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The effect of adjustment on multifunction instruments for electrical metrology: case examples

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Abstract- Top-class multifunction instruments (multimeters and calibrators) implement in their firmware adjustment procedures requiring a minimal set of adjustment standards. The small set of standards' values provided have effects on the (usually very broad) ranges of values and frequencies which the instrument can measure. How errors and uncertainties in the adjustment of specific points affect measurements in such broad ranges has been experimentally investigated in top-class multimeters and calibrators; most interesting results have been observed in the 'ac voltage' function; a number of examples are reported.

Keywords: Calibration; Multifunction instruments; Adjustment; Uncertainty

I. Introduction

High-accuracy multimeters and calibrators are nowadays the most common standards employed in electrical calibration laboratories. Such instruments measure or generate a number of electrical quantities (the minimum set always includes DC and AC voltage, DC and AC current, and DC resistance; but often other electrical functions are present) in a extended range, spanning from 5 to 9 decades in magnitude, and 5-6 decades in frequency for AC functions.

Manufacturers provide, for each instrument, the corresponding adjustment strategy. The strategy is constructed in order to achieve the specifications with the smallest possible set of adjustment point needed. Such a minimal set in turn minimize operator's time and, most important, the set of calibrated standards (or calibrated points of each standard) which is necessary for the adjustment. However, the strategy and corresponding algorithms embedded in instruments' firmware are not public or accessible in some way to the user, although in some cases useful hints are given in factory publications and application notes [1,2].

This raises the problem, on top-class instruments, of how an adjustment on a small number of measurement points affect subsequent measurements on whole ranges. Calibrated standards employed for the adjustment have a finite uncertainty, that is: certified or estimated values have a finite error with respect to ground truth values. Such errors propagate in an unknown way because of the adjustment algorithm, and become part of the reading error of the instrument when employed in a generic reading which does not coincide with an adjustment point.

The aim of the paper is to investigate experimentally such error propagation on some top-class instruments. The instrument is treated as a black box, and a number of adjustments and calibration phases are performed on it. Each adjustment is performed by artificially perturbing the estimate of an adjustment standard of a finite and known amount, hence simulating an adjustment error: then, a full calibration is performed, on a large number of calibration points, in order to assess the effect of the simulated error on a large measurement point set.

II. Experimental

The following instruments have been investigated:

- Multimeter Fluke mod. 8508A (two items);
- Multimeter Datron mod. 1281 (two items);
- Multifunction Calibrator Datron mod. 4808A (one item).

The investigations have been carried out with the INRIM multifunction instruments calibration facility

[3], which permits to perform the measurements in a largely automated way.

The measurement procedure is the following:

- a proper adjustment (that is, without introducing adjustment error) and calibration is carried out, to ensure the correct operation of the instruments and a verification of its specifications;
- the execution of a sequence of measurements covering a given range. One of the measurement points is the adjustment point (adj). The sequence is repeated (usually 3 times) to improve the statistics. We call $\{R_1\}$ the set of such (averaged) readings;
- the deviation, of a finite quantity, of one of the adjustment points;
- the execution of the same sequence of measurements on same points. This give the set $\{R_2\}$.

For each measured points, the quantities $\Delta R_a = R_2 - R_1$ (absolute) and $\Delta R_r = \Delta R_a / R_1$ can be computed; we call $\Delta R_{a(adj)}$ and $\Delta R_{r(adj)}$ those evaluated on the adjustment point.
To allow a comprehensible method of plotting the propagation of the adjustment act, we define the *sensitivity indexes* $IS_a = \Delta R_a / \Delta R_{a(adj)}$ and $IS_r = \Delta R_r / \Delta R_{r(adj)}$. Such indexes have the value 1 by definition on the adjustment points, and typically are smaller than 1 on the range of interest. If the adjustment value has no effect on a specific measurement, the sensitivity indexes will be 0.

III. Example of results

Because of the large number of experiments conducted, each one resulting in a large dataset, no complete report of results obtained can be given in the space of this paper. Hence, the following gives some examples for a measuring instrument, and for a reference generator. Reported data is relative to the function "a.c. voltage", which show the most interesting behaviour.

A. Example: Digital multimeter, Fluke mod. 8508

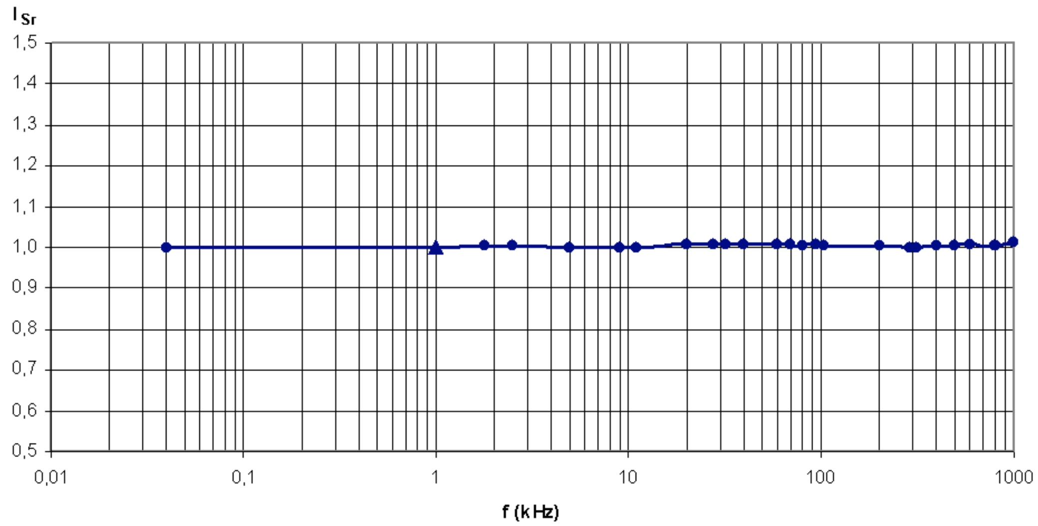

Fig. 1. IS_r measured on the 1 V ac voltage scale versus frequency, on the range 50 Hz - 1 MHz, after the variation of the adjustment point 1 V, 1 kHz

Fig. 1 shows the sensitivity index IS_r measured on the 1 V ac voltage scale versus frequency, on the range 50 Hz - 1 MHz, after the variation of the adjustment point 1 V, 1 kHz (LF adjustment point). One easily see that such adjustment point is taken by the instrument as a reference for the entire voltage scale: this happens despite the presence of other adjustment points on the voltage scale. The same behavior has been found in the other ranges.

Fig. 2 shows the same quantity IS_r for four adjustments and measurements, on the scales 100 mV – 1 V – 10 V – 100 V, when the corresponding adjustment point (0.1, 1, 10, 100 V) @ 60 kHz (HF adjustment point) is deviated. At variance with Fig. 1, it is apparent that such high-frequency adjustment point has effects only in the higher frequency range, with a complex behavior and an IS_r even higher than 1 for frequencies above the adjustment point. Apparently, such adjustment points set internal frequency correction parameters: the parameters have similar effects for the four voltage scales.

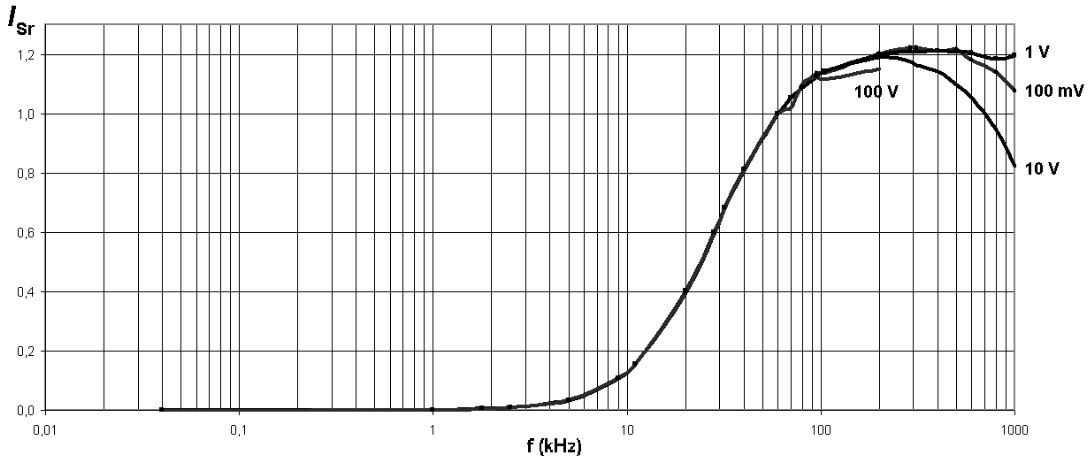

Fig. 2. I_{Sr} measured on the 100 mV – 1 V – 10 V – 100 V ac voltage scale versus frequency, on the range 50 Hz - 1 MHz, after the variation of the corresponding adjustment point 100 mV, 1 V, 10 V, 100 V at the frequency of 60 kHz.

Same measurements have been performed on the three digital multimeters investigated (one Fluke mod. 8508A, and two Datron mod. 1281); a behavior nearly identical to those reported in Fig. 1 and 2 has been found.

B. Datron mod. 4808, Multifunction calibrator

Fig. 3 shows the sensitivity index I_{Sr} measured on the 1 V ac voltage scale versus frequency, after the variation of the adjustment point 1 V, 1 kHz (LF adjustment point). A comparison with Fig. 1 show a very similar behavior, also fould when investigating other ranges.

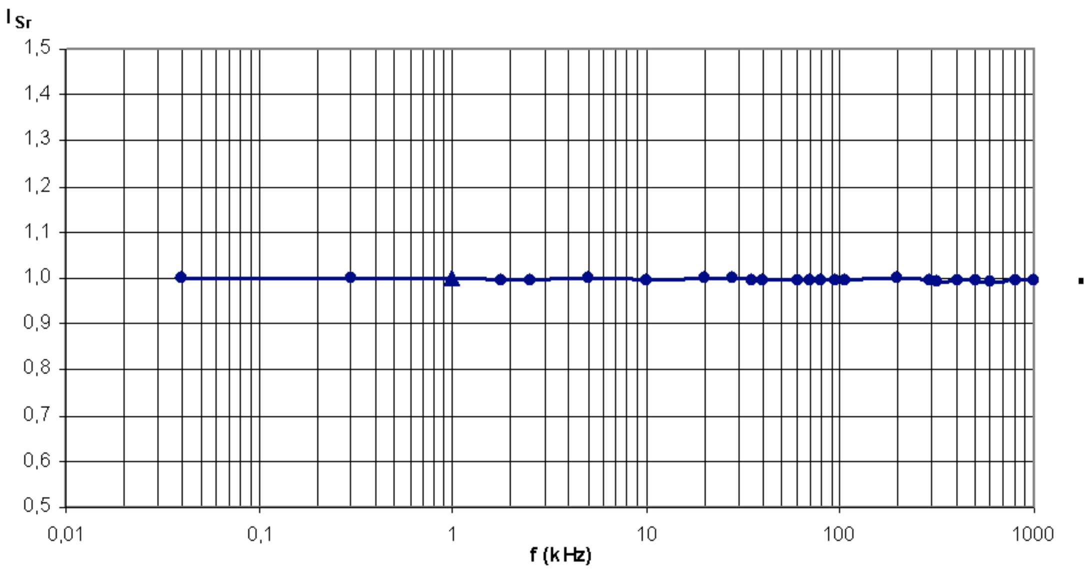

Fig. 3. I_{Sr} measured on the 1 V ac voltage scale versus frequency, on the range 40 Hz - 1 MHz, after the variation of the adjustment point 1 V, 1 kHz

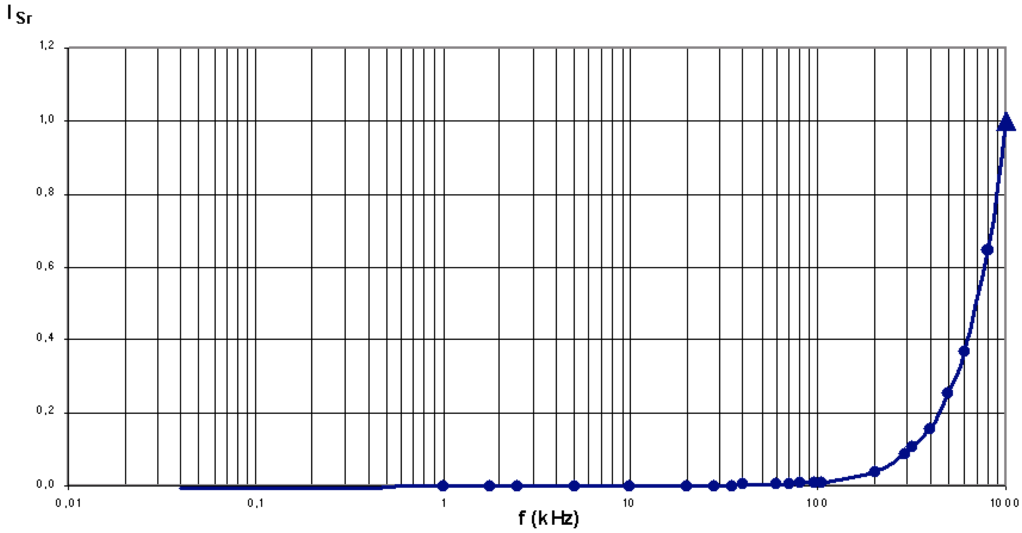

Fig. 4. I_{Sr} measured on the 1 V ac voltage scale versus frequency, on the range 40 Hz - 1 MHz, after the variation of the adjustment point 1 V, 1 MHz.

Fig. 4 shows I_{Sr} measured on the 1 V ac voltage scale versus frequency, after the variation of the adjustment point 1 V, 1 MHz (HF adjustment point). Similar results have been found for the ranges 0,1 V, 10 V and 100 V.
Fig. 5 show that the very same data of Fig. 4 is in a good agreement with the curve

$$I_{Sr}(f) = \left(\frac{f}{10^6}\right)^2$$

with f in Hz (note that 10^6 Hz is the HF adjustement point frequency)

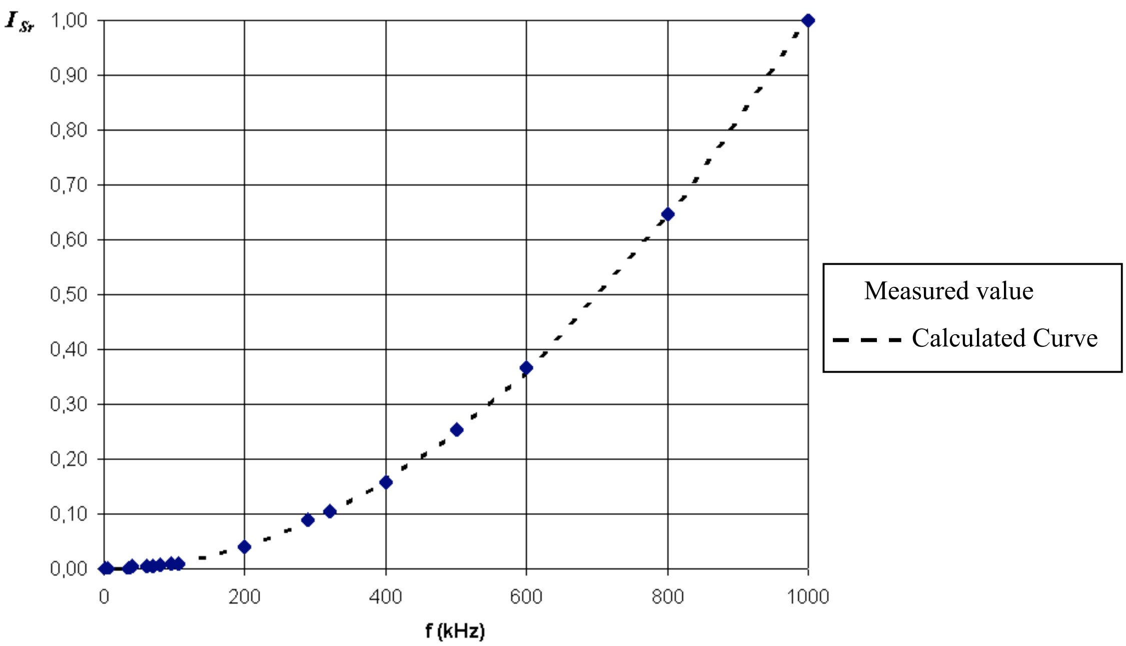

Fig. 5. Comparison between I_{Sr} determined on the 1 V ac voltage for HF adjustment point, and a simple calculated curve.

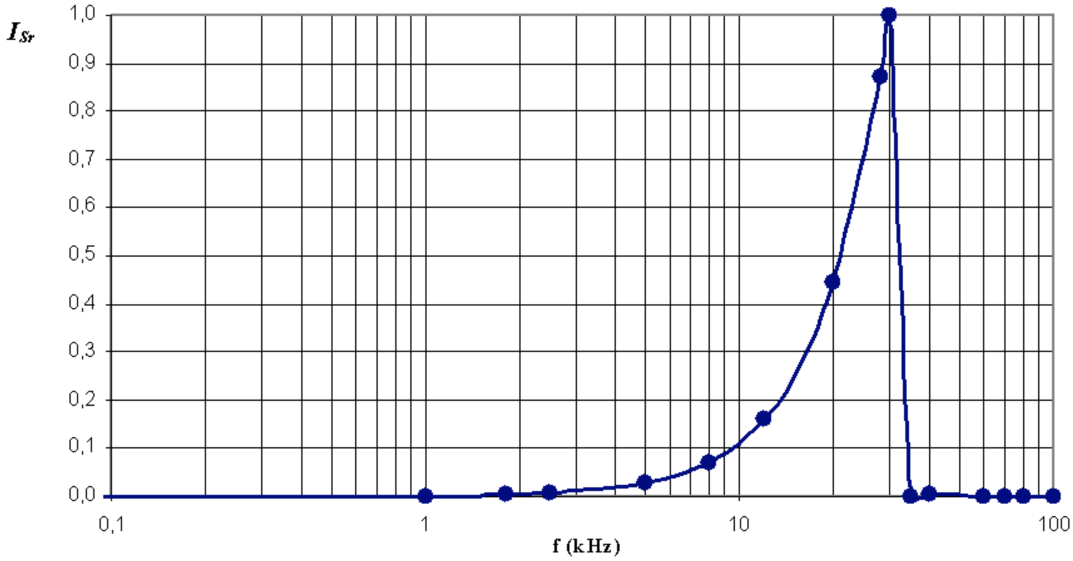

Fig. 6. I_{Sr} measured on the 1000 V ac voltage scale versus frequency, on the range 100 Hz - 100 kHz, after the variation of the adjustment point 1000 V, 30 kHz.

Fig. 6 shows the I_{Sr} measured on the 1000 V ac voltage scale, in correspondence with the 700 V value versus frequency, after the variation of the adjustment point 1000 V, 30 kHz (HF-1 adjustment point).

Fig. 7 shows I_{Sr} measured on the 1000 V ac voltage scale in correspondence of 700 V value versus frequency, after the variation of the adjustment point 700 V, 100 kHz (HF-2 adjustment point).

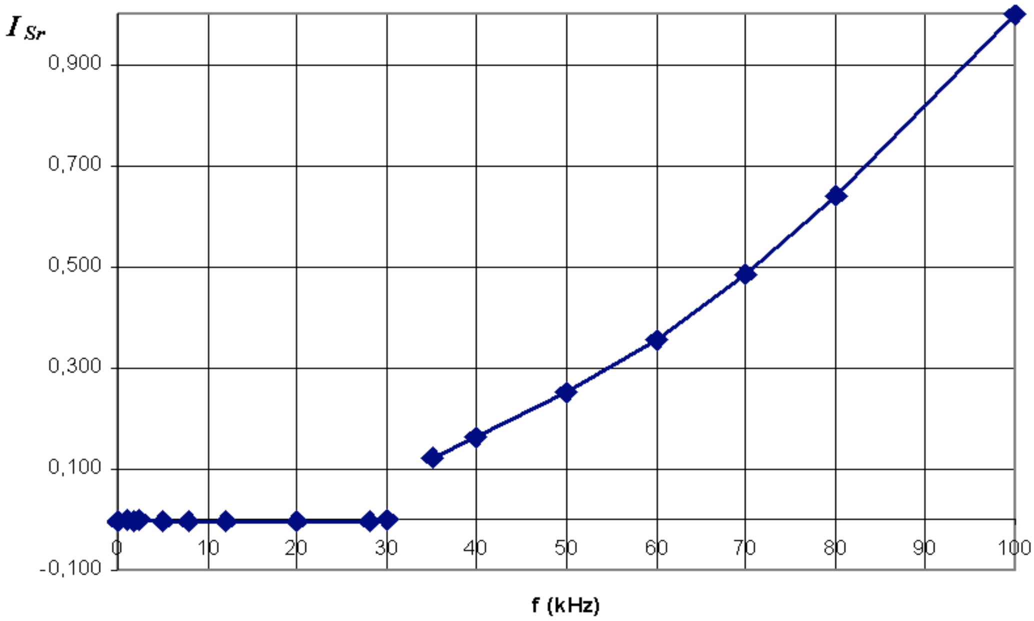

Fig. 7. I_{Sr} measured on the 1000 V ac voltage scale versus frequency, on the range 100 Hz - 100 kHz, after the variation of the adjustment point 700 V, 100 kHz.

IV. Conclusions

When an adjusted instrument is employed in a generic measurement, the accuracy of its reading is specified by the manufacturer as “relative to calibration standard”. However, the measured value is generally not coincident, or nearby, any adjustment point (that is, to any “calibration standard”). The user is left with the problem of how to express the uncertainty of the measurement. Such expression require to combine the uncertainty “relative to calibration standard” with the set of uncertainties of the estimates of adjustment points. According to the Guide on uncertainty in measurement (GUM), the combination becomes possible only if the appropriate set of sensitivity coefficients is available. The information given by the experiments described above, that is: how an adjustment error is propagated, is necessary to estimate the sensitivity coefficients. After these coefficients are experimentally obtained, it is possible to proceed with the uncertainty evaluation. This step will be the subject of following papers.

References

[1] W. C. Goeke, “High-performance digital multimeter with 'internal calibration'”, 5th Instrumentation and Measurement Technology Conference IMTC'88 proceedings, pp. 292-296, 1988.

[2] D. Strassberg: High-Performance DMMs and calibrators bring standards-lab specs to the benchtop - EDN, 4 February 1988.

[3] G. C. Bosco, R. Cerri, C. Cassiago, G. La Paglia, U. Pogliano, “Investigation on the use of multifunction programmable instruments for the transfer and the maintenance of the traceability”, Imeko TC-4 Symposium on Development in Digital Measuring Instrumentation and 3rd Workshop on ADC Modelling and Testing proceedings, pp. 489-492, 1998.

[4] Fluke Application Data, “A generic DMM test and calibration strategy”, Fluke Corp., 12 pp.

[5] C. Cassiago, G. C. Bosco, G. La Paglia, “IEN calibration laboratory for high precision multifunction instruments”, CPEM 2000 Conf. Dig., paper WEP1-3, pp. 367-368, 2000.

[6] Paul Roberts, “Achieving the best results with precision Digital Multimeter measurements”, NCSL Conference proceedings 2002.