

## 17RPT03 DIG-AC

A digital traceability chain for AC voltage and current

# WP3 – Data processing and uncertainty estimation for quick integration

CMI & CEM - Final meeting

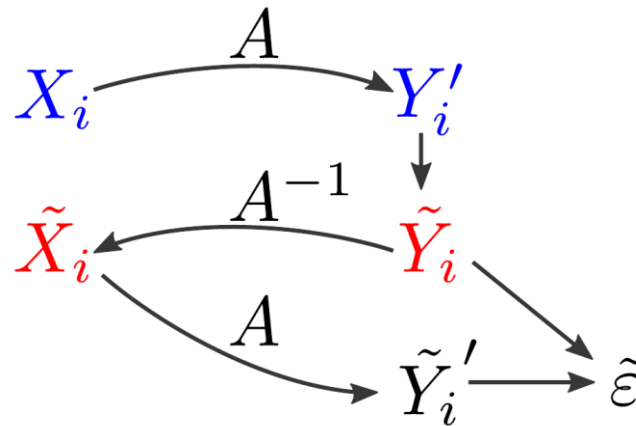
Madrid 19/05/2022

## WP3 – Data processing and uncertainty estimation for quick integration

- Task 3.1: Common data format and required software structure
- Task 3.2: Study of suitable algorithms
- Task 3.3: Uncertainty estimation
- Task 3.4: Integrated software for data processing and uncertainty estimation

# General description of algorithm errors

- Description of estimation of algorithm errors and its estimation
- Precalculation of uncertainties



## New part of QWTB: QWTBvar

- varyate input quantities or its uncertainties,
- calculate errors of output quantities to the nominal values,
- plot dependence of output quantities on the variated input quantitates or its uncertainties,
- create lookup table of uncertainties of output quantities,
- interpolate the lookup table for quick estimation of uncertainties.

## New part of QWTB: QWTBvar

- Variation of input quantities or its uncertainties
- inputs: algorithm, input Q, varied Q
- outputs: file name with results

```
[jobfn] = qwtbvar(algid , datain , datainvar , calcset )
```

- Plotting
- inputs: results, what to plot
- outputs: figure

```
[H] = qwtbvar(jobfn , varx , vary , varz )  
[H, x, y, z] = qwtbvar(jobfn , varx , vary , varz )
```

## New part of QWTB: QWTBvar

- LUT building
- inputs: results, axis of LUT
- outputs: LUT

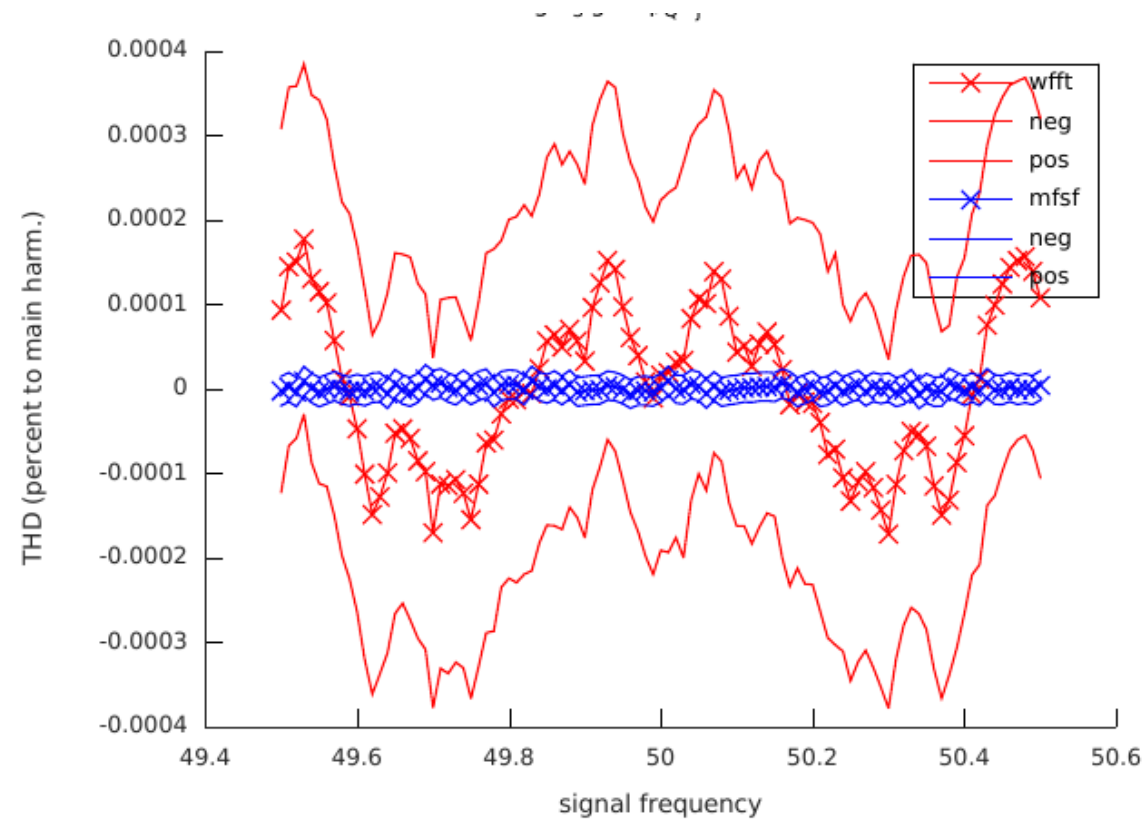
```
lut = qwtbvar('lut', jobfn, ax_set_lut, rqset_lut)
```

- Interpolation of LUT:
- inputs: LUT, interpolation point
- outputs: uncertainty

```
unc = qwtbvar('interp', lutfn, axip);
```

# QWTBvar example

- Example for comparison of two algorithms:



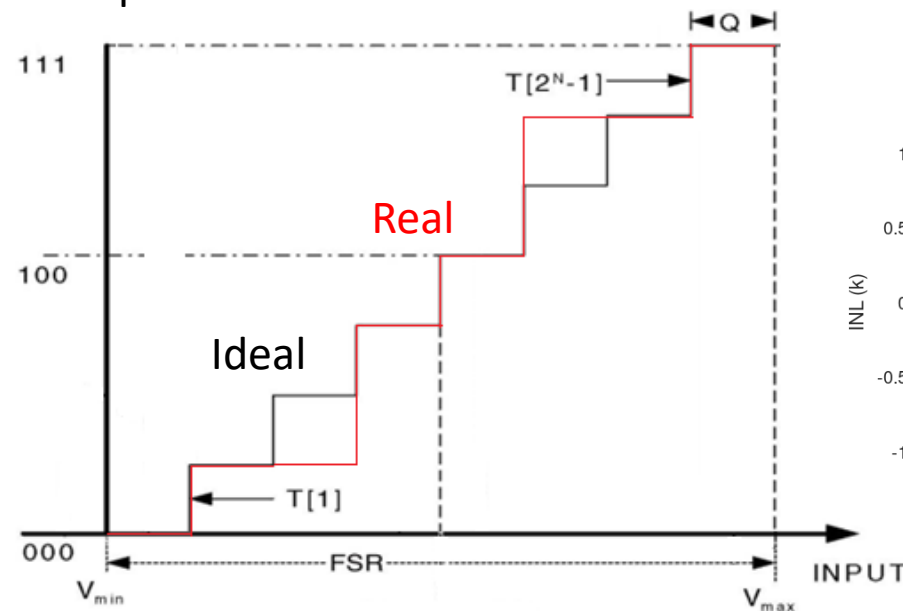
## QWTBvar example

Generation of look up table for **SFDR** algorithm:

- Preparation of waveform generator.
- Selecting values of quantities.
- Calculation of uncertainty propagation through algorithm.
- Generation of LUT and adding into the algorithm.

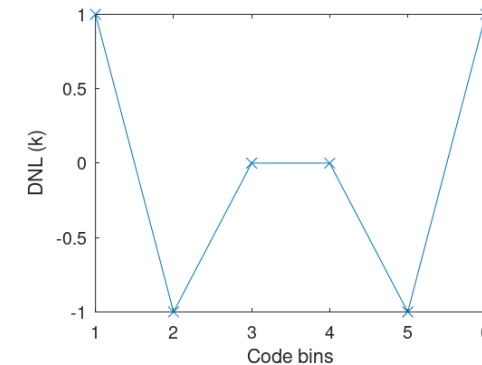
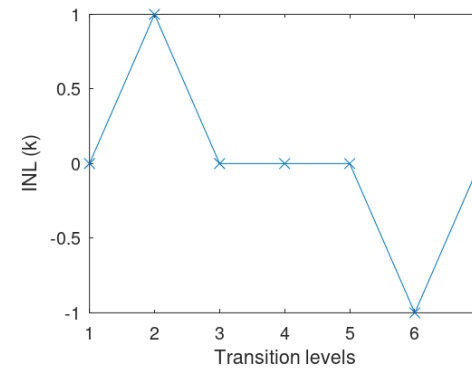
- INL: Integral non-linearity
  - Difference between ideal and measured **code transition levels**
- DNL: Differential non-linearity
  - Difference between **code bin width** and ideal code bin width

Example 3 bits:

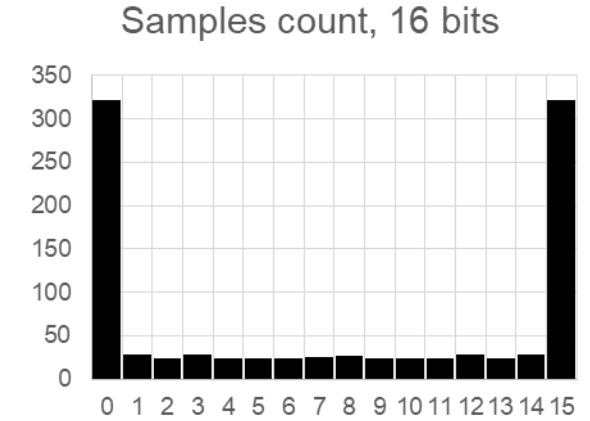
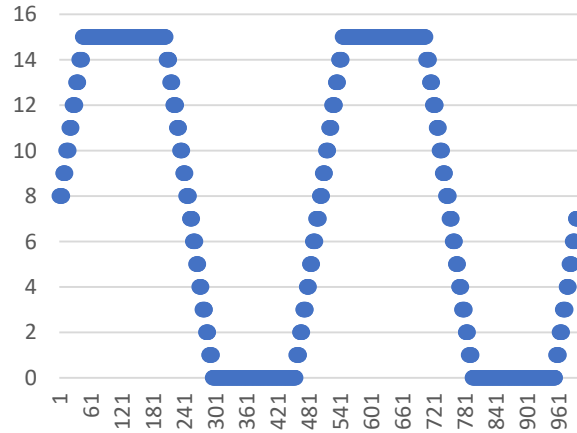
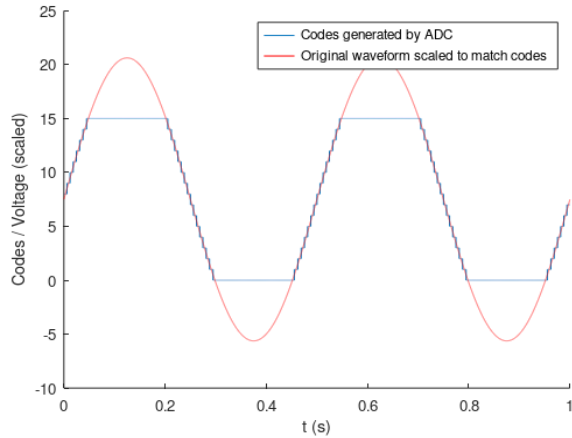


$$\text{INL} \approx [0 \ 1 \ 0 \ 0 \ 0 \ -1 \ 0]$$

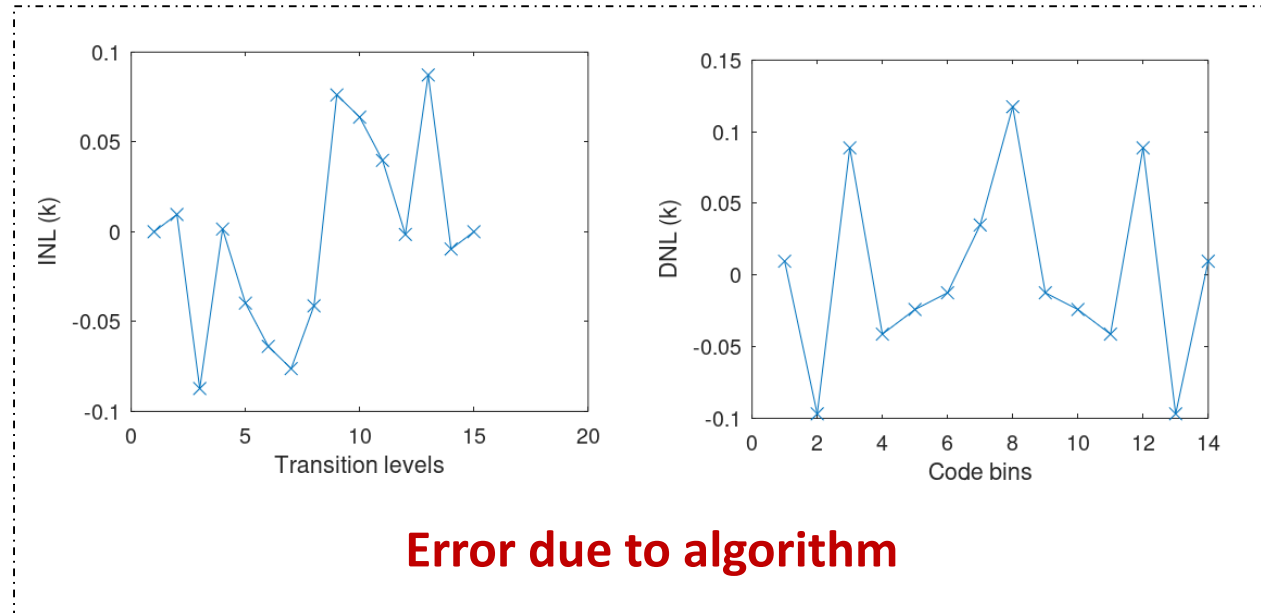
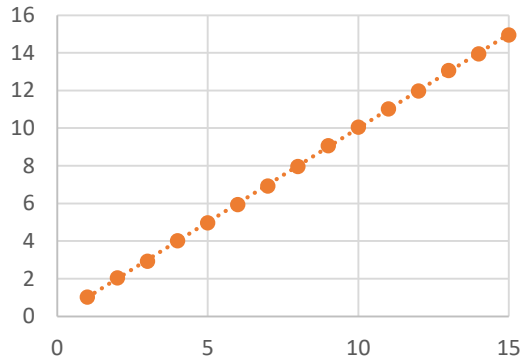
$$\text{DNL} \approx [1 \ -1 \ 0 \ 0 \ -1 \ 1]$$



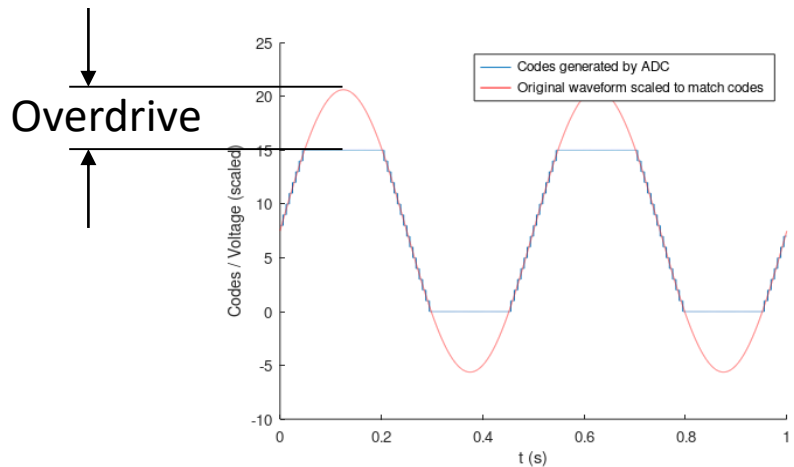
- Code transition location method: sine-wave histogram



Ideal vs Real



Influence variables:  $INL = f\left(\frac{f_s}{f_i}, \text{overdrive, bits, noise, INL, } m\right)$



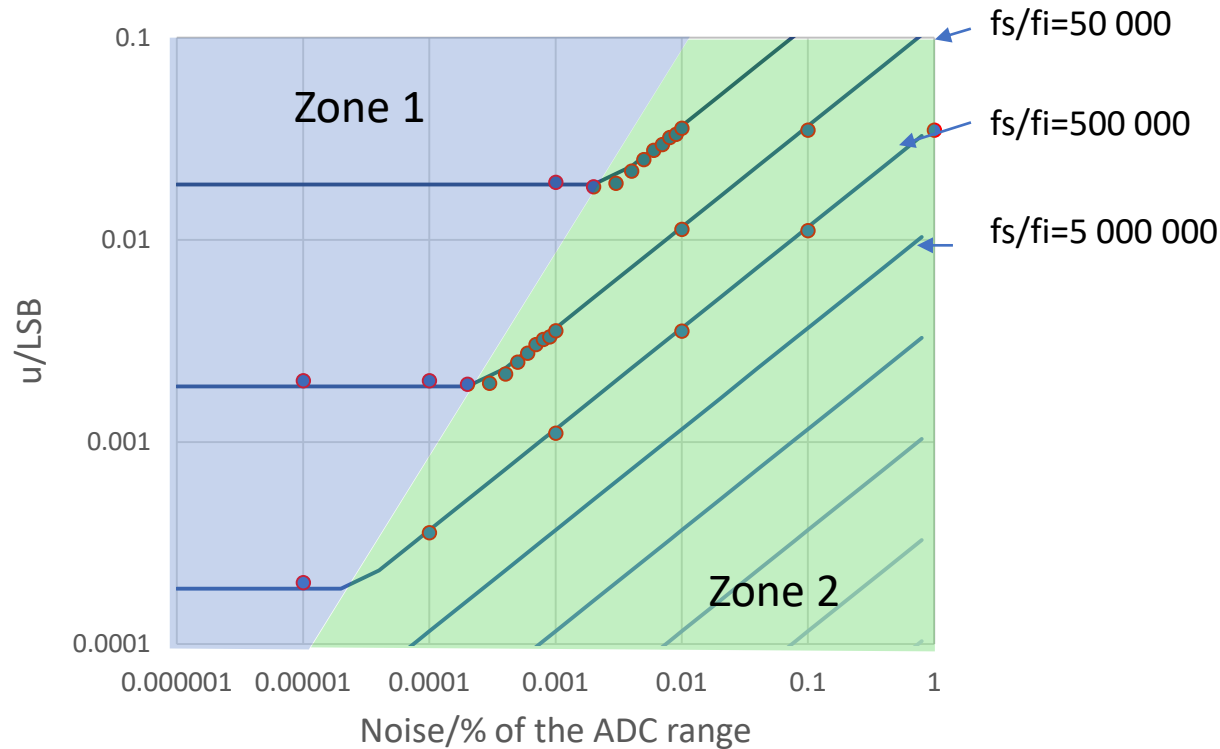
Sampling frequency/Input signal frequency

Noise: input signal noise: white noise

Number of periods

- Procedure to calculate algorithm error/uncertainty
  - Simulation from example included in qwtb
  - Input: Ideal waveform with INL and DNL varied from -1 to 1
  - Vary influence variables to calculate error/uncertainty

**Just uncertainty of the input signal (noise) is significant**



$$u = C \sqrt{\frac{\text{Noise}}{f_s/f_i}} \frac{1}{\sqrt{m}} f(O_v)$$

Zone 1: 
$$C = \frac{1.162(2^N - 1)}{\sqrt{\text{Noise} \cdot f_s/f_i}}$$

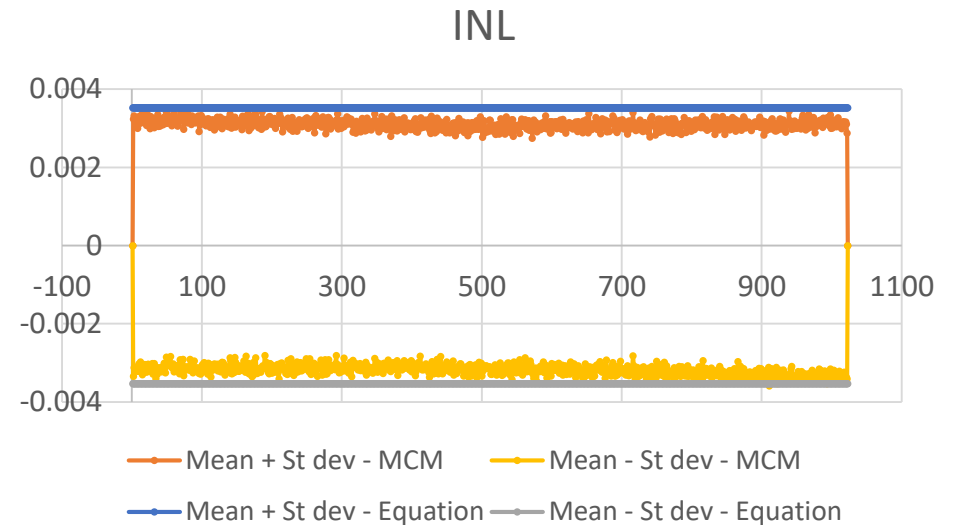
Zone 2: 
$$C = 0.1131(2^N - 1)$$

**Uncertainty equation found**

- Zone 1: Input noise is small: algorithm errors are quantized, and a maximum uncertainty can be provided. Extreme case: noise=0  $\rightarrow$  mean  $\neq$  0 and st dev = 0
- Zone 2: Input uncertainties are big: uncertainty prevails over algorithm error and an uncertainty can be provided: mean = 0 and st dev  $\neq$  0

- $N = 10$  bits
- Noise =  $20 \mu\text{V}$
- $f_s/f_i = 100 \text{ Hz}/0.02 \text{ Hz} = 500\,000$
- $m = 2$  periods
- 1 millions of records
- Recording time  $\sim 100 \text{ s}$  ( $T_a = 100 \mu\text{V}$ )
- Overdrive =  $1 \text{ V}$
- Range  $\pm 2 \text{ V}$
- MCM: 1000 trials

$$u = 0.003527 \text{ LSB}$$



Uncertainty in this case is very small, but gets higher quickly with ADC bits. For example for 18 bits,  $u = 0.26 \text{ LSB}$

**Uncertainty bounds by equation fit well MCM simulation**

- Algorithm used extensively compared to analytical solution calculated independently
- No issues found
- Calculation tips will be included in deliverable 4
- QWTB script speed increased significantly

Bits	18	20	22	24
Time previous version/s	10.8	41	165	658*
Time improved version/s	1.2	4.5	17.6	70

10 000 records  
 Common desktop computer  
 \*Estimated

**Time for calculations reduced almost a 90%**