RECHERCHE

MESURE MÉTROLOGIE

ESSAIS

CERTIFICATION

EXPERTISE ET INNOVATION

FORMATION

ADMIT
AC & DC High Frequency Instrument Transformers

CRÉER LA CONFIANCE

CHARACTERIZATION OF AC AND DC MV INSTRUMENT TRANSFORMERS IN EXTENDED FREQUENCY RANGE UP TO 150 KHz (ADMIT)

WP2 : VOLTAGE

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2024/01/15 , M9 MEETING

“The project 22NRM06 ADMIT 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.”

OVERVIEW OF THE WP2

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Infrastructure for voltage generation and traceable measurement chains

Task 2.1

Development of Generation systems

50 kV DC, 35 kV AC
+
500 V (9 kHz to 150 kHz)

Task 2.2

Development of reference measuring systems

Frequency	U (ratio Voltage)	U (phase)
DC and 50 Hz	0.01 %	0.01 crad
9 kHz to 150 kHz	0.2 % to 1 %	0.2 crad to 1 crad 0.1 ° to 0.6 °

Task 2.3

Industry-oriented VT test procedures

Development of Industrial test procedures
500 V (9 kHz to 150 kHz)

OVERVIEW OF THE WP2

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WB0—covering harmonics ≤ 13th harmonic.
WB1—harmonic frequencies ≤ 3 kHz.
WB2—Harmonic frequencies ≤ 20 kHz.
WB3—Harmonic frequencies ≤ 150 kHz.

Class 0.1 :
- 1 % up to 20 kHz
- 2 % up to 50 kHz
- 5 % up to 150 kHz

Class 0.2
- 2 % up to 20 kHz
- 4 % up to 50 kHz
- 5 % up to 150 kHz

Class 0.5
- 5 % up to 20 kHz
- 10 % up to 150 kHz

Class 1
- 10 % up to 20 kHz
- 20 % up to 150 kHz

Protection
- 10 % up to 20 kHz
- 30 % up to 150 kHz

The needed uncertainty : 5 to ten times lower than accuracies

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.							

NOTE 1 Accuracy class extension WB4 is intended for very wide bandwidth applications like travelling-wave protections and fault locators where signal frequencies reach as high as 500 kHz. The use of relays based on travelling-wave analysis is a promising solution offering very accurate fault location. For instance, new devices based on such principles claim to be much more accurate than conventional reactance-based fault locators. This field is still evolving, but CTs and VTs suitable for these relays need a very large frequency range, hence the "extended" range up to 500 kHz. No consensus for general requirements for this kind of application is available at the date of the publication.

NOTE 2 Travelling wave relays are designed especially for this purpose and are very special (very large bandwidth, etc.). Although WB4 compliant ITs are very desirable, inductive CTs and CVTs often have not a sufficient bandwidth allowing relays and fault locators to accurately measure the traveling wave arrival times.

NOTE 3 Owing to the high bandwidth, the classes WB3 and WB4 are not compatible with digital signals in accordance with IEC 61869-9 and its standardized sampling rates.

IEC 61869-1:2024, ***5.7.4 Accuracy requirements for harmonics***".

OVERVIEW OF THE WP2

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INRIM	Istituto Nazionale di Ricerca Metrologica	Italy
FFII	Fundación para el Fomento de la Innovación Industrial	Spain
LNE	Laboratoire national de métrologie et d'essais	France
RISE	RISE Research Institutes of Sweden AB	Sweden
VSL	VSL B.V.	Netherlands
VTT	Teknologian tutkimuskeskus VTT Oy	Finland
RSE	Ricerca sul Sistema Energetico – RSE S.p.A.	Italy
SUN	Università degli studi della Campania Luigi Vanvitelli	Italy
UNIBO	Alma mater studiorum Università di Bologna	Italy
UNIGE	Università degli Studi di Genova	Italy
ARTECHE	Electrotécnica Arteche Hermanos, Sociedad Limitada	Spain
UNARETI	Unareti SpA	Italy
METAS	Eidgenössisches Institut für Metrologie METAS	Switzerland

35.7 Months

- First part : Voltage generation systems
- Second part : Voltage measuring systems

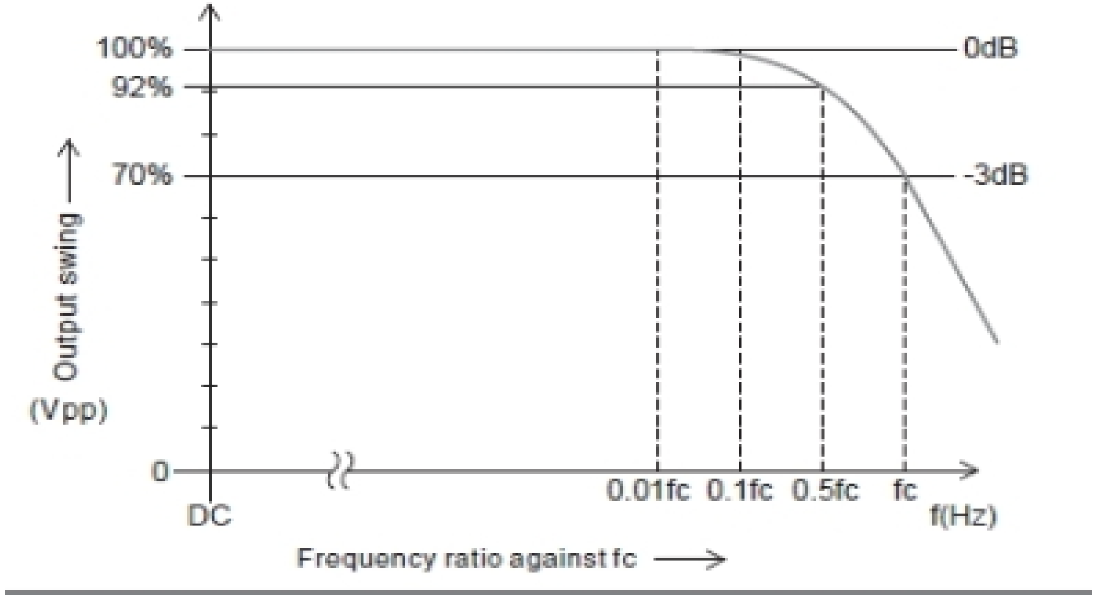
- First part : Voltage generation systems

DEVELOPMENT OF HV-HF GENERATORS

USE OF HIGH VOLTAGE AMPLIFIERS

Fundamental up to 50 kVp (DC or AC)
Up to 20 mA max
About 600 W
BW of a few kHz
Impossible to reach 500 V at 150 kHz

Model	Output Voltage [kVdc]	Output Current	Rated output power [W]	Slew Rate [V/μs]	Frequency Response (Typical value at sine wave operation with resistive load)		Safety Standards
					Full scale (-1 dB) *	Small bandwidth (10% of full scale)(-3 dB)	
AMPS-0.6B2000	-0.6 to +0.6 kV	±2000 mAmax or ±4000 mApk 1ms	1200 W	500 V/μs	DC to 100 kHz	DC to 200 kHz	CE
AMPS-2B200	-2 to 2 kV	±200 mAmax or ±400 mApk 1 ms	400 W	1000 V/μs	DC to 80 kHz	DC to 160 kHz	CE
AMPS-5B80	-5 to +5kV	±80 mAmax or ±160 mApk 1 ms	400 W	1000 V/μs	DC to 50 kHz	DC to 100 kHz	CE
AMPS-10B40	-10 to +10 kV	±40 mAmax or ±120 mApk 1 ms	400 W	1200 V/μs	DC to 20 kHz	DC to 40 kHz	CE
AMPS-20B20	-20 to +20 kV	±20 mAmax or ±60 mApk 1 ms	400 W	1200 V/μs	DC to 10 kHz	DC to 20 kHz	CE
AMPS-30B20	-30 to +30 kV	±20 mAmax or ±40 mApk 1ms	600 W	800 V/μs	DC to 5 kHz	DC to 20 kHz	-



DEVELOPMENT OF HV-HF GENERATORS

TRACTION POWER LOAD IMPEDANCE IDENTIFICATION

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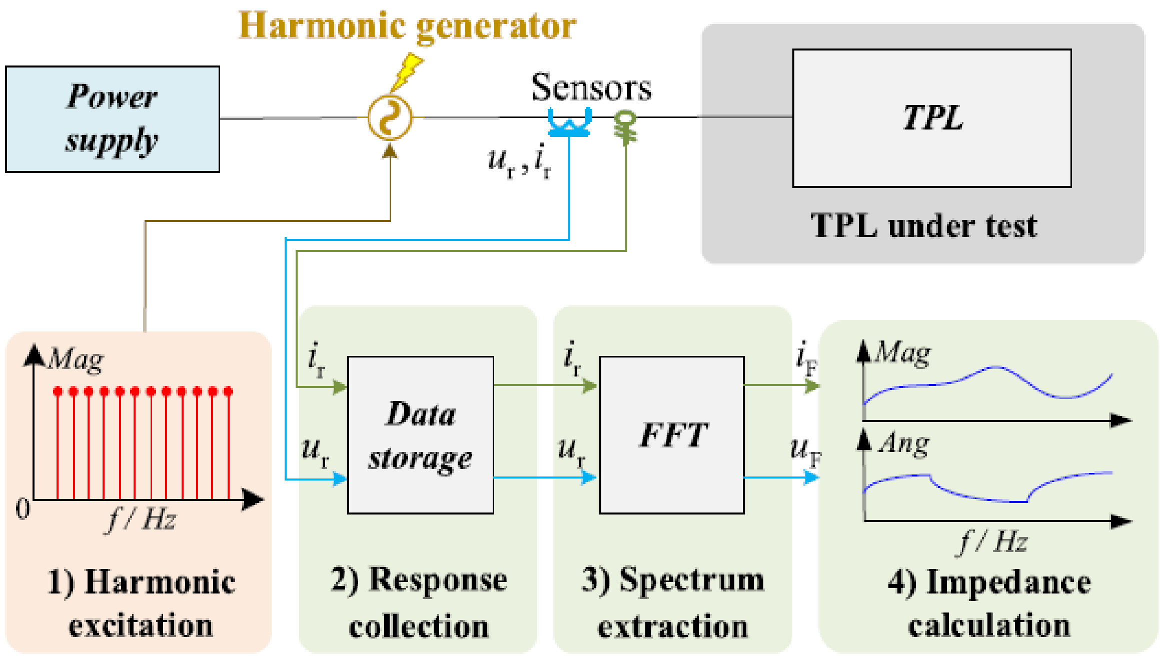
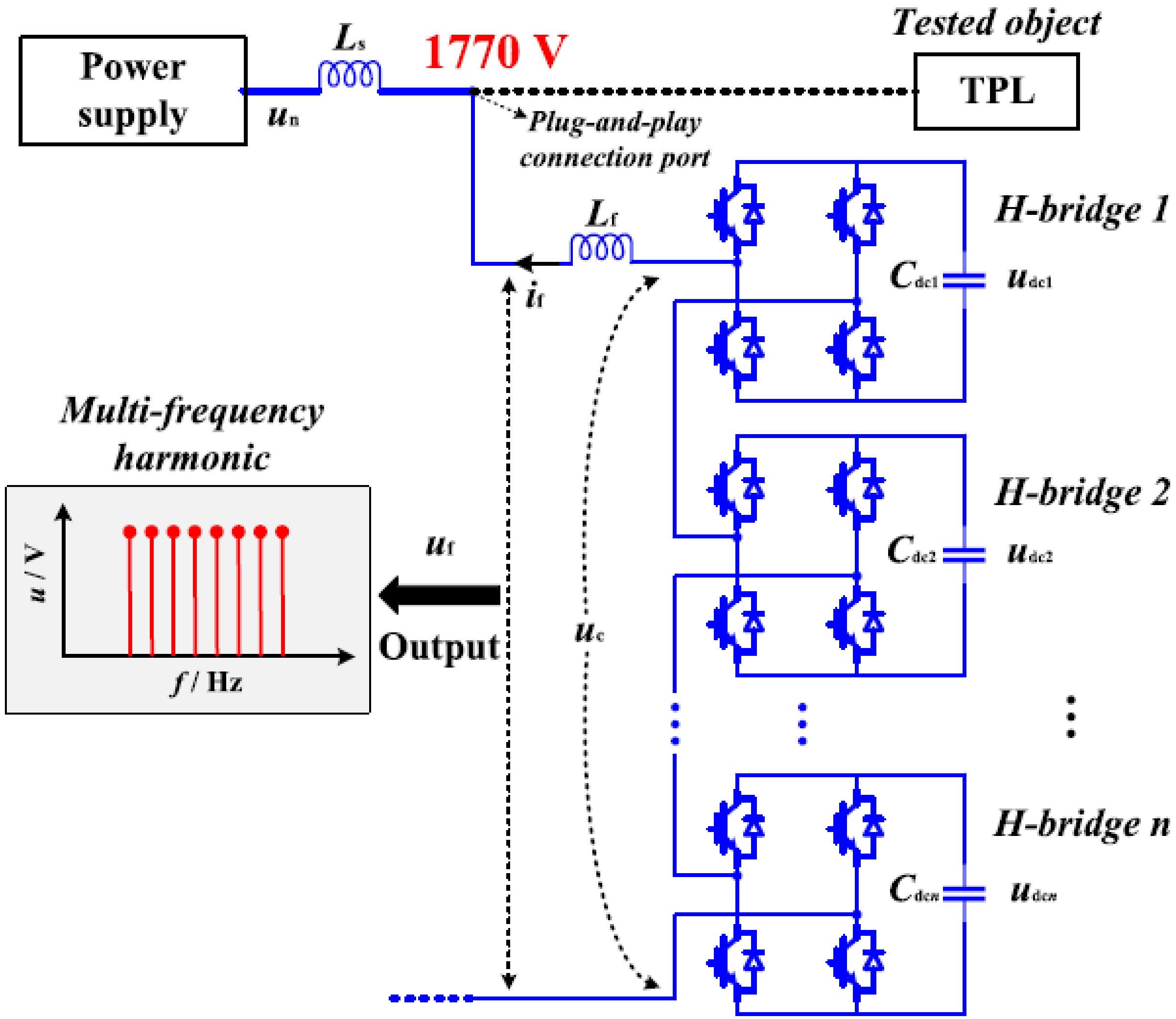
Traction Power Load Impedance Identification





Work well for frequency up to 5 kHz

LNE

DEVELOPMENT OF HV-HF GENERATORS

TWO GROUNDED GENERATORS (LNE)

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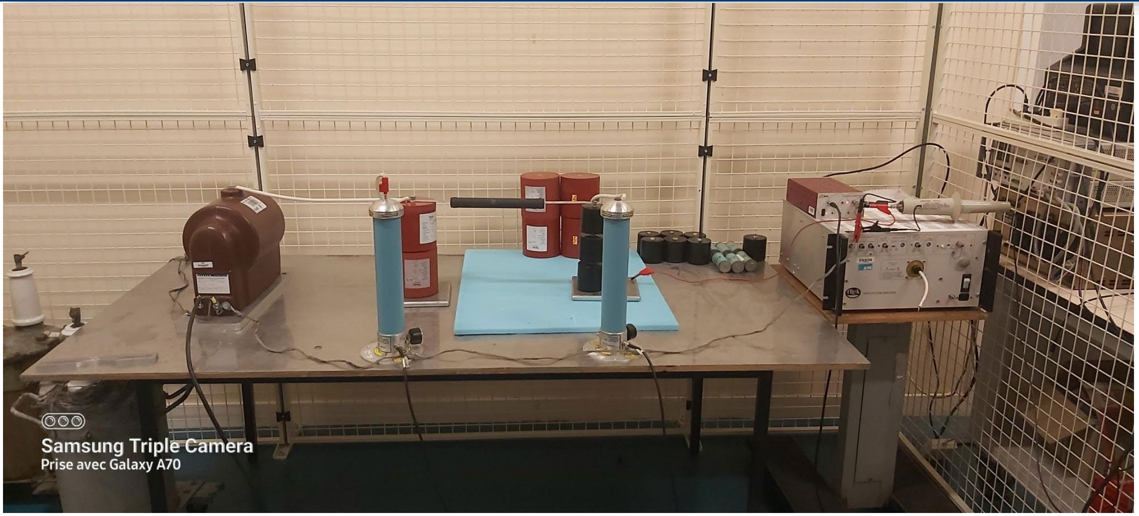

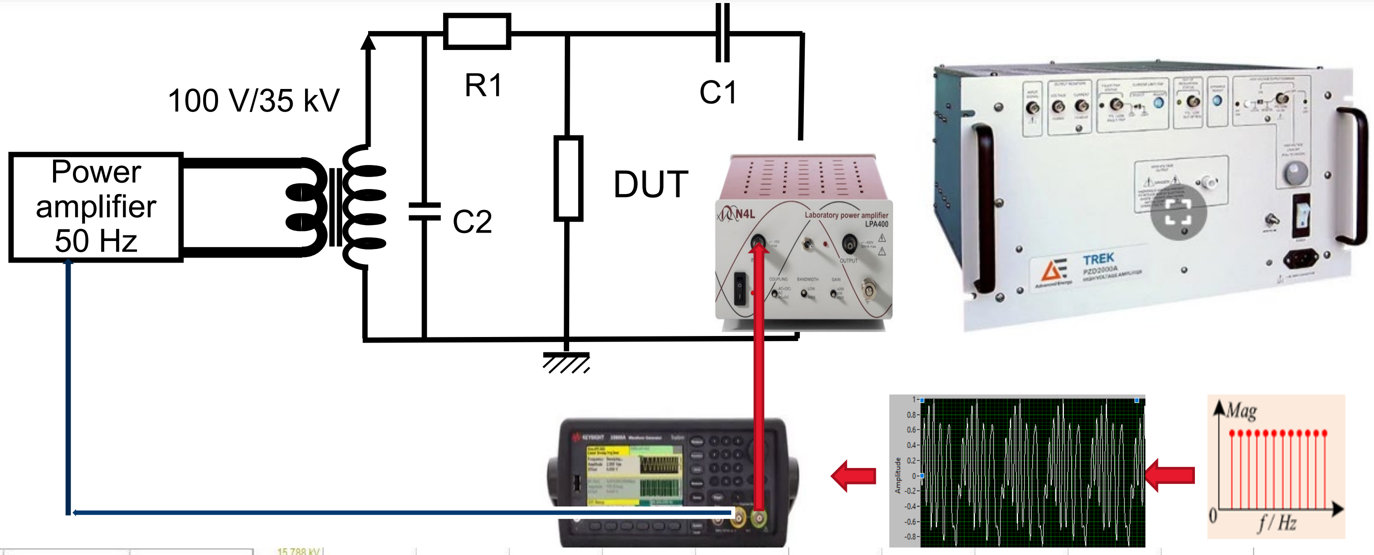

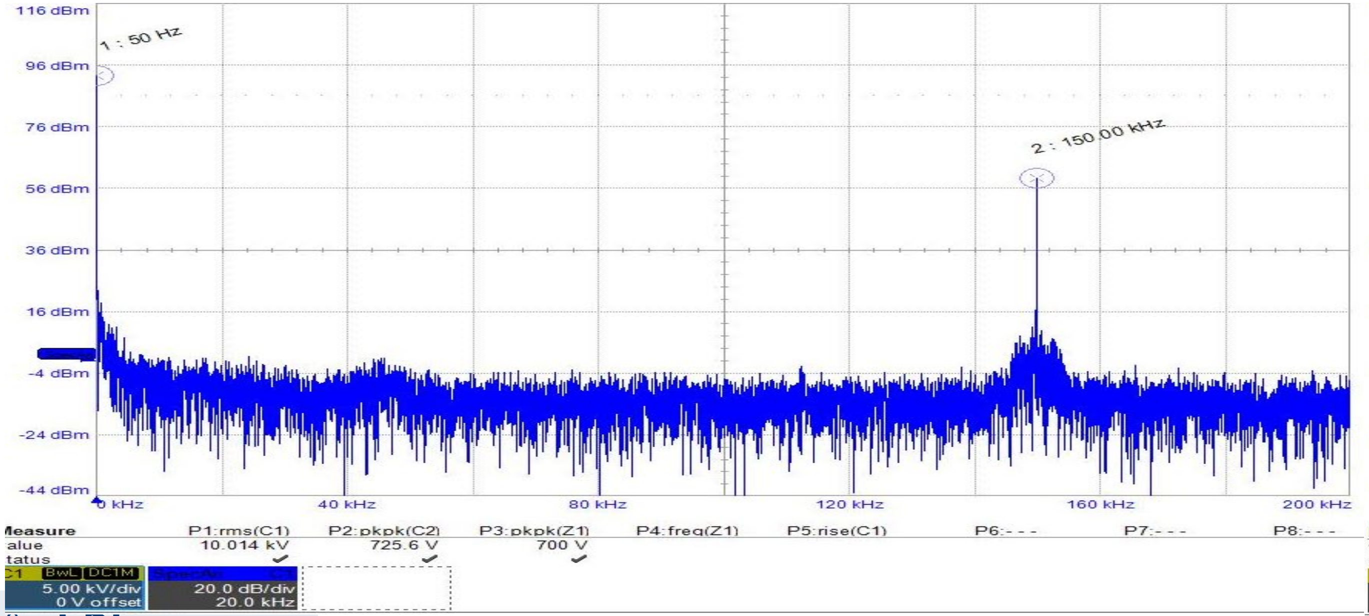

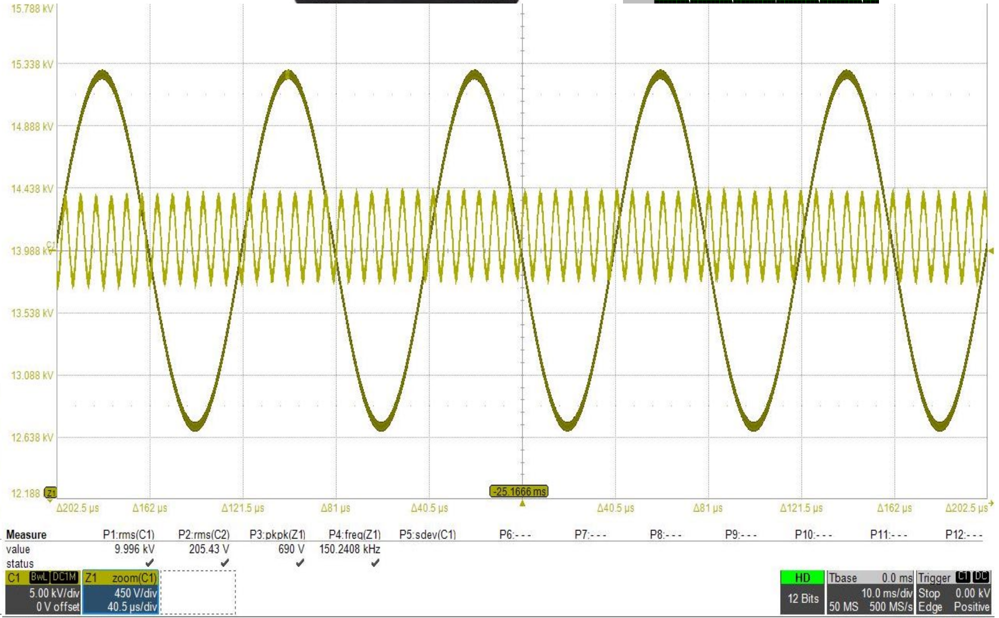

DEVELOPMENT OF HV-HF GENERATORS

TWO GROUNDED GENERATORS (LNE)

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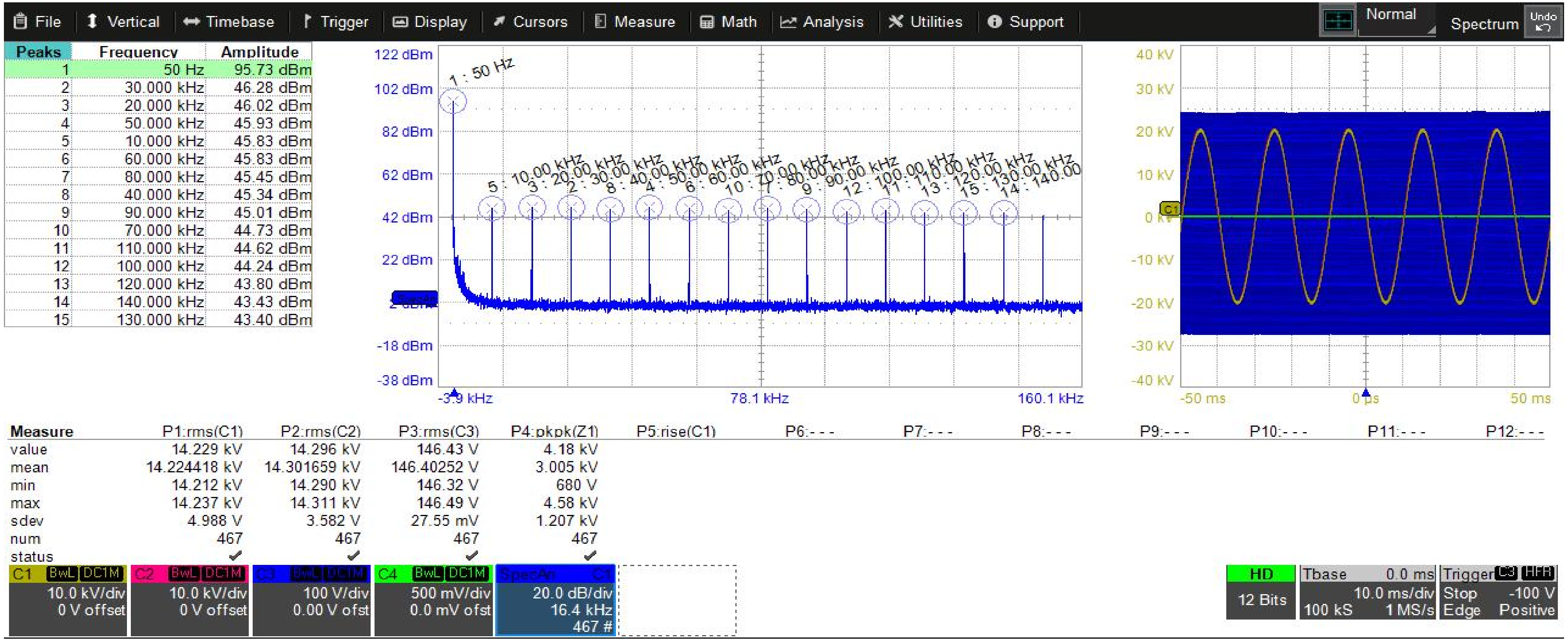


Up to 15 kV rms + 500 V (10-150 kHz)

- Better than 0.01 % for 50 Hz
- Better than 0.1 % up to 150 kHz

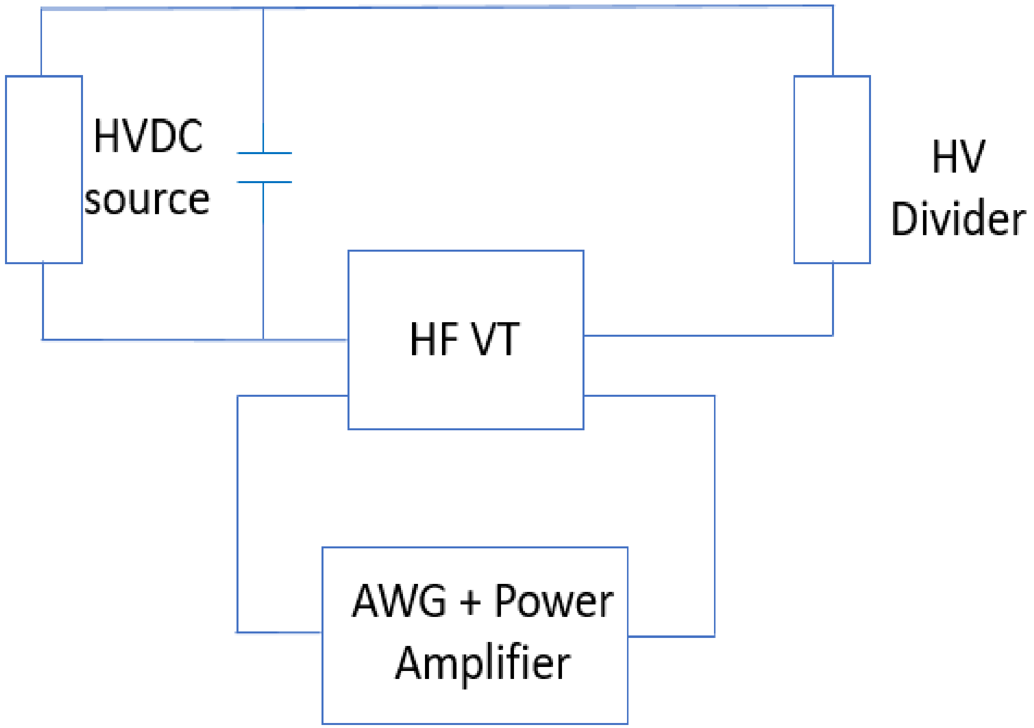
Next step →

Upgrade up to 35 kV (50 Hz):

- Using a 6 kVA amplifier
- 5 kVA transformer (purchased)
- Full remote control operation

DEVELOPMENT OF HV-HF GENERATORS

TWO SERIES GENERATORS (LCOE)



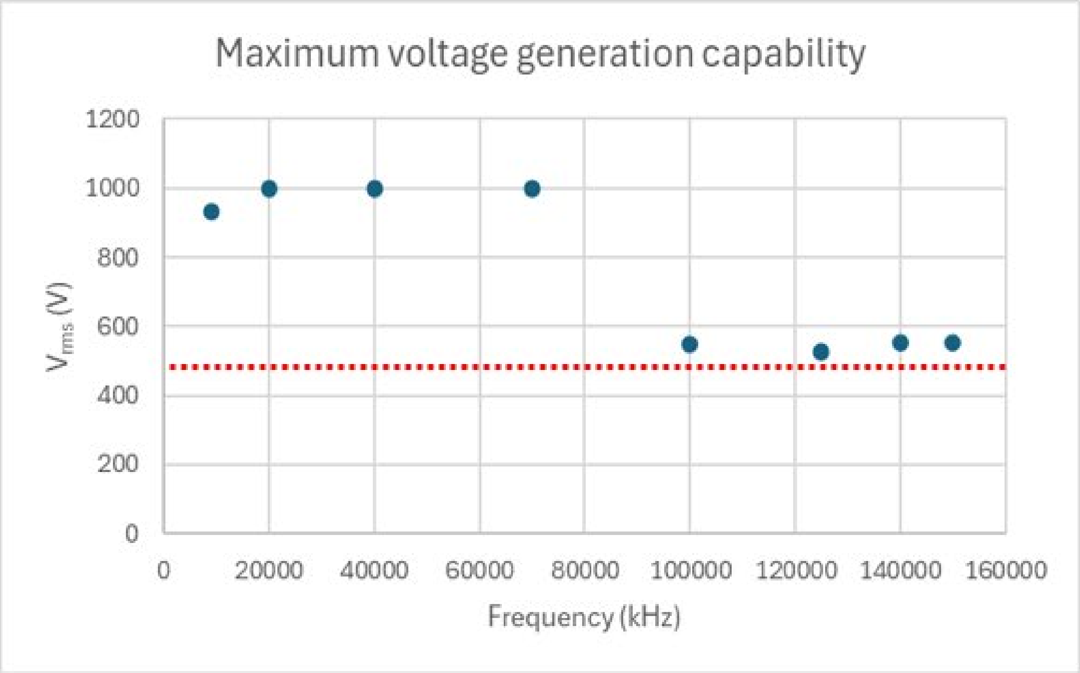
Test specifications.

1. High Voltage Divider + Sample.
    a. Estimated capacity ≈ 3.5nF.
2. AWG + power amplifier.
    a. Power requirement for testing at 150kHz, 500V: S_{max} ≈ 1kVA.
    b. Frequency range 9 – 150kHz.
    c. Output voltage > 50V.
3. High Frequency Voltage Transformer.
    a. Same power and frequency requisites as the power amplifier.
    b. Turn ratio of at least 10.
    c. Insulation between secondary and primary windings of $10kV_{dc}$.
4. HVDC source.
    a. Sufficient filter for a low harmonic content.
    b. $50kV_{DC}$

DEVELOPMENT OF HV-HF GENERATORS

TWO SERIES GENERATORS (LCOE)

1. AWG + Amplifier.
2. High Frequency Voltage Transformer.
3. Voltage divider.
4. Capacitor, simulating customer's divider.



Results from the tests.

- Capability of sumperimposing DC+harmonics from 9kHz – 150kHz.
- Capability of generating 500V_{ac} from ~75Hz – 150kHz with high capacitances. Voltage generation with lower capacitances would be higher.
- Capability of generating 1000V_{ac} from ~9kHz – 75kHz.

4

DEVELOPMENT OF HV-HF GENERATORS

TWO SERIES GENERATORS (SUN)

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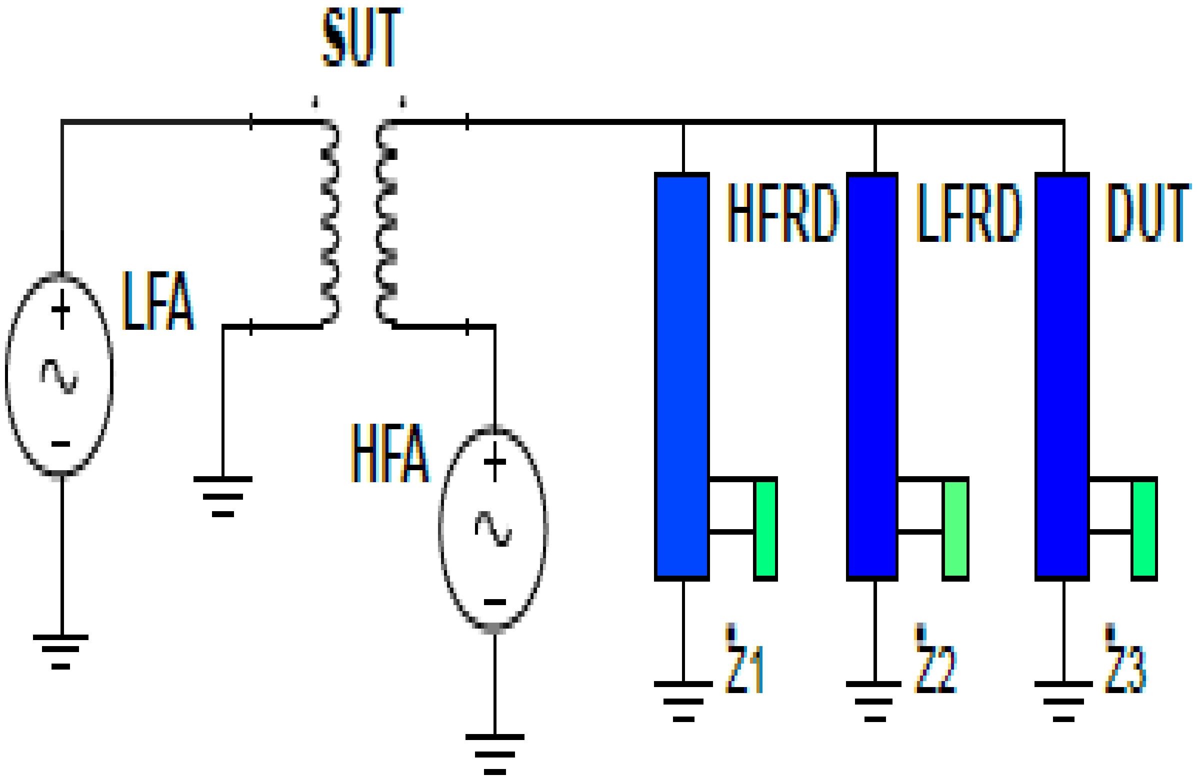
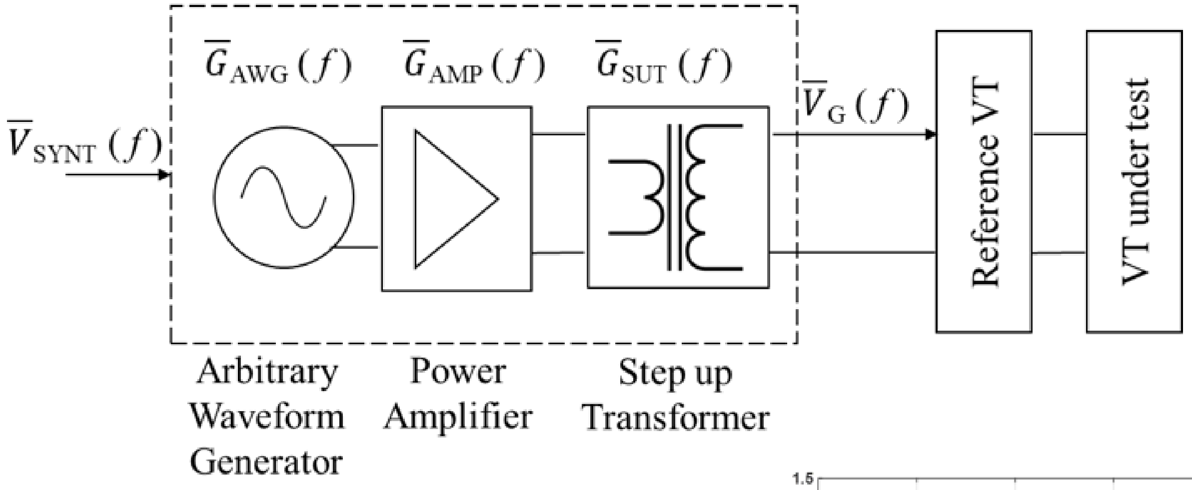


A reference setup for VT testing based on two series-connected voltage generators

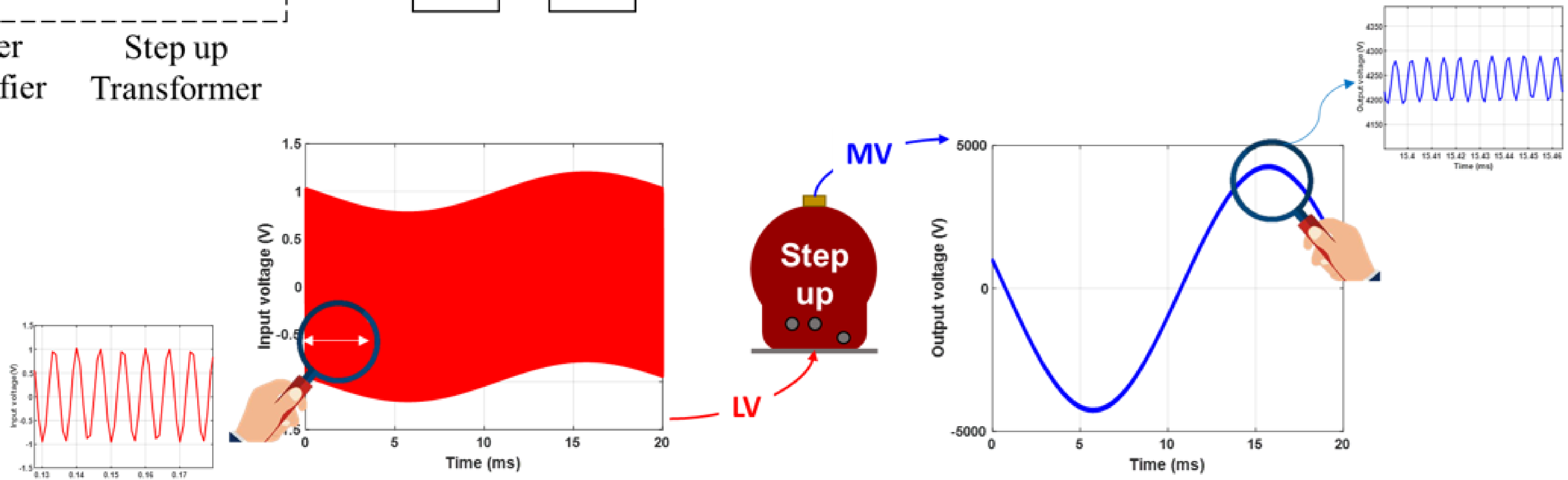
A setup for MV VT testing up to 150 kHz was developed. A Low Frequency Amplifier (LFA) drives a Step-Up Transformer (SUT) that generates the fundamental tone at MV level. The SUT is series connected to a High Frequency Amplifier (HFA) that generates the high frequency components (tens-hundreds of volt). Two reference devices are used, one for fundamental tone (LFRD) and one for the high frequency tones (HFRD).

DEVELOPMENT OF HV-HF GENERATORS
USING STEP UP TRANSFORMER (INRIM)

TARGET: Producing **distorted voltages at MV** using the simple circuit in figure compensating for the frequency behaviour of the generation setup components.



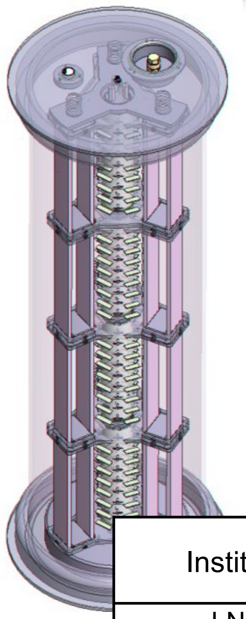
$$\overline{V}_{SYNT}(f) = \frac{\overline{V}_{G}(f)}{\overline{G}_{AWG}(f) \cdot \overline{G}_{AMP}(f) \cdot \overline{G}_{SUT}(f)}$$

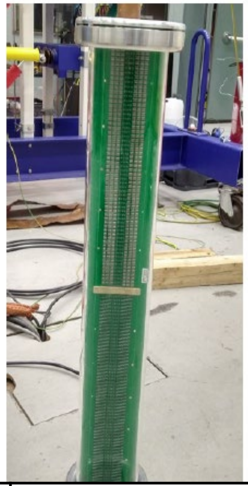


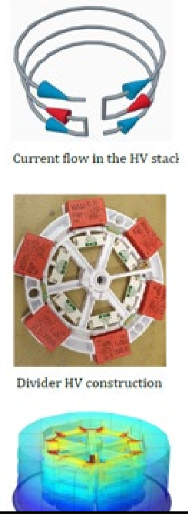
- Second part : Voltage measuring systems

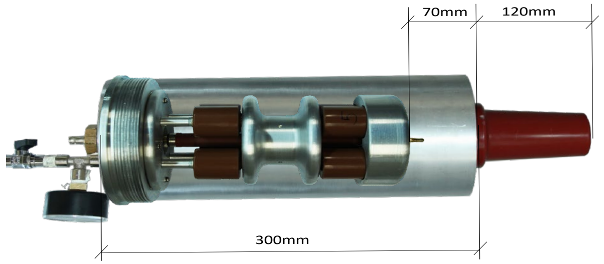
MEASURING SYSTEMS

CHARACTERIZATION OF AVAILABLE DIVIDERS









Institute	Voltage	Reference divider
LNE	DC and AC	ROSS Divider VD75, ratio 1000 into 1 MΩ, 300 MΩ, 10.8 pF
LNE	AC	Capacitive divider (compressed gas capacitor Vettiner 100 pF/100 kV)
FFII		
INRIM		ROSS VD45 + homemade RC divider 30 kV (DC and AC)
RISE	AC and DC	RCR125
VTT	DC	200 kV divider module developed in HVDC (ENG07) project. Ratio 20000:1 into >10 GΩ, 1 GΩ, 2 nF.
VTT	AC 50 Hz	Capacitive divider (compressed gas capacitor, Micafil 100 pF/200 kV)
VTT	DC and AC up to 10 MHz	200 kV RCR divider module developed in HV-com² (19NRM07) project. Ratio 2000:1 into 1 MΩ, 1.2 GΩ, 425 pF
VSL	DC	200 kV divider module developed in HVDC (ENG07) project. Ratio 20000:1 into >10 GΩ, 1 GΩ, 2 nF.

Some dividers are very flat in the frequency range up to 150 kHz < 0.1 %.

An uncertainty of 100 ppm at 50 Hz is not easy to reach with those dividers.

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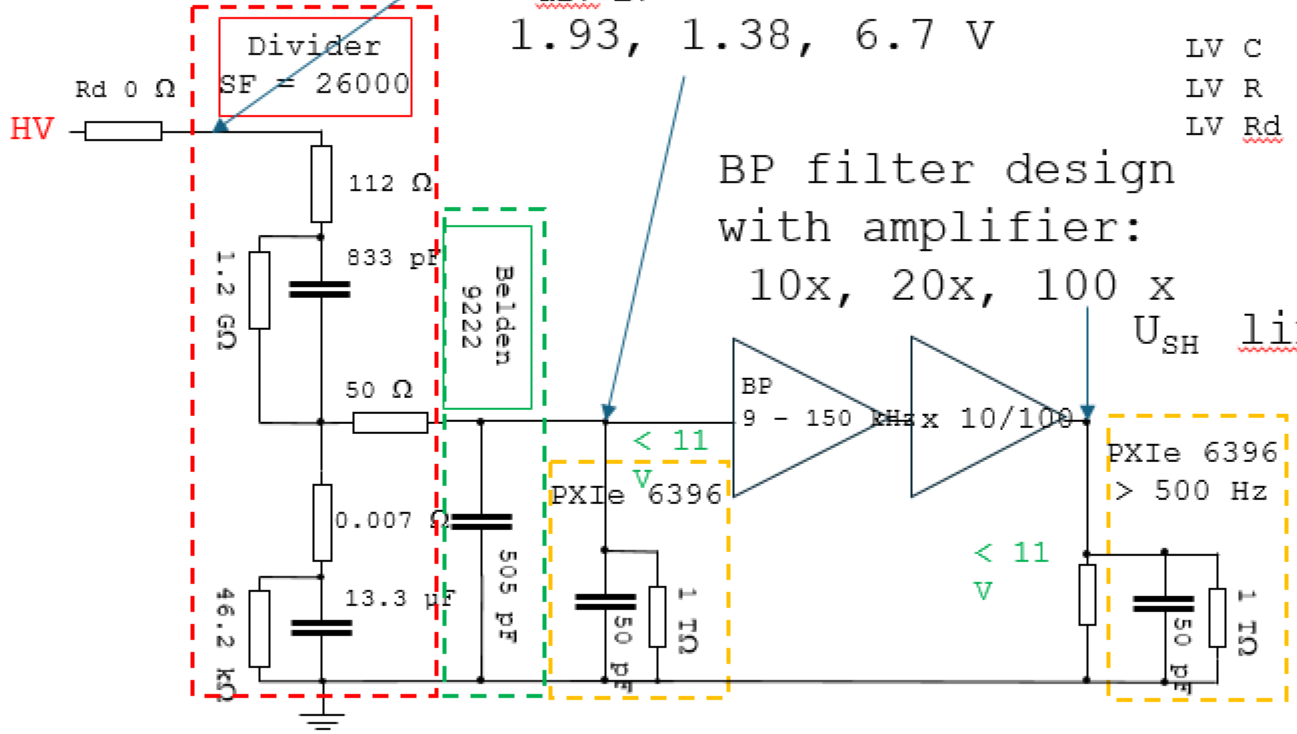
$U_{nominal}$ (test) (DC/AC/LI) = 50/36 (max 98/70/175) kV

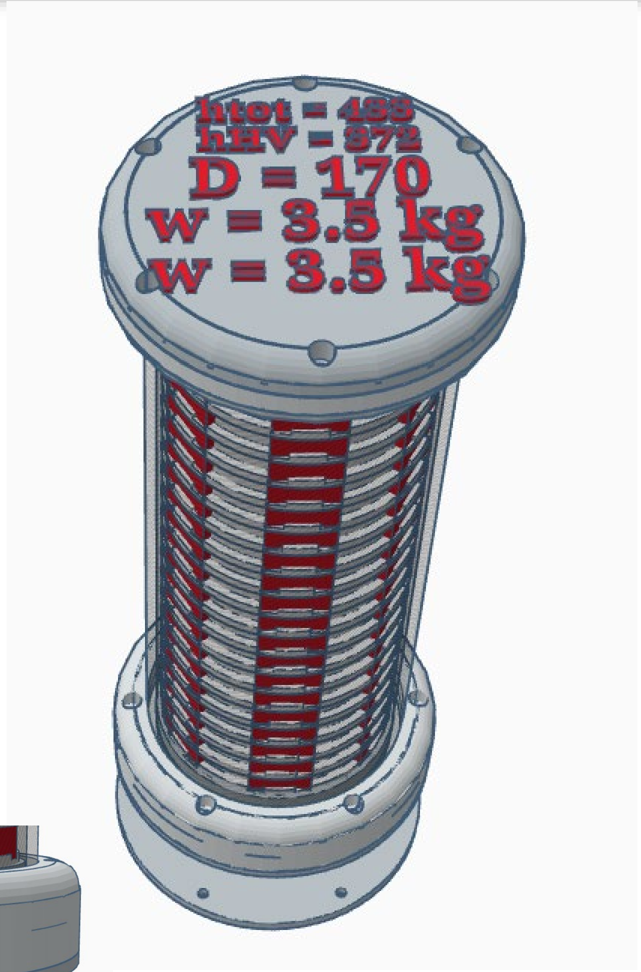
$U_{div\ LV}$ DC/AC/LI = 1.93, 1.38, 6.7 V

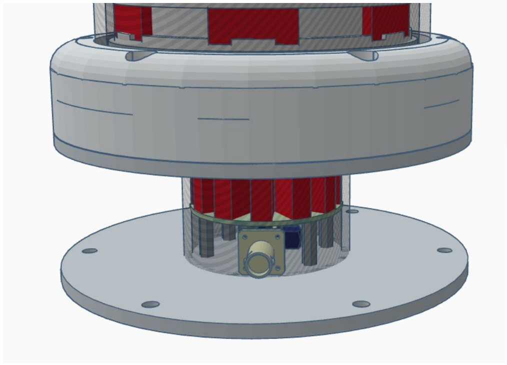
HV C,	100 nF,	FKP1	6 x 20	pc
HV R	10 MΩ,	Mox	6 x 20	pc
HV Rd	3.3 Ω,	MELF	2 x 20	pc
LV C	33 nF,	63V FKP2	15	pı
LV R	300 +15 kΩ,	Mox	1	pc
LV Rd	0.1 Ω,	MELF,	4 x 15	pc

BP filter design with amplifier: 10x, 20x, 100 x

U_{SH} limited to 10 V







MEASURING SYSTEMS

DIVIDERS UNDER DEVELOPMENT (LNE)

First prototype (RCr)

R = 110 MΩ
C= 1.8 nF
r=56 Ω

Wima capacitor FKP4, 200 ppm/ °C
Metal film resistor Vishay CMF60, 25 ppm/°C,0.3 ppm/V.

Frequency, temperature and voltage compensation

DC :

V.C = -1 ppm/kV
SEL heating = -1 ppm/min

0.1 % frequency stability up to 150 kHz

MEASURING SYSTEMS

DIVIDERS UNDER DEVELOPMENT (LNE)

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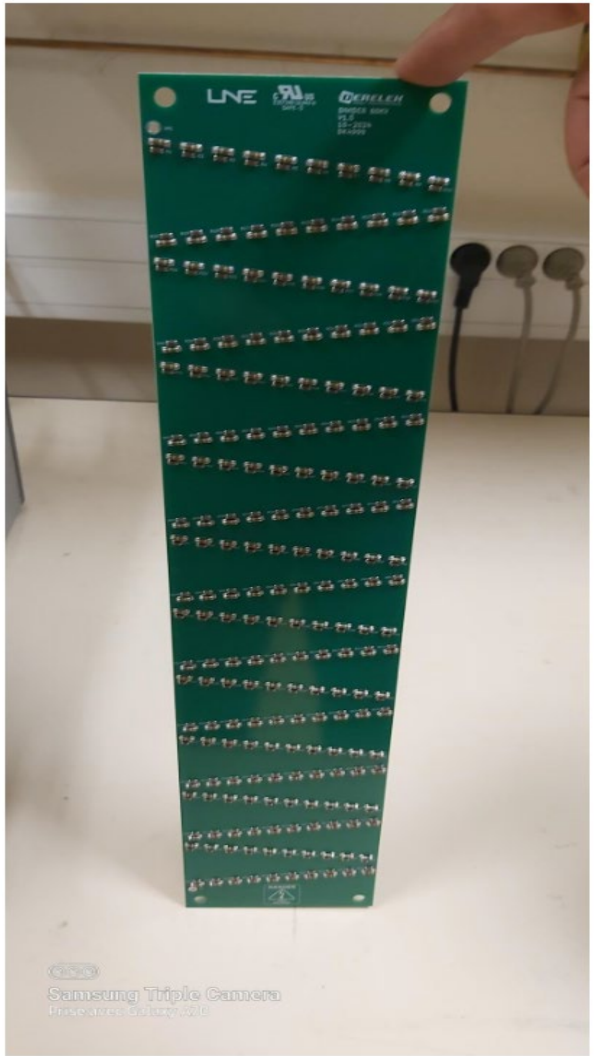
Second prototype (RC)

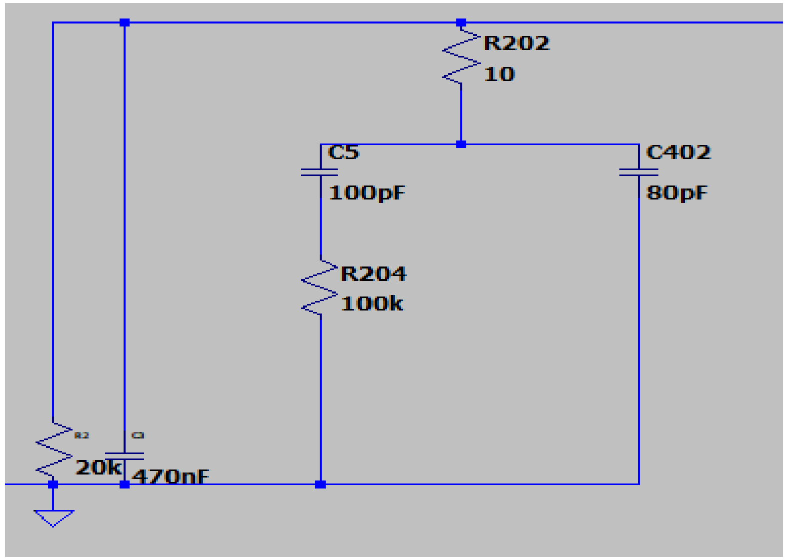


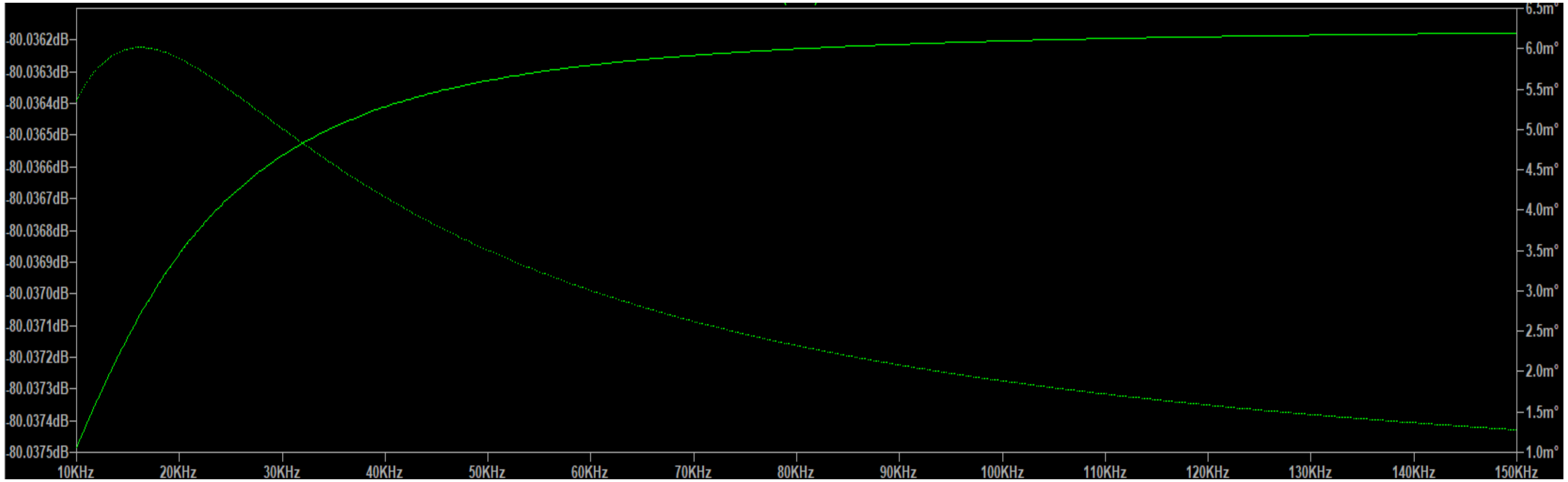
R = 200 MΩ = 200×1 MΩ
C= 50 pF ➔ 200× 10 nF

NPO capacitor, 0-30 ppm/°C, 10 nF/650 V.
MELF resistor (15 ppm/°C, 0.26 ppm/V)

DC :
V.C = < 1 ppm/kV
SEL heating = -2.5 ppm/min

Frequency compensation box :





MEASURING SYSTEMS

DIVIDERS UNDER DEVELOPMENT (LNE)

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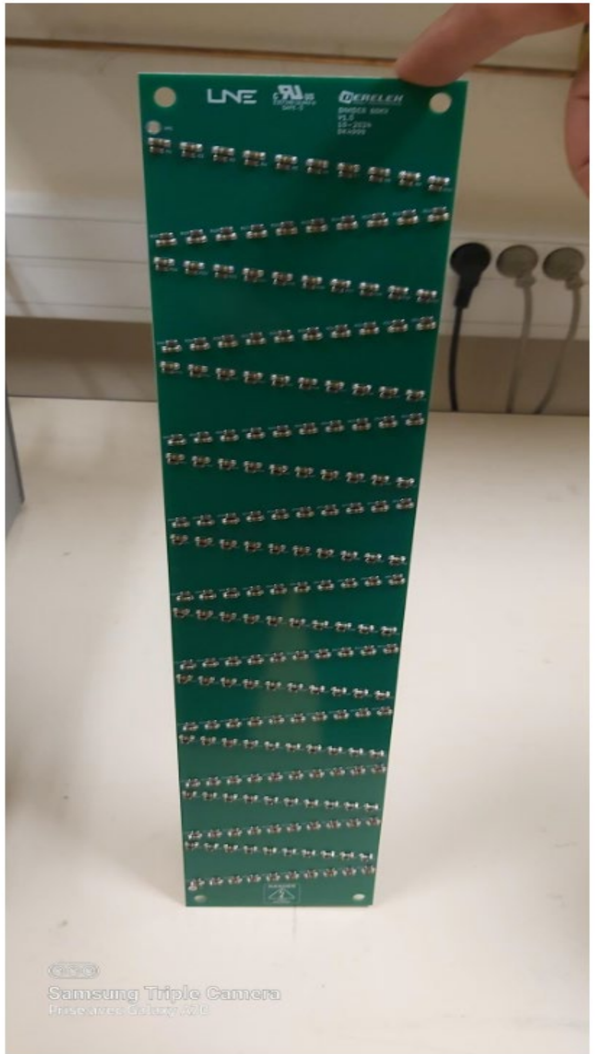
Second prototype (RC)



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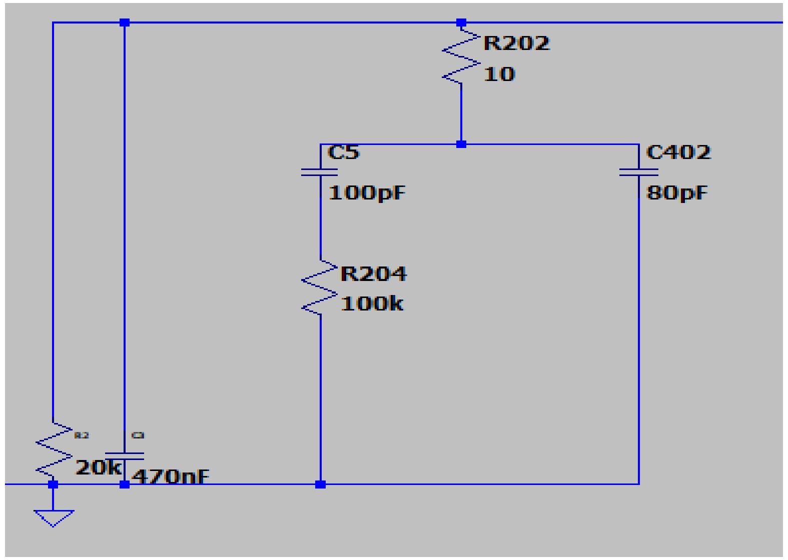
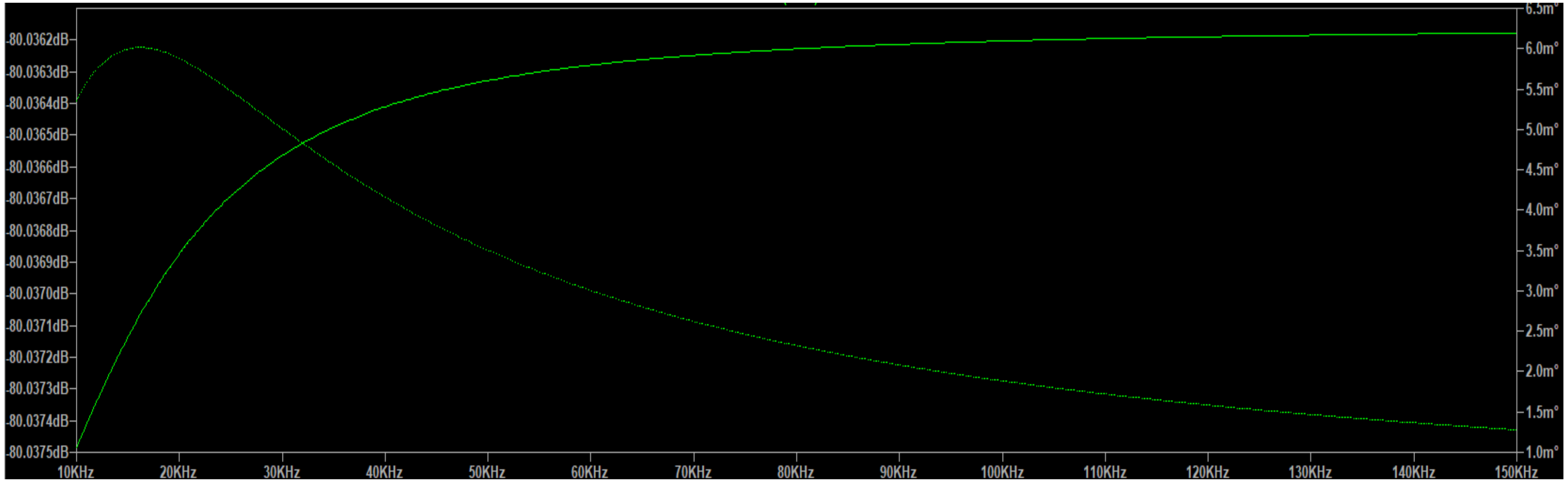
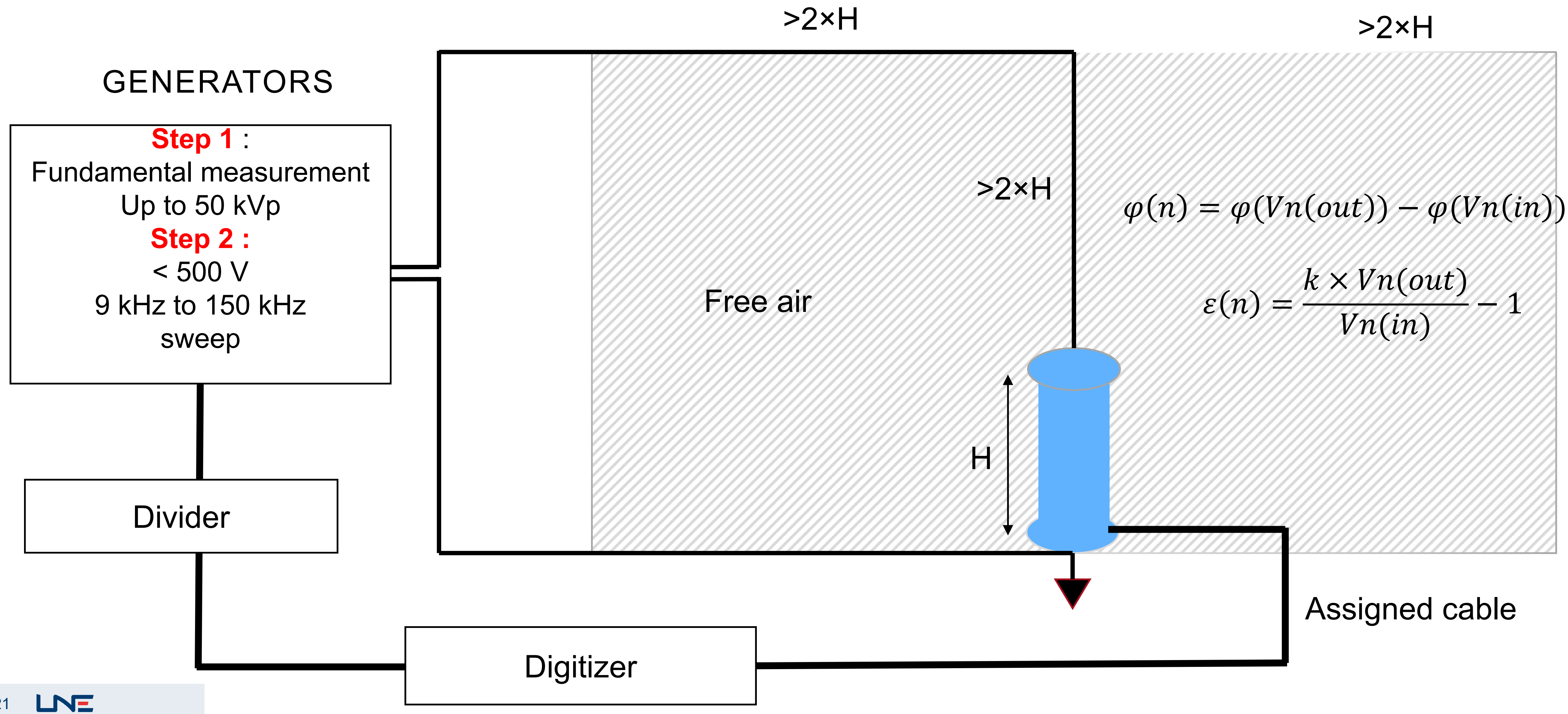


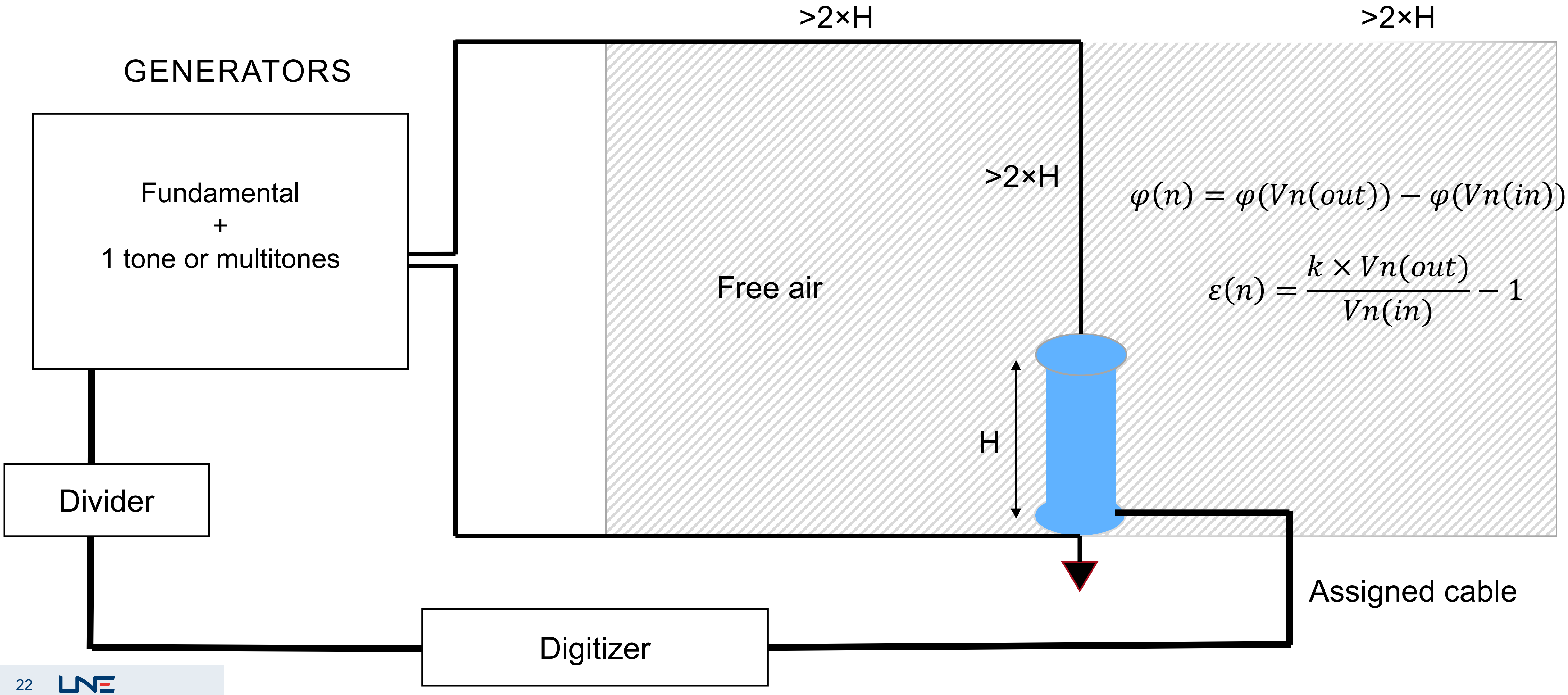


SIMPLIFIED PROCEDURE :



PROCEDURES

REFERENCE PROCEDURE :



$$\varphi(n) = \varphi(Vn(out)) - \varphi(Vn(in))$$

$$\varepsilon(n) = \frac{k \times Vn(out)}{Vn(in)} - 1$$

THANK YOU FOR YOUR ATTENTIONM