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Luca Callegaro
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INRIM Istituto Nazionale di Ricerca Metrologica
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A setup for linearity measurement of precision ac voltmeters in the audio frequency range

Luca Callegaro[1], Vincenzo D'Elia[1], Fabrizio Manta[1]

[1] *Istituto Nazionale di Ricerca Metrologica, Electromagnetism Division, Strada delle Cacce 91, 10135 Torino, Italy, phone +390113919435, fax +39011346384, email f.manta@inrim.it*

Abstract- A setup for the measurement of linearity of precision ac voltmeters in the audio frequency range is described. The setup is based on an inductive voltage divider (IVD) as linearity standard. Since the IVD is calibrated under no-load conditions, the setup is provided with a compensation of the loading current absorbed by the voltmeter. The compensation is automated and based on a commercial lock-in amplifier. As examples, measurements of the linearity of two top-class ac voltmeter (a J. Fluke 5790A and a Datron Wavetek 4920) are reported.

I. Introduction

The full calibration of the AC voltage function of precision digital multimeters should be performed not only on decadic or full-scale values, but also on intermediate values of each available scale. While decadic values traceability is given by ac-dc voltage transfer procedures with thermal converters, the calibration of intermediate values can be obtained via linearity measurements.

In the audio frequency range, inductive voltage dividers (IVD) provide excellent standard of linearity: for top-class commercial items the ratio deviation from nominal settings is better than 10^{-6} and the ratio can be calibrated by step-up procedures with an accuracy better than 10^{-7} [1]. Such performance is obtained if the IVD is unloaded, i.e. if from its tap no current is drawn.

The voltmeter under calibration could give a significant IVD loading [2]. Although calculated corrections to take into account the divider loading have been considered [3], a more clean approach is that the measurement circuitry achieves a zero-load condition by supplying the measurement current required by the voltmeter somehow. Such approach is called *compensation* [4-6].

In the following, we'll present a setup for the measurement of linearity of top-class ac voltmeters based on an IVD as linearity standard, and an automated compensation of the current load. The compensation functions (detection of current, and its nulling) are provided by a commercial lock-in amplifier controlled by a personal computer. At variance with other possible compensation implementations [4-6], no special hardware is required.

II. Measurement setup

The measurement setup block scheme is shown in Fig. 1; a photo of the implementation is shown in Fig. 2.

The inductive voltage divider IVD is a fixed two-stage divider with decadic ($k/10$) and undecimal ($k/11$) taps available. Its ratio can be calibrated with an accuracy of a few parts in 10^8 with a bootstrap method [1]. IVD is energized with a sinewave generated by a multifunction DAQ data acquisition board (National Instruments NI-Daq 6733, 16 bit resolution and 1 MHz sampling rate) and a buffer amplifier A. IVD divides the voltage V_{in} and at its taps voltages $V(k) = k \cdot V_{\mathrm{in}}(\mathrm{k})$. Ratio k is available from IVD calibration in the zero load condition.

The current sensor is composed of a current detector $\mathrm{T_L}$ (a feedthrough transformer), and of a lock-in amplifier L (Perkin-Elmer mod. 7265); its sensitivity is better than 2 nA at 1 kHz. The reference signal required by L is derived from another channel of the same DAQ; to avoid ground loops the signal is transmitted through an optical fibre link [7], composed of a transmitter $\mathrm{T_X}$, a plastic optical fiber, and a receiver $\mathrm{R_X}$. The compensation current generator is composed by the reference output of L and by an injection resistor R_{inj}; the particular L employed has a special function (synchronous oscillator mode) where the internal oscillator (which output is available at Osc Out connector) is locked to the external reference signal and can be varied in amplitude and phase. A software control loop (implemented with

National Instruments LabWindows/CVI development system) running on a personal computer PC reads L and adjusts Osc Out voltage in amplitude and phase: the control loop goal is to zero L reading, thus nulling the current at IVD tap.

The voltmeter under calibration V has two input connectors (Ch1 and Ch2) which can be remotely switched. A preliminary test shows that Ch1 and Ch2 give the same reading within the voltmeter noise.

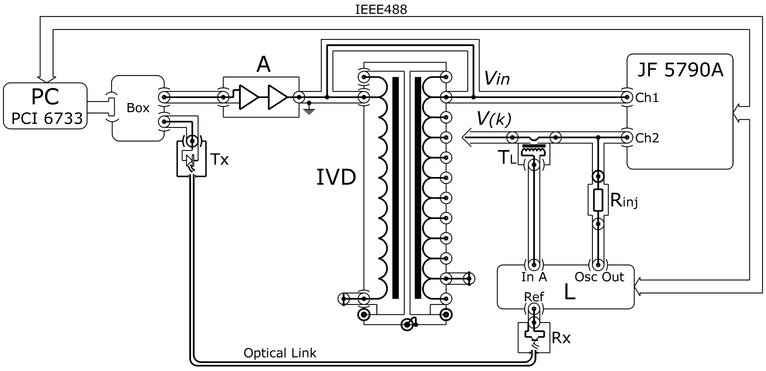

Figure 1. Schematic representation of the measurement setup. The compensation system is composed of a current detector (T_L), and a lock-in amplifier (L). L reads voltage in its input A (In A) and provide a compensation current from its voltage output Osc Out and the resistance R_{inj}.

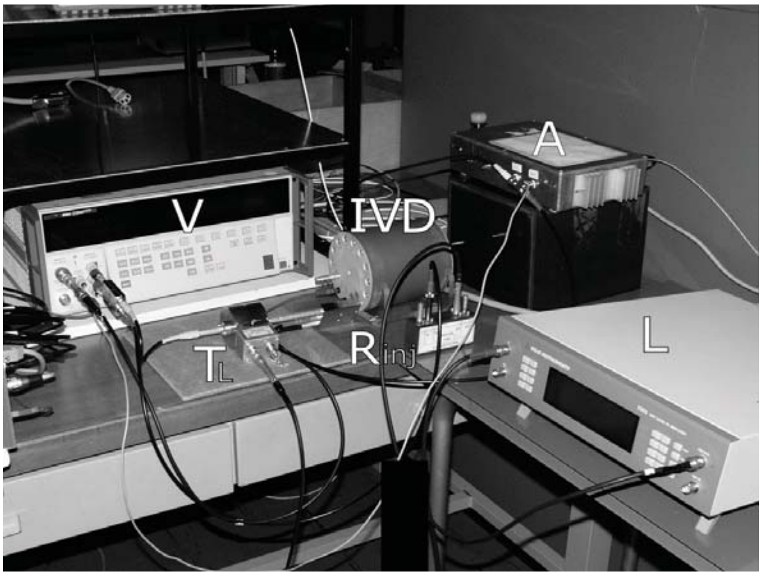

Figure 2. A picture of the measurement setup.

III. Measurement method

The linearity of the voltmeter is expressed by the linearity error ε_k , is given by:

$$\varepsilon_k = \left(\frac{L^*(k)}{L^*_{in}(k)} - k \right) \tag{1}$$

where k is the ratio divider chosen (by manually selecting a particular tap). $L^*(k)$ and $L_{in}{}^*(k)$ are the readings of the voltmeter V when fed with voltages $V(k)$ and V_{in}, respectively (we stress in the notation $L_{in}{}^*(k)$ the dependence on k, since V_{in} may drift during time and could be different during the measurement at different ks).

Both $L^*(k)$ and $L_{in}{}^*(k)$ should correspond to readings conducted in an unloaded condition (expressed in the notation by the asterisk *). Since only one compensation has been constructed and is applied to

IVD tap, a correction to the actual reading $L_{in}(k)$ must be applied in order to recover the reading $L_{in}^{*}(k)$. Assuming that the voltmeter load in the measurement of V_{in}, is constant for different k, the correction can be recovered with the measurement on tap $k = 1$:

$$L_{in}^{*}(k) = L_{in}(k) + \left(L_{in}^{*}(1) - L_{in}(1)\right) \tag{2}$$

Eq. (1) can be rewritten

$$\varepsilon_k = \left(\frac{L^{*}(k)}{L_{in}^{*}(1) + \left(L_{in}(k) - L_{in}(1)\right)} - k\right) \tag{3}$$

IV. Measurement procedure

After powerup and the choice of ratio k of interest, a first very rough adjustment of the compensation current is performed by hand. Then, the automatic compensation is switched on: L continuously measures the current signal and synthesize the corresponding compensation current. The control loop reaches equilibrium in a few seconds; it is stopped during V readings. V cycles through Ch1 and Ch2; typical acquisition is ten readings for each channel. The entire measurement (compensation adjustment and V readings) can be repeated automatically until the desired type A uncertainty is achieved.

V. Results

Measurements have been performed on two instruments, a J. Fluke 5790A ac transfer standard and on a Datron Wavetek 4920 ac voltage measurement standard, at the frequency of 1 kHz. The results are displayed in Fig. 3, 4 and 5.

Fig. 3 and 4 show the results of measurements on the 5790A on two ranges, 2.2 V (Fig. 3) and 700 mV (Fig. 4); lower measurement voltage correspond to the range lower limit. The linearity is measured with an accuracy of a few parts in 10^7, dominated by type A contributions, and is well within manufacturer specifications.

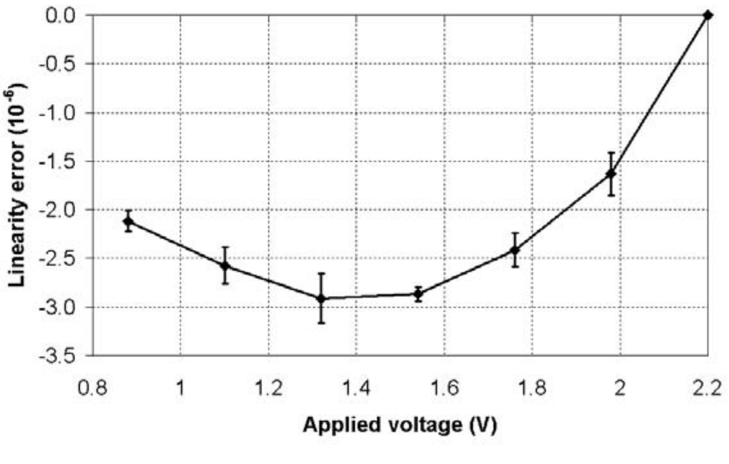

Figure 3. Linearity error of a J. Fluke 5790A voltmeter in the 2.2 V range, at the frequency of 1 kHz, measured with the setup of Fig. 1. Error bars correspond to the expanded uncertainty (95% coverage factor). The line connecting points is a guide to the eye.

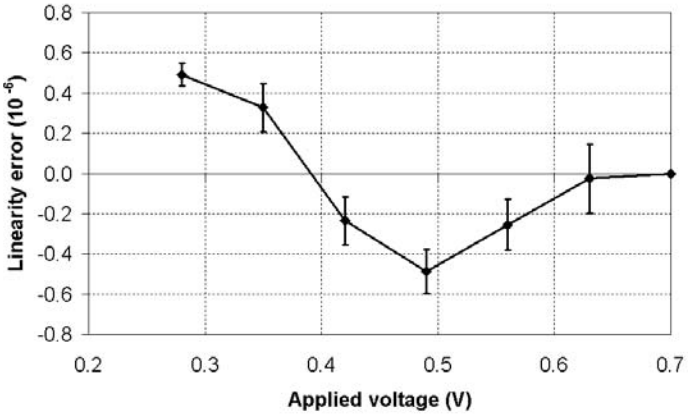

Figure 4. Same as Fig. 3, on the same instrument, for the 700 mV range at 1 kHz.

Fig. 5 shows the measurements performed on the 4920 for the 3 V range. In this range, the instrument has a relatively low input impedance (124 kΩ shunted by 150 pF). Two measurements have been performed, one (triangles) with the setup in normal operating conditions; another (circles) with the compensation deliberately excluded. A difference between the two curves of several parts in 10^6, of the same order of the linearity error itself, can be appreciated, showing the effect of the compensation and its relevance for a meaningful measurement.

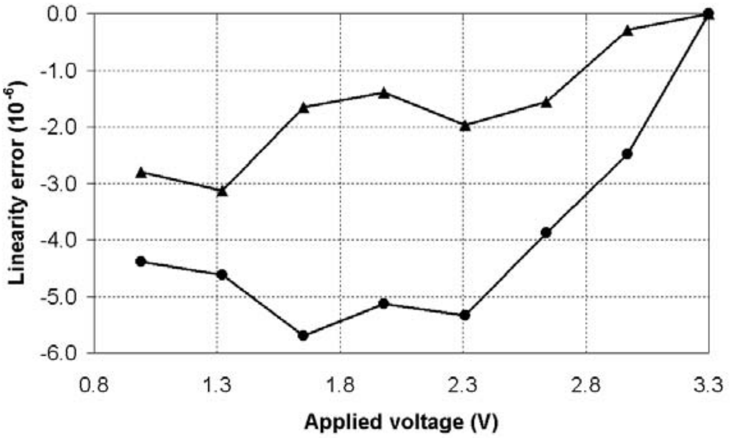

Figure 5. Measurements perfomed on a Datron Wavetek 4920 (Alternating Voltage Measurement Standard) in the 3 V range at 1 kHz, performed with the setup of Fig. 1. One measurement (triangles) is performed with the setup in normal operating conditions; the other (circles) is performed without applying the loading compensation, in order to show its effect.

IV. Conclusions

A method for the calibration of linearity of ac voltmeters in the audio frequency range is proposed. The implementation avoids the loading of the linearity standard employed (an inductive voltage divider) with an active compensation. The compensation is achieved by commercial instrumentation and is actually based on a particular commercial lock-in amplifier. Results of measurements on two instruments (J. Fluke 5790A ac transfer standard on the 2.2 V and 700 mV ranges, and Datron Wavetek 4920 on 3 V range, at the frequency of 1 kHz) are shown; in one (Fig. 5) the benefits of the compensation proposed can be directly appreciated.

References

[1] L. Callegaro, G. C. Bosco, and V. D'Elia, D. Serazio, "Direct-Reading Absolute Calibration of an AC Voltage Ratio Standards", *IEEE Trans. Instr. Meas.*, vol. 52, no. 2, pp. 380-383, 2003.

[2] N. Faulkner, "Comparing Different Method for the Calibration of the mV Ranges of an AC Measurement Standard", *Precision Electromagnetic Measurement Digest*, pp. 182-183, 2004.

[3] P. Simonson, K.-E. Rydler, "Loading Error in Low Voltage AC Measurement", *Precision Electromagnetic Measurement Digest*, pp. 572-573, 1996.

[4] F. Cabiati and G. La Paglia, *Proc. EUROMEAS77*, sess. 3, p. 50, 1977.

[5] L. Callegaro, V. D'Elia, "Automatic compensation technique for alternating current metrology based on synchronous filtering", *Rev. Sci. Instrum*, vol. 69, n. 12, pp. 4238-4241,1998.

[6] A. Carullo, M. Parvis, A. Vallan, and L. Callegaro, "Automatic compensation system for impedance measurement", *IEEE Trans. Instr. Meas.*, vol. 52, no. 2, pp. 1239-1242, 2003.

[7] L. Callegaro, C. Cassiago, and V. D'Elia, "Optical linking of reference channel for lock-in amplifiers", *Meas. Sci. Technol.*, vol. 10, pp. N91-N92 (1999).