



# COMPARISON AMONG THREE DIFFERENT DIGITAL MULTIMETER CALIBRATION METHODOLOGIES

João Claudio D. Carvalho<sup>1</sup>, Marcelo M. Costa<sup>2</sup>, Rafael T. Barros<sup>3</sup>, Thiago B. P. Souza<sup>4</sup>

<sup>1</sup>Eletronorte, Belém, Brasil, jclaudio@eletronorte.gov.br

<sup>2</sup>Eletronorte, Belém, Brasil, marcelo.melo@eletronorte.gov.br

<sup>3</sup>Eletronorte, Belém, Brasil, rafael.barros@eletronorte.gov.br

<sup>4</sup>Eletronorte, Belém, Brasil, thiago.brito@eletronorte.gov.br

**Abstract:** This paper presents the comparison among three methodologies of digital multimeter calibration, two established by Brazilian and international guides, and one developed by the Eletronorte Electrical Calibration Laboratory. In each methodology, aspects as number of calibration points, calibration time and reliability are evaluated.

**Keywords:** digital multimeter, calibration, calibration guides.

## 1. INTRODUCTION

Digital multimeters (DMMs) are electrical measurements instruments widely used in utilities in such activities as routine maintenance, daily measurements, and others. As all other measurement instruments, their measurements should be reliable, and so they must be periodically calibrated against traceable standards. The calibration process of such instruments can take from some hours to a few days, depending on the number of functions and ranges to be calibrated and evaluated, and on the number of calibration points in each function/range.

There are some published methodologies for DMM calibrations, like that established in [1] and [2]. Reference [1] defines a methodology especially for DMMs calibration, while the reference [2] establishes a general methodology for electrical measurements instruments calibration, which can be applied to DMMs calibration. The methodologies are different in terms of number and distribution of calibration points through the ranges, the need of negative points calibration (DC voltage and current), the uncertainty contributions to be considered, and other aspects.

Therefore, Eletronorte Electrical Calibration Laboratory developed a new methodology for DMMs calibration that specify, compared to the other two methodologies, less calibration points in few ranges, and more points in the other ranges.

## 2. OBJECTIVES

The main purpose of this paper is to compare the three methodologies in terms of reliability versus work-time expense. To do this, two different DMMs were calibrated, using the three methodologies and suitable electrical standards traceable to the Brazilian National Metrology

Laboratory (INMETRO). The DMMs differ in terms of accuracy, type of use (bench or hand-held) and number of digits or counts. Others aspects of the methodologies are also compared: uncertainty contributions, measurement characteristics, etc.

## 3. METHODOLOGIES

To perform the comparison of the calibration results, the three methodologies were used for AC and DC voltage calibration for each DMM considered. Each methodology has its particular characteristics. Some of these characteristics are present in more than one methodology. Table 1 summarizes the main characteristics of the methodologies: methodology denoted as M1 is the one defined by [1], the methodology defined by [2] is denoted by M2 and M3 is the methodology developed by Eletronorte Electrical Calibration Laboratory. The next three subsections show the definition of calibration point considering these two functions.

Table 1. Main characteristics of the methodologies applied

Main Characteristics	Methodologies		
	M1	M2	M3
Ensure that the instrument under calibration gives to the user traceable measurement results	X	X	X
Ensure the change in the instrument condition in each reading		X	X
Using of different frequencies from the mains on measurements of AC quantities	X		
For DC functions, perform preliminary zero operation in each range	X		X
Using of negative measurement points for DC functions	X		
Perform as a preliminary: functional verification, ACAL, SELFCAL, etc.	X		X
Guidance on the selection of calibration points may sometimes also be obtained from the manufacturer's instructions or according to the user needing	X	X	X

### a. Methodology 1

This methodology is based on [1], published by the European Association of National Metrology Institutes – EURAMET. The number of measurement points differs as to the accuracy of the instrument. In some cases, different frequencies are used for the same quantity value. The settings of the measuring points used are defined in the tables 1 to 4. The values of the measurement points are reported as a percentage of **full scale**.

**Table 2. Measurement points for low-accuracy DMMs (resolution of no more than 4 ½ digits) – DC voltage.**

Instrument ranges	Measurement points	
	No.	Values
All	3	10%, 90%, -90%
One (Intermediate)	5	10%, 50%, 90%, -10%, -90%

**Table 3. Measurement points for low-accuracy DMMs (resolution of no more than 4 ½ digits) – AC voltage.**

Instrument ranges	Measurement points		
	No.	Values and frequencies	
All	3	90%	58 Hz, 1kHz
Nominal value <0.5 V	5	10%, 90%	58 Hz, 1 kHz
One (Intermediate)	6	10%, 50%	58 Hz
		90%	58 Hz, 1, 20, 100 kHz
Nominal value >200 V	4	10%, 90%	58 Hz, 1 kHz

**Table 4. Measurement points for high-accuracy DMMs (resolution of more than 4 ½ digits) – DC voltage.**

Instrument ranges	Measurement points	
	No.	Values
All	3	10%, 90%, -90%
One (Intermediate)	7	10%, 30%, 50%, 70%, 90%, -10%, -90%
Nominal value >200V	4	10%, 50%, 90%, -90%

**Table 5. Measurement points for high-accuracy DMMs (resolution of more than 4 ½ digits) – AC voltage.**

Instrument ranges	Measurement points		
	No.	Values and frequencies	
All	8	10%	58 Hz, 1, 20 kHz
		90%	58 Hz, 1, 20, 50, 100 kHz
Nominal value <0.5 V	6	10%, 90%	58 Hz, 1, 20 kHz
One (Intermediate)	13	10%	58 Hz, 1, 20 kHz
		30%, 50%, 70%	1 kHz
		90%	58 Hz, 1, 20, 50, 100, 300, 1000 kHz
Nom. value >200 V	8	10%	58 Hz, 1, 20 kHz
		50%	1 kHz, 50 kHz
		90%	58Hz, 1, 30 kHz

### b. Methodology 2

This methodology is based on reference [2], published by INMETRO. Definitions of the measuring points used are shown in tables 5 and 6. The values of the measurement points are reported as a percentage of **full scale**.

**Table 6. Measurement points for DC voltage.**

Instrument ranges	Measurement points	
	No.	Values
All	1-2	50% <sup>(1)</sup> 95%
One (Intermediate)	3	10%, 50%, 95%

**Table 7. Measurement points for AC voltage.**

Instrument ranges	Measurement points		
	No.	Values and frequency	
All	1	50% <sup>(1)</sup> 95%	58 Hz
One (Intermediate)	3	10%, 50%, 95%	58 Hz

<sup>(1)</sup> Values to be done only on high-accuracy instruments (resolution equal to or higher than 5 ½ digits).

### c. Methodology 3

This methodology is documented on the Technical Procedures of Voltage Calibration, developed and currently used by the Eletrobras Eletronorte Electrical Calibration Laboratory. Definitions of measurement points for instruments of high and low accuracy are shown in tables 7 and 8. The values of the measurement points are reported as a percentage of full scale.

**Table 8. Measurement points for DC voltage.**

Instrument ranges	Measurement points	
	No.	Values
All	3	10%, 50%, 95%

**Table 9. Measurement points for AC voltage.**

Instrument ranges	Measurement points		
	No.	Values and frequency	
All	3	10%, 50%, 95%	60 Hz, 1, 10kHz

## 4. METHODOLOGIES APPLICATION

Two DMMs were calibrated to compare the methodologies. The main characteristics of these instruments are shown in table 10. The standards used to calibrate the DMMs, using the calibration methodologies under evaluation, were traceable to metrological standards, and had adequate Test Uncertainty Ratio (TUR).

**Table 10. DMMs used in the comparison.**

Brand and model	Basic accuracy	Resolution (Best)
Fluke 87 V	0.05%	5 999 counts
Fluke 8846A	0.0024%	6 ½ digits

Table 11 shows the points for the Fluke 87 V (fig. 1) calibration, while table 12 shows Fluke 8846A (fig. 2) calibration points, considering in both cases only DC voltage and AC voltage.



Fig. 1. Fluke 87 V digital multimeter.

Table 11. Fluke 87 V DMM calibration points considered.

Function	Methodology 1	M2	M3
DC Voltage	60mV, 540mV, -540mV, 0.6V, 5.4V, -5.4V, 6V, -6V, 30V, 54V, -54V, 60V, 540V, -540V, 100V, 900V, and -900V – total 17 points	570mV, 5.7V, 6V, 30V, 57V, 570V and 950V – total 7 points	60 mV, 300mV, 570mV, 0.6V, 3V, 5.7V, 6V, 30V, 57V, 60V, 300V, 570V, 100V, 500V and 950V (total 15 points)
AC Voltage	60mV (58Hz, 1kHz), 540mV (58Hz, 1kHz), 5.4V (58Hz, 1kHz), 6V (58Hz), 30V (58Hz), 54V (58Hz, 1kHz, 20, 100 kHz), 60V (58Hz, 1kHz), 540V (58Hz, 1kHz), 100V (58Hz, 1kHz) and 900V (58Hz, 1kHz) – total 20 points	570mV, 5.7V, 6V, 30V, 57V, 570V and 950V (all in 58 Hz) – total 7 points	60 mV, 300mV, 570mV, 0.6V, 3V, 5.7V, 6V, 30V, 57V, 60V, 300V, 570V, 100V, 500V and 950V (all in 60 Hz) – total 15 points



Fig. 2. Fluke 8846A digital multimeter.

Table 12. Fluke 8846A DMM calibration points considered.

Function	Methodology 1	M2	M3
DC Voltage	10mV, 90mV, -90mV, 0.1V, 0.9V, -0.9V, 1V, 3V, 5V, 7V, 9V, -1V, -9V, 10V, 90V, -90V, 100V, 500V, 900V and -900V – total 20 points	50mV, 95mV, 0.5V, 0.95V, 1V, 5V, 9.5V, 50V, 95V, 500V and 950V – total 11 points	10mV, 50mV, 95mV, 0.1V, 0.5V, 0.95V, 1V, 5V, 9.5V, 10V, 50V, 95V, 100V, 500V and 950V – total 15 points
AC Voltage	10mV (58Hz, 1, 20kHz), 90mV (58 Hz, 1, 20kHz), 0.1V (58 Hz, 1, 20kHz), 0.9V (58 Hz, 1, 20, 50, 100 kHz), 1V(58 Hz, 1, 20kHz), 3V (1 kHz), 5V (1 kHz), 7V (1 kHz), 9V (58 Hz, 1, 20, 50, 100, 300, 1000 kHz), 10V (58 Hz, 1, 20kHz), 90V (58 Hz, 1, 20, 50, 100 kHz), 100V (58 Hz, 1, 20 kHz), 500V (1 kHz, 50 kHz) and 900V (58Hz, 1, 30 kHz) – total 43 points	50mV, 95mV, 0.5V, 0.95V, 1V, 5V, 9.5V, 50V, 95V, 500V and 950V (all in 58Hz) – total 11 points	10mV, 50mV, 95mV, 0.1V, 0.5V, 0.95V, 1V, 5V, 9.5V, 10V, 50V, 95V, 100V, 500V and 950V (all in 60 Hz) –total 15 points

## 5. RESULTS

Tables 13 and 14 summarize the results of calibration of the Fluke 87 V DMM and the Fluke 8846A DMM. *Total points* describes the number of measurement points used in the DMM calibration. *Points in conformance* indicate how many points are inside the limits of conformance. *Worktime* shows the time in minutes of calibration.

Until the moment of conclusion of this paper, the measurement points with high frequencies were not performed, therefore were not considered in the results.

Table 13. Fluke 87 V calibration results

	M1	M2	M3
Total points	27	14	30
Points in conformance	27	14	30
Worktime (min)	41	15	53

Table 14. Fluke 8846A calibration results

	M1	M2	M3
Total points	30	22	30
Points in conformance	30	22	30
Worktime (min)	87	66	85

Figure 3 illustrates graphically the calibration time of each DMM. The columns represent the quantity of time in

minutes corresponding to each methodology as shown in the legend.

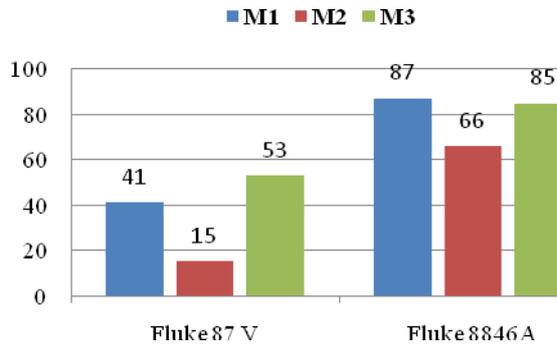


Figure 3. Worktime comparison graphs (in minutes)

As it can be seen in the previous tables and graphs, calibration time considering methodologies 1 and 2 reduced in comparison to methodology 3 calibration time. This reduction was proportional to the reduction of calibration points. Of course there was a work time reduction in other activities related to the calibrations, like the calibration certificate elaboration. In spite of the reduction of calibration points, calibration results shown that the process of metrological confirmation (which includes the calibration) remained reliable.

It was also possible to verify that, if methodology M1 should be followed in the strict sense, traceability of the standards have to be extended, in order to cover frequencies from the fundamental up to hundreds of kilohertz.

## 6. CONCLUSIONS

Comparison results shown that, with the use of methodology with lower number of points, calibration time can be saved while the reliability of the metrological confirmation process of the DMMs remains. Regarding to the methodologies comparison, it could be seen that none of them must be followed in the strict sense: definitions should be considered as orientations and suggestions. Manufacturers' definitions and users' needs should always be considered. In the case of AC quantities (voltage), one of the methodologies suggests the frequencies different of the fundamental frequency (kHz) that should be calibrated, while the others do not suggest.

For further work, it is planned the evaluation of the calibrations of more DMMs, differing in terms of brand, accuracy and resolution, using the methodologies discussed in this paper. The results of these researches must support the revision of Eletrobras Eletronorte Calibration Technical Procedures.

## REFERENCES

[1] Guidelines on the Calibration of Digital Multimeters, EURAMET Calibration Guide 15/v.01, Jul. 2007.

[2] Electrical Digital and Analog Measurement Instruments Calibration Guide, INMETRO Guidance Document, Sep. 2006.

[3] Calibration: Philosophy in Practice, 2<sup>nd</sup> ed., Fluke Corporation, 1994.