# Voltage-ratio Calibration System up to 50 kHz

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**Abstract**: This paper describes a voltage-ratio measuring system up to 50 kHz. It is based on two Keysight 3458A digital multimeters, working in DCV sampling mode. An external trigger based on a rubidium clock, drives both digital multimeters.

**Keywords**: ratio measurement, sampling method, digital multimeter, high precision.

## 1. INTRODUCTION

We are running a project [1], [2] to design and construct a reference system for measuring electric voltage, current and power up to 100 kHz. This project is being jointly developed by the National Metrology Institutes of Brazil, Argentina and Uruguay (Instituto Nacional de Metrologia, Qualidade e Tecnologia (Inmetro) in Brazil, Instituto Nacional de Tecnología Industrial (INTI) in Argentina, and Administración Nacional de Usinas y Transmisiones Eléctricas (UTE) in Uruguay). The objective is the construction of three measuring systems, one for each institute. This project will contribute to provide calibration services in measuring ranges still not covered by these institutes. The project will also contribute to improve the traceability not only of electric power but also of related quantities like ac-dc transfer, voltage ratio, phase angle, ac voltage and ac current.

For the voltage input, this standard system requires voltage dividers to scale the input values from 4 V to 1024 V, to the value allowed by the analogue-to-digital converter (0.8 V) [3], [4].

Different methods can be used to calibrate this type of dividers. One of them is to compare the divider under test against an ac-dc thermal converter, other to measure the step response [5], [6], and third, to perform a step-up test. For this last one, it is required a measuring system that can compare the output of the two dividers under test. Previous developments of a low-frequency power-quality meter [7], [8] based on two Keysight 3458A digital multimeters (DMM) [9] allowed to perform step-up calibrations for voltage dividers up to 5 kHz. In this work, an extension of that method, that reaches 50 kHz, is described. This method measures the amplitude ratio error and the phase displacement between the outputs of the two voltage dividers to be compared.

## 2. STEP-UP METHOD

The set of dividers includes the following nominal input voltages: 4 V, 8 V, 16 V, 32 V, 64 V, 128 V, 256 V, 512 V and 1024 V. The step-up method consists in comparing two adjacent dividers up to the voltage of the lower one. As the ratio between them is 2:1, the output voltages to be compared will be up to 0.8 V and 0.4 V. One of the dividers reaches its nominal voltage, but the other reaches half of nominal voltage. So, this method requires the characterization of the voltage linearity of each divider. As the non-linear behavior is mainly due to temperature variation, a low-frequency or dc test is enough for that. This ratio variation against the applied voltage is considered for correcting the step-up data.

## 3. CALIBRATION SYSTEM

The voltage ratio calibration system comprises two DMMs [9], whose inputs are connected to the voltages to be compared. They work in DCV sampling mode. To be able to digitize signals up to 50 kHz, the DMMs are configured with an aperture time of 1.4 µs, so that they have a resolution of 16 bits. Both DMMs are synchronized in parallel by a function generator [10] using a TTL signal of 100 kHz. The function generator is driven by a rubidium clock to reduce jitter [11]. A block diagram of the voltage-ratio calibration system is shown in Fig. 1.

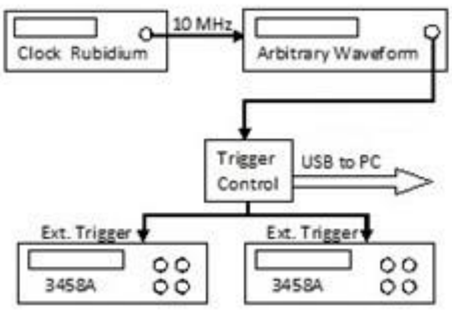


Fig. 1. Block diagram of the voltage-ratio calibration system.

The 1-V range is used in both DMMs. Before starting a ratio measurement, the same voltage signal is applied to both DMM to compensate for scale errors. The program runs the configuration software and reconstructs the digitized signals using Interpolated Fast Fourier Transform (IFFT) techniques to get the amplitude ratio and phase difference. A Hanning window of the length of the original vector to be analyzed was used. Then, Discrete Fourier Transform is performed, analyzing the spectral leakage. With this information, the frequency of the signal is calculated allowing to compute modulus and angle of the original vector.

There is no synchronization between the signals and the sampling frequency. Each DMM runs at its internal 10 MHz clock. The sampling time is around 0.7 s. Even very small differences between clocks, of few parts in $10^6$, ensure asynchronous sampling, so that random points are sampled in each burst.

The configurations of commands of both DMMs are sent sequentially, so that one DMM is ready to measure before the other. The trigger control module enables the arrival of the pulses to the external trigger inputs of both DMM only when both DMMs are ready. The enabling and disabling of pulses is done by software.

### *3.1 Multimeter error sources*

We consider five different influence factors on DMM errors when operating in DCV sampling mode at 1-V range [12], [13]: linearity, aperture time, dissipation factor of the input divider, input low-pass filter, and time differences of external trigger.

Linearity error in the 1-V range was studied in dc voltage, and this value is less than 1 µV/V.

Aperture time error is corrected in modulus and phase by (1) and (2)

$$Aperture\ Amplitude\ Error\ (f) = \frac{\sin(\pi \times f \times Taper)}{\pi \times f \times Taper} - 1 \quad (1)$$

$$Aperture\ Phase\ Error\ (f) = \frac{1}{2} Taper \times f \quad (2)$$

where *Taper* is the value of the aperture time. These errors are large at 50 kHz, mainly due to *Taper* uncertainty. Nevertheless, only the difference between both DMMs is relevant and it can be compensated measuring these errors in a self-calibration test with the same signal applied to both DMMs.

Dissipation factor of the capacitance of the DMM input stage reduces the DMM input resistance at high frequency and attenuates the signal. The influence of this factor depends on the impedance of the voltage sources to be compared. In case of the voltage dividers previously mentioned, all of them have an output resistance of the same value, around 200 Ω. With this impedance and taking into account that the capacitances of both DMM are nearly equal, the error for this effect is compensated and can be neglected.

The DMM has a low-pass filter at its input with cut-off frequency around 130 kHz. The amplitude and phase error generated by these filters are evaluated by (3) and (4).

$$Bandwidth\ Amplutude\ Error\ (f) = \frac{1}{\sqrt{1+(\frac{f}{bandwidth})}} \qquad (3)$$

$$Bandwidth\ Phase\ Error\ (f) = \mathrm{TAN}^{-1}(\frac{f}{bandwidth}) \qquad (4)$$

These corrections work very well at low frequencies, but near the cut-off frequency the amplitude and phase errors are large. However, in ratio measurements only the bandwidth difference of both DMMs is significant and it can be corrected during the self-calibration test. Even, trigger systematic differences can be corrected from the results of that test.

However, random variations due to all mentioned factors must be admitted, being part of the type-A uncertainty of the method. It is evaluated from the dispersion of the measurements.

### *3.2 Experimental results*

First test was done applying to both DMM inputs the same signal (0.7 V rms). Table 1 shows the results. The uncertainty columns (U) refer only to type-A uncertainty (expanded, k=2), averaging 20 measurements. These values show that the method have acceptable dispersion. There is some departure from linear behavior at the higher frequencies due to several error sources previously analyzed. Some of them can be mathematically compensated at low frequencies (up to some kHz), but at high frequency residual errors remain.

Table I. Voltage ratio errors.

| Frequency (kHz) | Modulus ($\times10^{-6}$) | Phase (μrad) | U modulus ($\times10^{-6}$) | U phase (μrad) |
|---|---|---|---|---|
| 1 | -22,4 | 0,3 | 0,3 | 0,8 |
| 10 | -33,3 | 10,9 | 0,6 | 3,8 |
| 20 | -35,8 | 21,0 | 1,5 | 6,8 |
| 30 | -35,2 | 59,6 | 2,1 | 8,7 |
| 40 | -18,0 | 92,8 | 3,5 | 15,3 |
| 50 | 34,0 | 179,5 | 3,5 | 13,8 |

A complete uncertainty evaluation with more tests results will be presented at the conference.

## 4. CONCLUSIONS

A measuring system for voltage ratio has been presented, reaching frequencies up to 50 kHz. It is based on two high precision multimeters which are synchronized by a high stable external trigger.

Experimental results show errors around $40\times10^{-6}$ in modulus and 20 μrad in phase displacement, at 20 kHz. At 50 kHz, phase errors increase, but still are appropriate for many ratio measurements applications.

## 5. REFERENCES

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## ACKNOWLEDGMENTS

This work was partly supported by the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), of the Ministry of Science, Technology and Innovation of Brazil, under Grant CNPq/Prosul Processo Nº 490271/2011-1.