



**UME**

**17RPT03 DIG-AC**

***WP4: Comparison of the Quantum/Digital to  
Thermal Method***



**20/05/2022**

**Madrid, Spain**

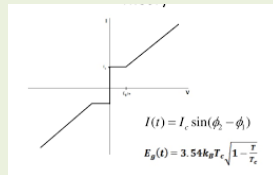
Comparison of the quantum & digital and thermal techniques in AC measurements.

1. Comparison of the PJVS and thermal voltage converter (TVC) at AC voltage using a digitizer,
2. Comparison of the digitizer-divider combination to the TVC at AC voltage
3. Comparison of digitizer-shunt combination to TVC-shunt combination at AC current.

## Quantum Voltage Standards

Intrinsic standards based on Josephson effect:

$$V = hf/2e$$



Accuracy:

DC Voltage:

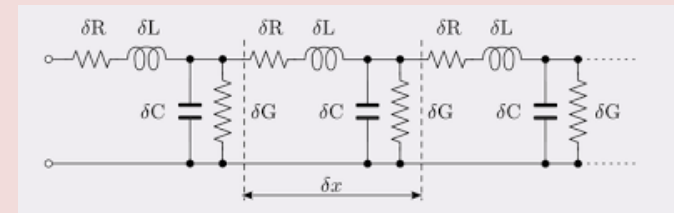
$$\pm 10 \text{ V}, \Delta V/V_{10\text{V}} = 1 \times 10^{-10}$$

AC Voltage:

12 nV/V @ 250 Hz (JAWS)

## Thermal Converters

Modeling using lumped parameters (LCR) and/or Transmission line theory.



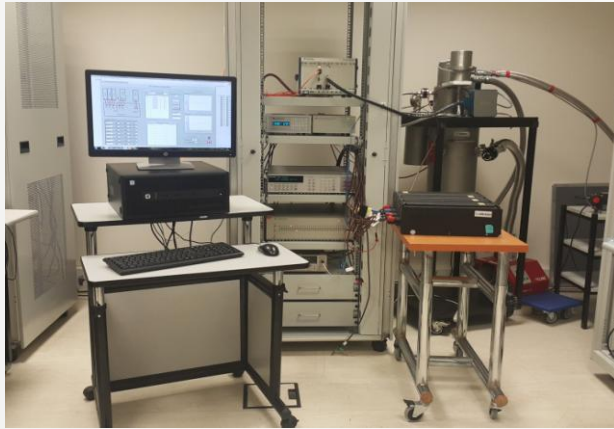
Link AC to DC Voltage;

$$\text{AC} = \text{DC}(1 + \delta)$$

Accuracy: 1  $\mu\text{V/V}$  @ 3 V, 1 kHz

Only RMS!

# Comparisons



PJVS



TVC



Divider



Digitizer



TVC



Shunt



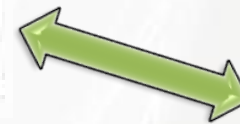
TCC



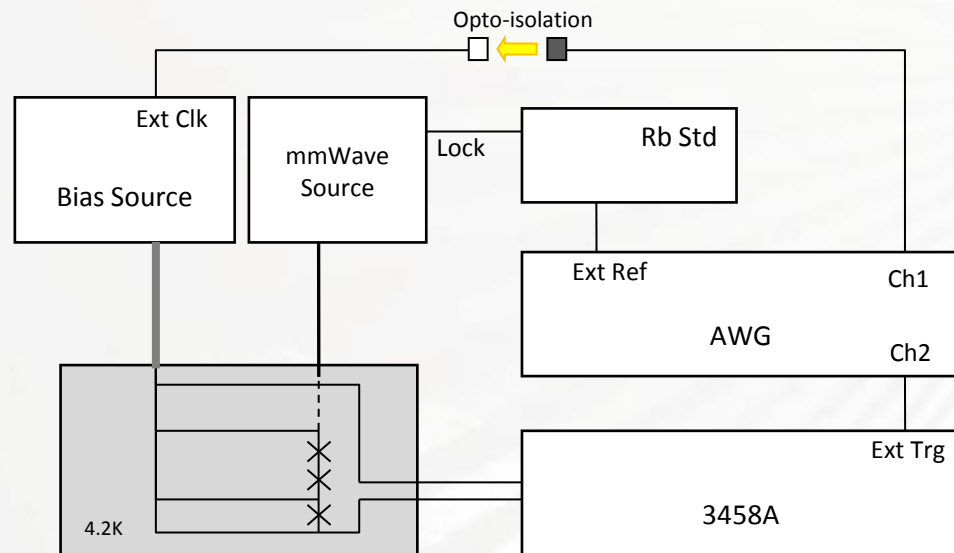
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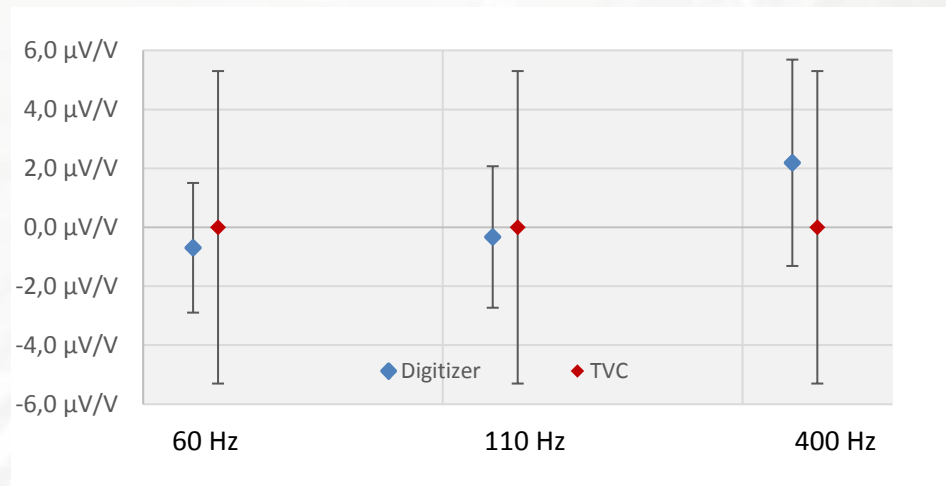
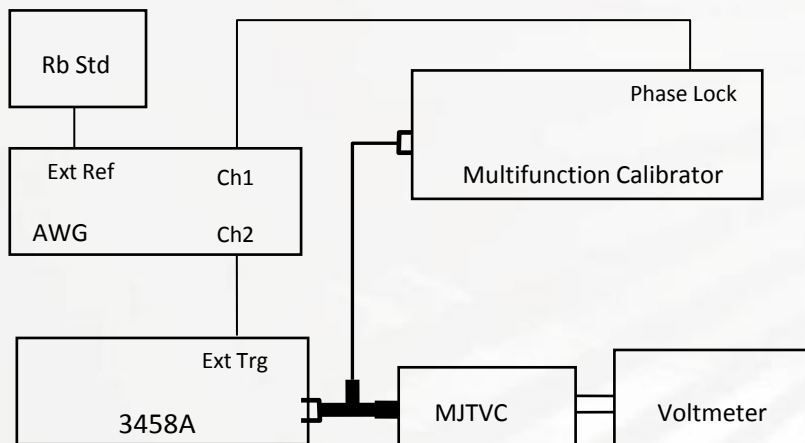
# PJVS –TVC, step 1



10 steps per period  
 Number of periods: 100  
 15 measurements averaged

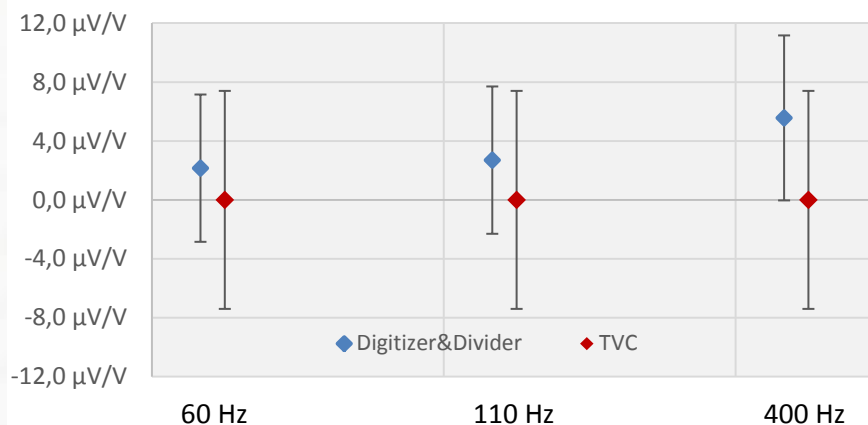
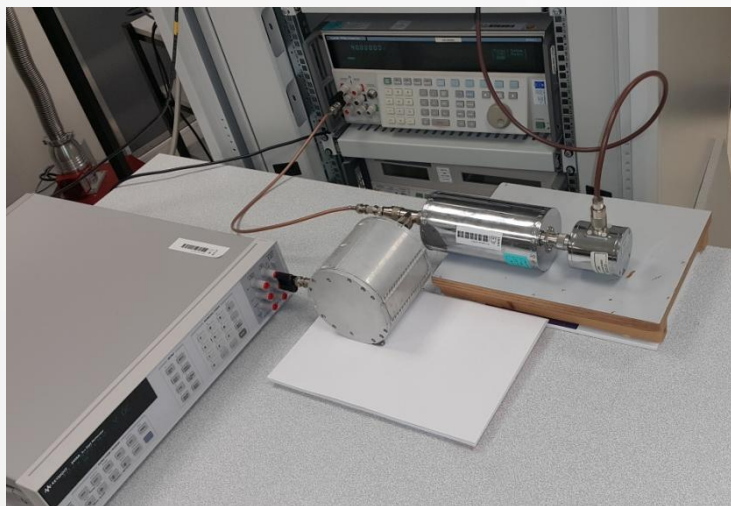
Frequency ( Integration Time )	DC (1 s)	60 Hz (1,6 ms)	110 Hz (850 $\mu$ s)	400 Hz (220 $\mu$ s)
Gain	1,0000033	1,0000033	1,0000034	1,0000073
Uncertainty	0,035 $\mu$ V/V	0,50 $\mu$ V/V	0,85 $\mu$ V/V	2,0 $\mu$ V/V

# PJVS –TVC, step 2



Frequency	60 Hz		110 Hz		400 Hz	
	Measured	Uncertainty	Measured	Uncertainty	Measured	Uncertainty
TVC	6,999734 V	5,3 µV/V	6,999740 V	5,3 µV/V	6,999732 V	5,3 µV/V
Digitizer	6,999739 V	2,2 µV/V	6,999743 V	2,4 µV/V	6,999716 V	3,5 µV/V
$\Delta_{\text{TVC-Digitizer}}$	-0,7 µV/V	5,7 µV/V	-0,4 µV/V	5,8 µV/V	2,3 µV/V	6,4 µV/V
$E_n$	0,2		0,1		-0,4	

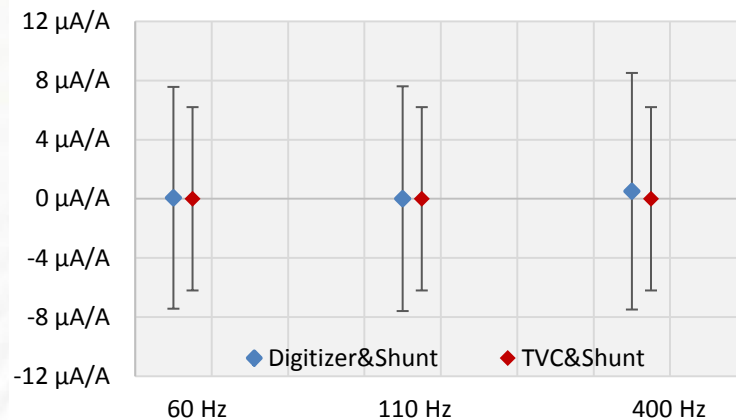
# Digitizer-Divider – TVC



Frequency	60 Hz		110 Hz		400 Hz	
	Measured	Uncertainty	Measured	Uncertainty	Measured	Uncertainty
TVC	39,99810 V	7,4 μV/V	39,99818 V	7,4 μV/V	39,99810 V	7,4 μV/V
Digitizer-Divider	39,99802 V	5,0 μV/V	39,99807 V	5,0 μV/V	39,99788 V	5,6 μV/V
$\Delta_{\text{TVC-Digitizer}}$	2,2 μV/V	8,9 μV/V	2,7 μV/V	8,9 μV/V	5,6 μV/V	9,3 μV/V
$E_n$	-0,3		-0,4		-0,8	



# Digitizer-Shunt to the TVC-Shunt



Frequency	60 Hz		110 Hz		400 Hz	
	Measured	Uncertainty	Measured	Uncertainty	Measured	Uncertainty
TVC-Shunt	19,99907 mA	6,2 μA/A	19,99907 mA	6,2 μA/A	19,99908 mA	6,2 μA/A
Digitizer-Shunt	19,99907 mA	7,5 μA/A	19,99907 mA	7,6 μA/A	19,99907 mA	8,0 μA/A
$\Delta_{\text{TVC-Digitizer}}$	0,1 μA/A	9,7 μA/A	0,0 μA/A	9,8 μA/A	0,5 μA/A	10,1 μA/A
$E_n$	0,0		0,0		-0,1	



## 17RPT03 DIG-AC



WP4, Activity A.2.4  
Report on Comparison of the Thermal and  
Quantum/Digital Calibration Methods

Thank you for your attention!

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TRUE  
MEASUREMENT  
EXCELLENCE