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Final dissemination workshop
26/5-2019, Brno, Czech Republic

Calibration Methodes

Calibration must be done for all components for correction and uncertainty calculations

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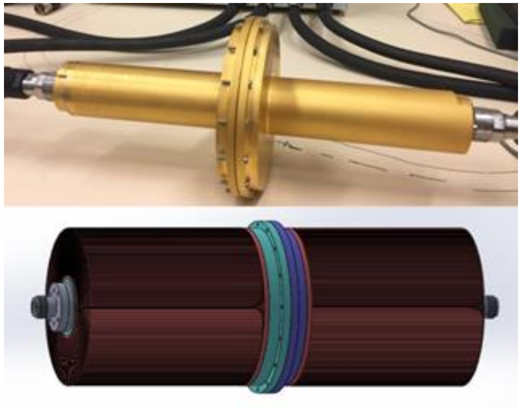
Overview:

- Shunt-calibration
  - AC-RMS
  - Phase angle error
- Voltage divider calibration
  - AC-RMS
  - Phase angle error
- DMM:calibration(3458A and NI5922)
  - Linearity
  - Distortion
  - Stability
- Uncertainty (short)

Current shunt calibration

JV Current shunts



LNE 10A current shunt

- **Amplitude (AC-RMS)**
  - Level dependency
  - Temperature dependency
- **Phase angle error**

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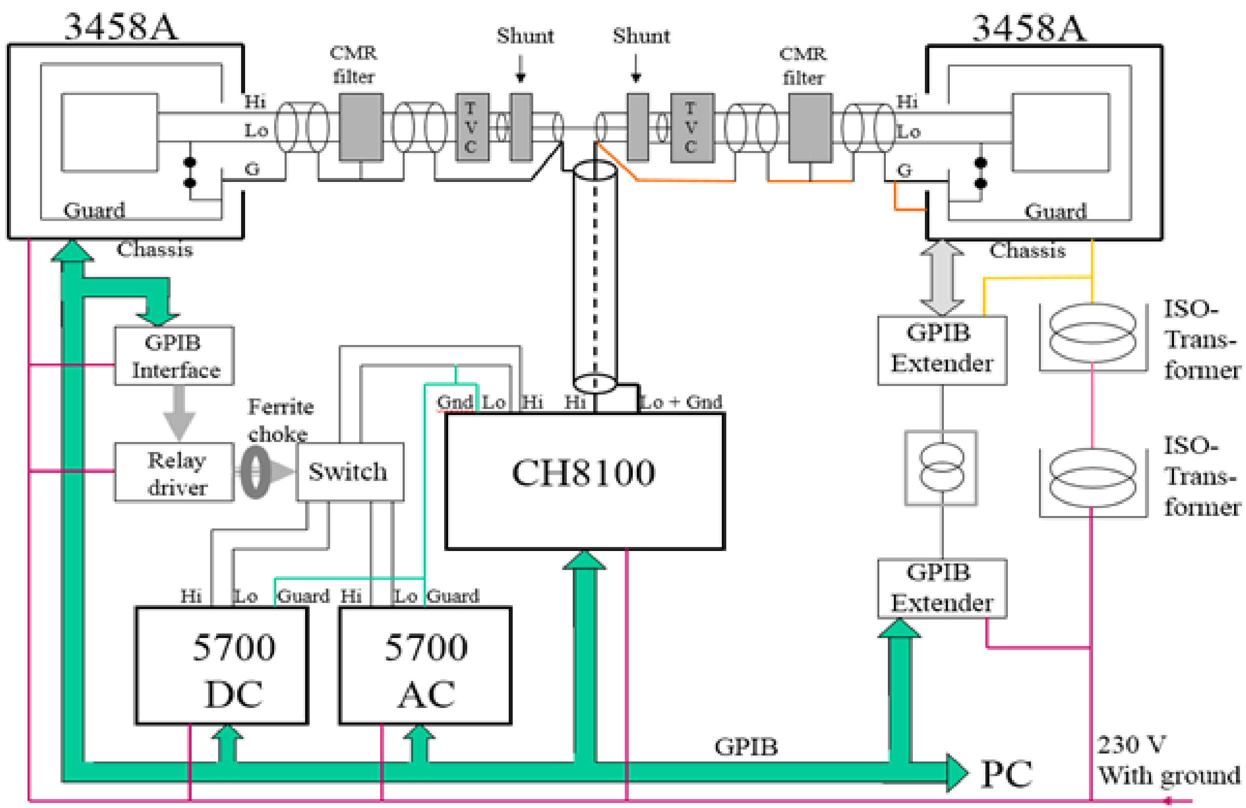
Calibration setup:



Schematic description of the AC-DC difference setup at JV.

Calibration steps: Shunt AC-RMS

Traceability transfer from DC to AC: AC-DC-difference.

$$\delta = \frac{V_{\mathrm{AC}} - V_{\mathrm{DC}}}{V_{\mathrm{DC}}}, \text{ when } E_{\mathrm{AC}} = E_{\mathrm{DC}}$$

- DUT, Reference Resistor and AC/DC-source in series.
- TVCs connected to the outputs of DUT and Ref.resistor
- Measure while switchtng possition of the two TVC's

From this the relative AC/DC difference is known, and only the AC/DC difference in the ref.resistor has to be known to know AC/DC difference of DUT.

Shunt AC-RMS Calibration

Leakage:

This is the current that flows outside the shunts, through paracitic capasitance unintentionally.

- Frequency dependent.
- Give rise to symmetry in the setup

Combating leakage:

Recomanded to put the DMM of the high side floating (ISO-traformer) and isolated GPIB

- <10kHz improved by guarding
- >50 kHz Float the Power supply by transformer(s)

Uncertainty contributors in AC-RMS calibration:

- Leakage
- Drift in shunt
- Stability of source (signal generator)
- Power dependancy
- Step-up/step-down calibration-prosess

Current Shunts: **Level Dependence**

- Shunts can have a significant change in resistance value for different load values.

- The calibration of Level dependence is done by calibrating the resistor value at different load.

Current shunts - **Level dependence**

Two main methodes of calibration:

Output Voltage Ratio

$Rx=Ux/Us*Rs$

Several primary standards needed to cover one working standard

Dirrect Current - Comparator Bridge

$R_p=U_{rp}/I_p$

- MI 6010C

Current Shunts – Output Voltage Ratio

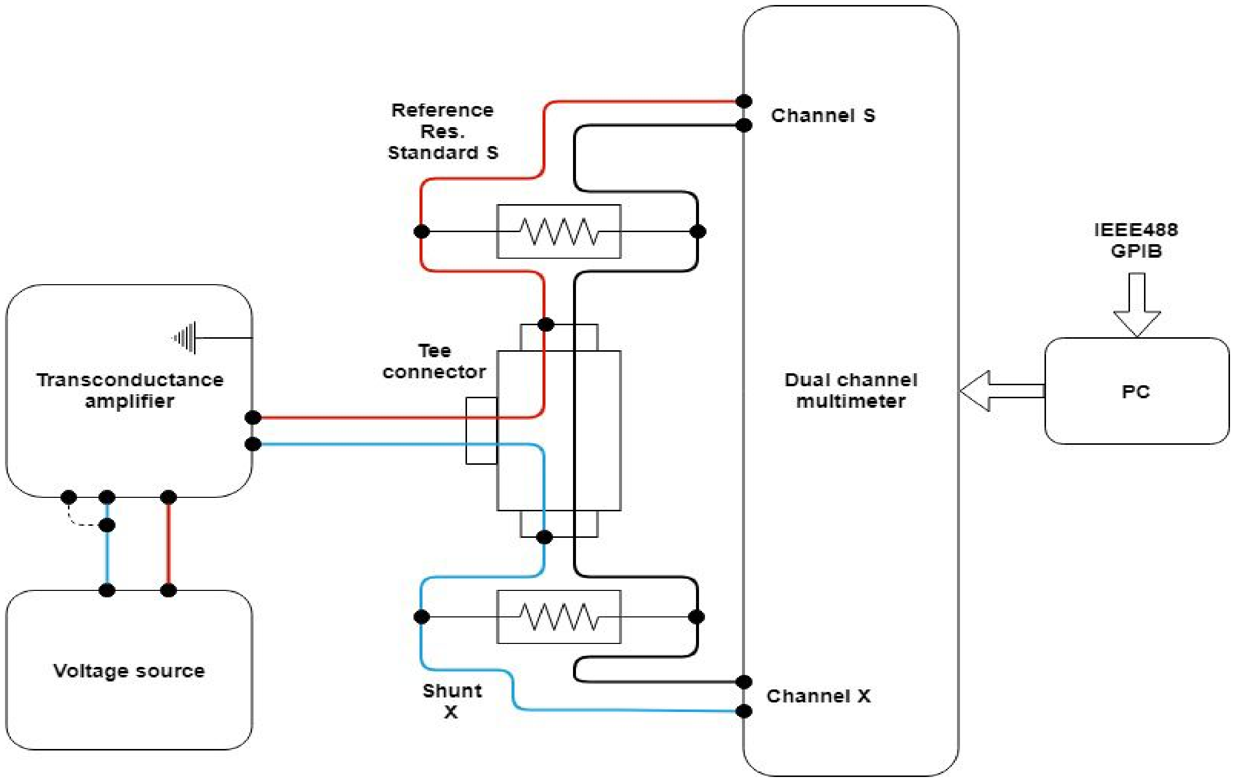
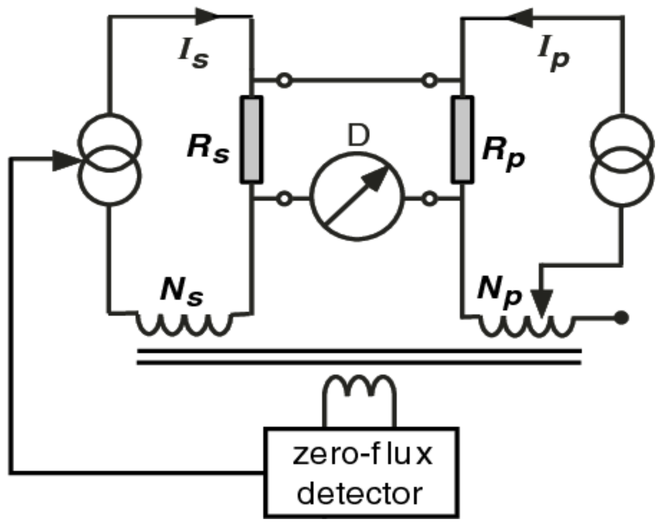


Figure 2.4: Shunt's level dependence measurement setup.

Current Shunts:

Dirrect Current Comtarator Bridge



DC current comparator bridge:

- Establishes the zero-flux condition
- Accurately sets the current ratio I_p/I_s to the winding ratio N_s/N_p

Typical Uncertainties

Level dependence measurement:

- Reference resistors is placed in oil bath
- Shunts in ambient laborathory temperature.
- Stable temperature in oil bath and laboratory

Typical Uncertainties:

Shunt type	PCR, ppm/W	Uncertainty, ppm/W
Foil	< 4	< 3.1
Cage	< 1.5	< 1.5
Fluke A40A	< 69	< 9

Table 2.1: Typical power coefficients of different type of shunts.

Current shunts – **Temp. dependence**

Temperarure coefficiant of resistance (TCR)

The shunt resistor under test is place in an enclosure where the ambient temerature of the shunt can be controlled.

Calibration with same tecnique as for AC-RMS

Two influence factors are controlled:

- **Load**: from 1/10, to Full load
- **Ambient temperatuer**: from 18^{o}C to 30^{o}C

Current shunts – **Temp. dependence**

Typical Uncertainties:

Shunt type	PCR, ppm/W	Uncertainty, ppm/W
Foil	< 4	< 3.1
Cage	< 1.5	< 1.5
Fluke A40A	< 69	< 9

Table 2.1: Typical power coefficients of different type of shunts.

Current Shunts: Phase angle error

The phase error in these components is smal, however, phase is en important component in the power calculation, and any phase error will influence the error and uncertainty of power greately

$$P=U\cdot I\cdot \cos(Phi), \quad Q=U\cdot I\cdot \sin(Phi)$$

The methode presented here is based on comparing of the shunt resistor under test, with a reference with known phase, an absolute phase reference.

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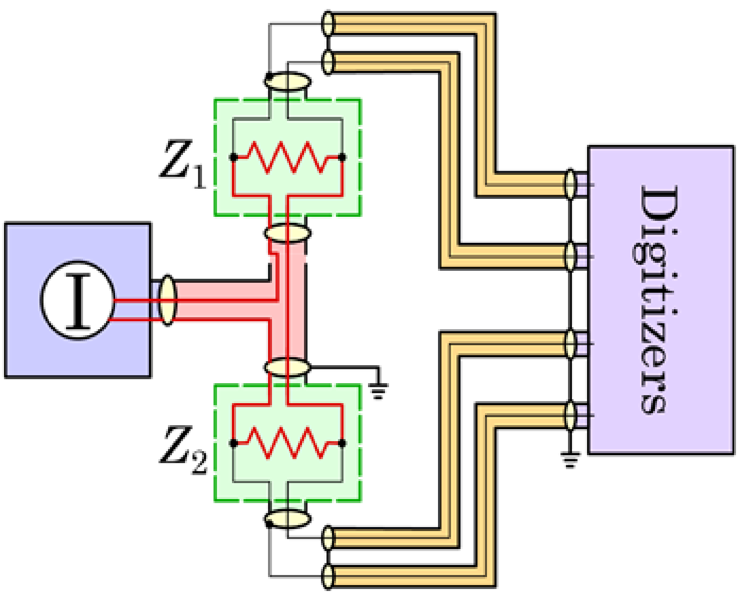
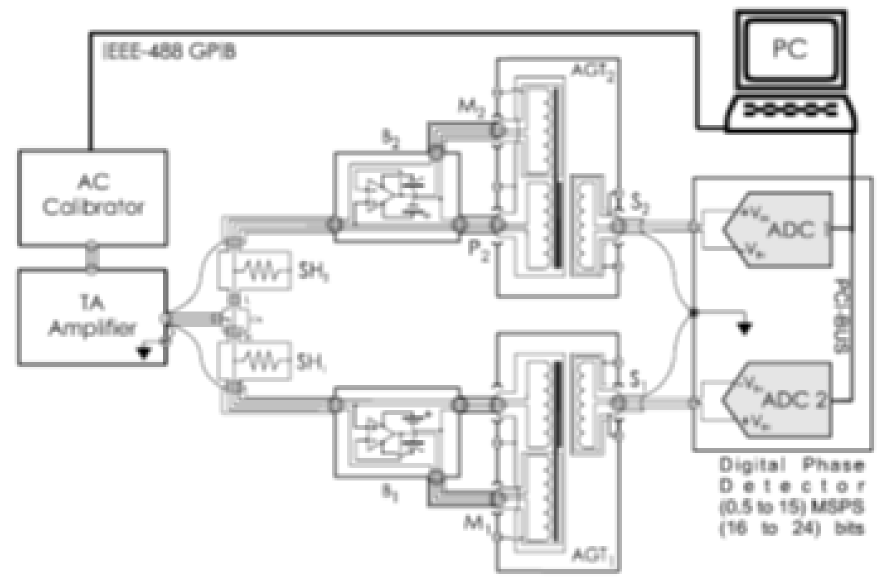
Current Shunts: Phase angle error

Digital bridge, RISE



RISE: synchronized digitizers, using NI 5922

Wideband digital phase comparator. INRIM



Wide band Phase comparator at INRIM
The system was developed to compare shunts from 2A to 100A

Voltage divider Calibration

NMIA Inductive Voltage Divider (IVD).

RISE Resistive Voltage Divider (RVD).

- AC-RMS
- Phase angel error

Voltage Dividers

Tree main methodes of calibration:

Traditional AC-DC Difference Method

- Using planar multijunction thermal converters and nano voltmeter
- Time-consuming, and not available in all labs

Digitizer Method

The absolute divider ratio of one dividers can be measured directly

Both amplitude and phase response can be characterized

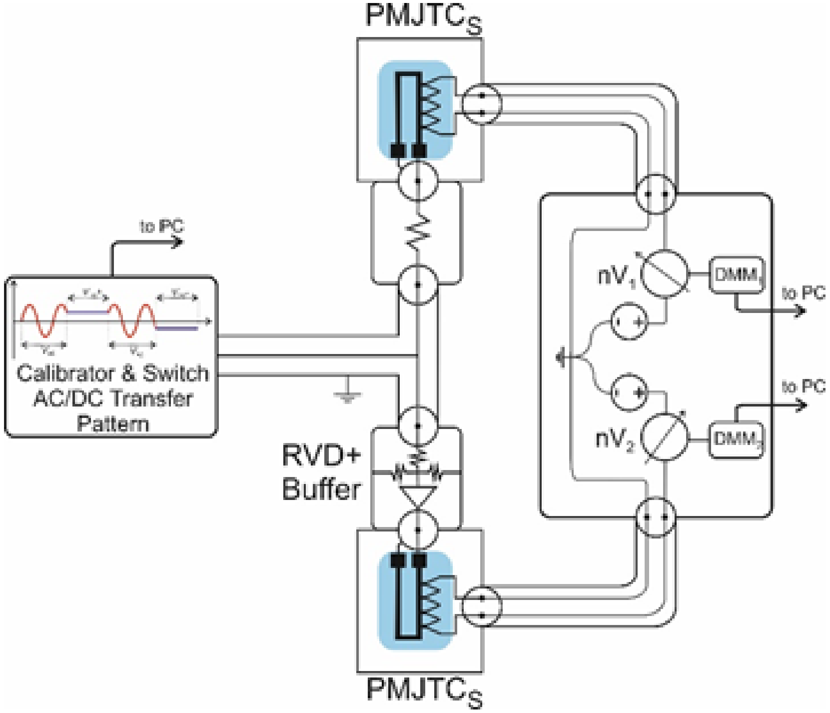
- Using same digitizer as for the watt-merter setup
- Not as accurate as the AC-DC-Difference method

Digitial sampling impedance bridge:

Complex voltage ratio measurement:

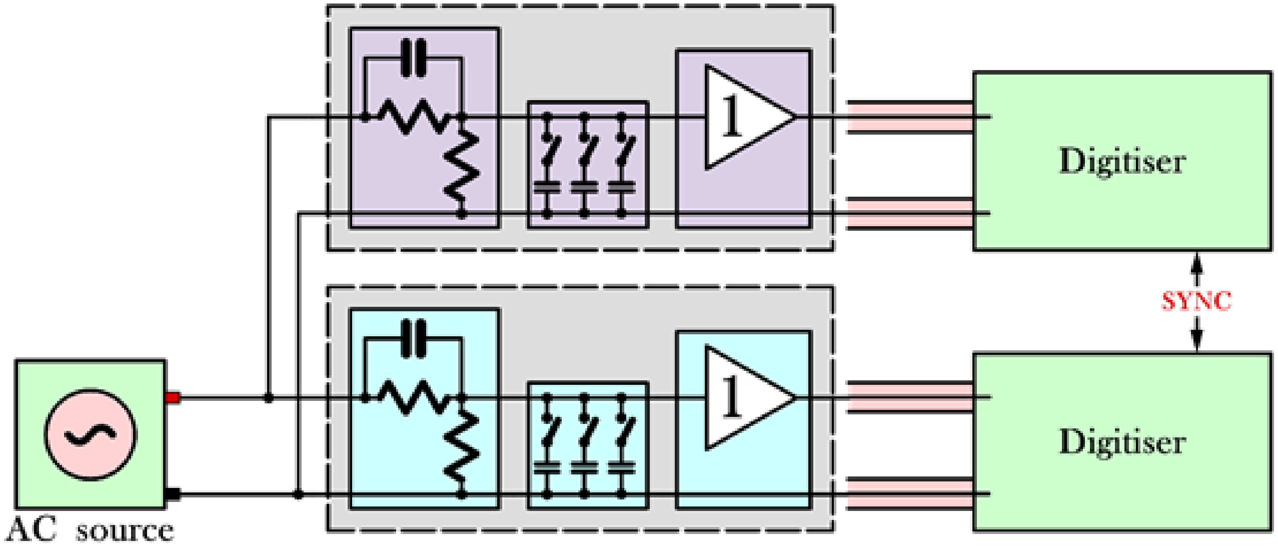
- between the output of two different dividers
- the input-output ratio of one individual divider

Voltage Dividers - AC-DC Difference Method



INRIM setup based on an automatic ac-dc transfer facility for high precision characterization of ac-dc amplitude error of RVDs and buers.

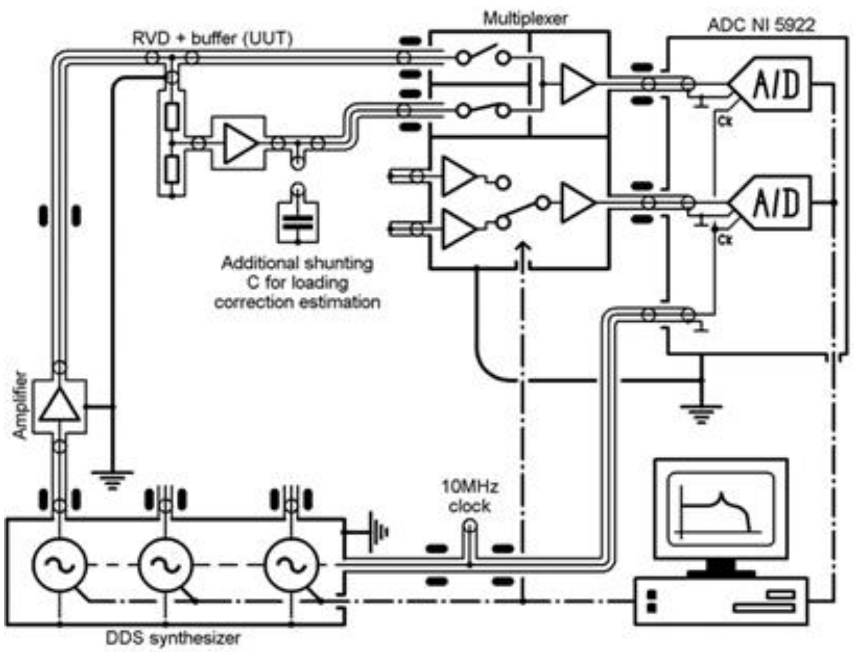
Voltage Dividers - Digitizer method



RISE setup for wideband calibration of voltage dividers.

Measure the complete voltage ratio of either two divider outputs, or the input-output ratio of one divider

Voltage Dividers - Digitital sampling impedance bridge



CMI setup for calibration of voltage dividers.

Measure the complex voltage ratio of either two divider outputs, or the input-output ratio of one divider

Voltage Dividers - Phase angle error

Phase angle error of dividers are typically measured with a digitizer setup.

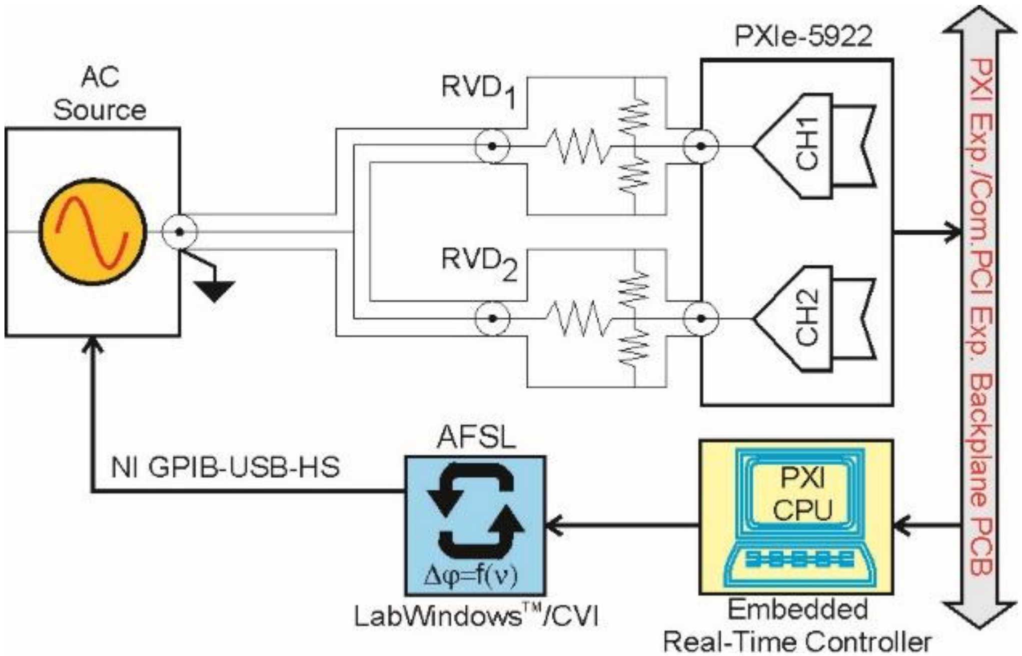
Dominant error source of uncertainty:

- Capacitive load from cabling and circuit connected to the divider output.
- Therefor important with rigid connection to buffer amplifier.

For high ratio dividers, the output amplitude is small relative to the input.

- Results in higher noise if measured directly
- By using ***step-up*** procedure (lover ratios pr. step) noise can be lowered

Voltage Dividers - Phase angle error



INRIM setup for calibration of high ratio voltage dividers.

The automatic asynchronous digital phase comparator, for phase angle calibration of high ratio voltage resistive dividers. Ratios: 1:3 – 1:52, 3V – 150V, 10Hz to 1MHz

Voltage Dividers – Level dependence

Measurement for Level dependency is done the same way as for AC-RMS calibration. The Reference is selected to match the voltage level with known response, while the DUT is exposed to all selected input voltage levels.

Source of Level dependence in dividers:

- Self-heating which changes resistor values and division ratio of divider.
- For highter frequency: heating changes geometry of resistive leads and thus the skin depth and resistance
- For highter frequency: heating of substrate changes geometry and thus paracitic capasitanse
- Heating changes the dielectric in compensation and guard capasitors, which changes phase

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Voltage Dividers – Level dependence

- (1.) DC level dependence

The DC ratio should be calibrated at least at full and half nominal value of the divider 10% of nominal.

- (2.) & (3.) AC level dependence - amplitude

AC-DC difference: The level dependence may be quadratic, dependence may be quadratic, but it may also be more complex.

- (4.) Linear AC level dependence - phase

Some designs include capacitors in parallel with the resistors in the high voltage. Resistors and PCB also contribute.

- (5.) Quadratic AC level dependence – phase

Temperature dependent, This dependence is mainly quadratic.

Voltage Dividers – Environmen dependence

Temperature
- Same implication for components as self heating
- Reduce influence by good design.
- Reduce influence by good air temperature control

Humidity
- Resistors can be sensitive to humidity by soaking up moisture from the air over time. Time scale of up to days.
- Hermetic sealing is a solution

Measurement considerations

Voltage dividers and Current Shunts:

- Grounding
  - Ground loops
  - Undefined gnd-ref.
    - Chokes
    - Transformers
    - dif.amps
- Output-loading
  - Changes
    - effective shunt resistance
    - division factor of Volt.divider
- Current leakage
  - Current bypassing the current sensor element through parasitic capasitance.
    - Spessially for $f > 50\text{kHz}$

Measurement considerations

Temperature

- Current shunts
- Resistive Voltage dividers

Can change:

- Shunt resistance
- Voltage divsion ratio

- Caracterise as for DC-ratio cal.
- Dessign and temp.control for prevention

Humidity

Some resistors are sensitive.

- Caracterise as for DC-ratio cal.
- Hermetic sealding for prevention

Digitizers

- Phase
- Gain

- Cabel delay,
- Complex input impedanse

Calibration of the 3458A DMM

Calibration of the 3458A DMM

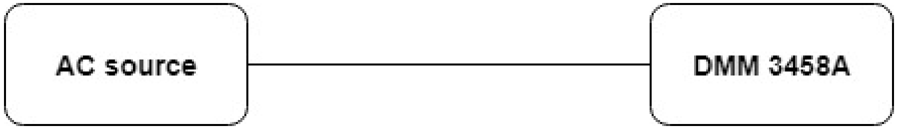
Frequency response measurement, repeated for different frequency, typically in the 10 Hz to 20 kHz range

- AC-RMS-response
- Phase angel error

The frequency response at the certain DMM's range is calculated using:

$$K_f = \frac{A_{\text{sampled},f} \; / \; A_{\text{ref},f}}{A_{\text{sampled},1} \; / \; A_{\text{ref},1}}$$

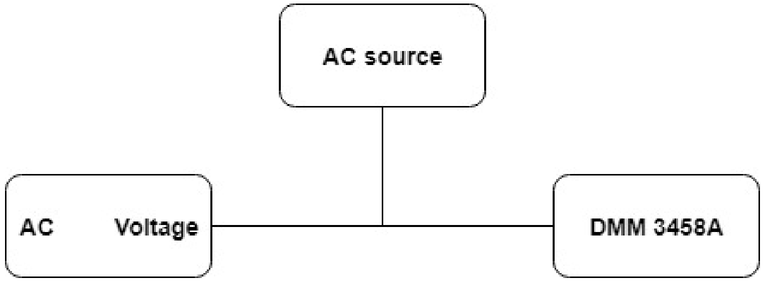
3458A DMM - Connection



Connection for frequency response measurements

The DMM 3458A can be connected directly to AC source. The signal is then sampled by the DMM 3458A, Afterwards, the sampled signal is analyzed by on the apropriatee estimating algorithm.

3458A DMM - Connection

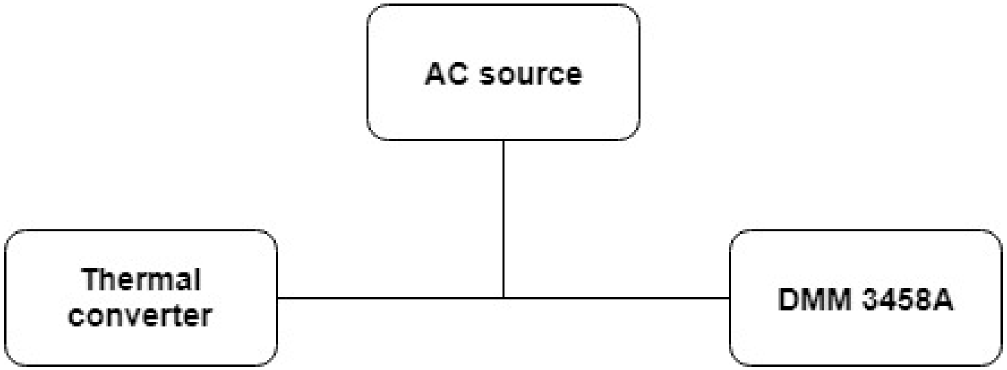


Frequency response - A simplied calibration connection
where AC source set value is used as a reference

AC voltage standard (e.g. Fluke 5790A), Stable sine-wave signals are generated by the calibrator and connected to DMM.

The accuracy of the frequency response measurements could be further improved if the thermal convertors instead of the AC voltage standard:

3458A DMM – improved by TVC

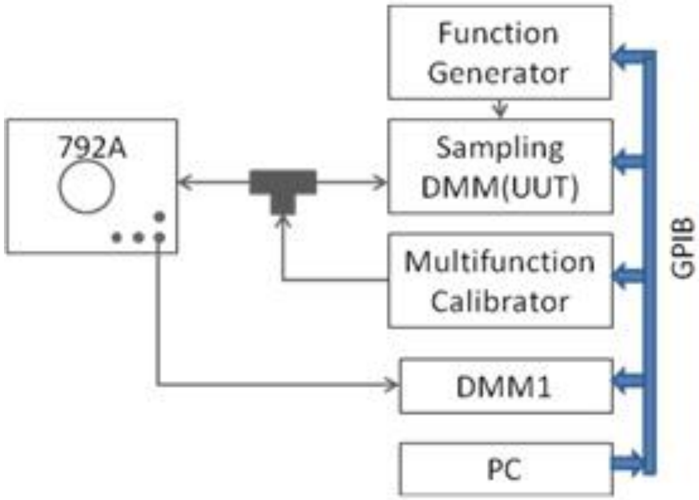


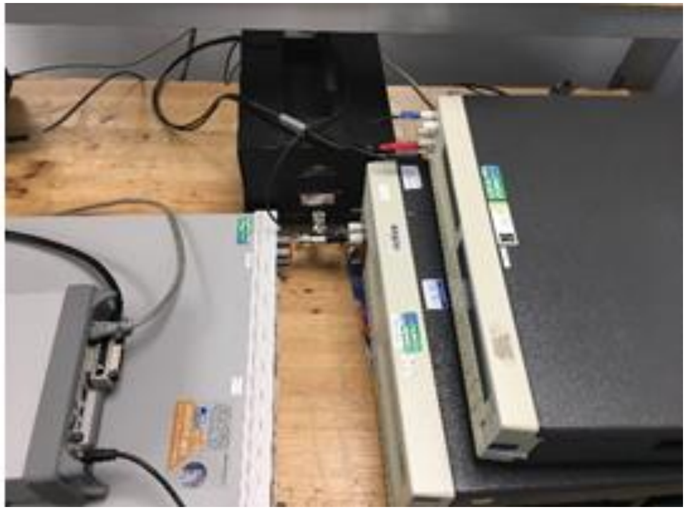
Frequency response - A calibration connection where thermal convertors are used as a reference

3458A DMM - Connection

- DMM (3458A) - Dynamic linearity
  - Measurement of signals with low harmonic distortion
  - Measurement of harmonically distorted signals (xed sampling rate)
  - Amplitude linearity and phase angle dependence
- DMM (3458A) – Distortion
- DMM (3458A) - Evaluation of the stability
- DMM (3458A) - Temperature dependence
- DMM (3458A) - Input impedance

3458A DMM - Dynamic linearity



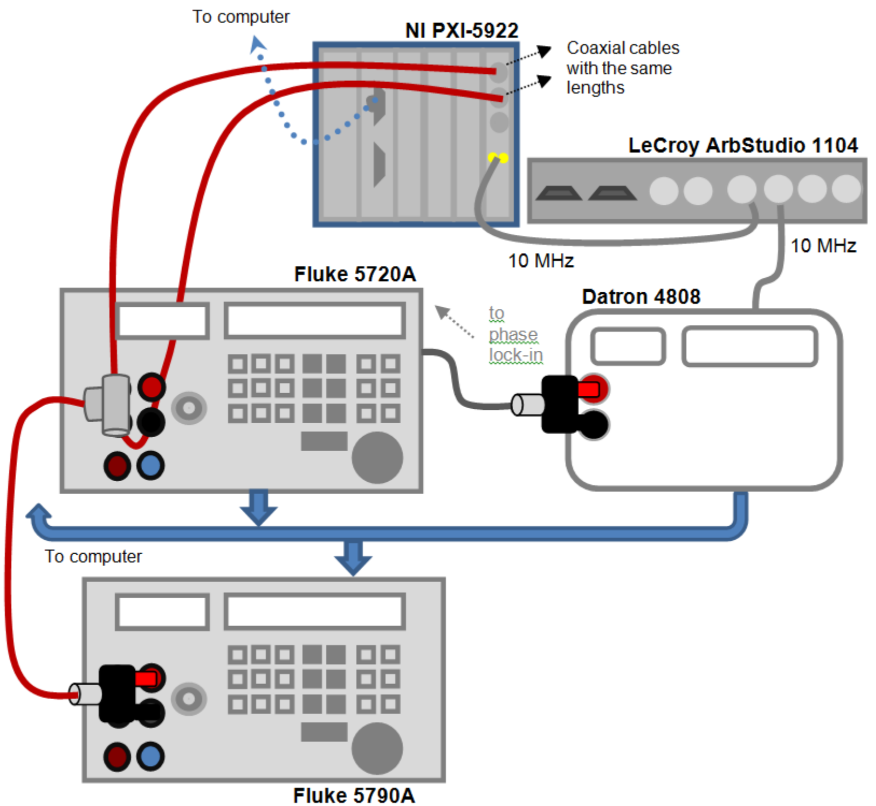


Schematic diagram (left) and picture (right) of the measurement setup used in characterization of the sampling DMM - Dynamic linearity

Methods for calibration of the digitizers (NI 5922)

Two ranges, 2 Vpp and 10 Vpp. Sampling rates from 50 kSa/s with 24 bit resolution up to 15 MSa/s with 16 bit resolution. Up to 10 MSa/s for frequencies from 100 kHz up to 1 MHz.

Methods for NI 5922

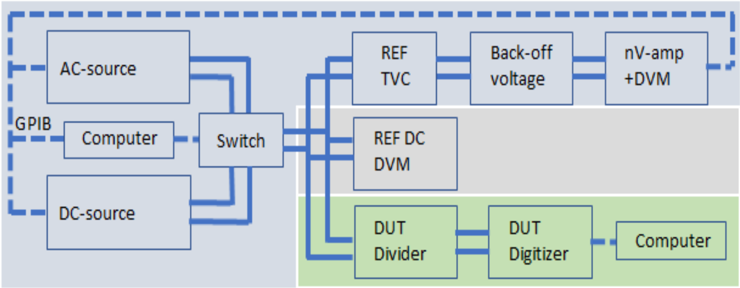


Calibration setup for characterization of NI 5922 wideband digitizer.

Methods for NI 5922

Considerations:

Digitizer (NI 5922) - Frequency response
Digitizer (NI 5922) - Level dependence
Digitizer (NI 5922) - Phase angle error between channels
Digitizer (NI 5922) – Distortion
Digitizer (NI 5922) - Evaluation of the stability of phase and Amplitude
Digitizer (NI 5922) - Evaluation of the input impedance
Methods for calibration of the entire system



ac-dc calibration system modied for ac calibration of the voltage channel

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