22NRM06 ADMIT 2nd Stakeholder Workshop

Flexible Generation Architecture for Current Transformers Testing up to 150 kHz

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Overview

✓ Background and motivation

✓ General architecture of the proposed solution

✓ Preliminary experimental activity for the validation of the proposed approach:

- Test procedure
- Two case studies

✓ Conclusions

Background and motivation

The recently released **IEC 61869-1 Edition 2** introduces extensions to the accuracy classes of ITs in frequency. However, it lacks guidance on **how** to assess accuracy at frequencies other than the power frequency.

Accuracy class	Ratio error at frequencies shown below %			Phase error at frequencies shown below Degrees		
WB1	$f_r < f \leq 1$ kHz	$1 < f \leq 1{,}5$ kHz	$1{,}5 < f \leq 3$ kHz	$f_r < f \leq 1$ kHz	$1 < f \leq 1{,}5$ kHz	$1{,}5 < f \leq 3$ kHz
WB2	$f_r < f \leq 5$ kHz	$5 < f \leq 10$ kHz	$10 < f \leq 20$ kHz	$f_r < f \leq 5$ kHz	$5 < f \leq 10$ kHz	$10 < f \leq 20$ kHz
WB3	$f_r < f \leq 20$ kHz	$20 < f \leq 50$ kHz	$50 < f \leq 150$ kHz	$f_r < f \leq 20$ kHz	$20 < f \leq 50$ kHz	$50 < f \leq 150$ kHz
WB4	$f_r < f \leq 50$ kHz	$50 < f \leq 150$ kHz	$150 < f \leq 500$ kHz	$f_r < f \leq 50$ kHz	$50 < f \leq 150$ kHz	$150 < f \leq 500$ kHz
0,1	±1	±2	±5	±1	±2	±5
0,2 – 0,2 S	±2	±4	±5	±2	±4	±5
0,5 – 0,5 S	±5	±10	±10	±5	±10	±20
1	±10	±20	±20	±10	±20	±20
Protection	±10	±20	±30	-	-	-

The accuracy classes 0,2 S and 0,5 S apply only for current transformers.

Existing **literature** on ITs and PQ emphasizes the need to test IT under conditions close to actual one.

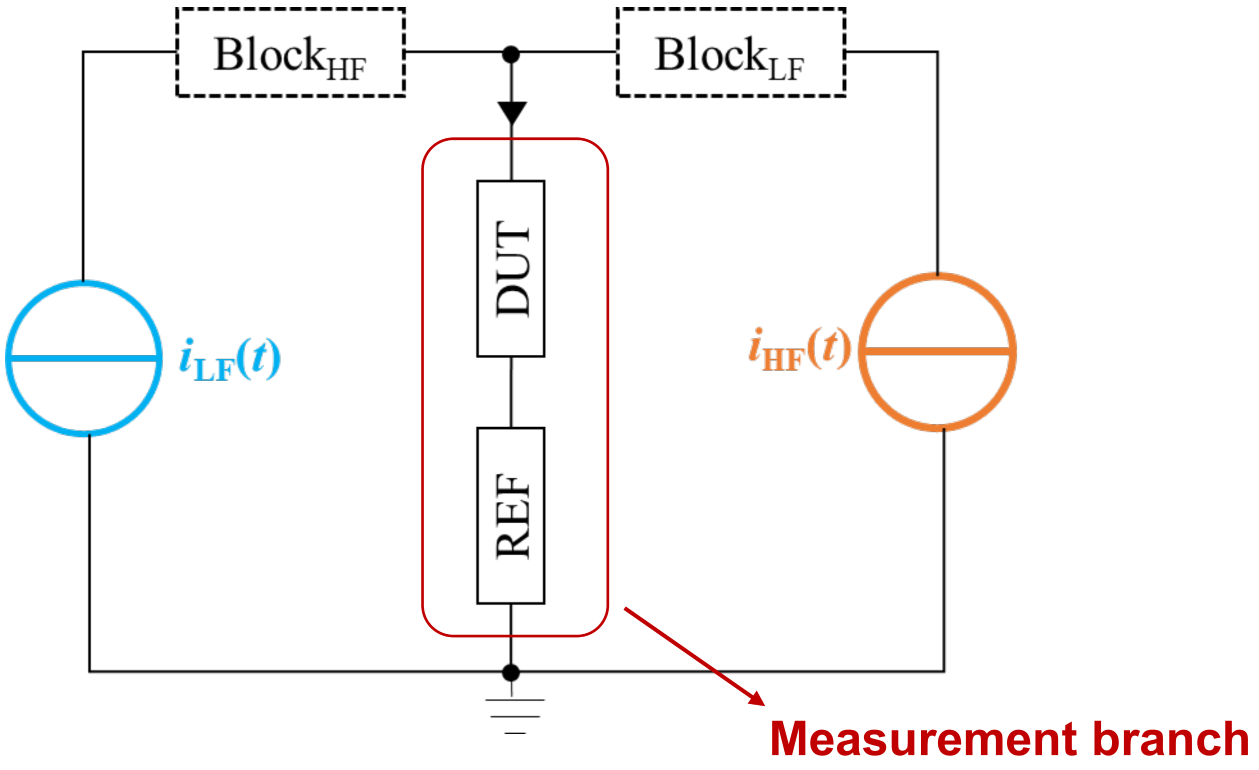
Generators capable of producing both high-current fundamental components (DC or AC 50/60 Hz) and superimposed low-amplitude high-frequency components are **not available on the market**.

Scope of the work here presented: to propose a setup to generate high current distorted waveforms with spectral content up to 150 kHz.

Proposed Generation Architecture (1/2)

Two different current sources:

- $i_{LF}(t)$ is dedicated to generating Low Frequency (LF) DC or AC 50/60 Hz current with high amplitude.
- $i_{HF}(t)$ generates low-amplitude currents with High Frequencies (HFs) up to several kilohertz.

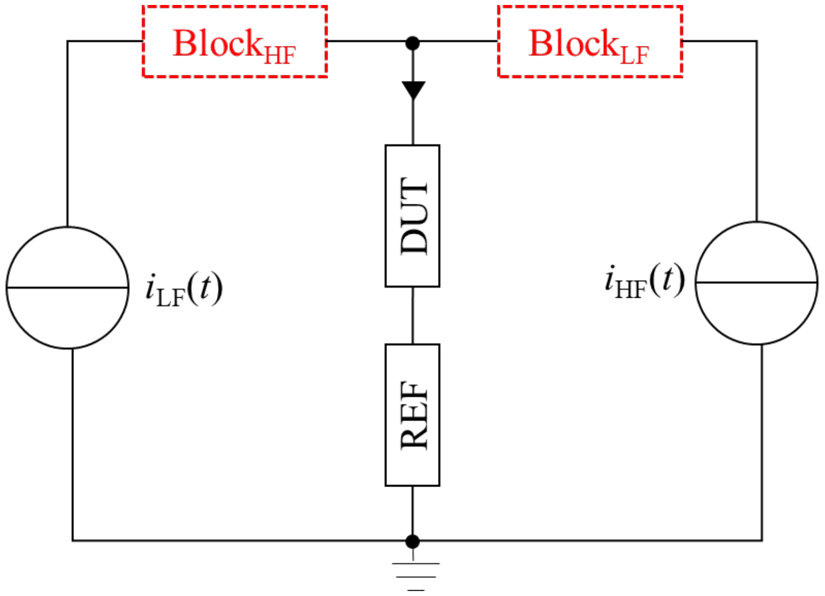


Proposed Generation Architecture (2/2)

Two blocking elements are connected in series with the current generators when it is necessary to protect each generator from the current generated by the other one.

Block_{HF} Element:

- Prevents HF currents into LF generator.
- Achieved by high impedance at HF using an inductance L.
- Impedance $Z_L = j\omega L$ should be ≥ 10 × impedance of measurement branch.

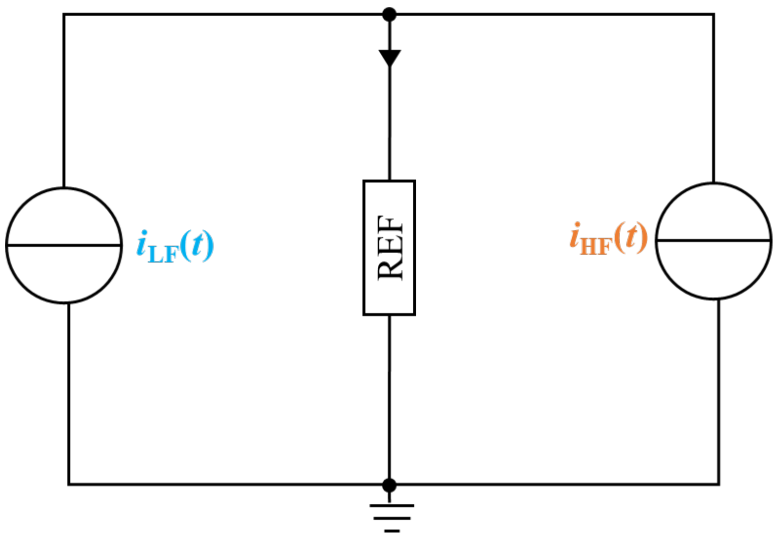


Block_{LF} Element:

- Prevents LF currents into HF generator.
- Achieved by high impedance at 50/60 Hz using a capacitor C.
- Capacitance chosen so $Z_C = 1/j\omega C$ is ≥ 10 × impedance of measurement branch.

Experimental activity

Main goal → to quantify how each source affects the current in the measurement branch generated by the other source when they are both active.



Test procedure involves three steps:

1. the solely generation of $i_{LF}(t)$
2. the solely generation of $i_{HF}(t)$ and

⇨ subscript "**S**": **S**ingle Tone current

3. the simultaneous generation of the two currents $i_{LF}(t)$ and $i_{HF}(t)$.

⇨ subscript "**FHF**": **F**undamental tone plus 1 component at **HF**

The **index** used to quantify the generation system performance:

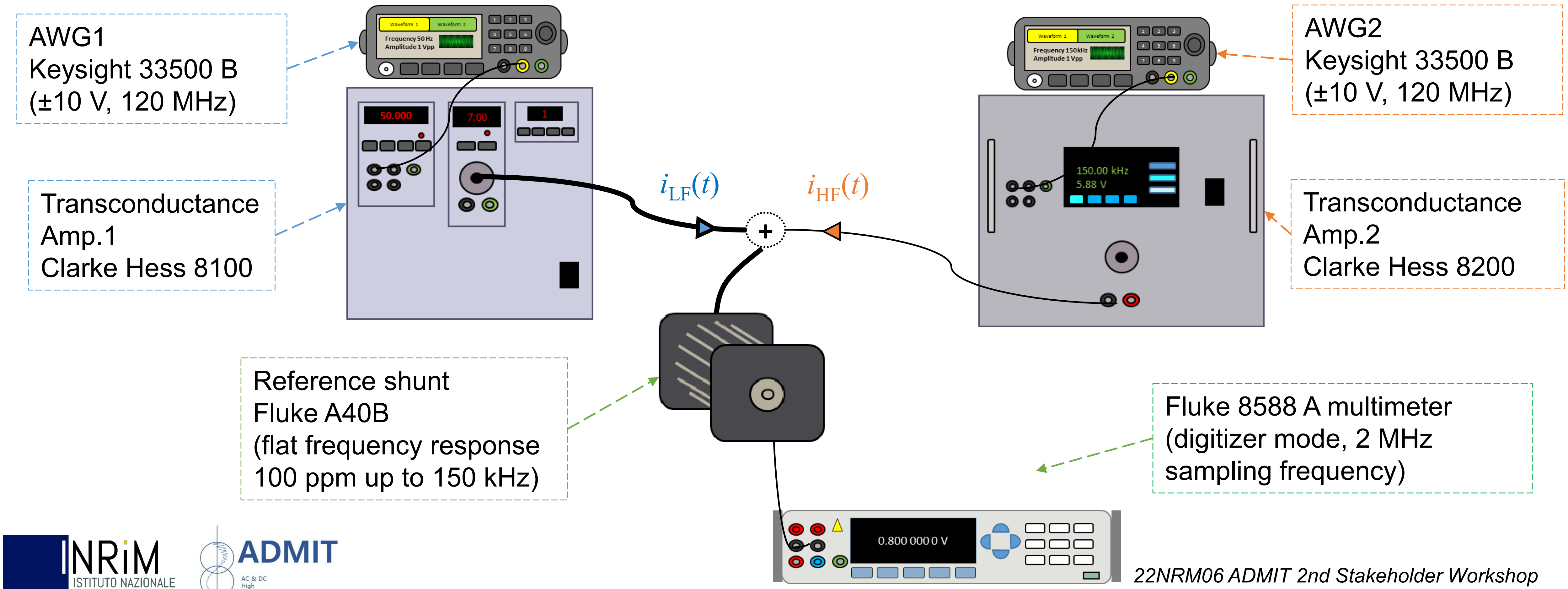
$$\varepsilon(f) = \frac{I_{FHF}(f) - I_S(f)}{I_n(f)}$$

- $I_{FHF}(f)$ and $I_S(f)$ are the RMS values of the current at frequency f measured under FHF and S test;
- $I_n(f)$ is the desired RMS value of the current at frequency f.

Generation and Measurement Setup

Starting from the general scheme, **two** investigated cases:

- ***Case A:*** ***Connection of two transconductance amplifiers***



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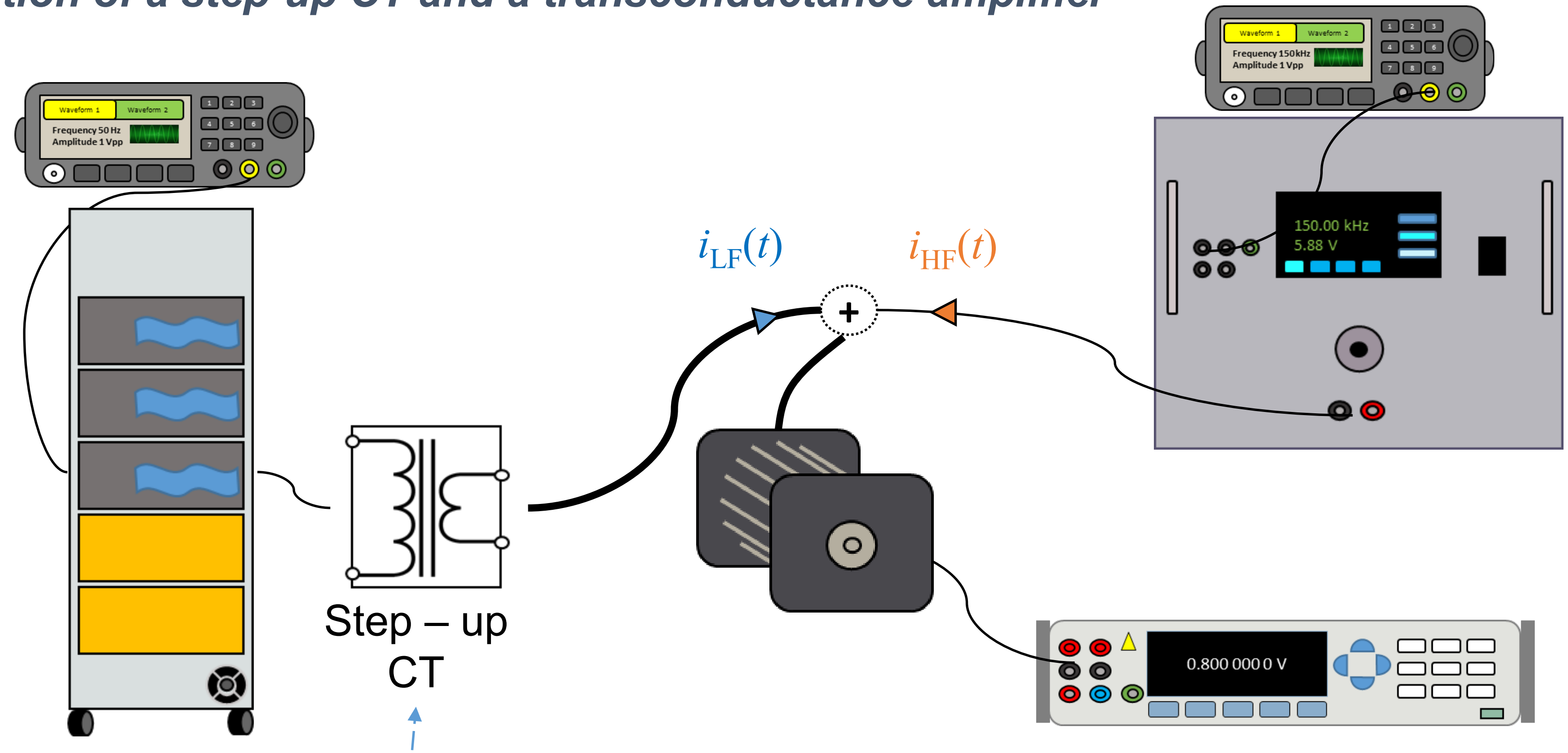
Generation and Measurement Setup

- ***Case B:*** *Connection of a step-up CT and a transconductance amplifier*



Power
Transcundactance
Amplifier
(1.2 kA, 100 V
@ 50 Hz)

Tests performed with **<u>two</u>** CTs with different features

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Experimental Results

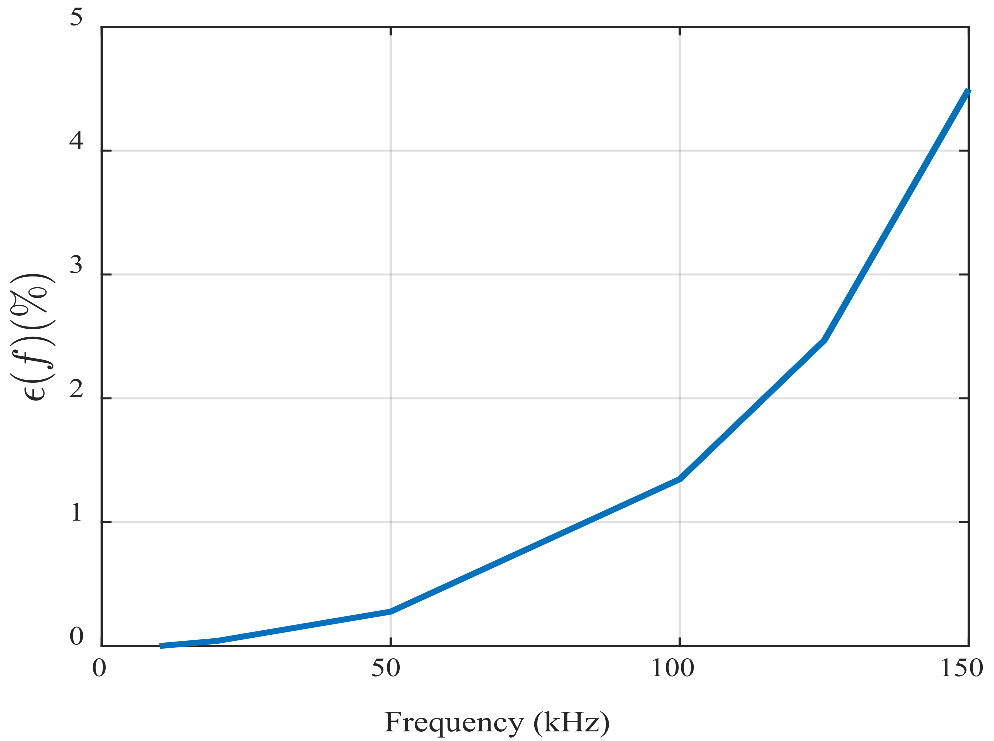
Connection of two transconductance amplifiers

Test parameters:

$i_{\mathrm{HF}}(t) \rightarrow$ 4 A from 10 kHz to 150 kHz

$i_{\mathrm{LF}}(t) \rightarrow$ 40 A at 50 Hz

@ 50 Hz the maximum $\varepsilon(50\ \mathrm{Hz})$ is 50 µA/A
@ 50 kHz the error $\varepsilon(f)$ is 0.3 %
@ 80 kHz $\varepsilon(f)$ =1 %
@ 150 kHz the error increases to 4.50 %



$$\varepsilon(f) = \frac{I_{\mathrm{FHF}}(f) - I_{\mathrm{S}}(f)}{I_{\mathrm{n}}(f)} \rightarrow \varepsilon(f) > 0 \rightarrow I_{\mathrm{FHF}}(f) > I_{\mathrm{S}}(f)$$

Experimental Results

Connection of two transconductance amplifiers

$I_{FHF}(f) > I_S\ (f)$

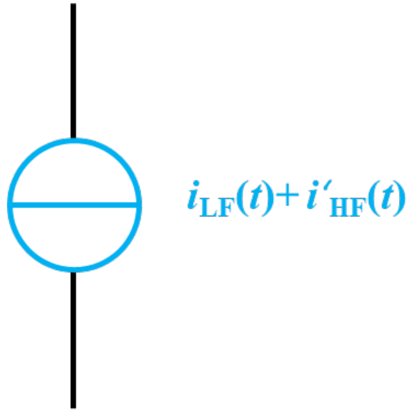
Same test is performed by selecting two different gains of the transconductance amplifier used to generate the $i_{LF}(t)$ current at 40 A and 50 Hz: 10 S and 100 S.

IMPACT OF THE GAIN OF THE TRANSCONDUCTANCE USED TO GENERATE 50 HZ CURRENT ON THE HF TONES

Frequency (kHz)	**ε (%)**	
	10 S	**100 S**
20	0.042	0.022
50	0.278	0.493
100	1.347	3.053
125	2.468	7.130
150	4.496	21.141

The difference increases as the frequency increases.
@ 150 kHz there is a x5 factor

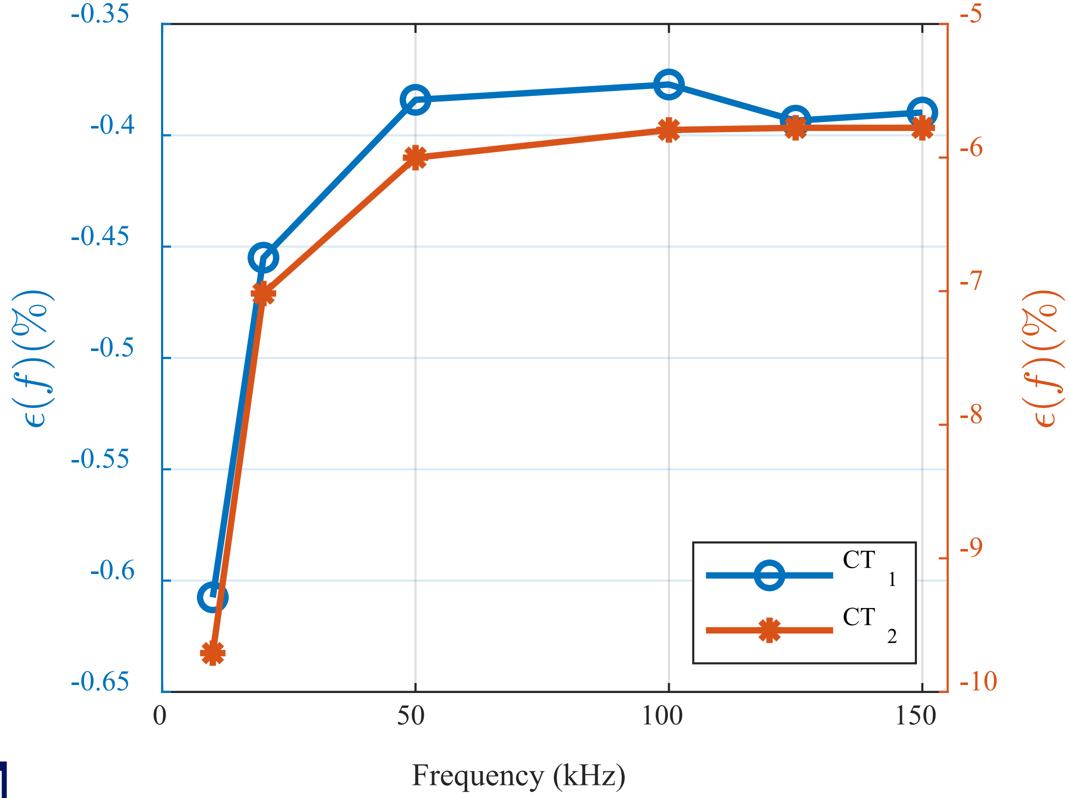
→ There is a coupling between the two generators that leads the LF generator to capture, amplify and generate HF components too.



Experimental Results

Connection of step-up CT and transconductance amplifier

- CT_1: for MV application, 5/75 A/A
- CT_2: window type, 5/250 A/A



LF: @ 50 Hz error lower than 50 μA/A (both)

HF: same behaviour but $\varepsilon(f)$ differ significantly by an order of magnitude.
-For CT_1 $\varepsilon(f)$ is always lower than -1 %
-For CT_2 $\varepsilon(f)$ goes from -9.7 % at 10 kHz to -5.7 % at 150 kHz.

$$\varepsilon(f) < 0$$
$$I_{\mathrm{FHF}}(f) < I_{\mathrm{S}}(f)$$

Experimental Results

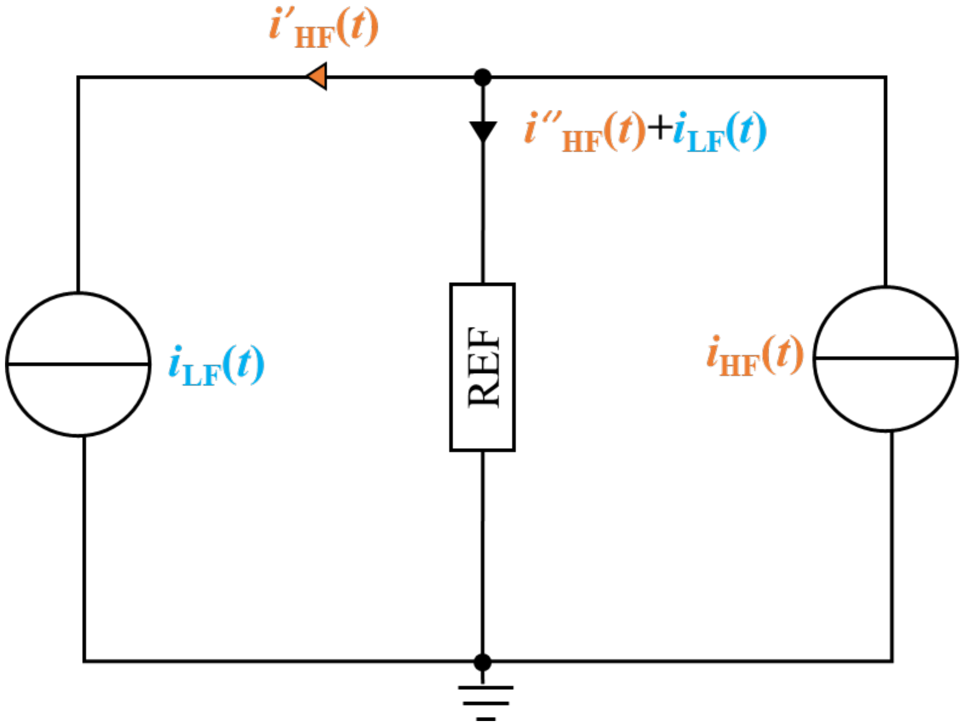
Connection of step-up CT and transconductance amplifier

- CT_1: series inductance L_s of 19 μH.
- CT_2: series inductance L_s of 0.5 μH.

$I_{FHF}(f) < I_S(f)$

As the frequency increases, the output impedance of the step-up transformer ($\sim Z = j\omega L_s$) also increases.

➢ L_s of $CT_1 \approx 38$ times L_s of CT_2



Conclusions

1. The activity proposed a flexible generation system for testing CTs in the presence of signals consisting of a high-current in DC/AC (50 Hz) with superimposed disturbances at reduced amplitude up to 150 kHz.
2. Two different configurations were tested: one based on the use of two transconductance amplifiers and one based on the use of step up transformers and transconductance amplifiers. The two configurations highlighted different associated issues.
3. The generation setup composed by two transconductance amplifiers poses no significant issues for the generation of the $i_{LF}(t)$ at 50 Hz with superimposed HF tones up to 80 kHz ($\varepsilon(f)$ < 1 %). When frequencies increase the coupling between the generators leads to a rise in the error $\varepsilon(f)$ up to 4.5 % at 150 kHz.
4. The case based on the use of step-up CTs has highlighted that the parameters of the adopted step up CT are crucial and, in some cases, it can be necessary to insert into the circuit blocking elements.

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Thanks for your attention!
Questions?

ACKNOWLEDGMENT

The results presented were developed in the framework of the project 22NRM06 ADMIT that has received funding from the European Partnership on Metrology, co-financed by the European Union's Horizon Europe Research and Innovation Programme and from by the Participating States

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