JOSEPHSON-VOLTAGE STANDARD IN A WORKING CALIBRATION LABORATORY

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Abstract

One might ask if it is really necessary to use a Josephson Voltage Standard in an accredited calibration laboratory. Yes, there are circumstances that make the use of such a standard necessary. With the evolvement of dc reference standards and calibrators towards very small specifications on Direct Voltage it becomes a good tool to bring measurement uncertainties to a level with which these instruments can be checked to be within specifications. This papers describes the use of a Josephson Voltage Standard in an accredited calibration laboratory operated by Fluke Germany

Introduction

Josephson-Voltage Standards are widely used in National Institutes for their work in metrology and scientific research. However, there are several companies and other institutes in the United States of America that have established such systems, but none of them are used in a Customer Support environment or accredited laboratory. We saw the requirement of a Josephson-Voltage Standard coming with the evolvement of calibrators and dc reference standards designed and produced by Fluke Corporation Everett/USA. The requirement to service and calibrate these instruments for Fluke in Europe, made it necessary to develop and find new ways for low measurement uncertainties required to calibrate and verify the specifications of these instruments. The only way this could be accomplished was with the use of a Josephson Voltage Standard. However, there are some aspects that need to be defined before such an investment may be done. Cost of purchase and operating costs were the most significant, but after looking at them very closely it became obvious that it will be paid back in the long term.

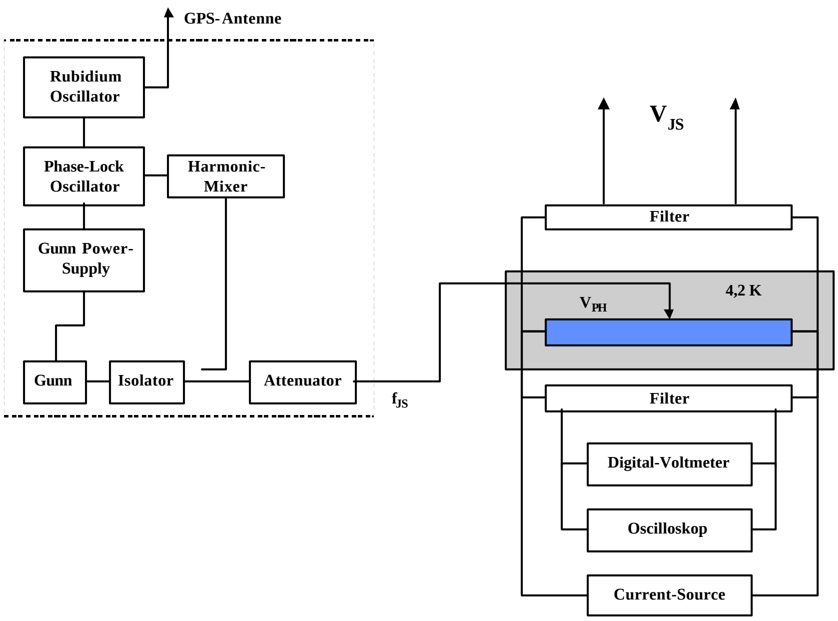
The Josephson Voltage Standard

The Josephson effect is a super conducting physical phenomenon that relates voltage to frequency through the ratio of fundamental constants. A Josephson array, using an integrated circuit containing a number of Josephson junctions, is an intrinsic, independently reproducible standard that is used to represent rather than realize the SI volt.[i]
The output of a single Josephson junction is defined as:

$$V_J = \frac{h}{2e} \bullet n \bullet f$$

V_J = Junction voltage
f = Frequency in GHz
e = elementary charge
h = Planck´s constant
n = a positive or negative integer

The Josephson Voltage Standard used by Fluke Germany is a system that was originally designed by the Physikalisch-Technische Bundesanstalt (PTB) in Braunschweig Germany[ii]. It is designed as a „Fixed-Frequency-System“ which operates at a frequency of 75 GHz. The Josephson Array is a 10 Volt array made by PTB built into a probe. (see Picture 1)



Picture 1: 10V Josephson Voltage Standard

The system consists of a 75 GHz Gunn-oscillator which is locked by a Phase Lock Oscillator all made by Farran/Irland. The Phase Lock Oscillator is locked to a Fluke 910R, a GPS controlled Rhubidium Frequency Standard. During operation, the Probe is immersed in a 42 litre helium dewar.
Because of the system being a Fixed-Frequency system, the use of an EIP counter is not necessary

The Advantages

The use of a Josephson Voltage Standard in an accredited calibration laboratory may not be obvious at first sight. But on second sight, there are a large number of advantages. A Josephson Voltage Standard brings the legal volt right into a calibration laboratory. And besides the fact that it is not necessary anymore to have DC Reference Standards calibrated at the National Laboratory along with this and the use of good metrological methodologies, many traceable calibrations are made easier.
Calibration of several instruments and products are simplified, these are as such:

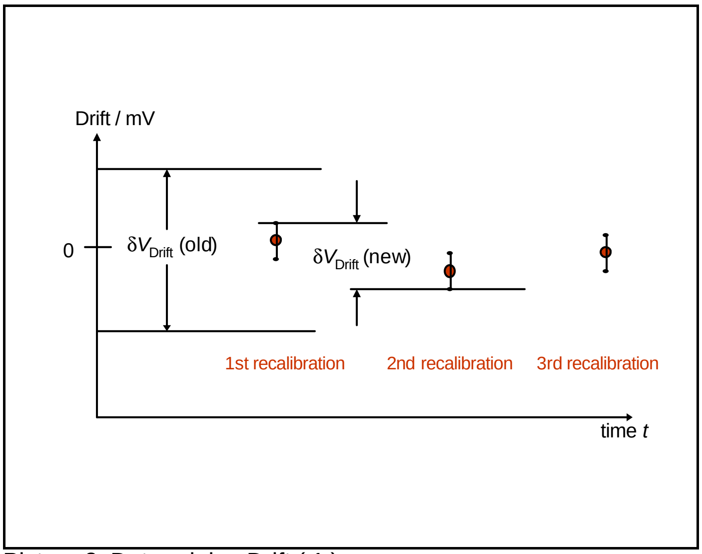
- Long-Scale Digitalmultimeters (e.g. Fluke 8508A, Datron 1281, Agilent 3458A. Especially focused on the calibration of the dc linearity of these instruments.)
- DC Voltage Dividers like Fluke 720A and 752A (The calibration of the ratio over its scale)
- DC Reference Standards (e.g. Fluke 732A/B, Datron 4910/11)

Many other calibrations may be simplified by deriving from the calibration of the instruments mentioned above and by applying calibration methodologies. Which of course goes along with a completely matched uncertainty budget that fits all of it.

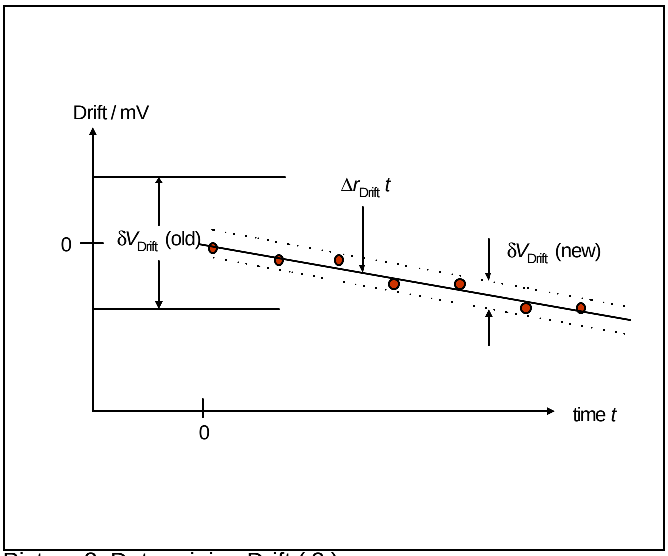
Day by day use

The primary focus in the day-by-day use of a Josephson-Voltage Standard is to bring the measurement uncertainties down to a very small level. The reason is that the awareness in the use of standards and calibrators, driven by the implementation of ISO17025 and GUM, has changed tremendously in the past years.

It is our task to calibrate instruments within their specifications and maybe determine its drift over time. Small measurement uncertainties are required to be able to accomplish and achieve these tasks. A "Test Uncertainty Ratio " (TUR) of at least more than 2:1 would be the minimum requirement, a TUR of 4:1 would be appropriate. See picture 2 and 3 below for examples.

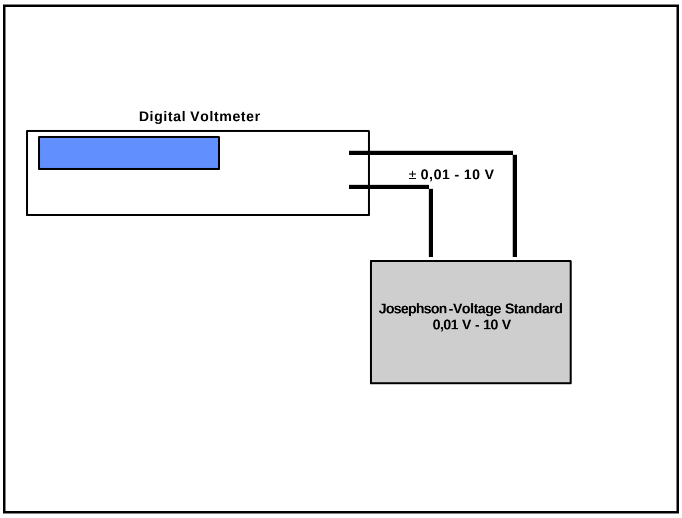


Picture 2: Determining Drift (1)

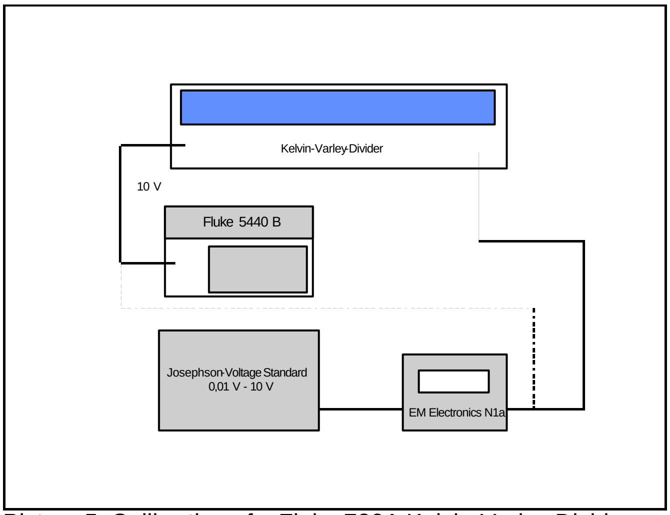


Picture 3: Determining Drift (2)

The measurement uncertainties that we were looking to achieve made it necessary to look for different methodologies and automated processes as the calibration of instruments can be expensive. So the practical use of the Josephson-Voltage Standard led to the development of calibration methodologies with low measurement uncertainties and helped to simplify the calibration in our facility. One is the capability to directly calibrate the DC Linearity of an 8½Digital Multimeter against the Josephson-Voltage Standard which then enabled us to define and simplify the calibration process of the DC output of a calibrator as well as the calibration of DC voltage dividers like the Fluke 720A.



Picture 4: Calibration of an 8½ Digital Multimeter



Picture 5: Calibration of a Fluke 720A Kelvin-Varley Divider

These capabilities enabled us to further develop processes and procedures to automate the calibration of calibrators and standards.

Interlabcomparison of Josephson Voltage Standards

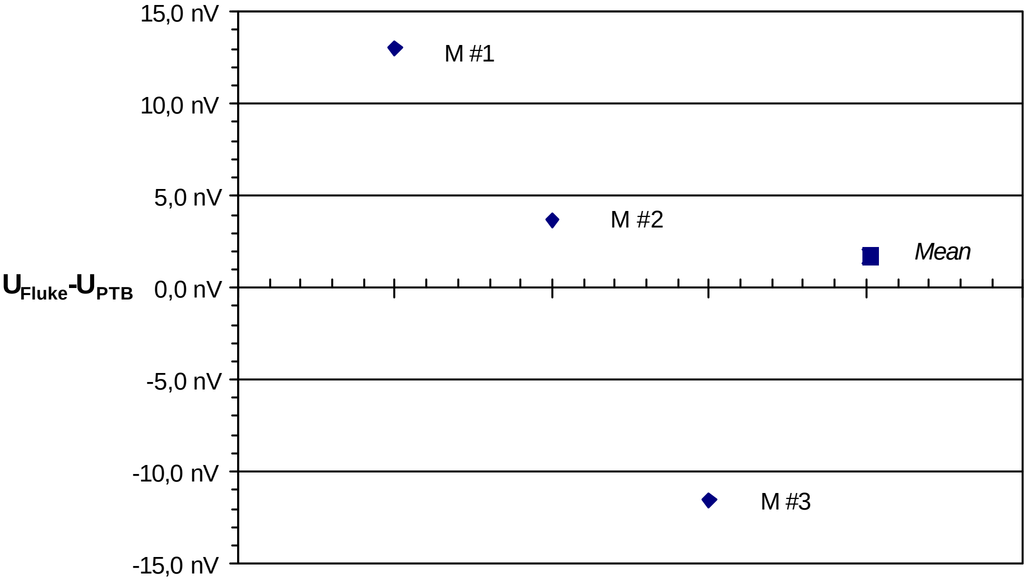
Although the Josephson-Voltage effect is a physical dimension, the use of it in an accredited environment came along with the need and requirement to justify that such a standard is used and operated correctly within its capabilities and within the accreditation.
It was decided that the Josephson-Voltage Standard used by Fluke Germany had to be compared against a Portable Josephson-Voltage Standard also designed and built by PTB.
This Interlab-comparison was done on-site at the Fluke calibration laboratory in November 2000. The results of the intercomparison are shown in the table and graphs below.

Results of „On-Site“ Inter-labcomparison with two Josephson-Voltage Standards (November 2000)					
U_{PTB}	u (U_{PTB})	U_{Fluke}	u (U_{Fluke})	U_{Fluke} - U_{PTB}	E_n
9,975 465 253 V	1,5 nV	9,975 465 266 V	25 nV	13,1 nV	52,1%
9,975 609 708 V	1,5 nV	9,975 609 712 V	25 nV	3,7 nV	14,7%
10,017 875 760 V	1,5 nV	10,017 875 748 V	25 nV	-11,5 nV	-46,0%
			Mean	1,7 nV	7,0%

Table 1: Results of the Interlab comparison of two Josephson Voltage Standards

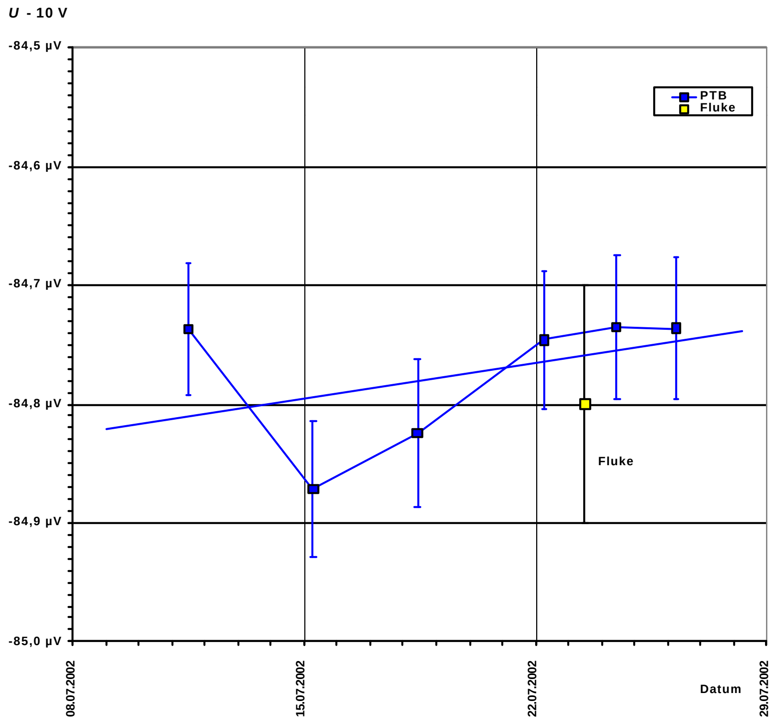
Three independent measurements between the two Josephson Voltage Standards were made using a Keithley 2182 Nanovoltmeter/Nulldetector. For each measurement the Standards were set to a slightly different output voltage. The difference between these measurements, ranging from 13,1 nV to –11,5 nV, are mostly related to the noise and instability of the Nanovoltmeter used.

As a result of the review of the uncertainty budgets due to the implementation of ISO 17025 and GUM in the accreditation and the application for a new accreditation schedule for DC Voltage. Another Interlab-comparison was recently done between PTB and Fluke Germany using a PTB owned and well known Fluke 732A DC Reference Standard. The results are shown in the graph below.



Picture 6: Interlab-comparison between two Josephson-Voltage Standards

The points marked with “M#1 to M#3”, in picture 6, represent the difference of the three independent measurements taken between the two Josephson-Voltage Standards. The point marked with ”Mean” represents the average of the three independent measurements.



Picture 7: Interlab-comparison between Josephson-Voltage Standard and Fluke 732A

Conclusion

The use of a Josephson Voltage Standard and the appropriate use of calibration methodology led to the accreditation schedule of DC Voltage as shown in the table below.

Range	Uncertainty	Remarks
0,01 V to 10 V	13 nV	Calibration of Digital Voltmeters against Josephson-Voltage Standard
1 V 1,018 V 10 V	0,2 µV	Calibration of DC – Reference Standards
0,01 V to 10 V	$2,3 \cdot 10^{-8}$ V/U_{JPH}	Calibration of the linearity of Digital Voltmeters U_{JPH} = Josephsonvoltage
0,01 V to 10 V	$2 \cdot 10^{-8} \cdot [23 + (67/k_{ÜF}^{2})]^{½}$	Calibration of Dividers $k_{ÜF}$ = Transmission factor of the Divider
10 µV to 1 V	$2 \cdot 10^{-7}$ $\cdot [(2,4 + (1,1\ V/U)^{2}]^{½}$	Calibration of measuring devices U = Voltage to be calibrated
>1 V to 10 V	$2 \cdot 10^{-7}$ $\cdot [(0,3 + (1,1\ V/U)^{2}]^{½}$	
>10 V to 100 V	$3,5 \cdot 10^{-7}$	
>100 V to 1000 V	$6,3 \cdot 10^{-7}$	
10 µV to 10 V	$2 \cdot 10^{-7}$ $\cdot [(0,7 + (1,1\ V/U)^{2}]^{½}$	Calibration of sources U = Voltage to be calibrated
>10 V to 100 V	$3 \cdot 10^{-7}$	
>100 V to 1000 V	$6 \cdot 10^{-7}$	

Table 2: Accreditation schedule of DC Voltage of Fluke Germany [iii]

References

DIN ISO/IEC 17025:2000

DIN EN ISO 9001:2000

Calibration: Philosophy in Practice (Second edition) published by Fluke Corporation Everett/WA/USA

EAL-G12; Tracebility of Measuring and Test Equipment to National Standards

DKD-3; Expression of the Uncertainty of Measurement in Calibration

EAL-R2; Expression of the Uncertainty of Measurement in Calibration

[i] Calibration: Philosophy in Practice (Second edition) published by Fluke Corporation Everett/WA/USA
[ii] Developed by Dr. Gutmann PTB Braunschweig/Germany
[iii] Accreditation of Fluke Germany GmbH under registration DKD-K-00902 by German Calibration Services