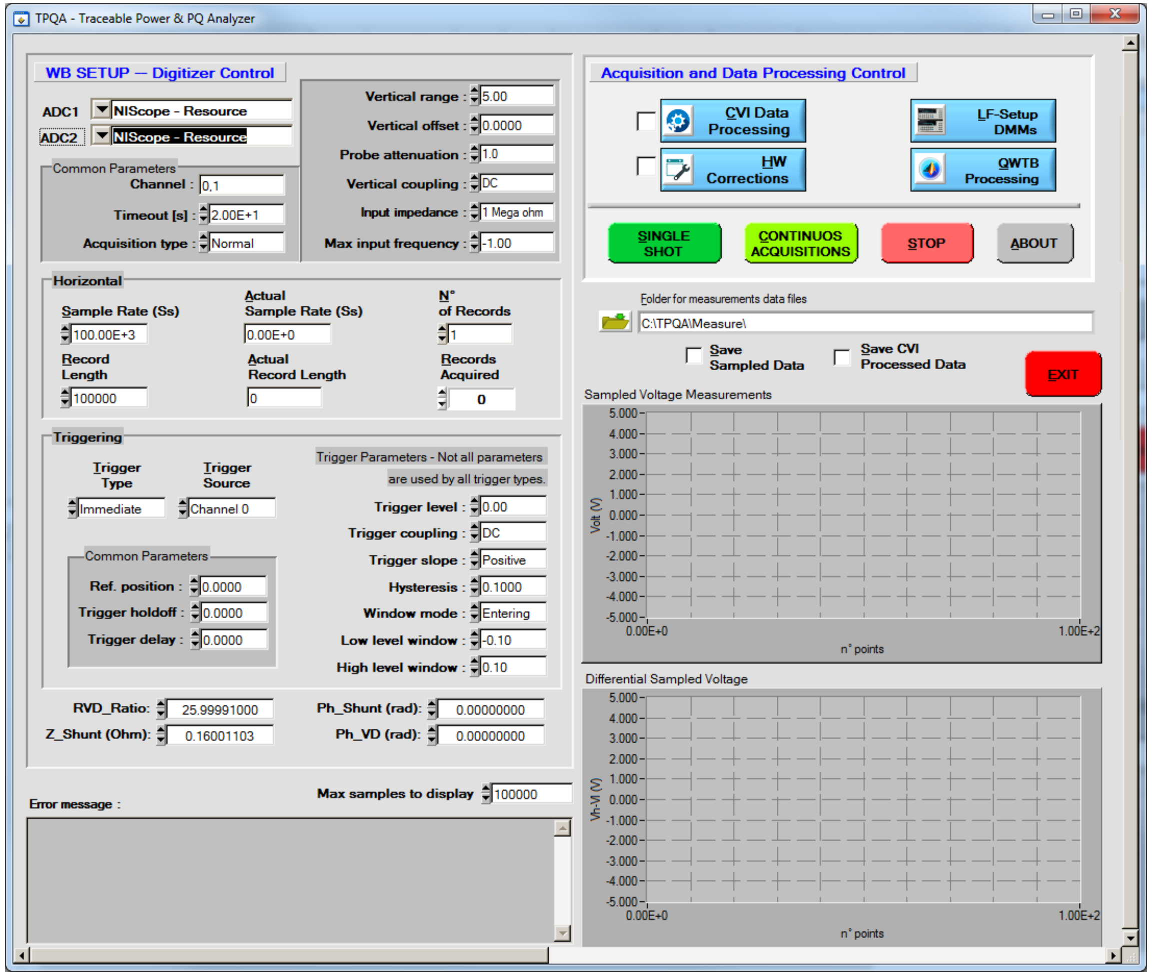
- Digitize without processing
- Batch processing later
- Reprocessing the raw data for new parameters
- Computationally expensive uncertainty evaluation on supercomputer
- Validation of algorithms
- New algorithms needs just a few m-files to be added



Open software tools - TPQA

- Functional equivalent of TWM
- Uses either internal processing or TWM algorithms
- Written in LabWindows/CVI (ANSI C)
- Open source

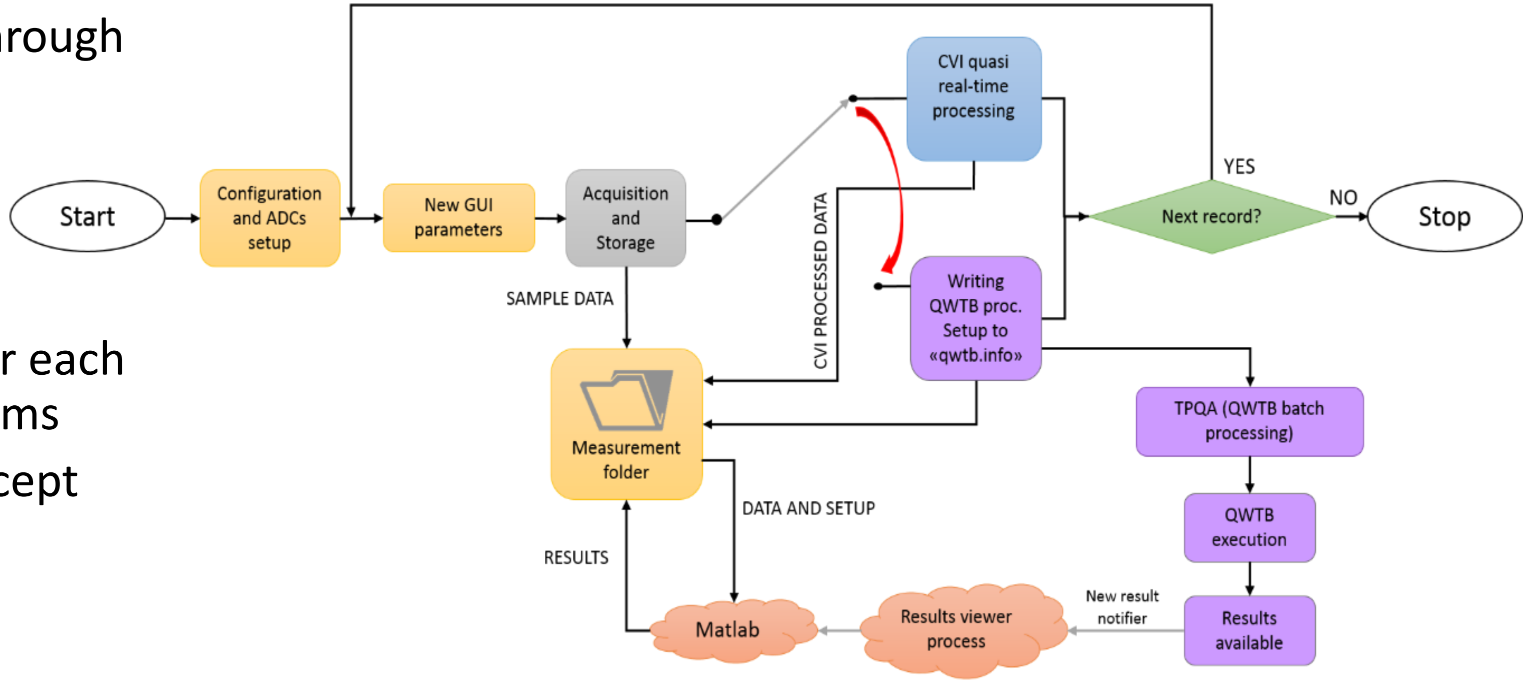
- Full open source: https://github.com/btrinchera/TPQA



TPQA - Concept

Two components:

- Control module in LabWindows/CVI
- Processing in Matlab and CVI native algorithms
- Matlab linked Labwindows/CVI through matlab runtime library.



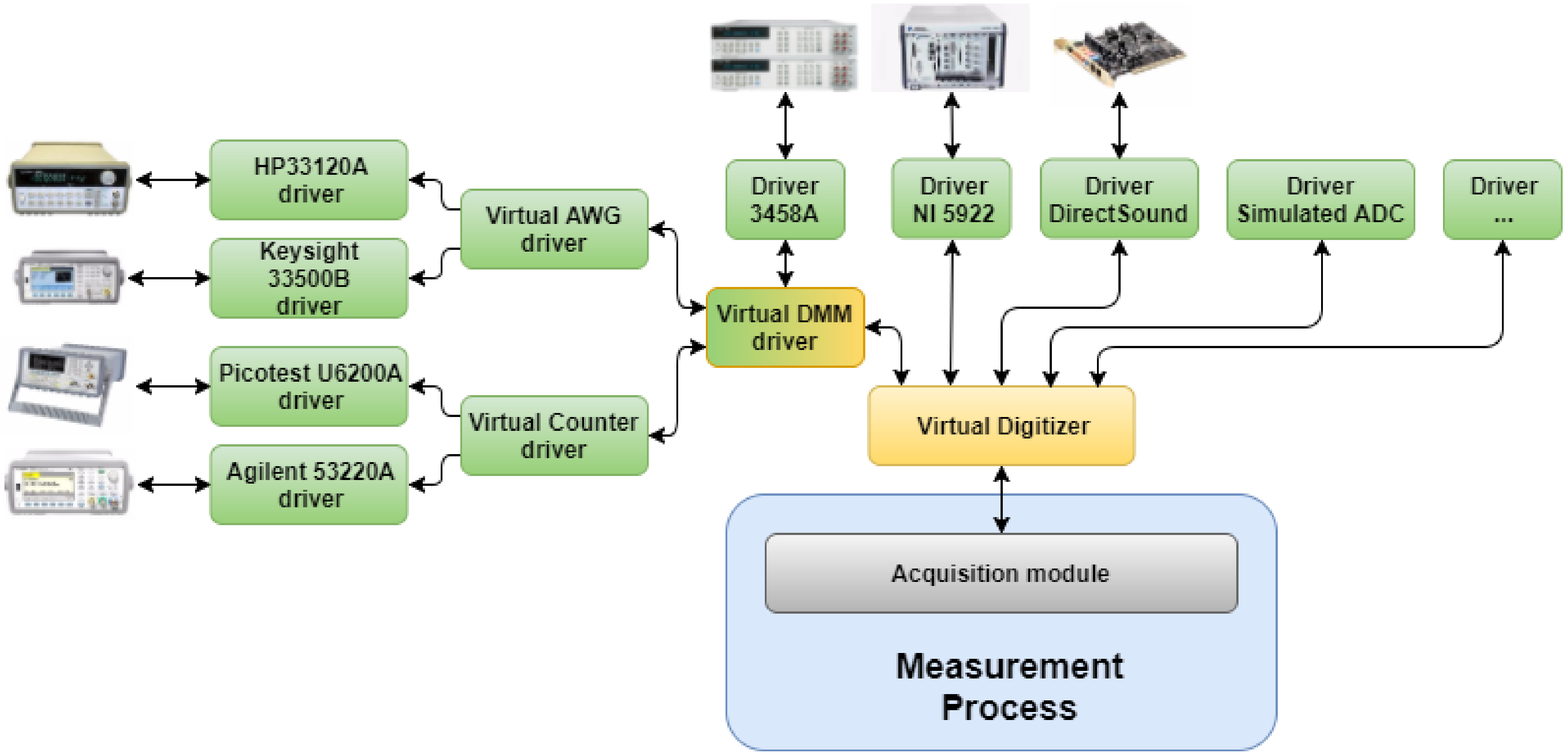
Both can operate standalone:

- Digitize without processing
- Data processing immediately after each acquisition sing using CVI algorithms
- Batch processing using TWM concept
- Reprocessing the raw data with new algorithms
- New algorithms needs just a few m-files to be added

TWM Concept – Digitizer drivers

Generalized digitizer:

- Acquisition module accesses HW drivers via virtual layer – same access to any digitizer
- Easy addition of new digitizer – just adding translation from HW drivers to Acquisition module

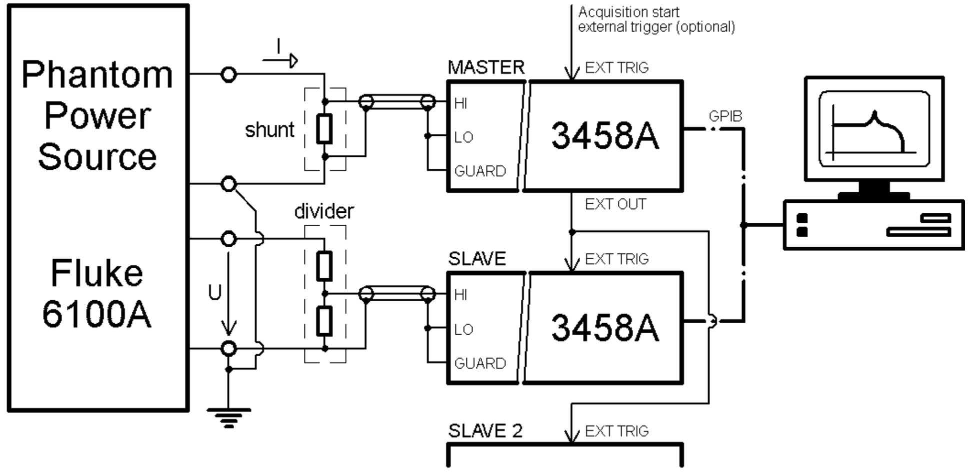


TWM concept – Sampling with Keysight 3458A

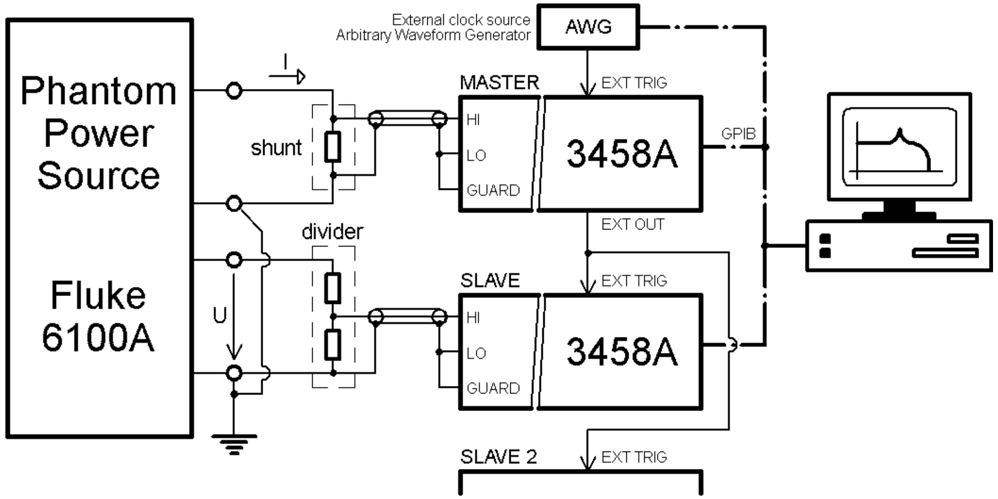
Features:

- Simultaneous sampling at any number of channels
- Sampling rate up to 100 kSa/s
- Memory mode (limited by internal RAM)
- Streaming mode (up to 16 MSamples per channel)
- Modes: DCV or DSDC, DSAC
- Sample clock modes:
  - MASTER-SLAVE, internal clocking (non-coherent sampling)
  - MASTER-SLAVE, external clock source
  - Modified HW, locked to 10 MHz (experimental)
- Trigger:
  - Immediate
  - Level
  - External

Internal clocking by MASTER:



External clocking from AWG or another pulse clock:

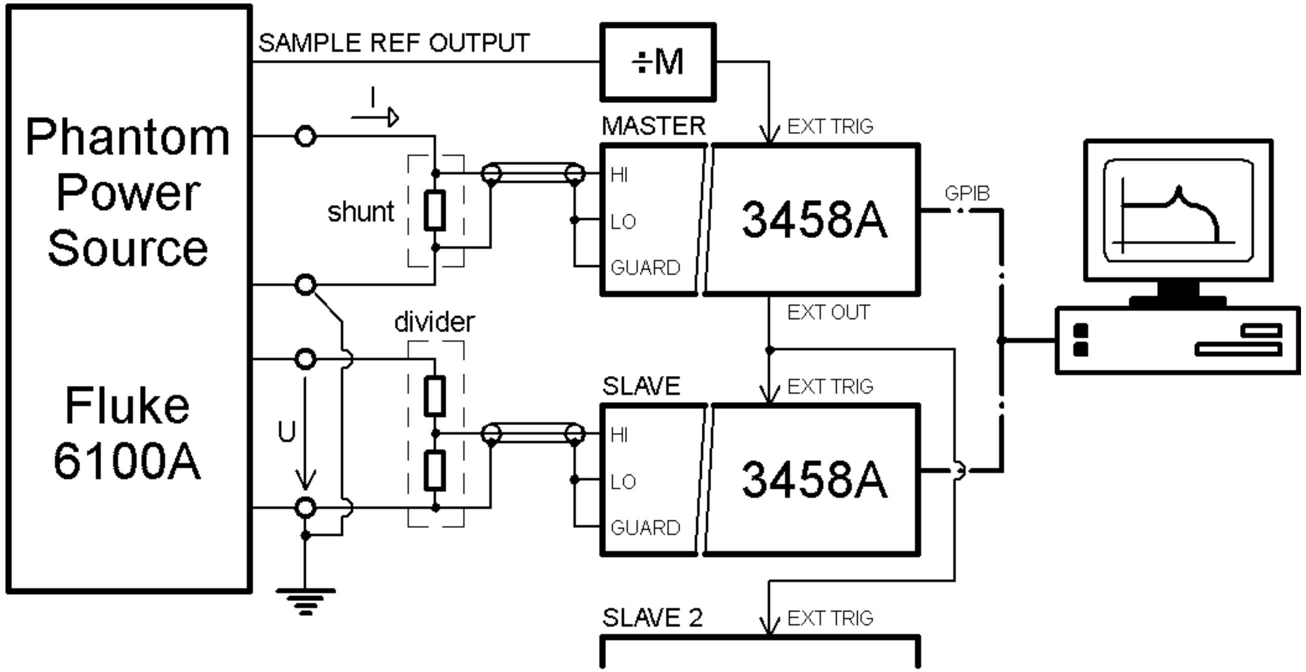


TWM concept – Sampling with Keysight 3458A

Special case:

- Sample clock taken from source
- Fluke 6100A outputs:
  - sample clock out = f_0*N
  - Must be enabled by command: OUTP:ROSC ON
- Useful for coherent sampling:
  - Integer number of signal periods per record
- Problem:
  - 6100A cannot control the N factor. It is set so sampling is always > 50 kHz => aperture of 3458A must be short => high noise and gain errors!

External sample clock from source:

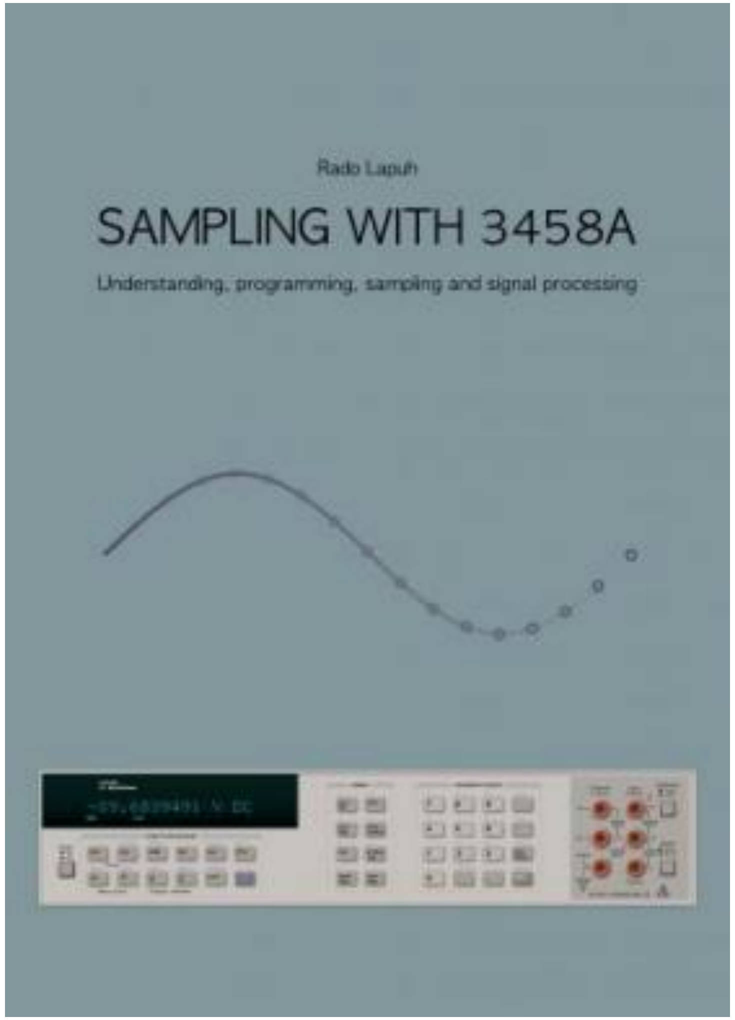


TWM concept – Sampling with Keysight 3458A

<u>Highly recommended literature:</u>

Excellent book from Rado Lapuh on 3458A:

- Sampling,
- Processing data,
- Connections,
- Special features
- Characterisation

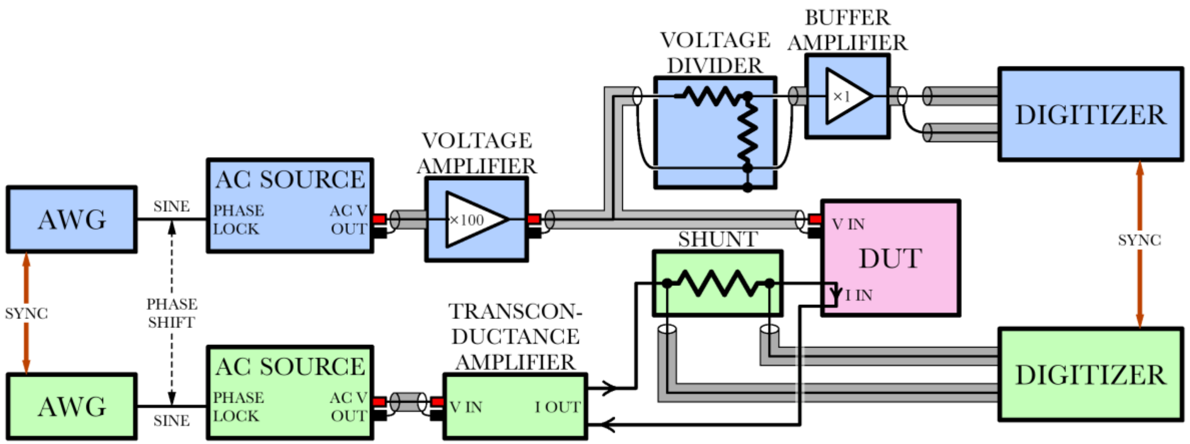


Source: **Rado Lapuh, "Sampling with 3458A",**
ISBN 978-961-94476-0-4

TWM concept – Sampling NI 5922 digitizers

Features :

- Any number of channels
- Coupling: DC, AC
- Input impedance: 1 MΩ or 50 Ω
- Connection mode: single-ended, differential
- Memory mode (up to board limit)
- Streaming mode (unlimited sample count)
- Multi-board synchronization (niTClk)
- Optional lock to external 10 MHz
- Trigger mode:
  - Immediate
  - Level
  - External



Wideband setup, with 5922 (RISE)

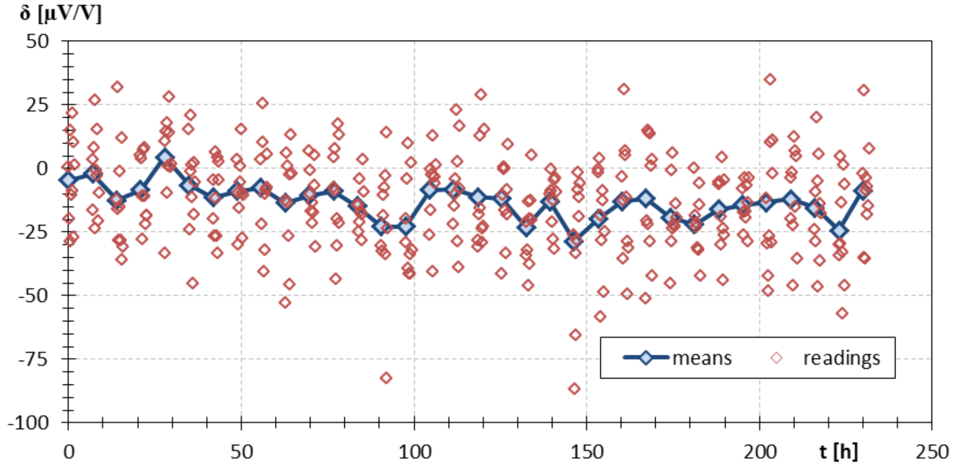
TWM concept – Sampling with NI 5922 digitizers

Features :

- Sampling rate 50 kSa/s to 15 MSa/s
- Unlike 3458 no aperture setting
- Resolution varies from 24 bit down to 16 bit depending on the sampling frequency

- Limited gain stability
- Temperature dependence: up to some 20 ppm/°C (internal temperature)
- Limited repeatability of self-calibration: up to ±90 ppm!

Repeatability of gain for repeated self-cal:



TWM concept – Sampling with SoundCard

Features :

- Experimental only!
- One or two channels
- Sampling rate limited by HW to some 192 kSa/s
- Typically high crosstalk
- Usable for e.g.:
  - Phase shift
  - Amplitude ratios
  - THD

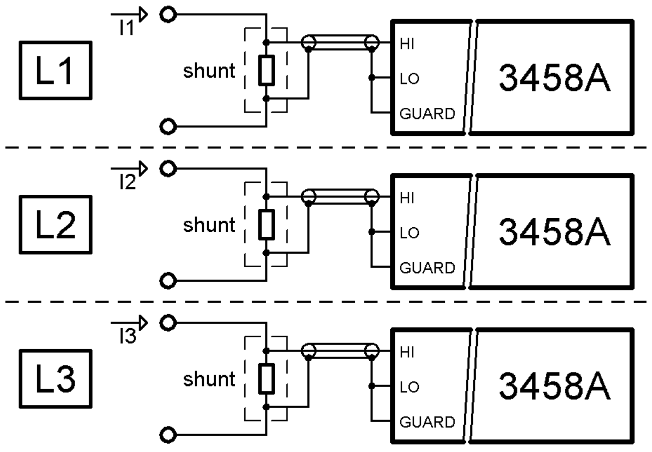
Source: Creative Technology Ltd.

TWM concept – versatility of transducer configuration

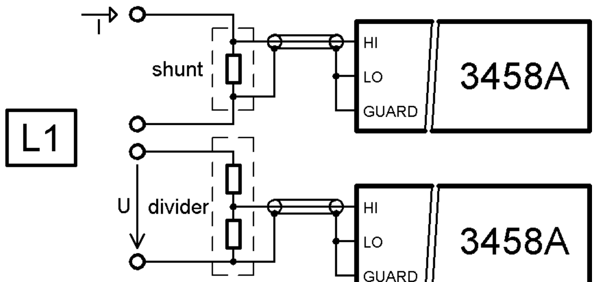
Designed to be able to operate:

- Single channel (single voltage or current input)
- Single phase operation (one voltage and one current input)
- Multiphase operation (multiple voltage and current inputs)

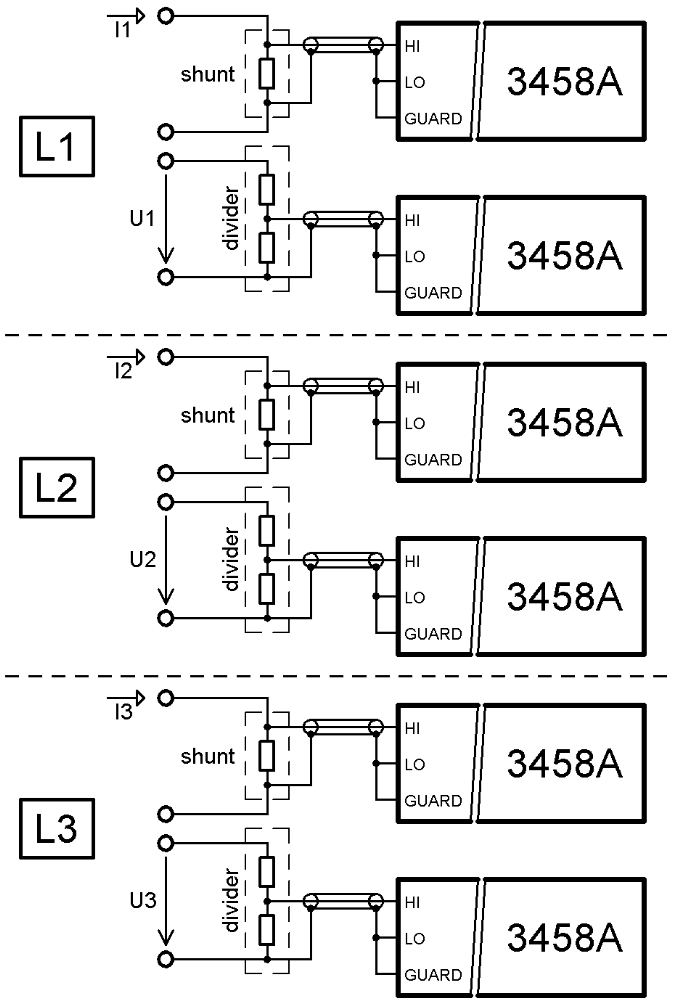
Single channel, multiphase operation:



Single phase operation (power):



Multiphase operation (power):

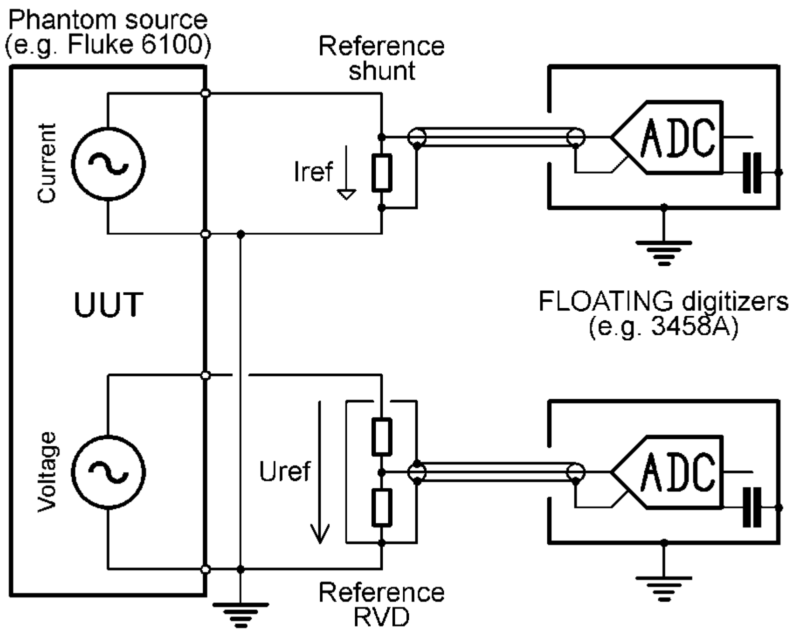


TWM concept – versatility of transducer configuration

Transducer configuration:

- Single-ended connection (low frequency)
- Differential connections (wideband operation)
- Mixed single-ended and differential

Single ended transducer connection (LF/HF):



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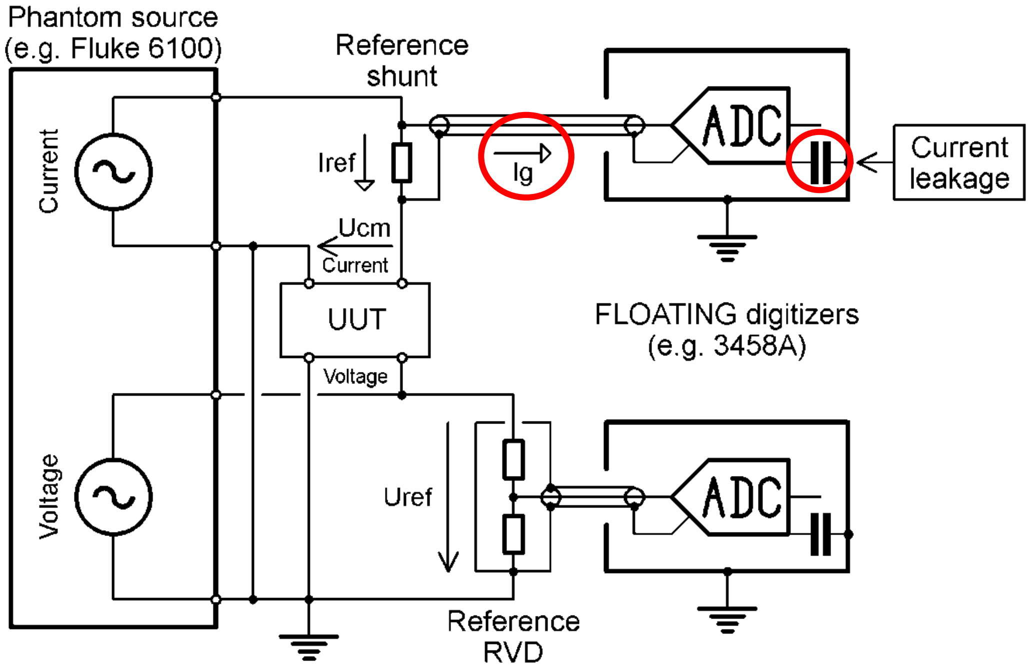

TWM concept – versatility of transducer configuration

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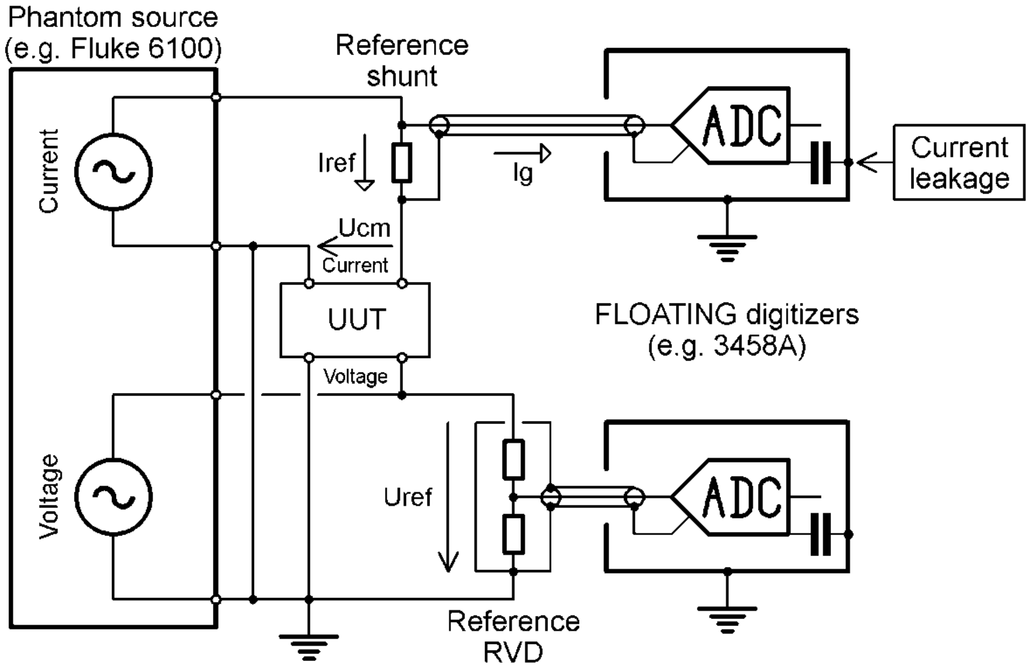
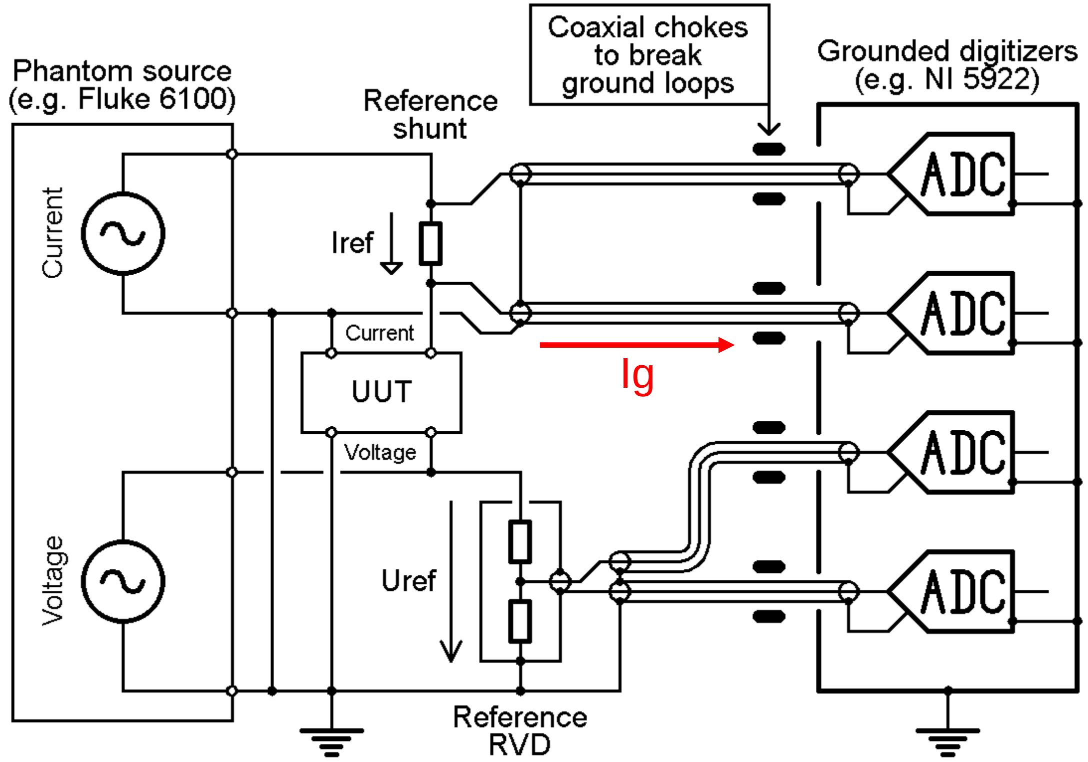
- Mixed single-ended and differential

Single ended transducer connection (usually LF):



Differential transducer connection (wideband):



TWM concept – versatility of transducer configuration

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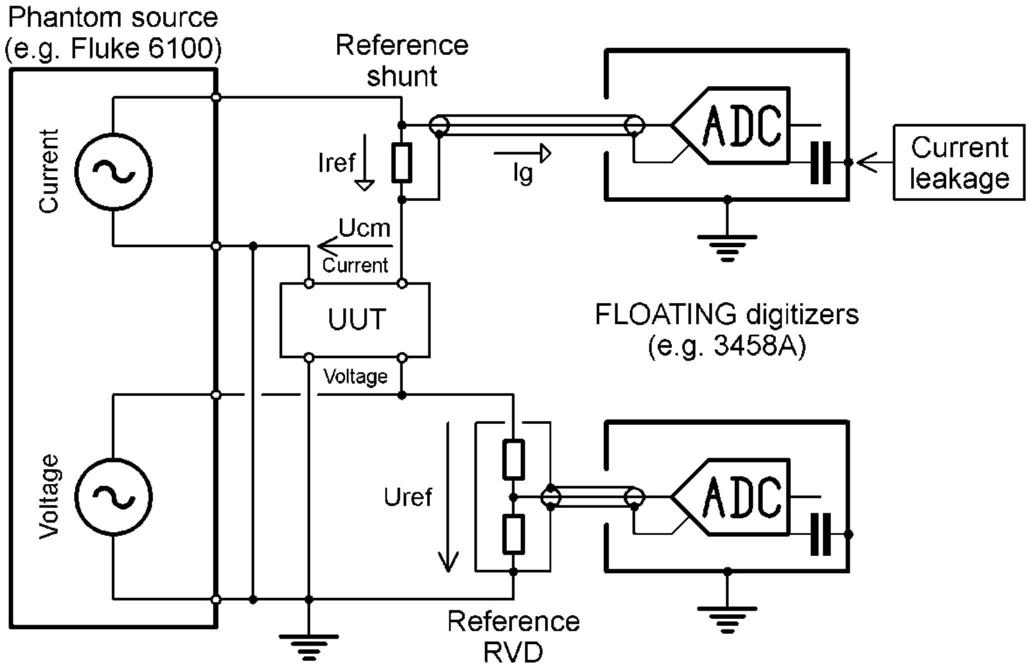
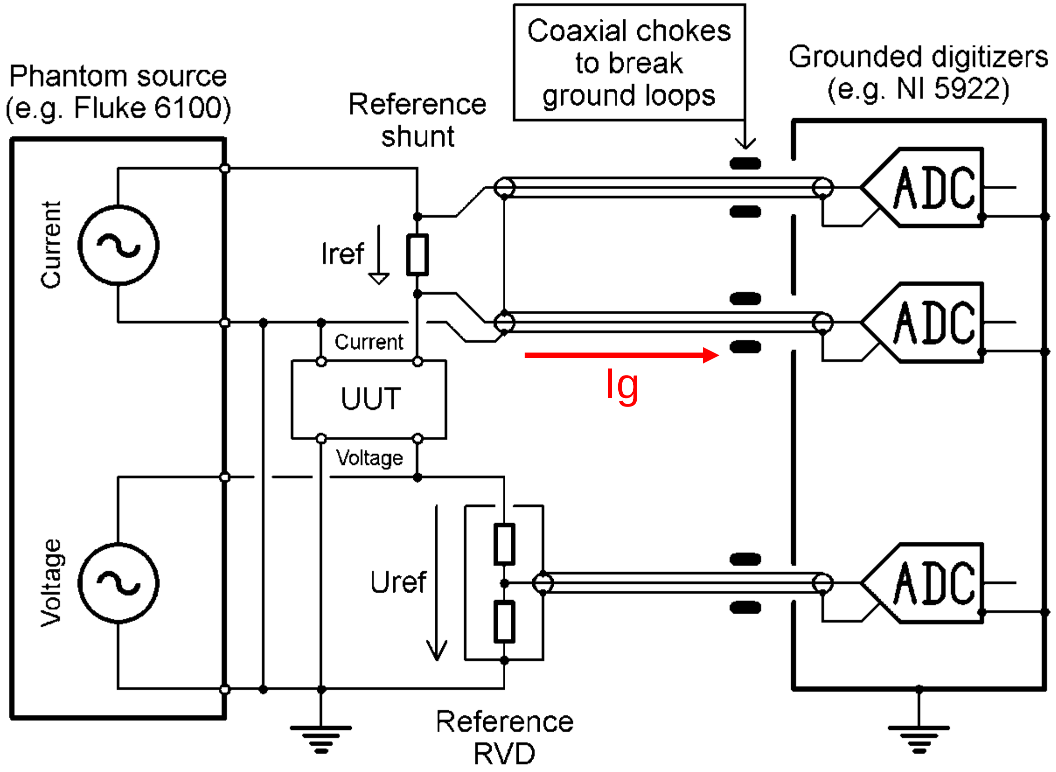
- Differential connections (wideband operation)
- Mixed single-ended and differential

Single ended transducer connection (usually LF):



Mixed mode transducer connection (wideband):



TWM concept – Corrections

Features:

- Every component of setup corrected
- All corrections are optional – no need to load any
- All corrections have assigned uncertainty
- Versatile human readable format
- Corrections may be dependent on digitizer attribute
  - Auto selection of various correction files e.g. by temperature or range selected

Types of corrections:

- Digitizer correction
- Transducer corrections
- Cable corrections (part of transducer)

TWM concept – Digitizer corrections

Gain:

- Corrects gain error of digitizer
- Composed of *Nominal gain* and *relative ac-dc* transfer (frequency-amplitude dependent)

Phase:

- Corrects phase shift of channel (frequency-amplitude dependent)
- Can be used to correct inter-channel phase error

Offset:

- Corrects DC offset of digitizer channel

Time-shift:

- Defines time-shift of each digitizer channel relative to first channel

Digitizer aperture:

- Corrects gain and phase error of channel for integration ADC (3458A):

$$gain = \frac{aperture \cdot \pi \cdot f}{\sin(aperture \cdot \pi \cdot f)}\ [\mathrm{V/V}];\ phase = aperture \cdot \pi \cdot f\ [\mathrm{rad}]$$

- Often sufficient to replace gain ac-dc and phase for 3458A

TWM concept – Digitizer corrections

Time-base correction:

- Corrects error of digitizer time-base (results in frequency estimation error)
- Used only for internally generated sample clock, e.g. for 3458A

SFDR – Spurious Free Dynamic Range:

- Defines spur levels of digitizer channel (frequency-amplitude dependent)
- It’s no correction – it’s used to estimate uncertainty e.g. for THD evaluation

Sampling time jitter:

- It’s no correction – it’s used to estimate uncertainty (increases standard deviation)

Input impedance:

- Defines input impedance of digitizer channel
- It is used as part of loading corrections
- Some digitizers have high input capacitance and low resistance, so this may be essential especially for phase angle

TWM concept – Transducer corrections

Gain:

- Corrects gain error of transducer
- Composed of *Nominal gain* and *relative ac-dc* transfer (frequency-rms dependent)
- Nominal gain is resistance for shunt, or input-to-output ratio for divider

Phase:

- Corrects phase error of transducer (frequency-rms dependent)

SFDR – Spurious Free Dynamic Range:

- Defines SFDR of transducer (frequency-rms dependent)
- It's no correction – it's used to estimate uncertainty e.g. for THD evaluation

RVD low-side impedance:

- Approximate impedance of low-side resistor of resistive voltage divider (part of loading corrections)

Loading corrections:

- Impedances of particular components of connection impedance model

TWM concept – Transducer corrections

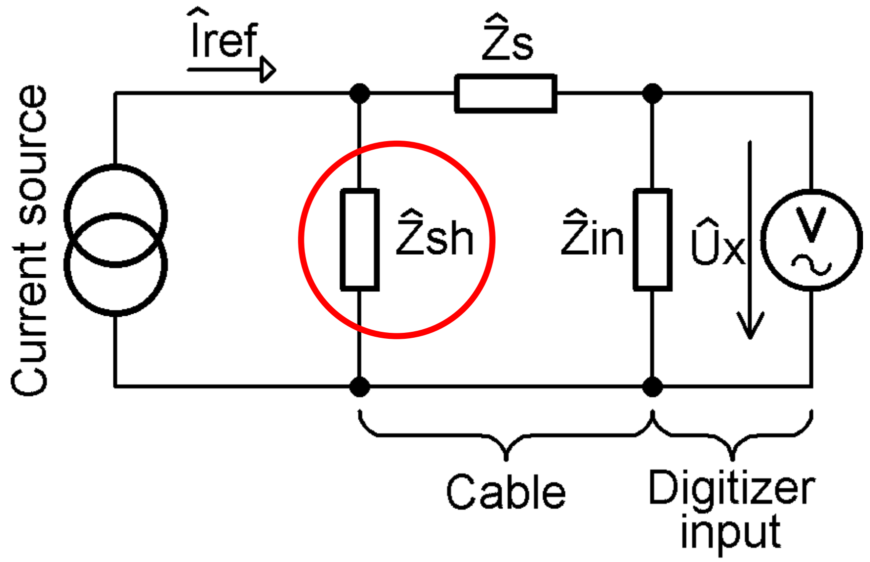
Loading corrections example:

- Shunt impedance Z_{SH} is reduced by parallel impedances (Z_S+Z_{IN}) to effective Z_{SH}':

$$\hat{Z}_{\mathrm{SH}}' = \frac{(\hat{Z}_{\mathrm{S}} + \hat{Z}_{\mathrm{IN}})\hat{Z}_{\mathrm{SH}}}{\hat{Z}_{\mathrm{SH}} + \hat{Z}_{\mathrm{S}} + \hat{Z}_{\mathrm{IN}}}$$

- Actual measured voltage U_X is connected to the shunt via divider Z_S:Z_{IN} with ratio:

$$\hat{k}_{\mathrm{LOAD}} = \frac{\hat{Z}_{\mathrm{IN}}}{\hat{Z}_{\mathrm{S}} + \hat{Z}_{\mathrm{IN}}}$$



Loading corrected current evaluation:

$$\boxed{\hat{I}_{\mathrm{X}} = \hat{U}_{\mathrm{X}} \frac{\hat{Z}_{\mathrm{SH}} + \hat{Z}_{\mathrm{S}} + \hat{Z}_{\mathrm{IN}}}{\hat{Z}_{\mathrm{SH}} \cdot \hat{Z}_{\mathrm{IN}}}}$$

Example:

Z_{SH} = 6 Ω, Z_S = 50 mΩ, Z_{IN} = 1 MΩ || 300 pF, f = 400 Hz

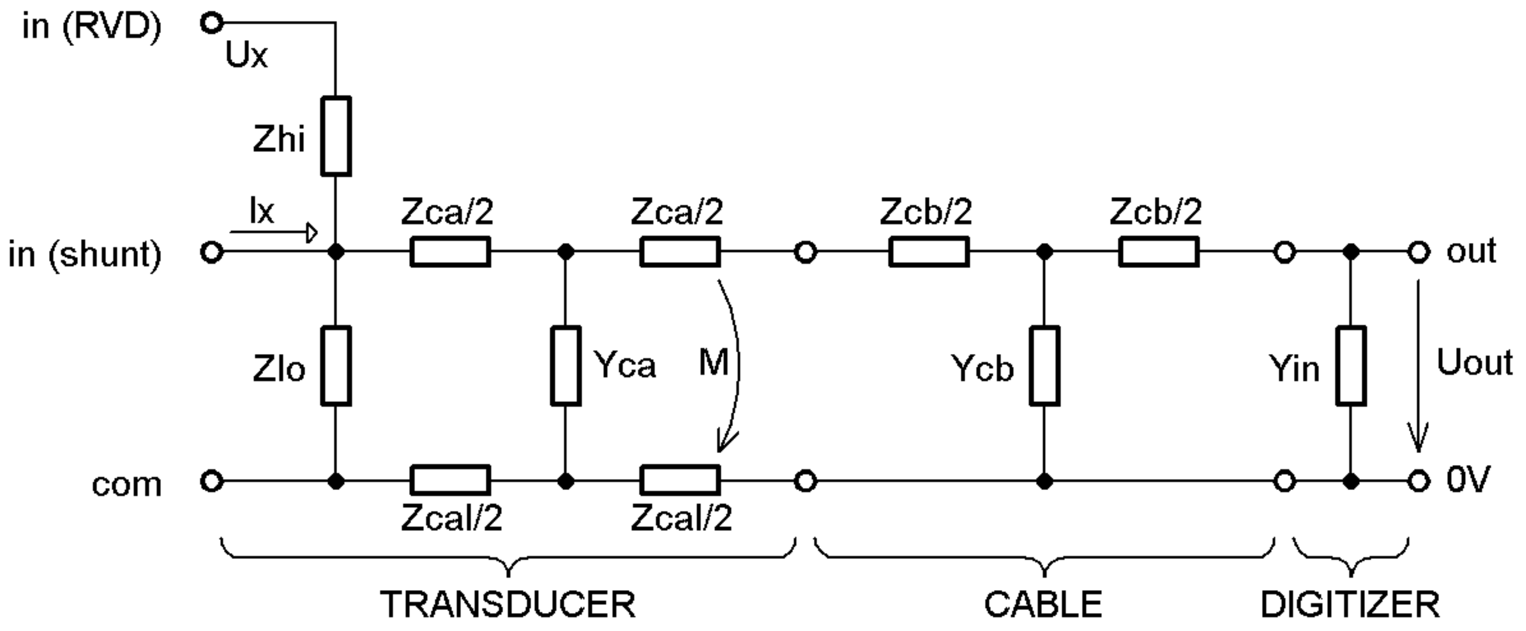
δI_X = +6.05 µA/A, $\Delta\varphi = +4.5\ \mu\mathrm{rad}$

TWM concept – Transducer corrections

Loading corrections:

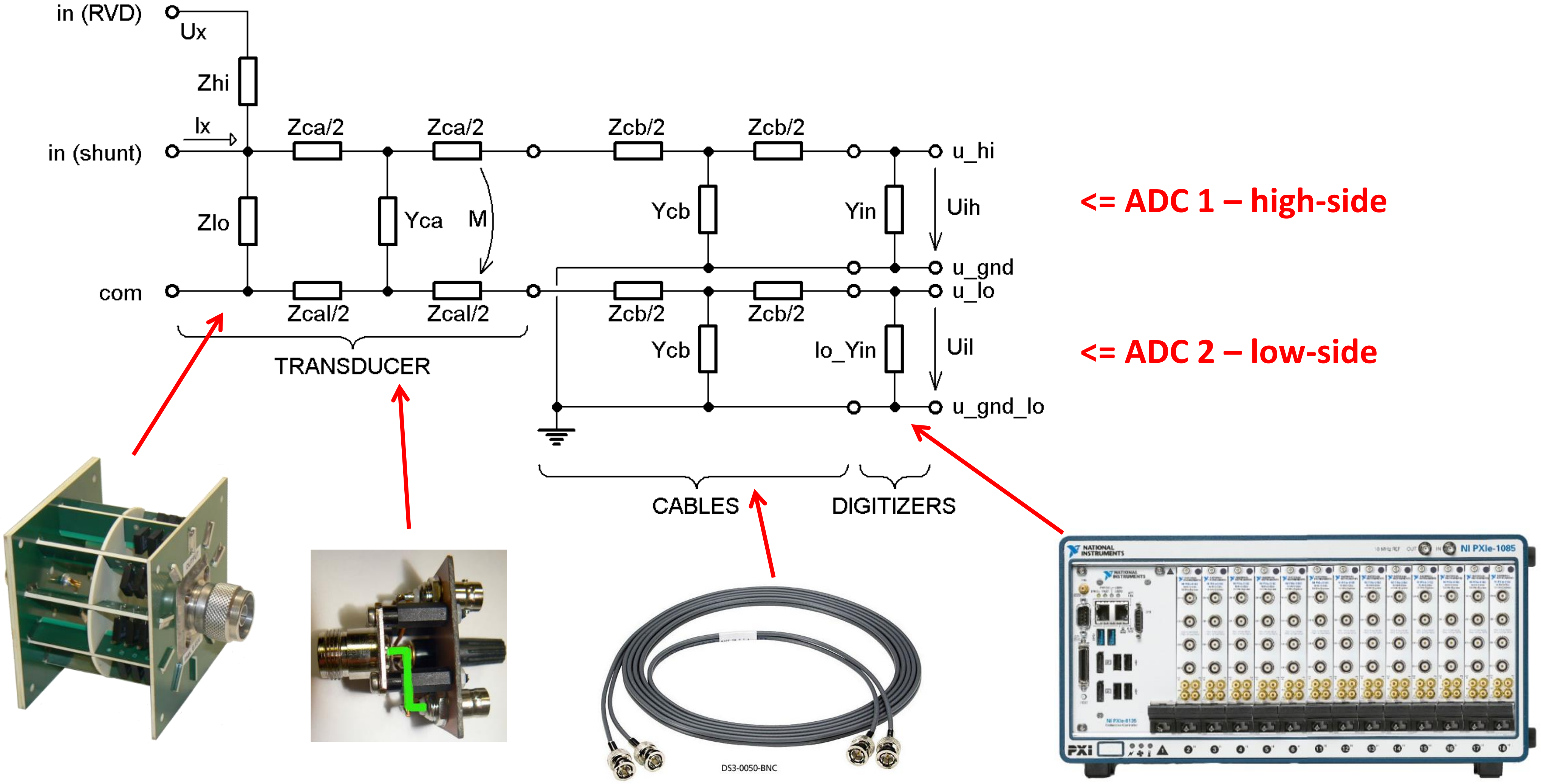
- Corrects effect of cable and digitizer input impedance to transducer transfer
- Requires defined impedance model of interconnections
- Applies mainly at higher frequencies

Single ended transducer loading correction model:



TWM concept – Transducer corrections

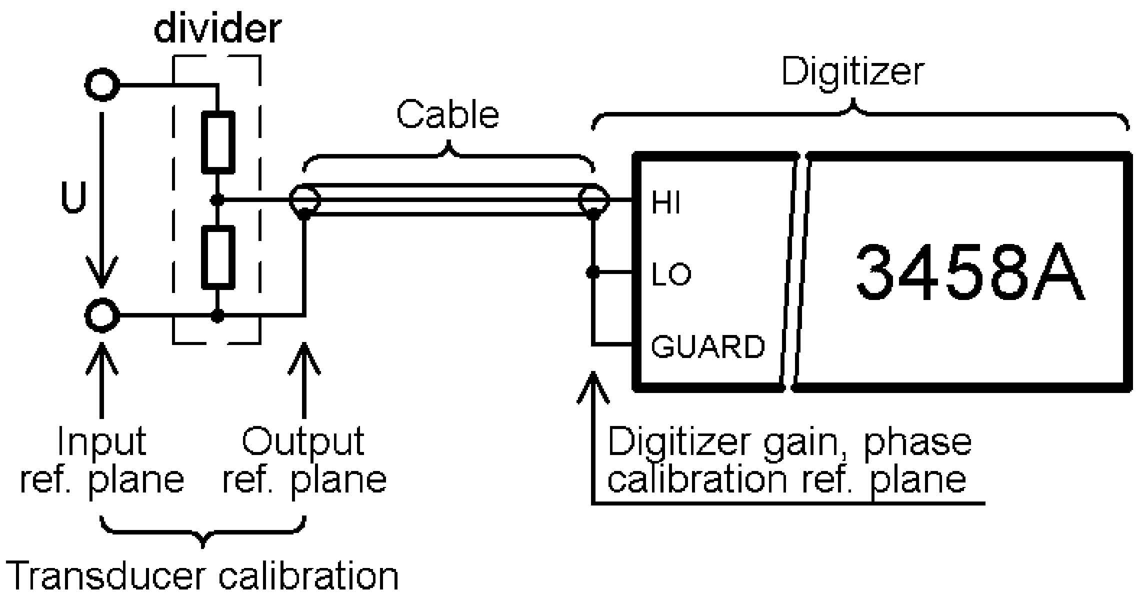
Differential transducer loading correction model:



TWM concept – Calibration concept

Separate transducer, cable and digitizer correction:

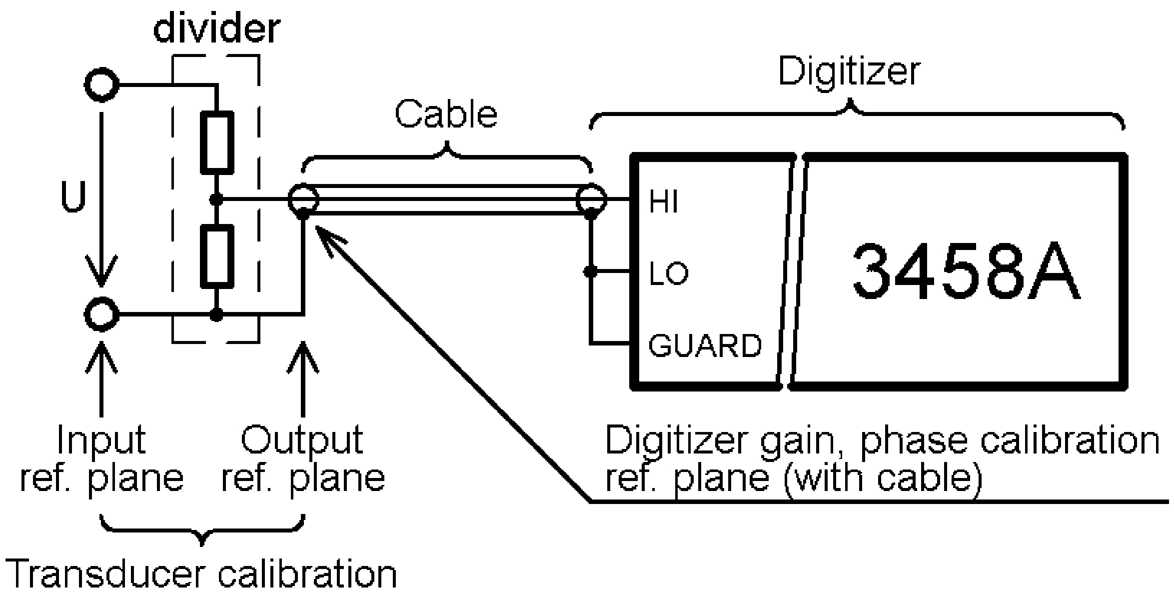
- Allows to use different cables and transducers while digitizer calibration stays unchanged
- Transducer calibrated for no loading condition (*gain*, *phase*, *SFDR*)
- Digitizer calibrated at its terminals (*gain*, *phase*, *offset*, *SFDR*)
- Cable parameters must be defined (part of loading correction)



TWM concept – Calibration concept

No cable calibration:

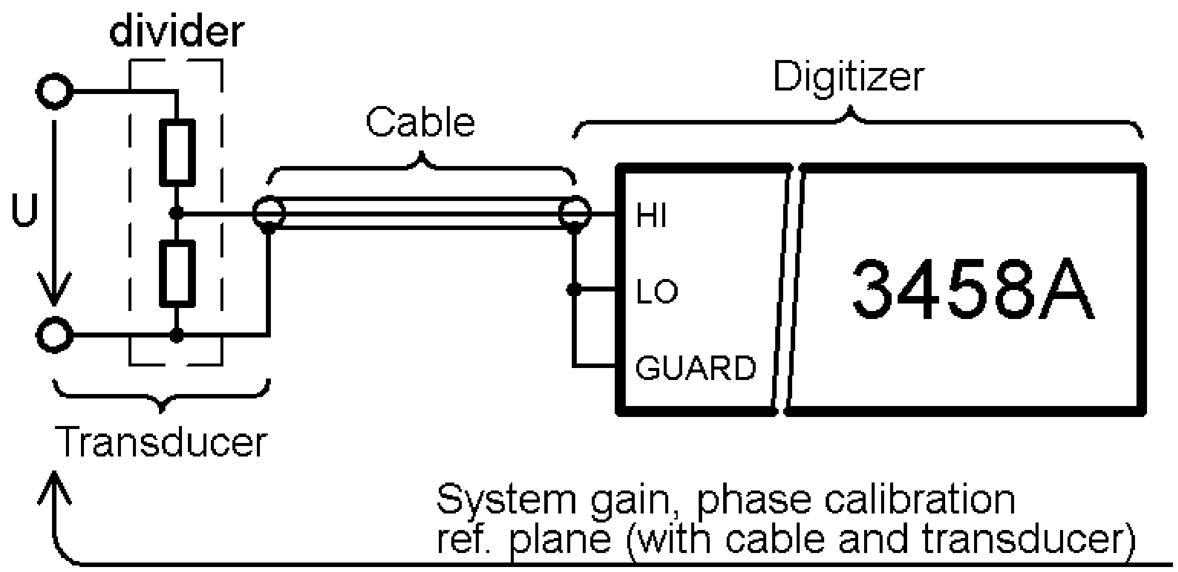
- Digitizer calibrated together with input cable
- The same cable must used for each transducer
- Digitizer+cable *gain*, *phase*, *offset*, *SFDR* are stored to digitizer correction
- Transducer *gain*, *phase*, *SFDR* are stored to transducer correction
- Cable corrections are left undefined (no correction)



TWM concept – Calibration concept

System calibration:

- Simple calibration – transducer, cable and digitizer calibrated together as single device
- Total channel *gain*, *phase*, *offset*, *SFDR* stored to digitizer correction
- Transducer and cable corrections are left undefined (no correction)
- Requires known source of input voltage/current (calibrator or precision voltmeter, e.g. Fluke 5790A)



TWM Algorithms

Coffee time!

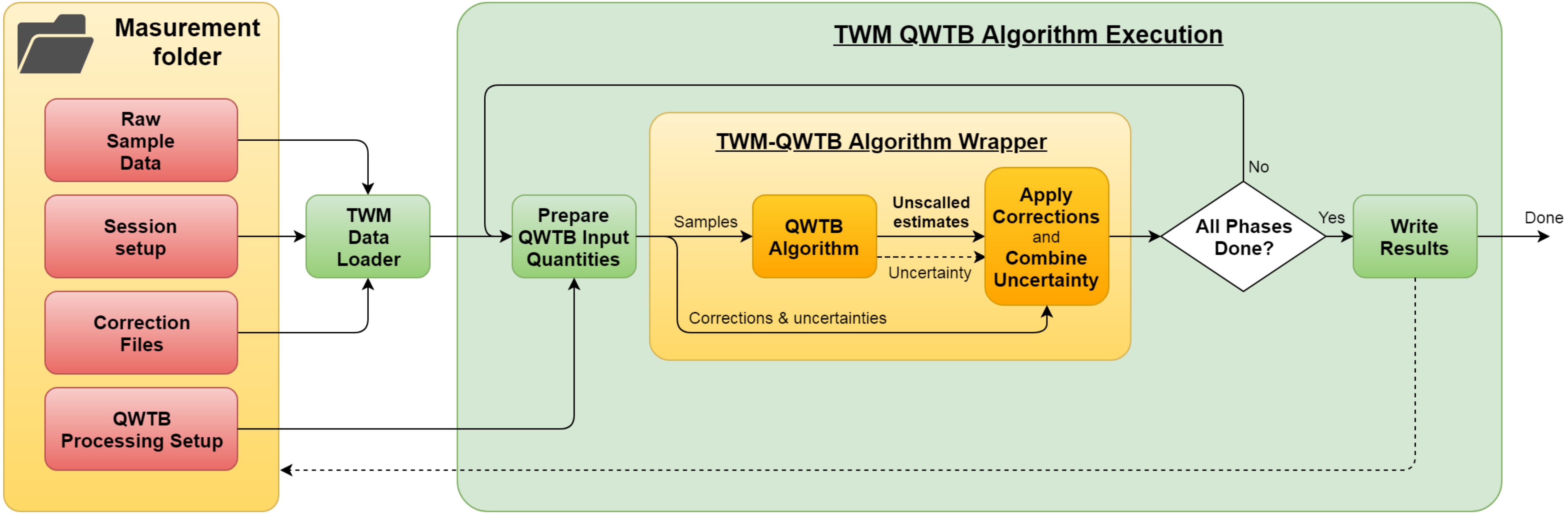
TWM Algorithms

Concept:

- All algorithms are integrated in QWTB toolbox developed in Q-WAVE https://qwtb.github.io/qwtb/
  - Fully transparent (mostly open source)
  - Compatible with Matlab or GNU Octave environments
  - Easy addition of new algorithms

- QWTB Toolbox:
  - Collection of signal processing algorithms
  - Unified format of Input and Output quantities
  - Contains plain algorithms with NO CORRECTIONS

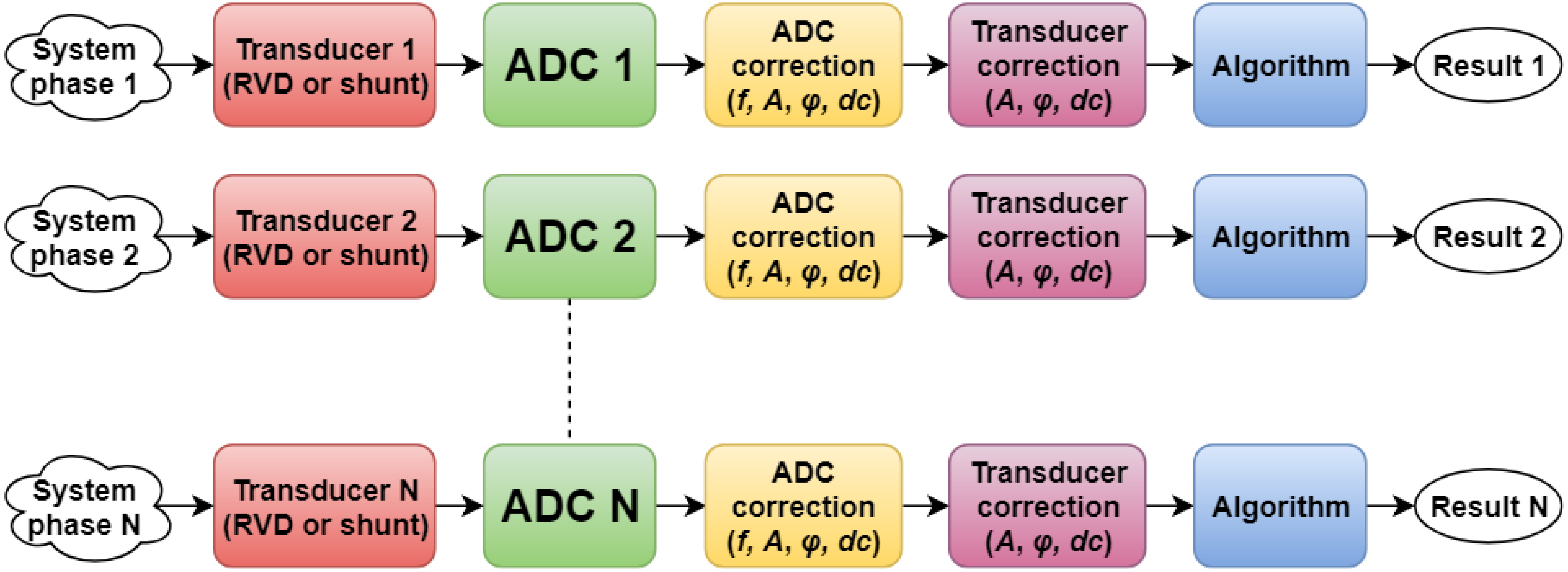
TWM Algorithms



TWM concept – Corrections logic flow

Single channel, multiphase operation:

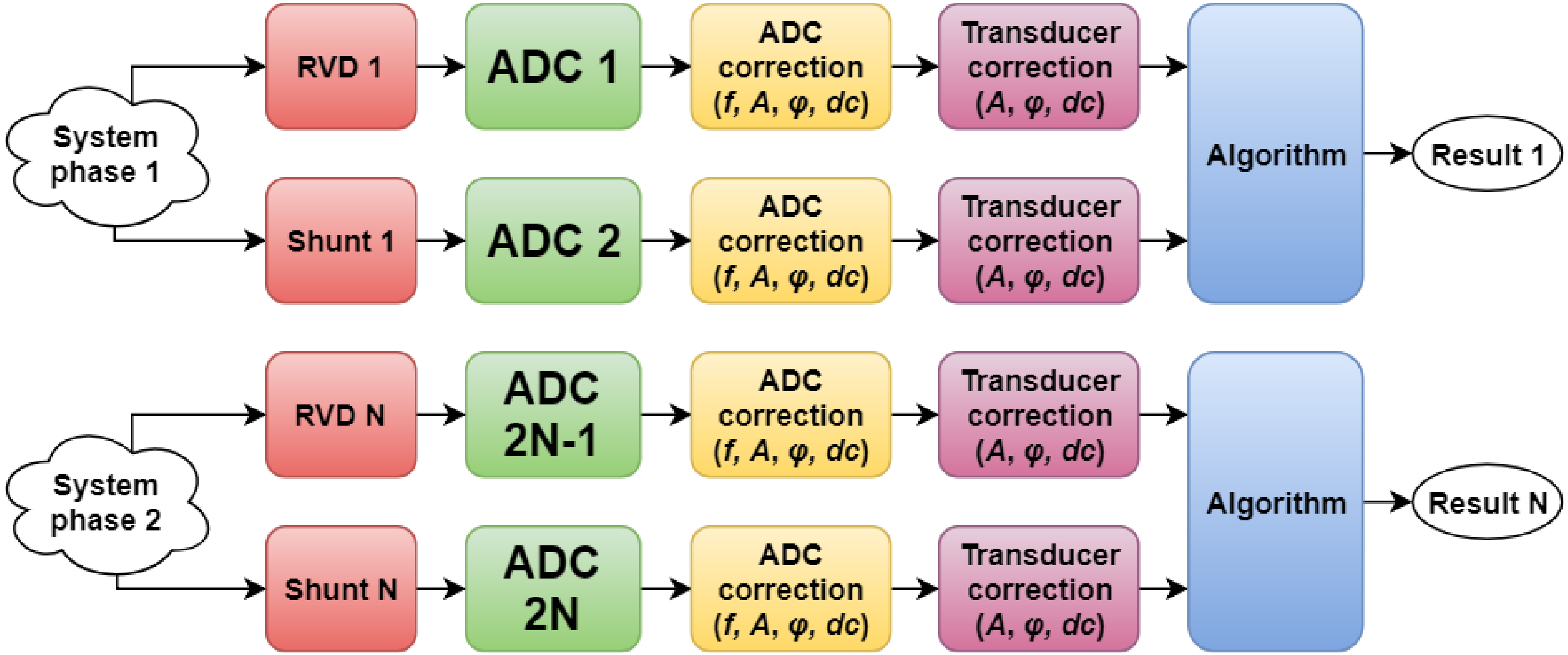
- Each available channel is processed using the same chain of corrections



TWM concept – Corrections logic flow

Multiphase, two input algorithms (power):

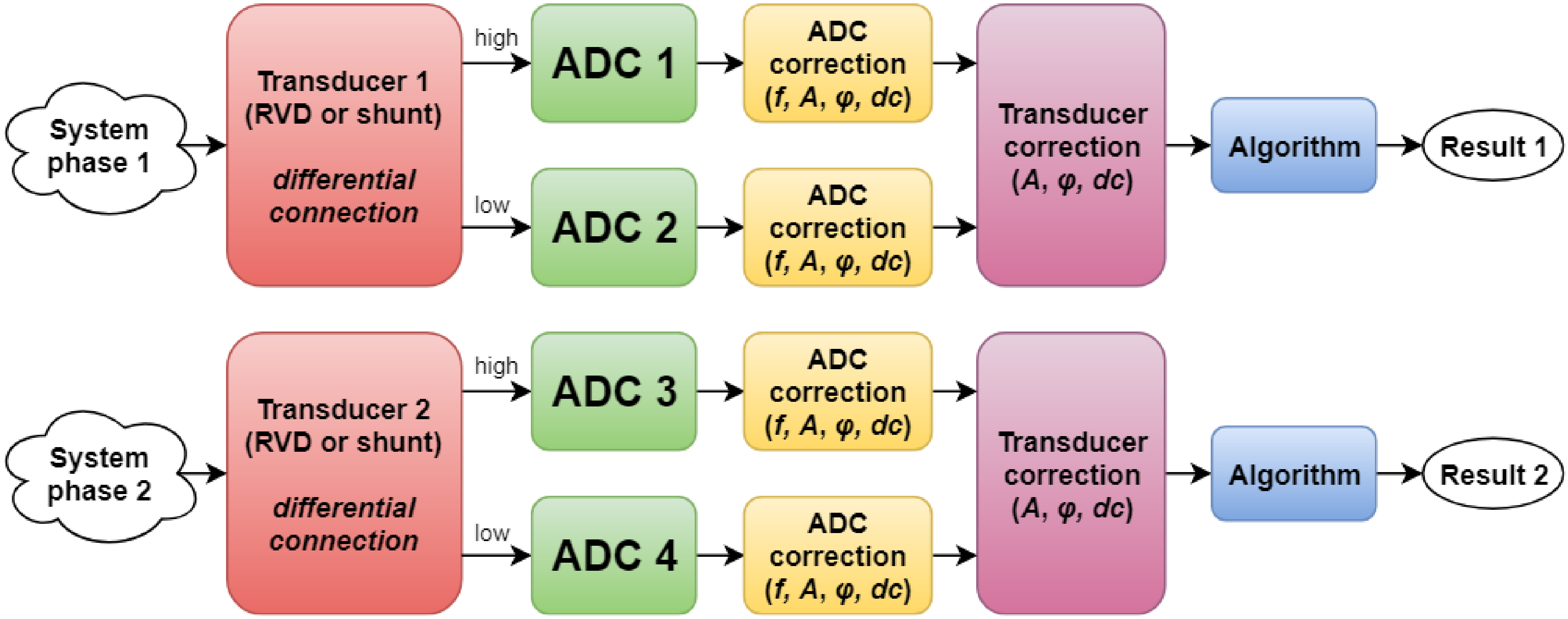
- TWM identifies matching pairs of voltage and current channels for particular phase and applies the same algorithm to all phases



TWM concept – Corrections logic flow

Single channel, multiphase, differential connections:

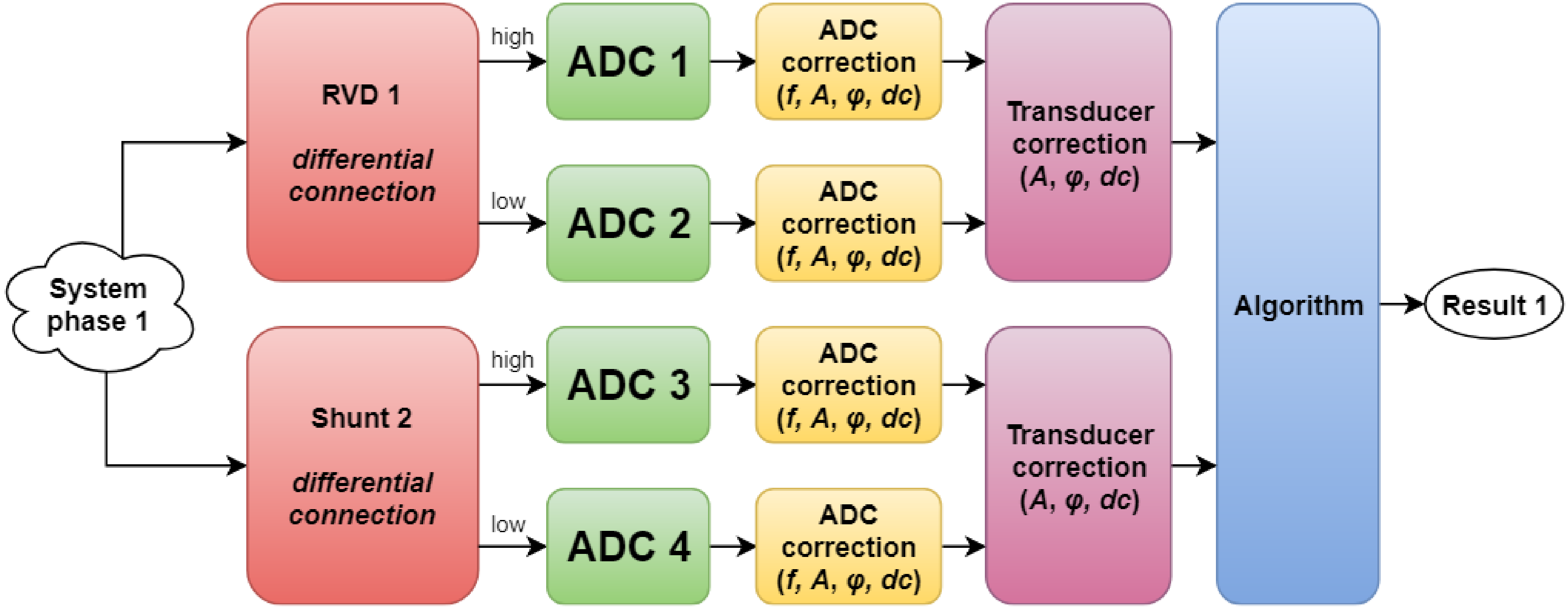
- TWM assigns two channels of digitizer per transducer
- TWM Repeats calculation of selected algorithm for each phase



TWM concept – Corrections logic flow

Multiphase, two input algorithm (power), differential connections:

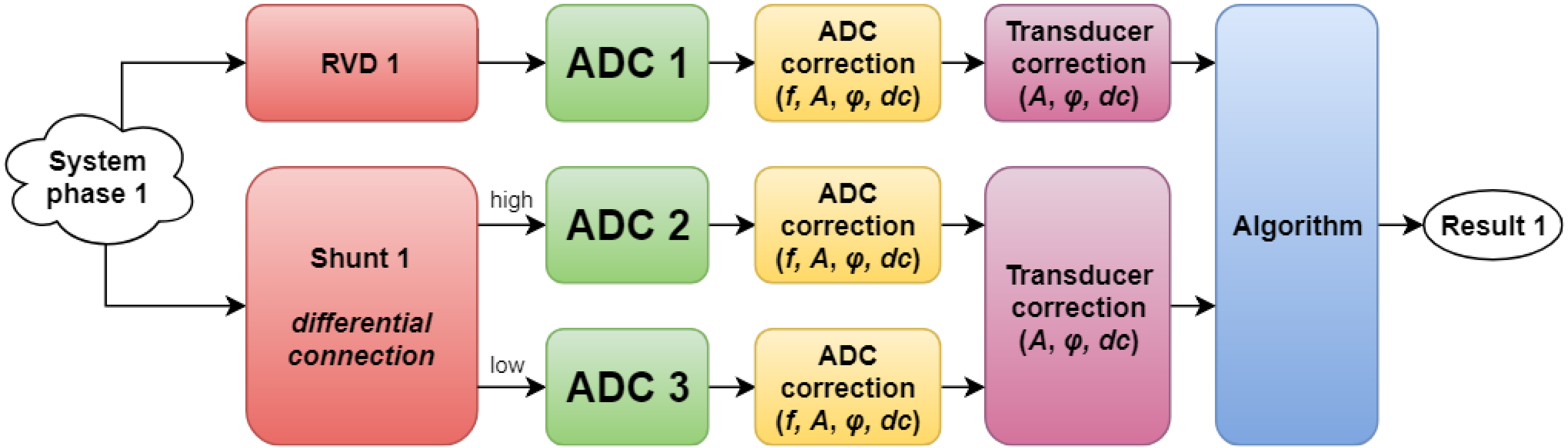
- TWM assigns two channels of digitizer per transducer
- TWM identifies pair of transducers (voltage, current) matching to each phase
- TWM Repeats calculation of selected algorithm for each phase



TWM concept – Corrections logic flow

Multiphase, two input algorithm (power), mixed connections:

- TWM assigns one or two channels of digitizer per transducer (single or differential connection)
- TWM identifies pair of transducers (voltage, current) matching to each phase
- TWM Repeats calculation of selected algorithm for each phase



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  - Fully transparent (mostly open source)
  - Compatible with Matlab or GNU Octave environments
  - Easy addition of new algorithms

- TWM contains QWTB with original PLAIN algorithms (*PSFE*, *WFFT*, …):
  - No corrections and mostly no uncertainty evaluation!

- TWM adds TWM wrappers of the algorithm (*TWM-PSFE*, *TWM-WFFT*, *TWM-WRMS*, …):
  - Implementation of digitizer and transducer corrections and uncertainty evaluation
  - Modifications to cooperate with TWM

TWM Algorithms – General concept

Features:

- Most algorithms for non-coherent sampling (no need for synchronization)
- Robust
- Equipped by uncertainty evaluator:
  - Monte-Carlo (slow, but accurate)
  - Fast estimator based on previous uncertainty analysis (fast, but lower accuracy)

Groups of algorithms:

- Single-harmonic analysis (Sine fitting, PSFE)
- Multi-harmonic analysis (FFT, Multi-harmonic fitting)
- RMS and Power
- Special PQ (Flicker, AM modulation, Half-cycle RMS, Dip/Swell/Interruption)
- Other (“helper” algorithms)

TWM Algorithms – PSFE

PSFE - Phase Sensitive Frequency Estimator:

f, A, φ

- Estimation of fundamental Frequency, Amplitude and Phase angle
- For non-coherent sampling
- Immune to harmonic distortion (up to some level)

- TWM wrapper for single-ended transducers only
  - Differential mode usable for frequency only
- TWM equipped by fast uncertainty estimator for Frequency only

Citation:

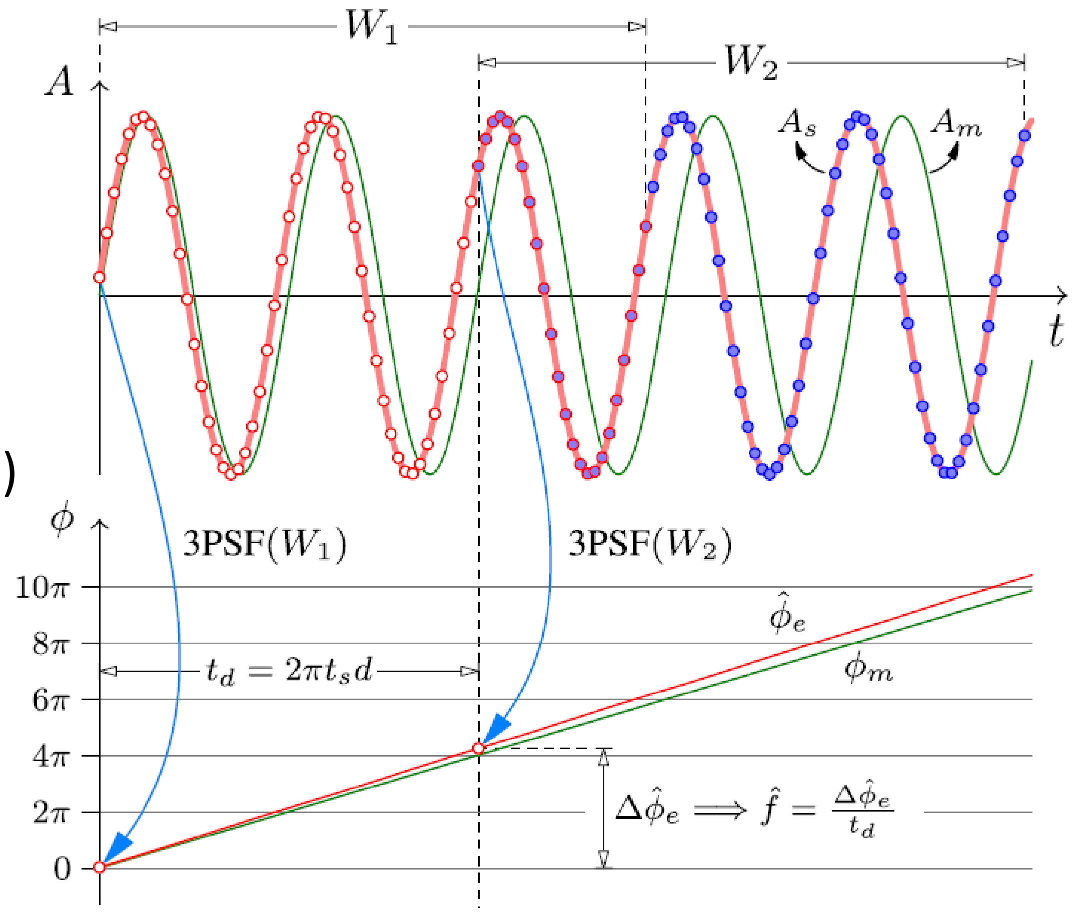
Lapuh, R., "*Estimating the Fundamental Component of Harmonically Distorted Signals From Noncoherently Sampled Data*," Instrumentation and Measurement, IEEE Transactions on , vol.64, no.6, pp.1419,1424, June 2015, doi: 10.1109/TIM.2015.2401211

TWM Algorithms – PSFE

Basic principle:

1. Initial estimate of fundamental frequency

2. Split the record into two parts W_1, W_2
3. Estimation of phase of both parts W_1, W_2 using 3-parameter fitting (3PSF)
4. Changing estimate of frequency and repeat from 3) until phase difference W_1 and W_2 is minimized



TWM Algorithms – FPNLSF (4-Param. Non Linear Sine Fit)

FPNLSF – Four Parameter Non Linear Sine Fit:

f, A, φ, DC

- Fitting of waveform by 4-parameter model: $y_m = o + A \cdot \sin(2\pi \cdot f \cdot t + \varphi)$
- Returns Frequency, Amplitude, Phase angle and DC offset
- For non-coherent sampling
- Highly sensitive to harmonic distortion – only for pure signals
- Needs initial estimate of frequency accurate to 500 ppm
- Needs as much samples per period as possible (ideally > 100)

- TWM wrapper for single-ended and differential transducers
- TWM equipped by fast uncertainty estimator

Citation:

M. Šíra and S. Mašláň, "*Uncertainty analysis of non-coherent sampling phase meter with four parameter sine wave fitting by means of Monte Carlo*," 29th Conference on Precision Electromagnetic Measurements (CPEM 2014), Rio de Janeiro, 2014, pp. 334-335. doi: 10.1109/CPEM.2014.6898395

TWM Algorithms – WFFT (Windowed FFT)

WFFT – Windowed Fast Fourier Transform:

A, φ, DC

- FFT with optional windowing function
- Returns harmonic Amplitude(s), Phase(s), DC offset and RMS estimate
- Designed for coherent sampling:
  - Good choice for inter-channel phase error measurement and amplitude ratio measurement

- Usable for non-coherent in special case:
  - Window functions other than rectangular (e.g. Blackman)
  - Needs sufficient harmonic spacing in the spectrum, e.g. 5 DFT bins for Blackman! (to avoid spectral leakage problems)
  - Measurement amplitude ratio, phase difference
  - Not usable for absolute amplitude measurement!

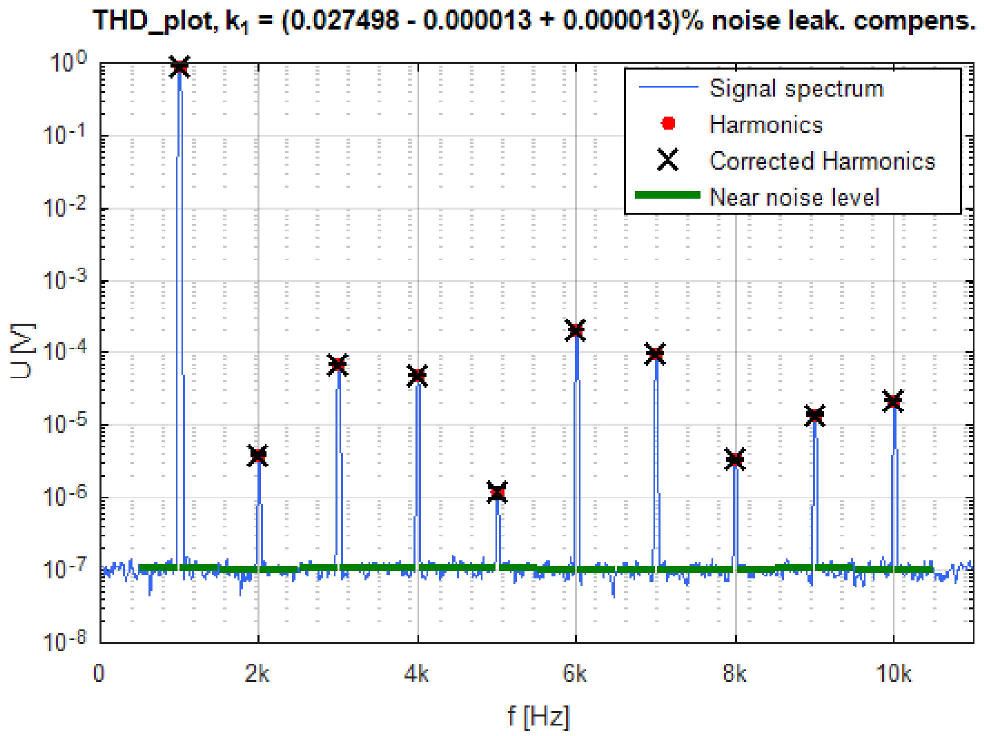
- TWM wrapper for single-ended and differential transducers
- TWM equipped by fast uncertainty estimator

TWM Algorithms – THDWFFT (THD by Windowed FFT)

A, THD

THDWFFT – Total Harmonic Distortion by Windowed Fast Fourier Transform:

- Returns Fundamental frequency, Amplitude(s) and THD estimates
- Additionally returns RMS noise estimate and THD+Noise estimates (no uncertainty)
- Designed for non-coherent sampling
- Uses wide window Flattop 248D:
  - Errors of amplitude estimates down to 50 ppm
  - Requires harmonic spacing at least 30 DFT bins
- Initially designed for low-THD measurement
- TWM wrapper for single-ended transducers only
- TWM equipped by fast Monte Carlo calculator



Citation:

S. Mašláň and M. Šíra, "*Automated non-coherent sampling THD meter with spectrum analyser,*" 29th Conference on Precision Electromagnetic Measurements (CPEM 2014), Rio de Janeiro, 2014, pp. 488-489.
doi: 10.1109/CPEM.2014.6898472

TWM Algorithms – MFSF (Multi Frequency Sine Fitting)

MFSF – Multi Frequency Sine wave Fitting:

- Fitting of signal by multi-harmonic model, non-coherent sampling
- Should produce no bias when all harmonics in the signal fitted
- Can fit inter-harmonics if frequency ratios are known in advance
- Returns Fundamental frequency, Amplitude(s), Phase(s), DC offset and THD estimate

f, A, φ, DC
THD

- TWM wrapper for single-ended transducers only
- TWM equipped by fast uncertainty estimator and Monte Carlo calculator

Citation:

J. Schoukens, R. Pintelon, and G. Vandersteen, "*A sinewave fitting procedure for characterizing data acquisition channels in the presence of time base distortion and time jitter*," IEEE Trans. Instrum. Meas., Vol. 46, No. 4, Aug. 1997, 1005-1010

R. Lapuh, "*Sampling with 3458A*", Left Right d.o.o., September 2018, ISBN 978-961-94476-0-4

TWM Algorithms – WRMS (Windowed RMS)

WRMS – Windowed Root Mean Square:

RMS, DC

- Traditional RMS algorithm improved for better immunity to non-coherent sampling:
  $rms = \sqrt{\frac{\sum_{k=1}^{N} y(k)^2 w(k)^2}{\sum_{k=1}^{N} w(k)^2}}$, where *w()* is window function and *N* number of samples
- Returns RMS and DC offset
- Uses Blackman-Harris window:
  - Error of the algorithm drops below ppm level when at least 8 periods of signals recorded
- Operates in time-domain

- TWM wrapper for single-ended and differential transducers
- TWM equipped by fast uncertainty estimator and Monte Carlo

Citation:

R. Lapuh, B. Voljc, M. Kokalj, B. Pinter, Z. Svetik and M. Lindic, "*Measurement of repetitive arbitrary waveform RMS value*," 29th Conference on Precision Electromagnetic Measurements (CPEM 2014), Rio de Janeiro, 2014, pp. 420-421. doi: 10.1109/CPEM.2014.6898438

TWM Algorithms – PWRTDI (Windowed RMS Power)

PWRTDI – Power using Time Domain Integration:

- Extension of traditional power in time-domain for non-coherent sampling:

  $P = \sqrt{\frac{\sum_{k=1}^{N} u(k)i(k)w(k)^2}{\sum_{k=1}^{N} w(k)^2}}$, where *w()* is window function and *N* number of samples
- Returns P, S, Q, PF, U_{RMS}, I_{RMS}, DC power, DC U, DC I
- Works in all 4 quadrants – detects quadrant using auxiliary FFT analysis:
  - Quadrant detection may fail for low power factors
- Uses Blackman-Harris window:
  - Error of the algorithm drops to ppm level when at least 30 periods of signals recorded
- TWM wrapper for single-ended and differential transducers
- TWM equipped by fast uncertainty estimator and Monte Carlo

RMS, DC

P, Q, S, PF

Citation:

K. B. Ellingsberg, "*Predictable maximum RMS-error for windowed RMS (RMWS),*" 2012 Conference on Precision electromagnetic Measurements, Washington, DC, 2012, pp. 308-309. doi: 10.1109/CPEM.2012.625092

TWM Algorithms – PWRTDI (Windowed RMS Power)

PWRTDI – Definitions of quantities:

Table 33: Definitions of the TWM-PWRTDI output quantities based on the basic quantities U, I, P, U_dc and I_dc. Note the input quantities marked * are obtained from the other output quantity.

Returned quantity	AC coupled definition	DC coupled definition
DC voltage Udc	U_dc	U_dc
DC current Idc	I_dc	I_dc
DC power component Pdc	$U\_dc \cdot I\_dc$	$U\_dc \cdot I\_dc$
RMS voltage U	U	$\sqrt{U^2 + U\_dc^2}$
RMS current I	I	$\sqrt{I^2 + I\_dc^2}$
Active power P	P	$P + U\_dc \cdot I\_dc$
Reactive power Q	$\sqrt{(UI)^2 - P^2} \cdot \mathrm{sign}(Q\_\mathrm{bud})$	$\sqrt{(UI)^2 - P^2} \cdot \mathrm{sign}(Q\_\mathrm{bud})$
Apparent power S	$(UI)^2$	$\sqrt{U^2 + U\_dc^2} \cdot \sqrt{I^2 + I\_dc^2}$
Power factor PF	$P/S*$	$P/S*$
Effective phase angle phi_ef	$\mathrm{atan2}(Q*, P)$	$\mathrm{atan2}(Q*, P)$

Budenau's definition of reactive power:

$$Q\_\mathrm{bud} = \sum_{h=1}^{H} (0.5 \cdot U(h) \cdot I(h) \cdot \sin\phi(h)),$$

TWM Algorithms – PWRFFT (FFT-based Power)

PWRFFT – Power using FFT:

- Power algorithm for coherent sampling
- Returns P, S, Q, PF, U_{RMS}, I_{RMS}, DC power, DC U, DC I
- Works in all 4 quadrants
- AC/DC coupling

- TWM wrapper for single-ended and differential transducers
- TWM equipped by fast uncertainty estimator

RMS, DC

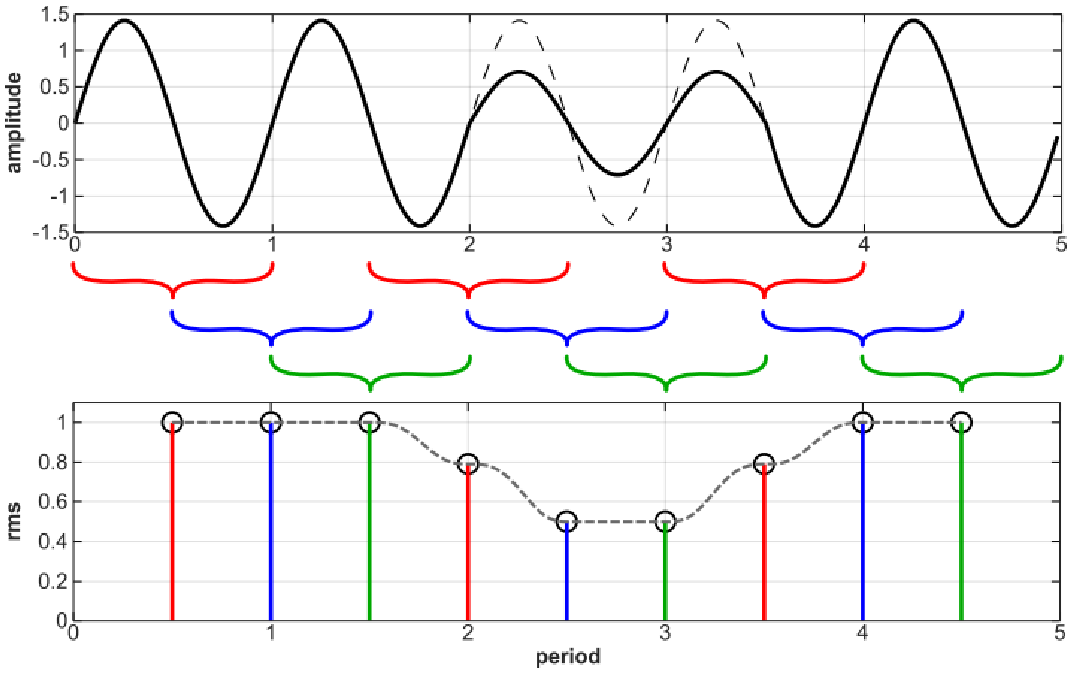
P, Q, S, PF

TWM Algorithms – HCRMS (Half-Cycle RMS)

HCRMS – Half-Cycle RMS:

HC-RMS

- Calculation of so called "Half Cycle" RMS value according IEC 61000-4-30
  - A class (half-cycle step) or S class (sliding window)
- Designed for non-coherent sampling (resamples the signal to coherent internally)
- Returns RMS level envelope as a function of time
- Usable to several PQ tests:
  - Mainly Dip, Swell, Interruption
- Requires as many as possible samples per period
- TWM wrapper for single-ended transducers only
- TWM equipped by fast uncertainty estimator



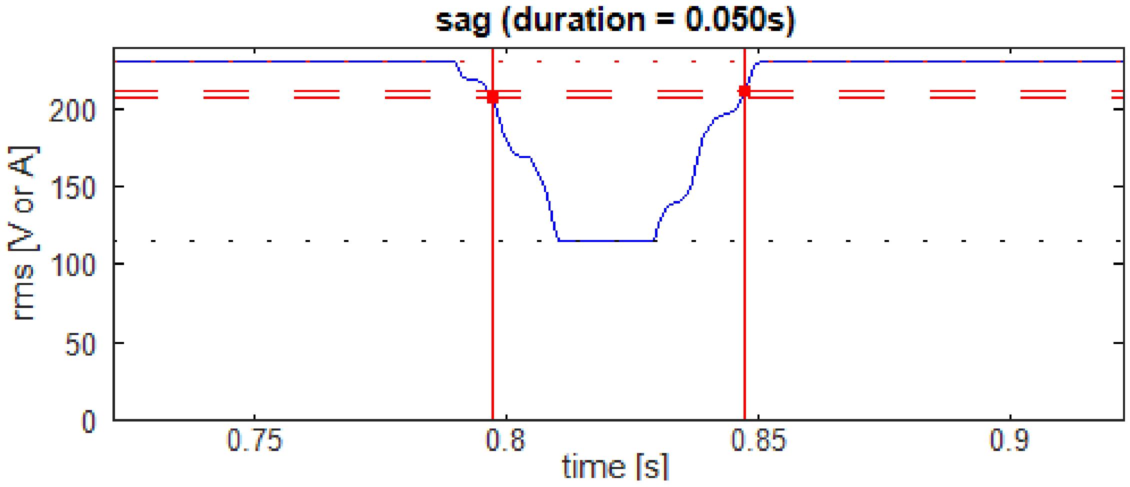
TWM Algorithms – InDiSwell (Interrupt, Dip, Swell)

InDiSwell – Interruption Dip Swell detector:

- Detection of event according IEC 61000-4-30 in A class (half-cycle step) or S class (sliding window):
  - Dip (Sag) – decrease of RMS
  - Swell – increase of RMS
  - Interruption – severe decrease of RMS (below 10% of nominal)
- Designed for non-coherent sampling (resamples the signal to coherent internally)
- Returns Duration of event, Relative event start time, Residual level
- Configurable Thresholds, Hysteresis

- TWM wrapper for single-ended transducers only
- TWM equipped by fast uncertainty estimator

HC-RMS
Dip, Swell
Interruption



TWM Algorithms – Flicker

Pst, Pinst

Flicker – Flicker detector:

- Detection of P_{ST} according IEC 61000-4-15
- Designed for non-coherent sampling
- Returns P_{INST}, P_{ST}
- Automatic resampling to optimal sampling rate
- Warning - Slightly different results in Matlab and GNU Octave
- Requires long record – at least 11 minutes of continuous record with sampling rate higher than 7 kSa/s

- TWM wrapper for single-ended transducers only
- TWM equipped by fast uncertainty estimator

Citations:

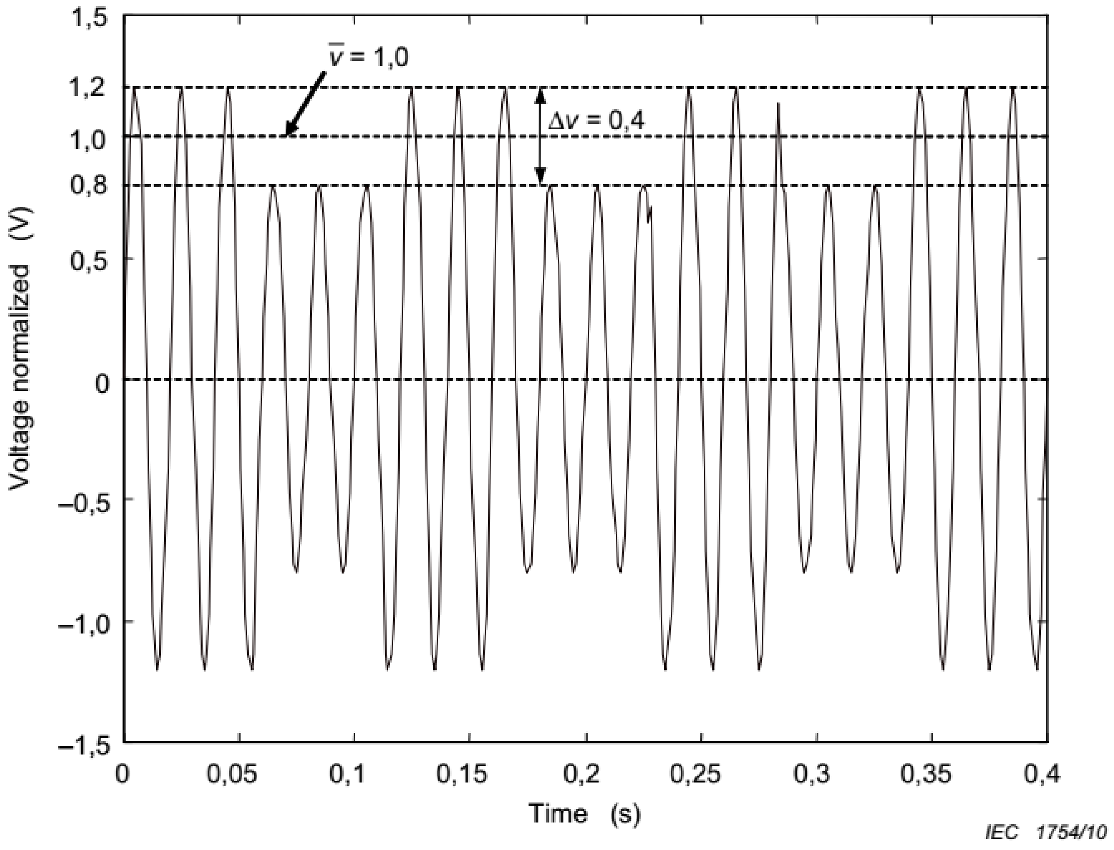
- IEC 61000-4-15, Electromagnetic compatibility (EMC), Testing and measurement techniques, Flickermeter, Edition 2.0, 2010-08
- Wilhelm Mombauer: "Messung von Spannungsschwankungen und Flickern mit dem IEC-Flickermeter", ISBN 3-8007-2525-8, VDE-Verlag
- Solcept Open Source Flicker Measurement-Simulator https://www.solcept.ch/en/tools/flickersim/
- NPL Reference Flickermeter Design http://www.npl.co.uk/electromagnetics/electrical-measurement/products-and-services/npl-reference-flickermeter-design

TWM Algorithms – Flicker

Definitions:

- P_{ST} – Short Term Flicker Severity:
  - Expresses human perceptibility to flickering light source
- ΔV/V (or ΔU/U) – modulation depth
- CPM – Changes Per Minute:
  - Different expression of modulating frequency f_M: CPM = $120 \cdot f_M$

Definition of ΔV/V:



Source: IEC 61000-4-15

TWM Algorithms – Flicker

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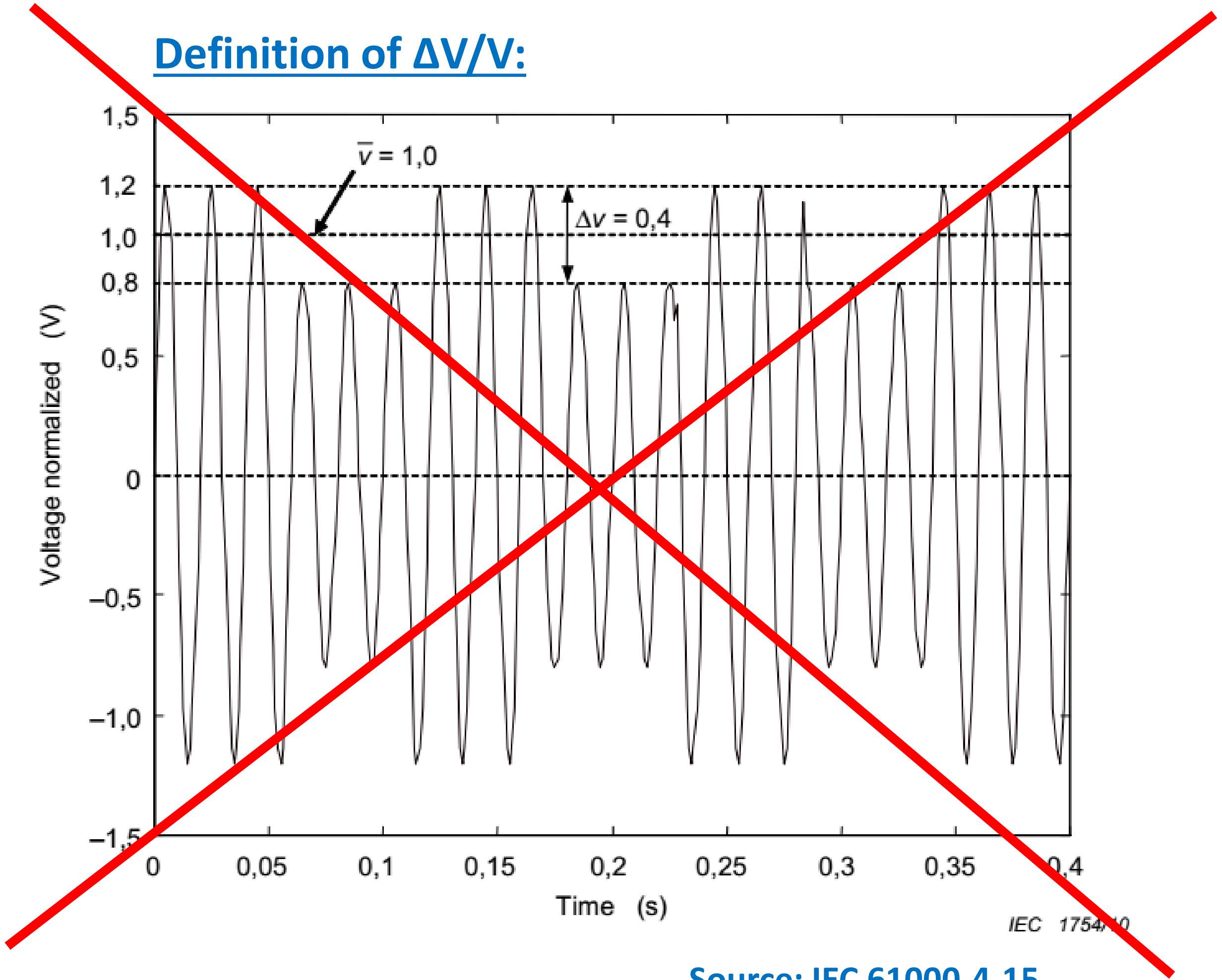
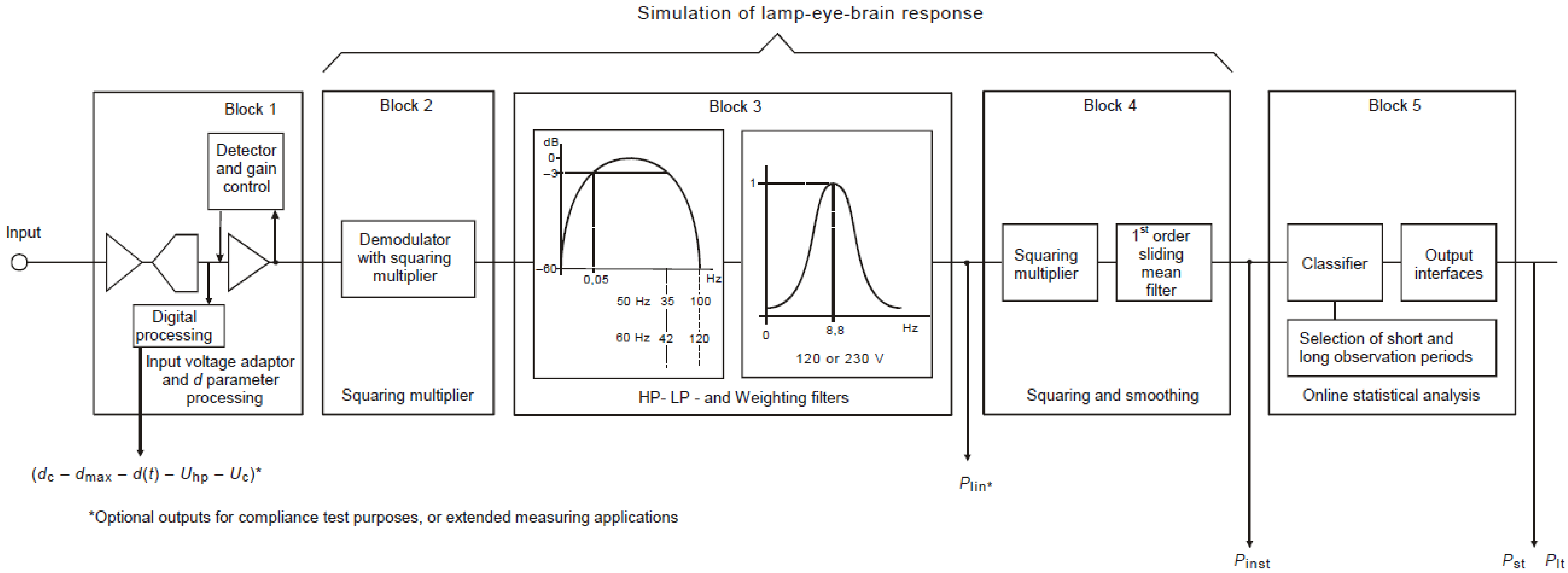
Definition of ΔV/V:



Source: IEC 61000-4-15

TWM Algorithms – Flicker

Flicker calculation according IEC 61000-4-15:



Source: IEC 61000-4-15

TWM Algorithms – Flicker

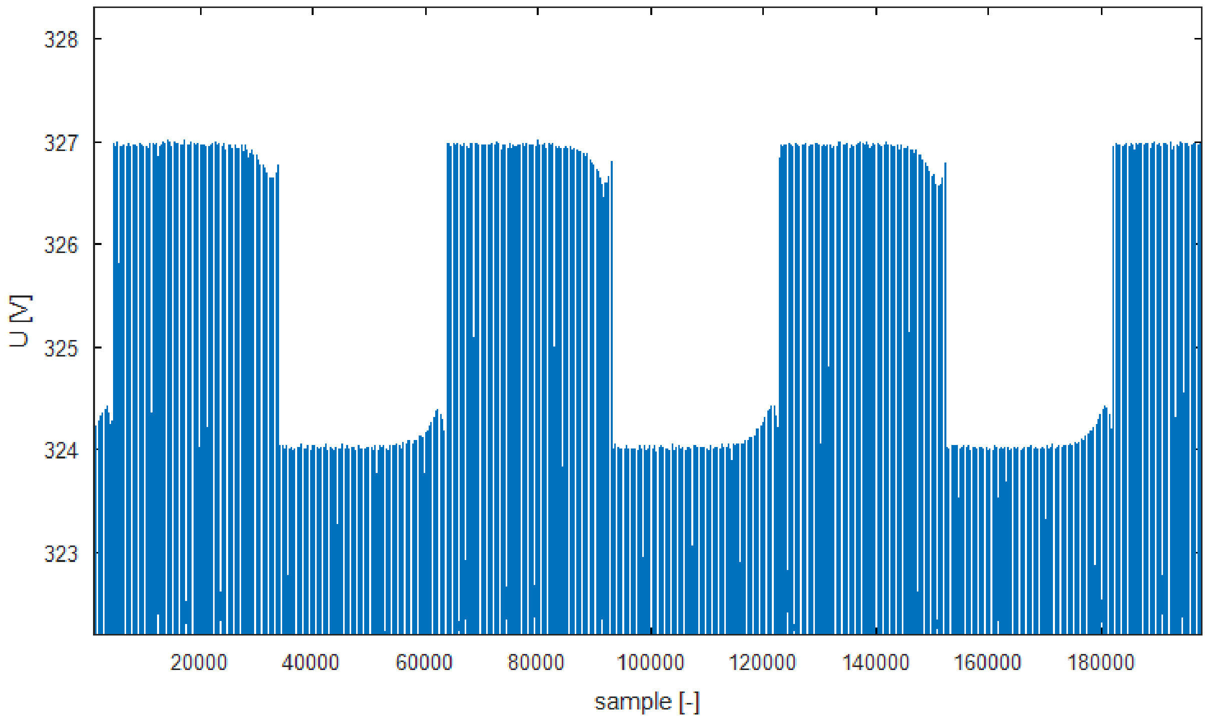
Hint for calibration:

- Manufacturers of calibrators uses two approaches:
  - Define CPM, dVV and shape of modulation, optionally shows user corresponding P_{ST} value
  - Select preset value of P_{ST} from a list

- Manufacturer may expect ideal shape:
  - Not always the case (see example)
  - The displayed value of P_{ST} may be incorrect because it is calculated from expected shape
  - Rather evaluate CPM and dVV instead

- See waveform whenever the measured P_{ST} does not match the set value

Actual measurement of Flicker modulation on calibrator:



TWM Algorithms – MODTDPS (AM modulation estimator)

MODTDPS – AM Modulation from quadrature Time Domain Phase Shift:

- Measurement of amplitude modulation parameters for sine or rectangular modulation of sine carrier
- Alternative to Flicker algorithm when evaluating just ΔV/V and CPM
- Designed for non-coherent sampling
- Based on complex analytical signal:

  $\hat{y}_m(t) = y(t) + j \cdot y\left(t + \frac{\pi}{2 \cdot f0}\right)$, where f_0 is carrier frequency
- Returns: Carrier frequency, Carrier amplitude, Modulating frequency, Modulating amplitude, Modulation envelope, dVV and CPM

- TWM wrapper for single-ended and differential transducers
- TWM equipped by fast uncertainty estimator only for single-ended case

ΔV/V, CPM

f_0, A_0, f_m, A_m