RESEARCH

METROLOGY

TESTING

CERTIFICATION

EXPERTISE AND INNOVATION

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MEASUREMENT OF DC VOLTAGE RIPPLE IN LABORATORY ENVIRONMENT

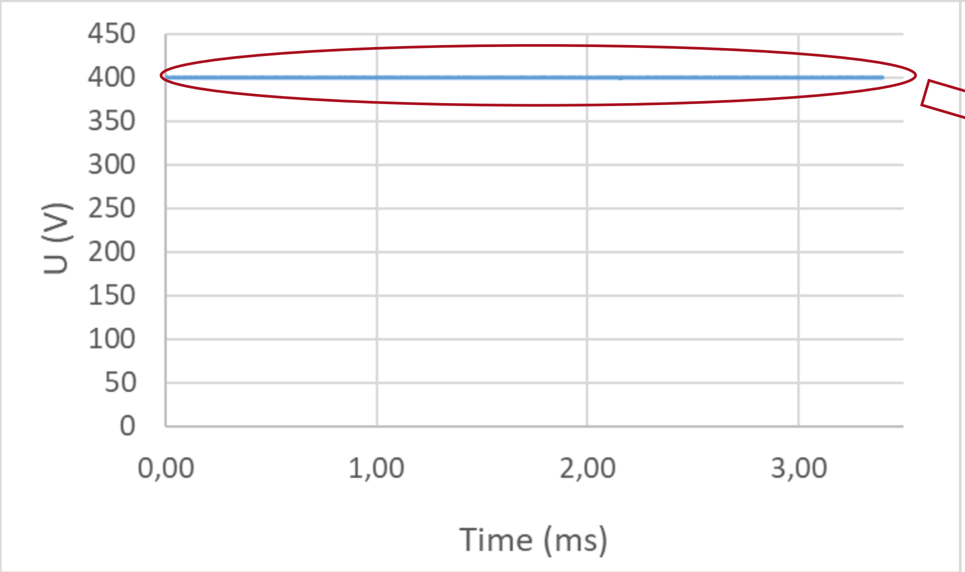
JRP 20NRM03 DC GRIDs WORKSHOP

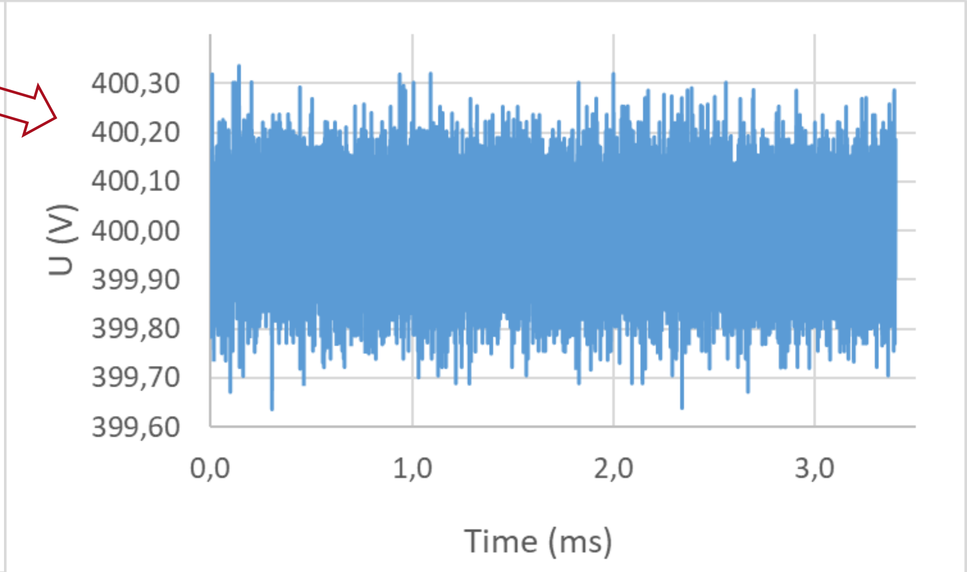
16th of May 2024

CONTENT

Ripple in DC

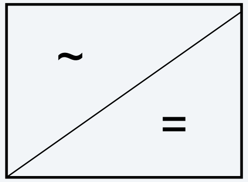
Steady-state phenomenon





Causes

Sources



Power electronic converters

- Semiconductor switching
- Rectifying an AC source voltage regulation
- Instability of the DC power source

Loads

PV, Electric storage, EV

- Connecting to the network
- Variations (operating modes or cyclic operations)

IEC IEV ref 312-07-02: "ripple"

set of unwanted periodic deviations with respect to the average value of the measured or supplied quantity, occurring at frequencies which can be related to that of the mains supply, or of some other definite source, such as a chopper

- ➢ **risk on the safe operation of grids**
- ➢ **stressing equipment**

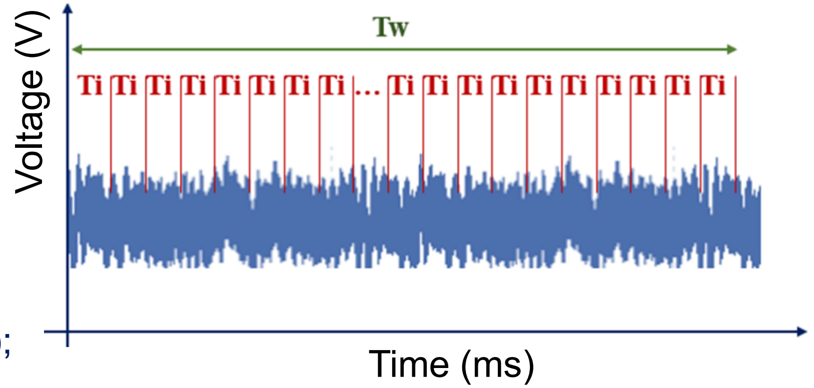
RIPPLE IN DC VOLTAGE

INDICATORS USED IN THIS STUDY (proposed in IEC TR 63282:2023)

Time domain

Ti <Tw ≤Tm

1. $Ripple_{pp}(V) = abs\left(Max_{V_{i,RMS}} - Min_{V_{i,RMS}}\right)$



With
Ti – time to determine the RMS value
Tw – time duration of observation window (is the length of DFT spectral analysis window);
Tm – PQ integration periode (used to record the steady state DC PQ indices).
$Max_{V_{i,RMS}}$, $Min_{V_{i,RMS}}$– the maximum and the minimum value among all the Tw/Ti determined RMS values

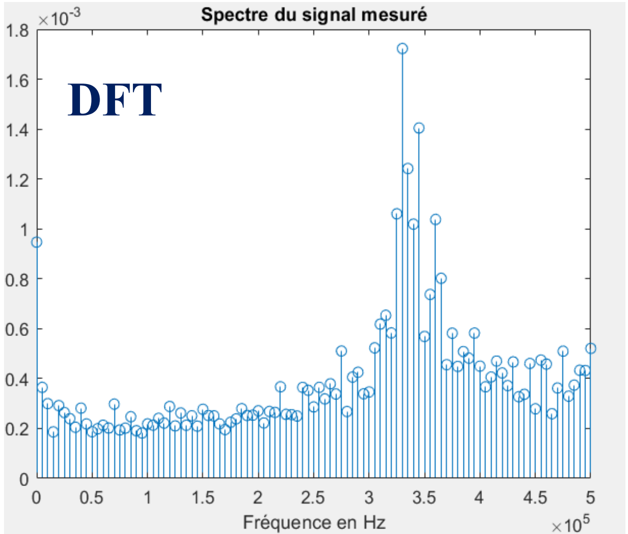
It gives an indication on the variation of the distortion during Tw analysis window.

2. $Ripple_{RMS,t}(V) = \sqrt{V_{rms}^2 - V_{mean}^2}$

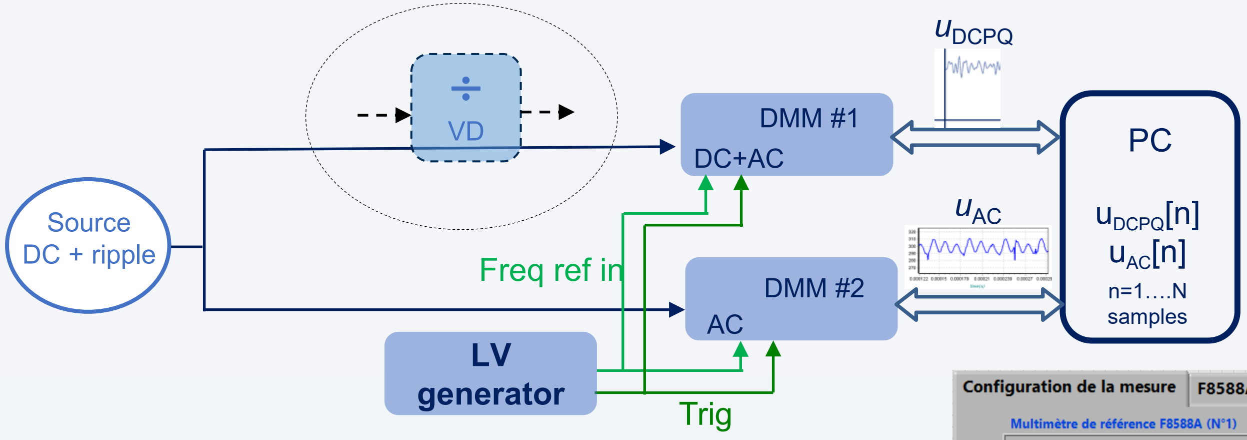
With
V_{RMS} – the RMS value of the measured signal over Tw duration
V_{mean} – the mean value of the measured signal over Tw duration

It gives the value of the ripple over Tw analysisi window.

Frequency domain

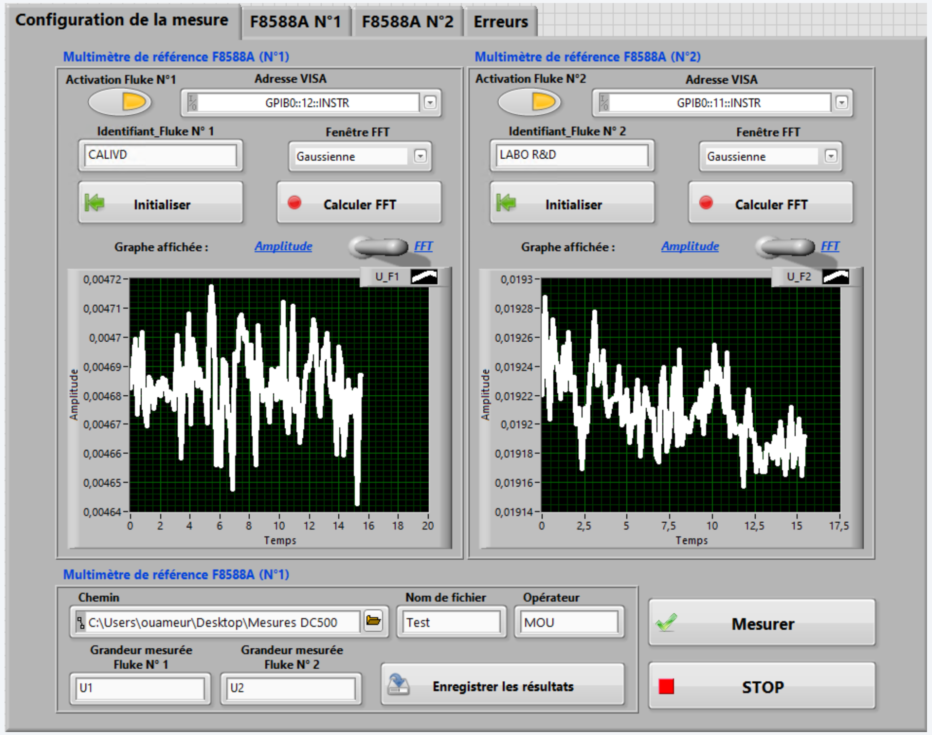


Measurement setup



Data acquisition & treatment

LabVIEW + MATLAB



DMMs

- 18 bits
- Input ranges: 100 mV, 1 V, 10 V, 100 V, 1000 V
- Frequency range: DC to 5 MHz
- Digitize mode
  - #1 DC coupling
  - #2 AC, 10 MΩ coupling

Voltage Divider

- Several ranges exist: 56 V, 240 V, 1000 V
- To be used if it offers a higher measurement precision (adapt the input signal to 1 V range of DMM)
- Bandwidth: DC to 150 kHz with less than 0.0075 dB attenuation

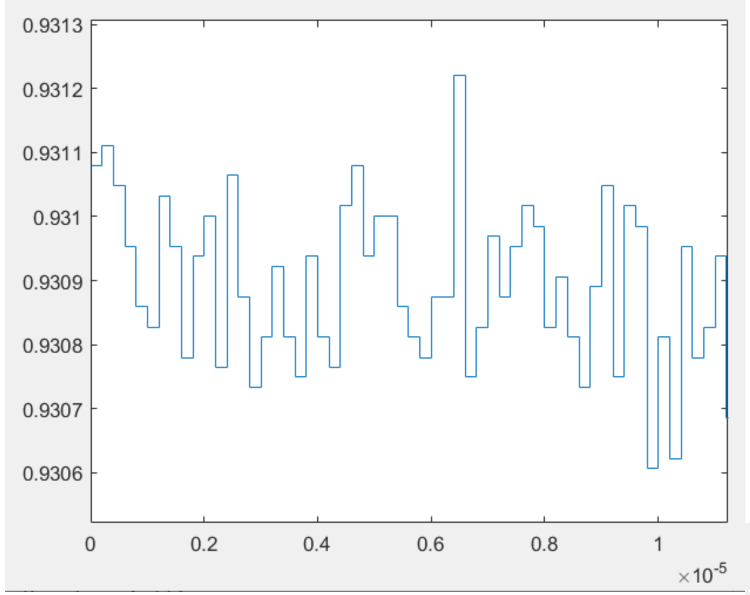
Data acquisition

- The 2 DMMs are synchronized to the same 10 MHz clock reference (Freq ref in)
- The External Trigger is used (100 Hz, ± 2.5 V signal)

DC Grids

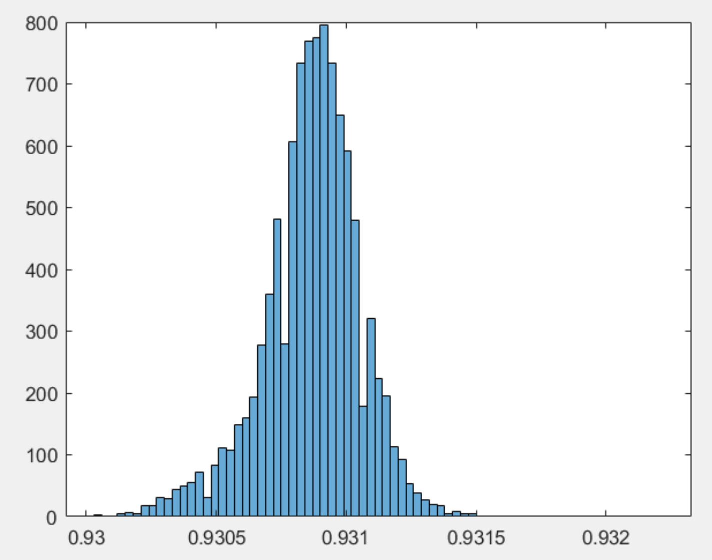
Quantization step

DC voltage sampled with 5 MHz. 90% of the DMM 1V range.



V_{DC} =0.931 V

Histogramme



ADC noise

DC voltage sampled with 5 MHz
Standard deviation of 10 000 samples
with respect to the full scale.

Range	Quantization step	ADC noise of FS (-)	ADC noise of FS
100 mV	1.7 µV	$1.8 \cdot 10^{-4}$	36 µV
1 V	16 µV	$9.2 \cdot 10^{-5}$	186 µV
10 V	160 µV	$4.6 \cdot 10^{-5}$	929 µV
100 V	1.6 mV	$7.0 \cdot 10^{-5}$	14 mV
1000 V	17 mV	$7.9 \cdot 10^{-5}$	83 mV

17 bits for the conversion

Processing the ripple of a LVDC switching source

DMM #1
- Input ranges: 10 V, 100 V, 1000 V
- Digitize mode : DC coupling
- Sampling frequency : 1 MHz

DMM #2
- Input ranges: 100 mV
- Digitize mode : AC, 10 MΩ coupling
- Sampling frequency : 1 MHz

Switching power supply features

- Output voltage up to 600 V
- Rated output power 1560 W
- Ripple rms 1 MHz, 60 mV
- Ripple & noise p-p 20 MHz, 300 mV

Configuration

Rated voltage (V)	DMM #1 DC coupling Range (V)	DMM #2 AC coupling Range (V)	Voltage choice
9	10		Low level supply Accurate DMM range
48	100		Communications, lighting
110		0.100	Inverter apliances
350	1000		DC bus
600			Maximum level supply

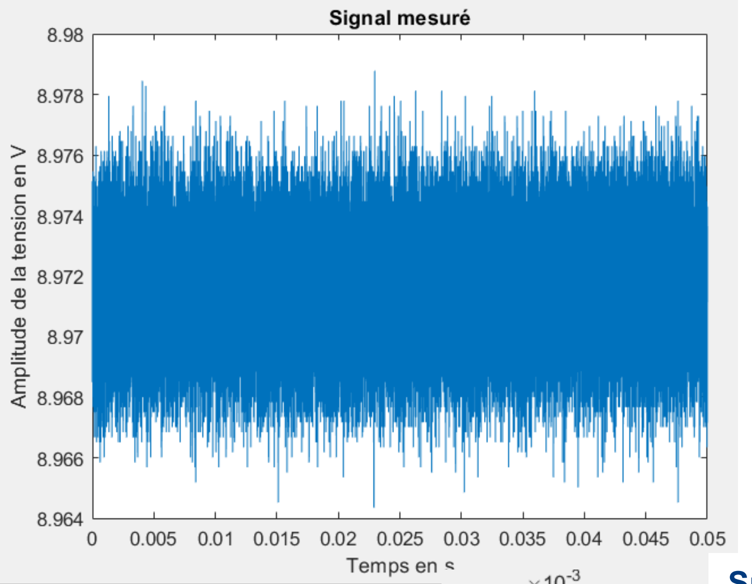
Questions

- ➢ **Is it possible to detect low-level ripple?**
- ➢ **What is the most appropriate configuration and measurement method?**
- ➢ **How does the ripple change with the voltage level?**

MEASUREMENT OF LVDC SOURCE RIPPLE

DC Grids

9 V



DC
Range: 10 V
Quanta: 160 µV

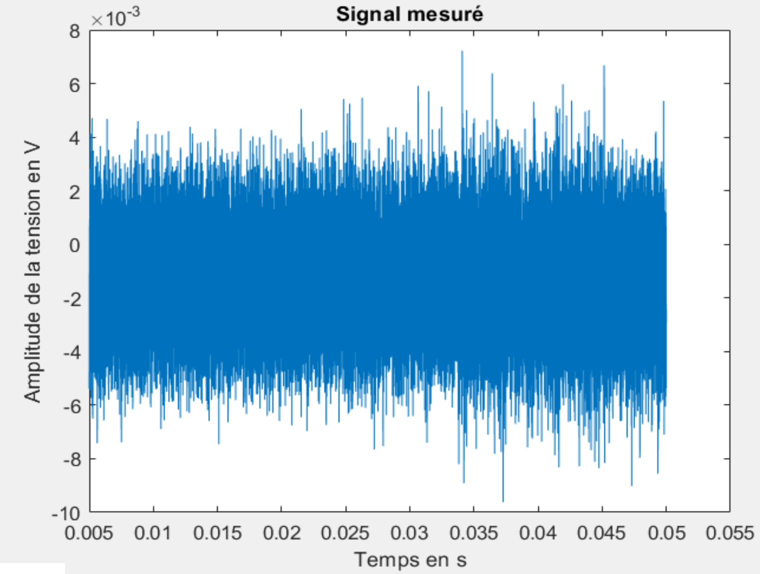
PQ — Raw data
Ripple_{PP} = 322 µV ≠ U_{PP} ≅ 9 mV

Ripple_{PP} covers 2 quantization levels

AC
Range: 100 m V
Quanta: 1.7 µV

PQ
Ripple_{PP} = 426 µV

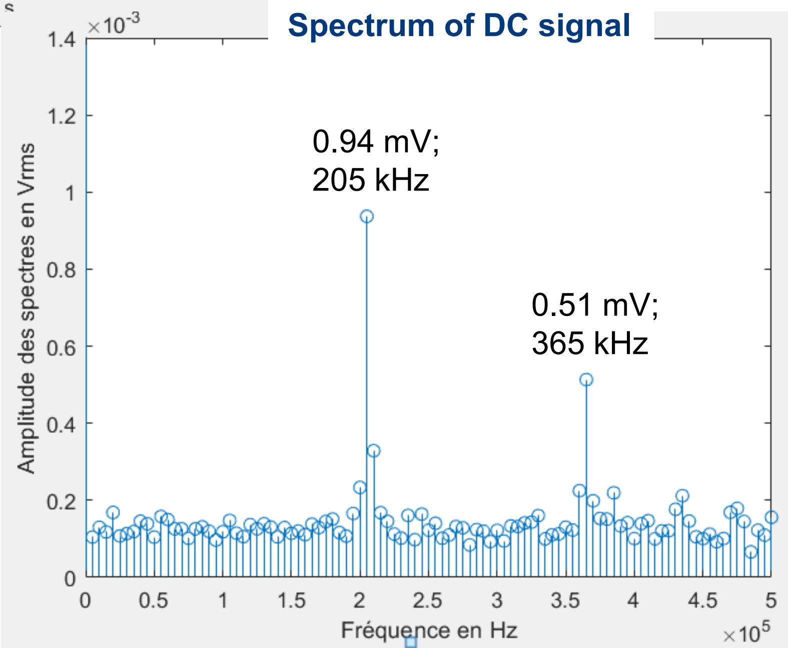
Ripple_{PP} covers 250 quantization levels



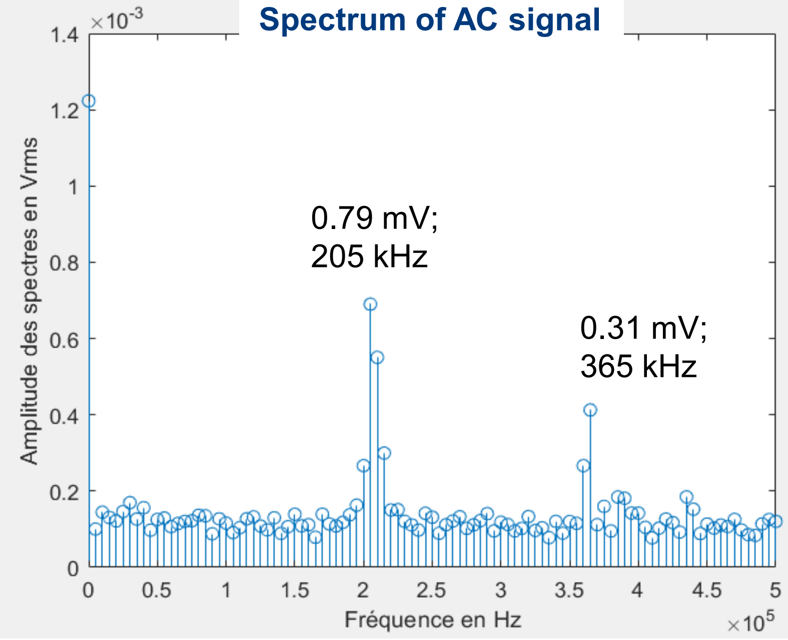
!! Calculating Ripple_{PP} on raw values gives indicators for product standards.

!! Our Ripple_{PP} indicator based on RMS values targets power grid quality standards.

Spectrum of DC signal

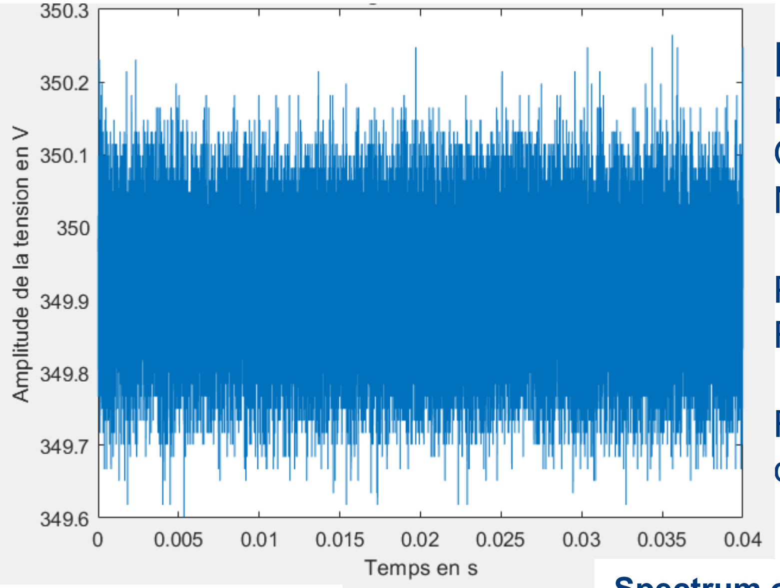


Spectrum of AC signal



- **Ripple_{PP} well determined since it's based on the averaged values, less influence of the quantization noise**
- **Frequencies detected both on DC & AC acquisitions**
- **Almost the same noise on DC and AC signals**
- **1 DMM could be sufficient in this case**

MEASUREMENT OF LVDC SOURCE RIPPLE



350 V

DC

Range: 1000 V

Quanta: 8 mV

Noise: 105 mV

PQ | Raw data

$Ripple_{PP}$ = 12,42 mV ≠ U_{PP} ≅ 430 mV

$Ripple_{PP}$ covers 2 quantization levels

AC

Range: 100 m V

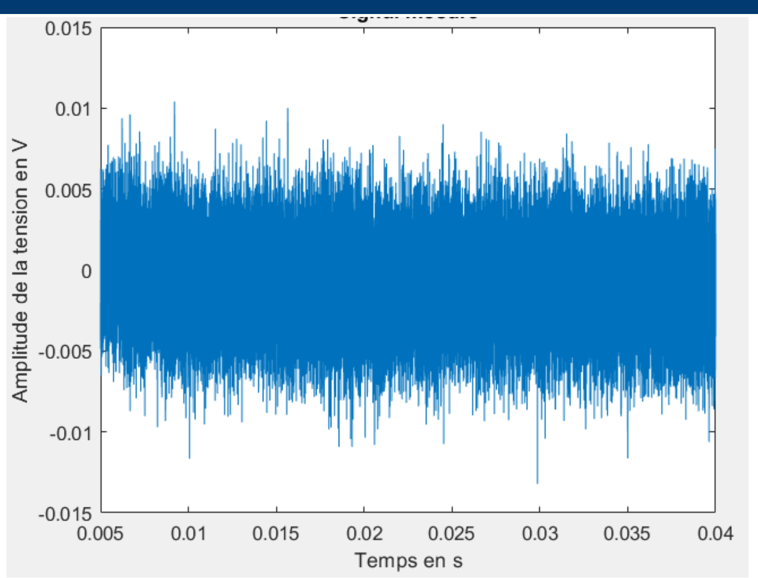
Quanta: 1.7 µV

Noise: 36 µV

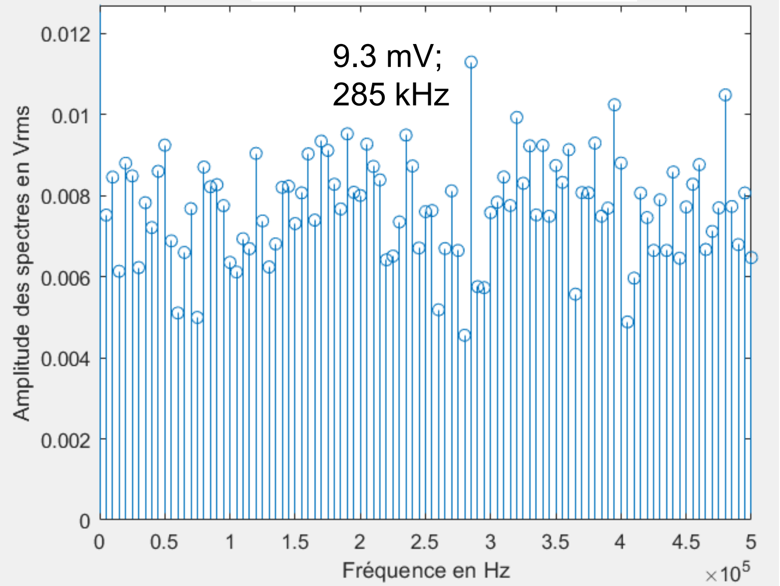
PQ

$Ripple_{PP}$ = 1.35 mV

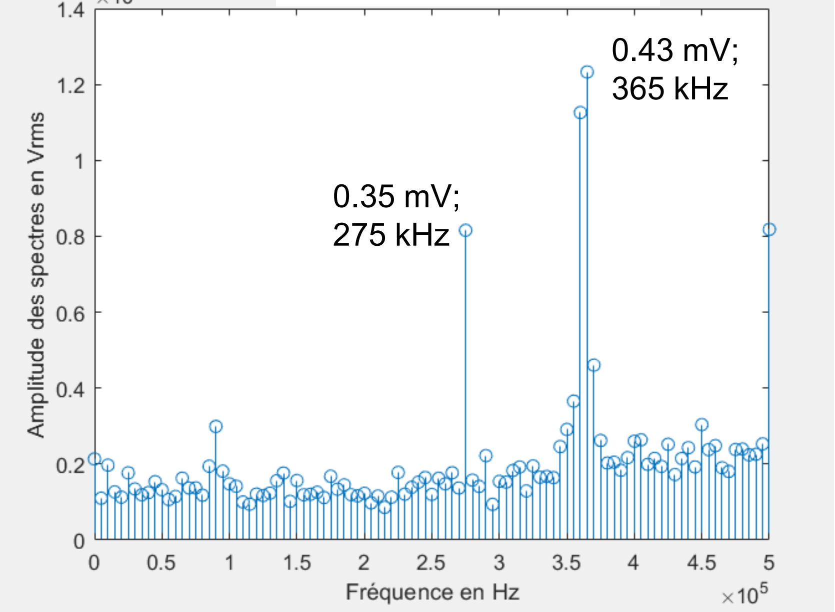
$Ripple_{PP}$ covers 794 quantization levels



Spectrum of DC signal



Spectrum of AC signal

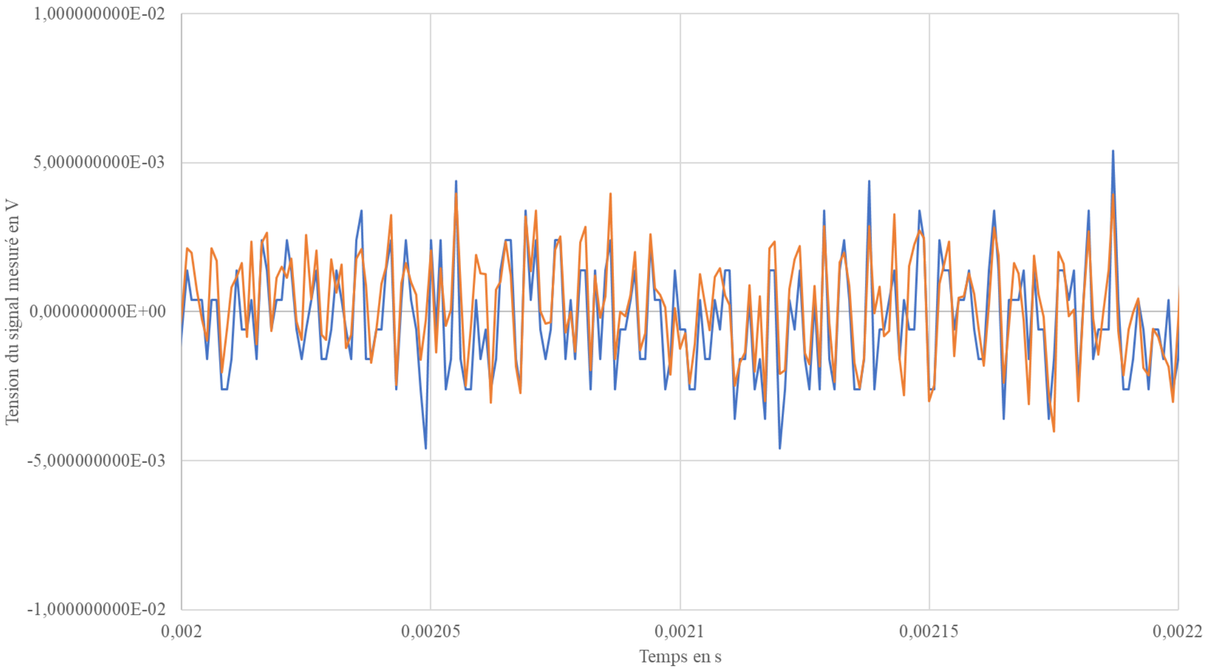


- **Frequencies detected only on the AC acquisition**
- **High impact of noise on DC @ 1000 V range**
- **White noise due to ADC of DMMs**
- **2nd DMM is recommended for AC signal acqusition**

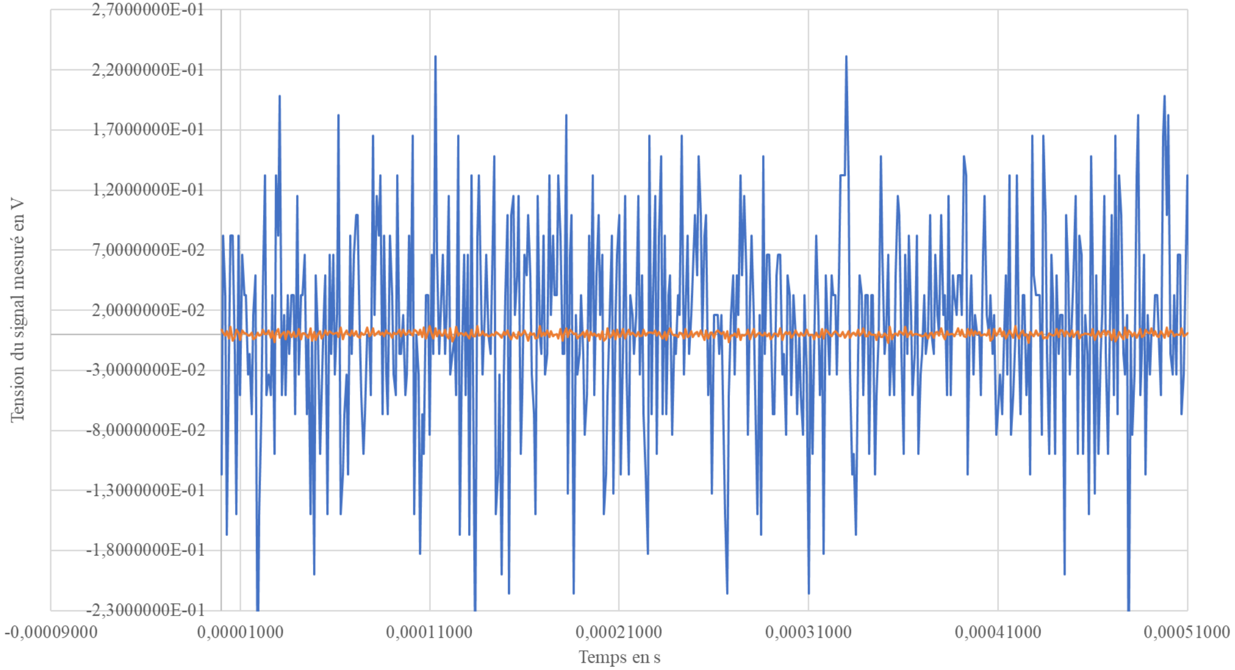
MEASUREMENT OF LVDC SOURCE RIPPLE

DC Grids

9 V



350 V

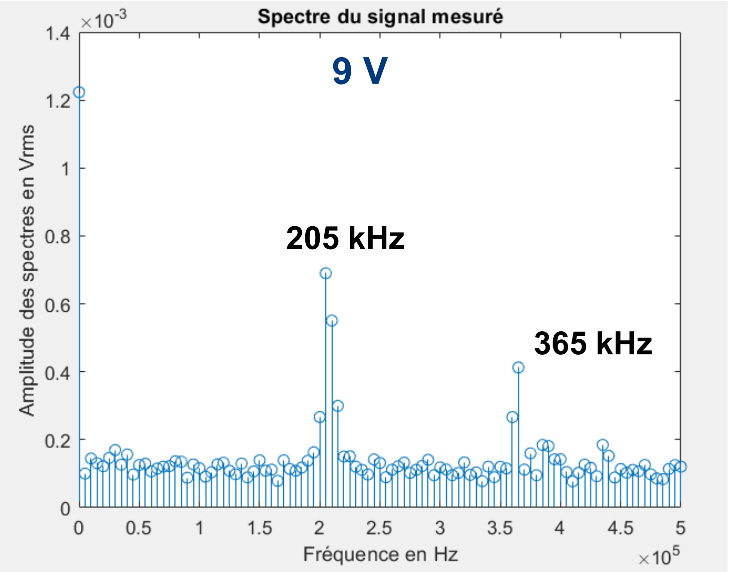


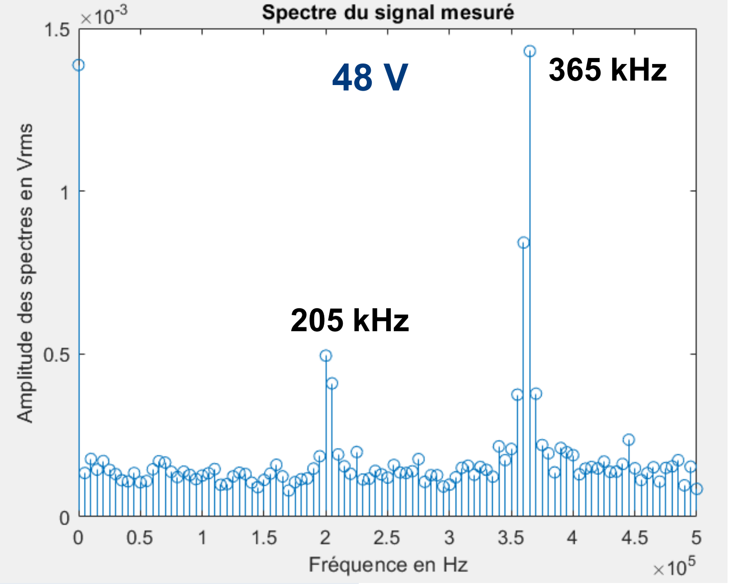
Superposed ripples

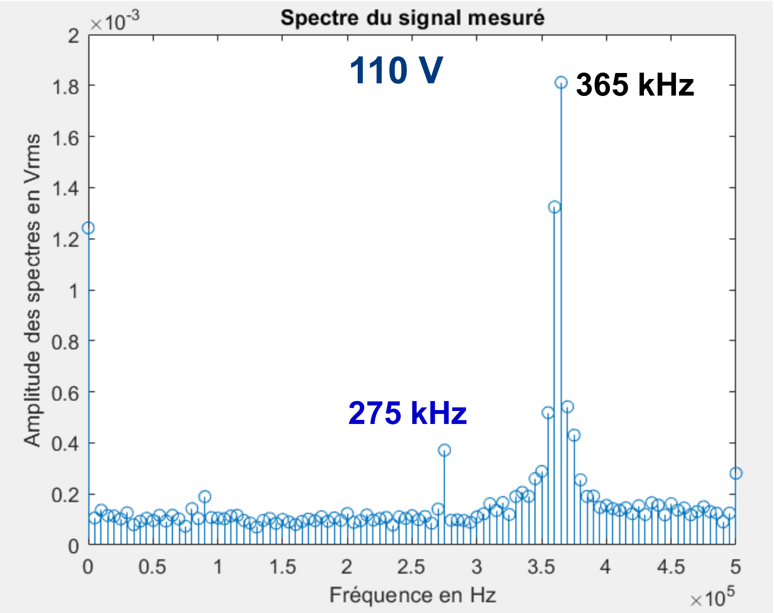
- Blue: #DMM1 acquired signal = DC signal without DC component
- Orange: #DMM2 acquired signal = AC signal

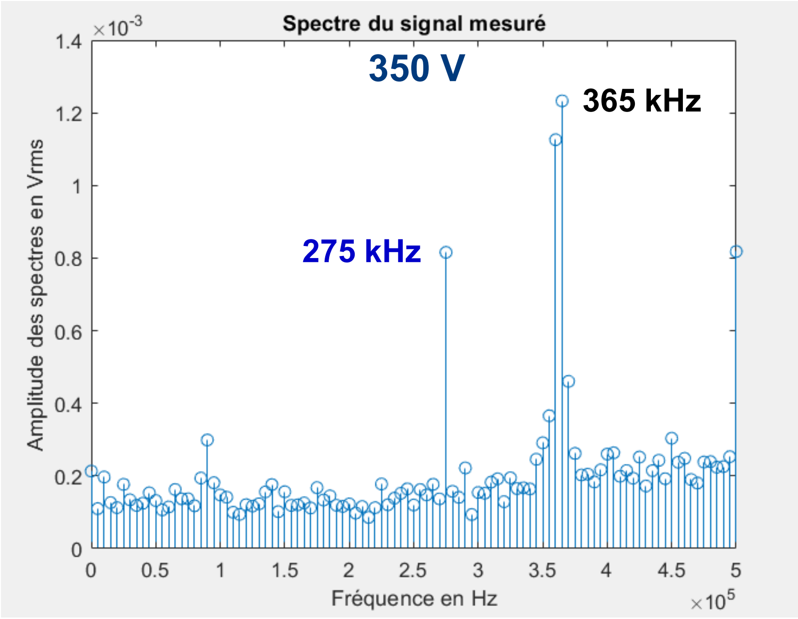
- **Both DMM are well shynchronised**
- **The ADC noise of DMM on 1000 V range predominates**

MEASUREMENT OF LVDC SOURCE RIPPLE
SPECTRUM OF AC SIGNAL, 100 mV RANGE



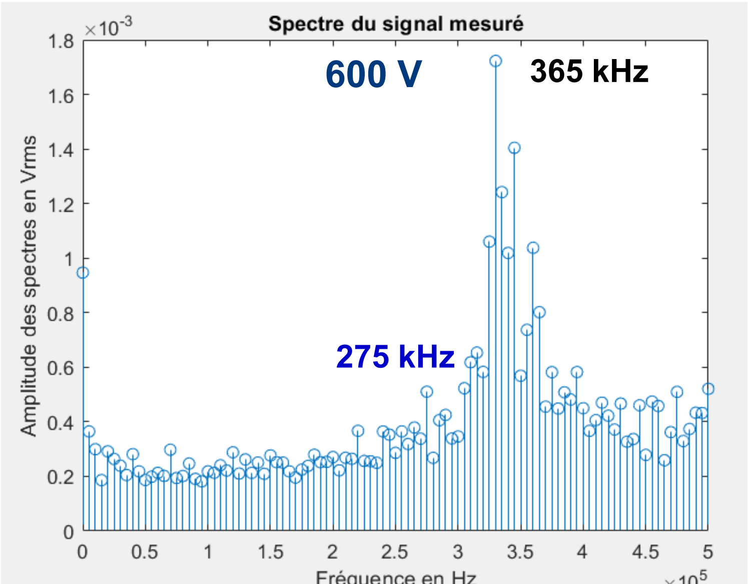






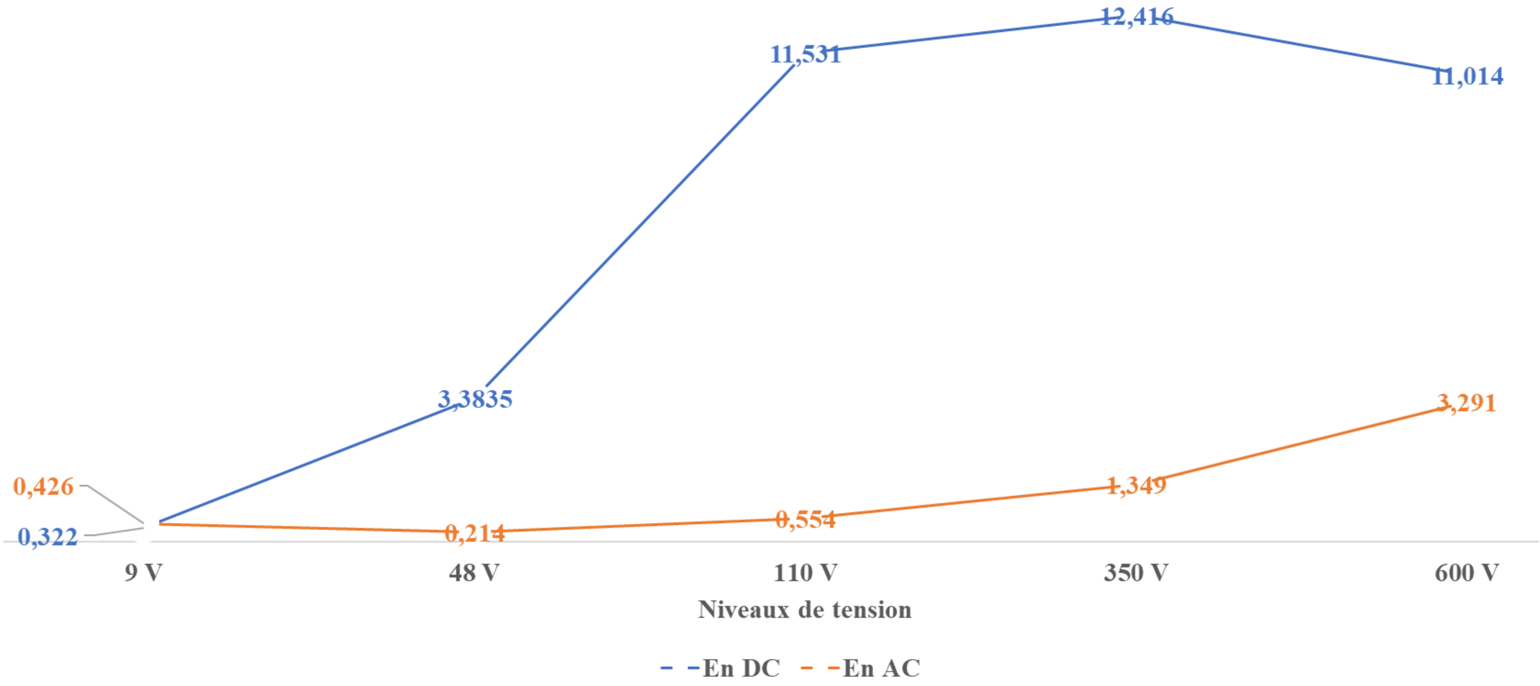
205 kHz becomes
275 kHz for U_{supply} > 100 V

Probably the source behaviour, since all the spectra are for the AC signals acquired with the same DMM on the same range.



MEASUREMENT OF LVDC SOURCE RIPPLE

$Ripple_{PP}$ (mV)



$$Ripple_{pp}(V) = abs\left(Max_{V_{i,RMS}} - Min_{V_{i,RMS}}\right)$$

Rated voltage (V)	V_{DC} (V)	$Ripple_{PP,}$ (mV) DC signal	$Ripple_{PP,}$ (mV) AC signal
9	8.97	0.322	0.426
48	48.02	3.384	0.214
110	110.12	11.531	0.554
350	349.92	12.416	1.349
600	599.94	11.014	3.291

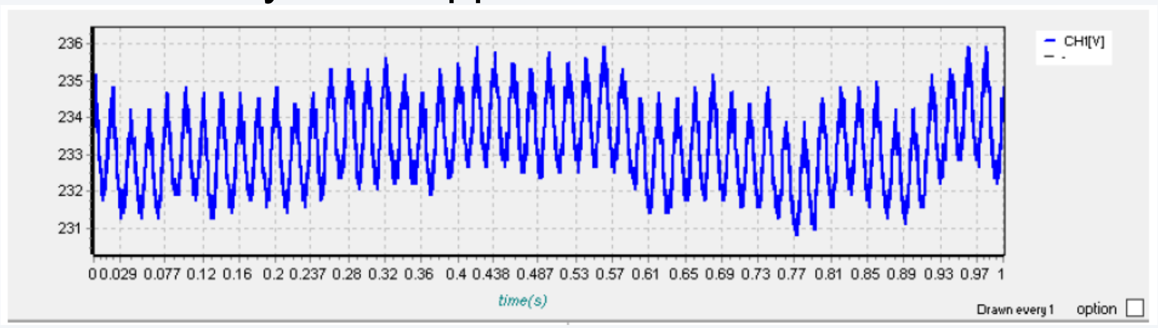
Technical specifications

Ripple & noise p-p 20 MHz, 300 mV

- **Obtained $ripple_{PP}$ lower than the technical specifications**
- **What method and measurement equipment was used to get the technical specifications?**

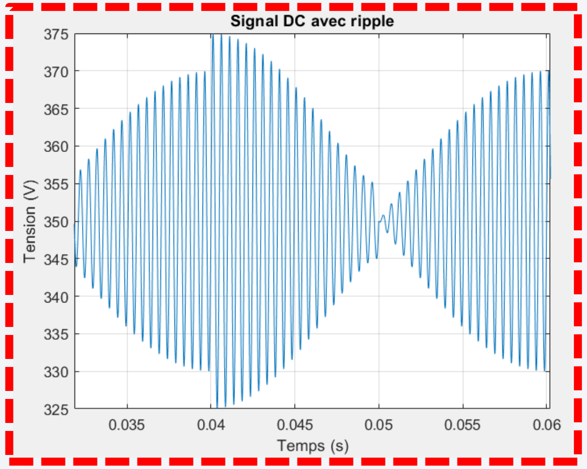
Some conclusions

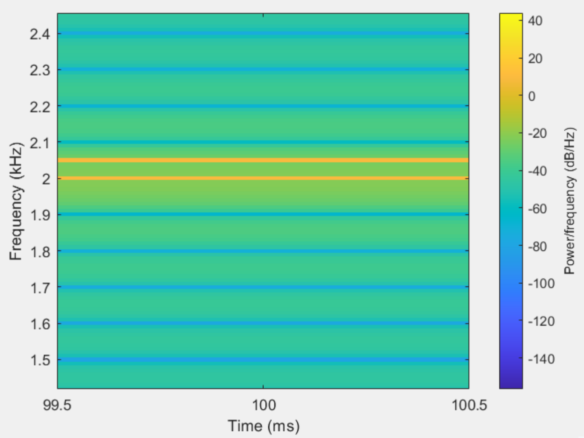
Steady-state ripple

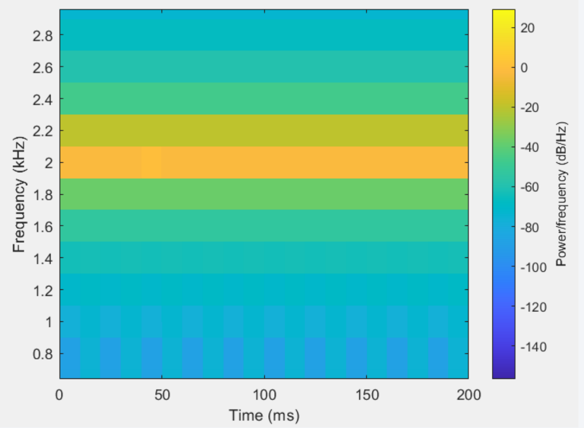


- Accurate acquisition of DC + ripple voltages in the laboratory based on 18 bits, 5 MHz DMMs
- Low level steady-state ripple (< 13 mV ripple_{PP}) is detected (high frequency switching source)
- If the ripple to measure is expected to be higher than the noise of the DC measurement device, only 1 DMM is enough
- Otherwise, it is necessary to use the 2nd DMM to acquire only the AC component notably for high input DC voltage
- Future data treatment investigations are necessary.

Emulate ripple







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THANK YOU FOR YOUR ATTENTION

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