DISSEMINATION METHOD FOR STANDARD METER RATIO USING TWO DC VOLTAGE STANDARD SOURCES

Metoda Diseminasi Rasio Untuk Meter Standar Menggunakan Dua Sumber Standar Tegangan DC

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Abstract

Since 2004, Research Center for Metrology – Indonesian Institute of Sciences (RCM – LIPI) has maintained the DC voltage standard traceability from 1.018 V up to 1000 V based on two standard source types, namely standard cell groups and a multifunction calibrator that work as secondary standards . In this research, a new method was developed in maintaining the tertiary standard accuracy using a meter ratio. The accuracy of the standard meter ratio could be achieved by a dissemination process. This dissemination process was validated using an error number (En) through a comparison between two voltage standards obtained from indirect measurement method and direct measurement method. The result showed that the standard meter ratio that was validated on 3 ranges of comparison measurement namely 1.018:1.018, 1.018:10, and 1.018:100 worth to be implemented based on the validation values En of 0.87, 0.05, and -0.041 respectively.

Keywords: *meter ratio, measurement, DC voltage standard, dissemination method*

Abstrak

Sejak tahun 2004, Pusat Penelitian Metrologi - Lembaga Ilmu Pengetahuan Indonesia (RCM - LIPI) telah mempertahankan ketertelusuran standar tegangan DC dari 1.018 V hingga 1000 V berdasarkan dua jenis sumber standar, yaitu kelompok sel standar dan kalibrator multifungsi yang berfungsi sebagai standar sekunder . Dalam penelitian ini, metode baru dikembangkan dalam mempertahankan akurasi standar tersier menggunakan rasio meter. Keakuratan rasio meter standar dapat dicapai dengan proses diseminasi. Proses diseminasi ini divalidasi menggunakan nomor kesalahan (En) melalui perbandingan antara dua standar tegangan yang diperoleh dari metode pengukuran tidak langsung dan metode pengukuran langsung. Hasil penelitian menunjukkan bahwa rasio meter standar yang divalidasi pada 3 rentang pengukuran perbandingan yaitu 1.018: 1.018, 1.018: 10, dan 1.018: 100 layak untuk diimplementasikan berdasarkan nilai validasi En masing masing 0.87, 0.05, dan -0.041.

Kata kunci : meter rasio, pengukuran, standar tegangan DC, metoda diseminasi

1. INTRODUCTION

As a scientific institution that is responsible for managing the National Standard for Measurement Unit in Indonesia, RCM - LIPI uses a PJVS (Programmable Josephson Voltage System) as the primary DC standard (R. Hadi Sardjono, 2013) and an integration of Zener diodes (standard cell group of 4 x F–732B, SCG) and a multifunction calibrator (F-5720A, MC) as the secondary DC standard (Sardjono & Wijonarko, 2018). The secondary standard has measuring capabilities of 1 V, 1,018 V and 10 V. The secondary standard, having a single range type, must be disseminated to a tertiary standard (multifunction calibrator F-5700A) that has a variable range type from 1 V to 1000 V. This dissemination process requires a direct measurement method supported by DC voltage dividers. Based on the type of DC voltage dividers, the direct measurement method can be classified in two techniques, namely standard voltage divider and standard meter ratio (Fluke Calibration, 2013). The RCM-LIPI utilizes the first technique.

The aim of this study was to develop the second technique applied at RCM-LIPI (Figure 1). The quality of this technique is guaranteed through a technical qualification process, so that it can fulfill the metrological traceability requirement (Hadi Sardjono, 2007). The technical quality of the meter ratio can be assured by performing a calibration process. Basically in the calibration process, two main variables namely the standard variable (STD) and the instrument variable (Unit Under Test or UUT, Instrument Under Test or IUT) are required (Sosso et al, 2015).

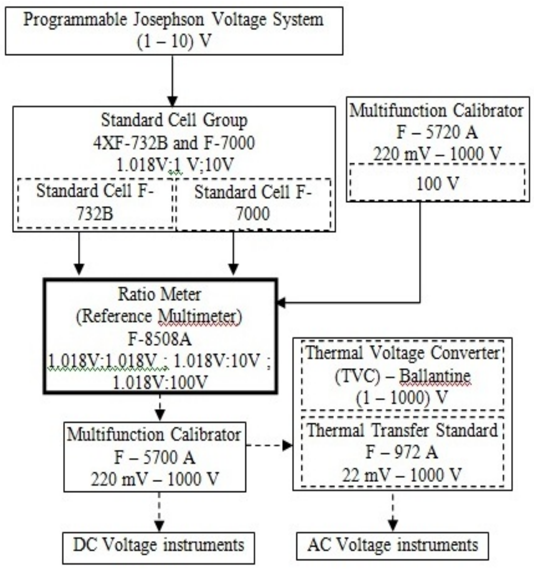

Figure 1 The traceability chart of voltage using standard meter ratio technique at RCM-LIPI.

Note : Solids arrows were described the traceability chart building that was performed before the research and the dashes arrows were described the traceability chart building that was achieved from these research.

The calibration process of the standard meter ratio is performed using standard zener diodes at 1.018 V and 10 V and a multifunction calibrator at 100 V. From these three measuring points, three ratio measurements that are 1.018:1.018, 1.018:10, and 1.018:100 are attained. The working principle of the meter ratio is based on a voltage comparison at two inputs of the meter ratio. The ratio was obtained from the voltage comparison between the front direction and back direction (Dack, 2001). The quality for each ratio is assured via a validation by comparing the direct measurement and indirect measurement.

The measurement system is built by installing the same cable length between the front-end terminal and the rear-end terminal to each of the standard DC voltage sources. The ratio measurement results are free of cable losses, so that the real values of both DC voltage sources can be obtained. The measurement results for 1.018:1.018, 1.018:10, 1.018: 100 standard ratios had values 1.0001420, 9.823148, and 98.23696 with the measurement uncertainty of 0.0000110, 0.000385, and 0.08520 respectively. Each measurement ratio is valid based on the validation process that is equal to 0.87, 0.05, and -0.041 respectively.

From this meter ratio research, RCM - LIPI has been able to build a full independent traceability system in the standard DC voltage field by combining traceability from a single and multiple measurement ranges from 1 V to 1000 V. Traceability of a single range of 1,018 V, 1 V and 10 V is constructed by a process of dissemination from PJVS (Programmable Josephson Voltage System) to Standard Cells (Sardjono & Suprianto,2015) while the multiple ranges are built by a dissemination process using a meter ratio from a standard cell to a multifunctional calibrator.

2. LITERATURE REVIEW

Maintaining standard and traceability of DC voltages has been declared as the central task of the Electrical Metrology Laboratory (EML), RCM-LIPI, since 1997 by Presidential Decree No. 13. The maintaining process was first confirmed by the accreditation process by an international assessor of Korean National Metrology Laboratory (KRISS) in 2004. The DC voltage standards are obtained from two types of instruments known as generators and measuring devices. Generally the type of generator has two kinds of scale i.e videlicet single scale and variable scale.

Traceability of DC voltage at EML at present is maintained by the measurement relation among three kinds of standards (PJVS, SCG, and MC), so that the chain is not disconnected. An autonomous traceability can be built based on competencies that can be realized through a series of calibration processes. The calibration processes can be done using a direct comparison method with the provision that the two quantities involved in the calibration process have the same point value (having a ratio of 1:1). Hence, the direct comparison method could not be performed on a calibration process between SCG which has only 3 measuring points with multifunction calibrator that have measuring points varying from 1 V up to 1000 V.

The dissemination process from the integration of SCM and MC (multifunction calibrator F-5720A) to multifunction calibrator F-5700A can be carried out using a standard DC voltage comparator known as the Divider Voltage Standard (DVS). The range of DVS is so limited. This became an obstacle in order to build an autonomous traceability system of DC voltage standard. This handicap, however, can be coped in this research utilizing a standard measuring instrument known as reference multi-meter (RMM) or meter ratio (Fluke 2008 FPM, 2008).

The calibration process of this ratio is then validated using the direct measurement method and indirect measurement method.

2.1. Direct Measurement Method

The basic circuit of a DC voltage divider can be visualized as presented on Fig. 2.

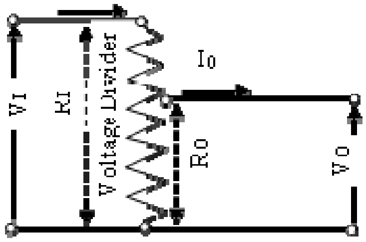

Figure 2 Basic circuit for DC voltage divider.

The variables relationship contained in the Figure 2 can be determined using the law of basic circuit for a DC voltage divider as follows:

$$V_O = \frac{R_O}{R_I} V_I \qquad (1)$$

where:
V_I = input voltage (V)
R_I = input resistance (Ω)
V_O = output voltage (V)
R_O = output Resistance (Ω)

In accordance with the equation (1) above, changes in R_O variable may result changes in V_O. Similarly, these changes will also occur on the value of the comparison variable R_0/R_1. The comparison variable or in this case is referred to as the ratio variable as it can be schematically presented into Figure 3 as follows:

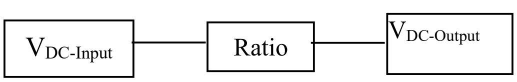

Figure 3 Analogue block ratio of DC Voltage Divider Circuit.

Without changing the working principle of DC voltage divider circuit when $V_{DC-Output}$ and ratio are replaced by $V_{DC-Input}$ and meter then ratio measurement process can be carried out. In the ratio measurement process, the characteristics of the $V_{DC-Input}$ ($V_{DC-Input1}$) and $V_{DC-Output}$ ($V_{DC-Input2}$) variables are standard characteristic values or as $V_{DC-STD1}$ and $V_{DC-STD2}$, respectively. Thus the variable DC voltage divider circuit can be analogous to the ratio measurement circuit as shown in Fig. 4 below (Fluke, 2002).

In accordance with its function, the calibration circuit ratio in equation (1) then can be developed to the following equation,

$$R_M = \frac{V_{DC-F}}{V_{DC-R}} + \frac{\Delta_{RK-F}}{\Delta_{RK-R}} \qquad (2)$$

Where:
R_K = ratio for direct measurement method
Δ_{RK} = correction for ratio due to losses from direct measurement method
V_{DC-F} = standard DC voltage for FRONT terminal (V)
V_{DC-R} = standard DC voltage for REAR terminal (V)

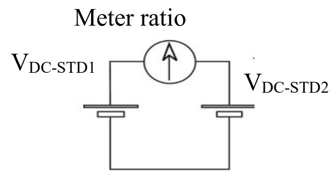

Figure 4 Basic circuit of DC voltage ratio calibration.

2.2. Indirect Measurement Method

Based on the working principle of the Fig. 3 circuit, we can derive a mathematical model of the ratio value at each change that occurs to the value of the comparison between the two VDC standard values as

$$R_A = \frac{V_{DC-STD1}}{V_{DC\_STD2}} + \frac{\Delta_{VDC-STD1}}{\Delta_{VDC-STD2}} \qquad (3)$$

Where:
R_A = ratio for indirect measurement method
Δ_{VDC} = correction for ratio due to losses from indirect measurement method
$V_{DC-STD1}$ = the first standard DC voltage (V)
$V_{DC-STD2}$ = the second standard DC voltage (V)

The ratio for this method can be derived using a calculation process. There are some limitations in the calculation process that cannot be avoided such as calculation rounding and measurement resolution in the calibration.

3. RESEARCH METHOD

In this study, the ratios were found utilizing two methods namely direct measurement method and indirect measurement method. The direct measurement method was performed to attain a new procedure that can be validated by the result of the indirect measurement method. Hence, the indirect measurement method was used as the validation reference.

The implementation process to get ratio values from the direct measurement method in this research was conducted by constructing a calibration circuit supported by several apparatus namely two DC voltage standard, measurement cable and standard ratio equipment. These apparatus were the source of variables that accompany equation (2) to form the following equation.

$$R_M = \frac{V_{DC-E}}{V_{DC-R}} + \frac{\Delta_{drop\ c-E}}{\Delta_{drop\ c-R}} + \frac{\Delta_{emf-E}}{\Delta_{emf-R}} + \frac{\Delta_{res-E}}{\Delta_{res-R}} \qquad (4)$$

With:

$\Delta_{drop\ c}$ = voltage drop across the cable
Δ_{emf} = thermal stress in calibration circuit
Δ_{res} = measurement resolution

The process of indirect measurement method was done by computing the ratio of two DC voltages involved in the above calibration process. There are two components involved in the process of indirect measurement method that are two DC voltage standards, so that the mathematical model of equation (3) can be developed into the following equation,

$$R_A = \frac{V_{DC-STD1}}{V_{DC\_STD2}} + \frac{\Delta_{res-STD1}}{\Delta_{res-STD2}} \qquad (5)$$

The dissemination process for DC voltage standard from a single range type with its measurement point of 1 V, 1,018 V, and 10 V to variable range type with measurement points from 1 V to 1000 V required standard ratio values. The ratio of measurement points required to satisfy the dissemination process from 1V to 1000V were 1.018: 1.018, 1.018:10, and 1.018: 100. These three ratios of measurement points could be achieved by preparing 3 combinations of standard DC voltage (1.018 V, 10 V, and 100 V). The standard DC voltage for 1.018 V and 10 V were derived from standard cells that are traceable to PJVS, while for 100 V was derived from the Multifunction Calibrator that is traceable to the 10 V standard cell.

The basic principle of performing calibration for standard DC voltage using ratio method is to compare DC voltage between two standards. This means that 1.018:1, 1.018:10, and 1.018:100 ratios can be obtained from the comparison between two standard cells of 1,018 V : 1,018 V, two standard cells of 1,018 V : 10 V, a standard cell and a multifunction calibrator of 1.018 V : 100 V. In accordance with the calibration circuit on Figure 3 and the actual value of each measurement point of 1.018 V, 10 V, and 100 V, some data such as terminal read error, lost data and calibration ratio results can be obtained.

4. RESULT AND DISCUSSIONS

4.1. Direct Measurement Result

The actual value for the 1,018 V measurement point was obtained from two standard zener diode cells. The first standard zener diode cell (F-7000 type) was 1.0179978 V and the second standard zener diode cell (F-734A type) was 1.0181566 V. The actual value for a 10 V measurement point, obtained from a standard cell of Zener diode (F-7000 type), is 9,9999744 V. The actual value for the 100 V measurement point, obtained through the calibration process of a Multifunction Calibrator (F-5720A type) to standard cells (F-7000 type), is 99.999926 V.

The sequential lost data in the ratio calibration process shows the linearity characteristic of FRONT and REAR input terminals (Table 1), the voltage drop absorbed by the measuring cables (Table 2), and the thermal voltage at the point of connection (see Table 3).

Table 1 Measurement errors due to offset

Input (DAC) (V)	FRONT Output (V)	REAR Output (V)	FRONT Offset (V)	REAR Offset (V)
1.0000000	1.0000018	1.000003	0.0000018	0.0000030
10.000000	10.000047	10.000049	0.0000470	0.0000490
100.00000	100.00031	100.00029	0.0003100	0.0002900
1000.0000	1000.0072	1000.0072	0.0072000	0.0072000

(W. Goeke et al, 1989; A. Sosso and R. Cerri, 2002).

Offset ratio error was obtained by measuring linearity of FRONT and REAR terminals. The characteristics of the two terminals illustration the nature of output values that occur based on the input DAC (Digital to Analog Converter) meter ratio. Furthermore the two output terminals were compared to set the ratio of offset error.

Table 2 Measurement error due to cable measurement load (cable losses).

	I_{Cabel} (A)	R_{Cable} (Ω)	V_{Cable} (V)
REAR	1.40432E-06	0.1080517	0.00000152
FRONT	1.40446E-06	0.1091871	0.00000154

The measurement error due to the loading of the measuring cable in this case is mentioned as the V_{Cable}. This was an error that is obtained from the multiplication of the measurement cable current with the measurement cable resistance. The cable current and cable resistance were measured by calculating the measured current flows at the terminals in a short circuit and the terminals are connected to the two measuring cables short-circuited.

Table 3 Result of measurement error due to emf voltage.

	REAR Terminal (V)	FRONT Terminal (V)
Forward	1.0000030	1.0000027
Reverse	1.0000042	1.0000049
Emf thermal	0.0000006	0.000001

The ratio for emf voltage can be obtained by comparing the forward and reverse direction measurement values. Forward direction measurement was performed by supplying the circuit with 1 volt DC voltage standard in normal polarity. For reverse direction measurement, the measurement was conducted as the forward direction measurement, but with reversing the Reference Multimeter.

The ratio values for 1,018:1,018, 1,018:10, 1,018:100 were calculated from the technical specification values in the formation $FRONT_{F\ 734A}$ to $REAR_{F-7000}$, $FRONT_{F-7000}$ to $REAR_{F-734A}$, and $FRONT_{F-5720A}$ to $REAR_{F-734A}$ respectively. The comparison formation is arranged such a way so that it can measure the ratio of standard meters of Reference Multimeter (RMM) ratio correctly.

Table 4 Ratio obtained from indirect measurement method.

	R_A ($R_{Calculus}$)	
1.018:1.018	1.018:10	1.018:100
1.0001560	9.823179	98.23197

Table 5 Ratio obtained from direct measurement method.

	R_K ($R_{Calibration}$)	
1.018:1.018	1.018:10	1.018:100
1.0001419	9.823143	98.23673
1.0001422	9.823135	98.23714
1.0001420	9.823154	98.23777
1.0001418	9.823153	98.23750
1.0001422	9.823158	98.23846
1.0001419	9.823142	98.23752
1.0001421	9.823153	98.23662
1.0001420	9.823145	98.23681
1.0001421	9.823147	98.23820
1.0001419	9.823154	98.23861

4.2. Validation Using Indirect Measurement Result

Data analysis for indirect measurement method was carried out by comparing the voltages (VDC-STD1 and VDC-STD2) between the first standard (F-7000 type standard cell diode) and second standard (F 732A type standard cell diode). Due to influence of standard resolution voltages, the ratio can be revised as the following equation.

$$R_A = \frac{V_{DC-STD1}}{V_{DC\ STD2}} + \frac{\Delta V_{DC-STD1}}{\Delta V_{DC-STD2}} = R_{A-VDC-STD} + \Delta R_{A-VDC-STD} \quad \text{.....(6)}$$

With:

$R_{A-VDC-STD}$ = ratio between the first ($V_{DC-STD1}$) and second standards ($V_{DC-STD2}$)

$\Delta R_{A-VDC-STD}$ = ratio between the first ($_{VDC-STD1}$) and second standard resolution voltages ($V_{DC-STD2}$)

The combined uncertainty was attained by combining the individual uncertainty. Hence, the combined uncertainty is composed of two DC voltage standard values and 2 standard resolution values *(JCGM 200-2008, 2012).*

$$U_{Combination} = \sqrt{c^2_{VDC-STD1} \cdot u^2_{VDC-STD1} + c^2_{VDC-STD2} \cdot u^2_{VDC-STD2} + c^2_{\Delta VDC-STD1} \cdot u^2_{\Delta VDC-STD1} + c^2_{\Delta VDC-STD1} \cdot u^2_{\Delta VDC-STD2}} \quad \text{...............(7)}$$

where:

$u_{VDC-STD1}$ = uncertainty of the first DC voltage standard

$u_{VDC-STD2}$ = uncertainty of the second DC voltage standard

$u_{\Delta VDC-STD1}$ = uncertainty due to the resolution of the first DC voltage standard

$u_{\Delta VDC-STD2}$ = uncertainty due to the resolution of the second DC voltage standard

$c_{VDC-STD1}$ = coefficient of first standard uncertainty $V_{DC-STD1}$

$c_{VDC-STD2}$ = coefficient of second standard uncertainty V_{DC-ST2}

$c_{\Delta VDC-STD1}$ = coefficient of first resolution uncertainty $\Delta V_{DC-STD1}$

$c_{\Delta VDC-STD2}$ = coefficient of second resolution uncertainty $\Delta V_{DC-STD1}$

In indirect measurement method, each standard uncertainty coefficient was obtained using one of the following formulas

$$c_{VDC-STD1} = \frac{\partial R_A}{\partial (V_{DC-STD1})} = \frac{1}{V_{DC-STD2}} \quad \text{...(8)}$$

$$c_{VDC-STD2} = \frac{\partial R_A}{\partial (V_{DC-STD2})} = \frac{-V_{DC-STD1}}{V_{DC-STD2}^{2}} \quad \text{...(9)}$$

$$c_{\Delta VDC-STD1} = \frac{\partial R_A}{\partial (V_{\Delta DC-STD1})} = \frac{1}{V_{\Delta DC-STD2}} \quad \text{...(10)}$$

$$c_{\Delta VDC-STD2} = \frac{\partial R_A}{\partial (V_{\Delta DC-STD2})} = \frac{-V_{DC-STD1}}{V_{\Delta DC-STD2}^{2}} \quad (11)$$

In addition to the above variables, there were some standard uncertainties caused by the process of calculations performed by RMM. The standard uncertainty at the ratio of 1.018 V : 1.018 V in the range 2 V was calculated using the following equation

$$u_{r-same1} = \pm\sqrt{\left(0.12 + 0.1 \times \frac{2}{1.018}\right)^2 + \left(0.12 + 0.1 \times \frac{2}{1.018}\right)^2} = 0.45\ ppm\ of\ the\ ratio \quad \text{.......} \quad (12)$$

While at the ratio of 1.018 V : 10 V in the range between 2 V and 20 V was computed using the following equation

$$u_{rdifference10} = \pm\sqrt{\left(4.5 + 0.5 \times \frac{2}{1.018}\right)^2 + \left(4.5 + 0.2 \times \frac{20}{10}\right)} = 5.91\ ppm\ of\ the\ ratio \quad \text{..........} \quad (13)$$

and at the ratio of 1.018 V : 100 V in the range between 2 V and 200 V was found using the following equation (Sosso et al, 2015; Everett and Wash, 2014).

$$u_{rdifference100} = \pm\sqrt{\left(4.5 + 0.5 \times \frac{2}{1.018}\right)^2 + \left(4.5 + 0.2 \times \frac{200}{100}\right)} = 5.91\ ppm\ of\ the\ ratio \quad \text{..........} \quad (14)$$

The uncertainty budget for the indirect measurement method was displayed on Table 6 (see Appendix).

Analysis for calibration method was done by measuring all variables for the first standard ($V_{DC-STD1}$) and second standard ($V_{DC-STD2}$) obtained from standard cell diode F-7000 and F 732A, respectively. In accordance with the calibration circuit constructed as in Figure 3, it can be derived a mathematic model as follows,

$$R_K = \frac{V_{DC-F}}{V_{DC-R}} + \frac{\Delta_{dropc-F}}{\Delta_{dropc-R}} + \frac{\Delta_{emf-F}}{\Delta_{emf-R}} + \frac{\Delta_{res-F}}{\Delta_{res-R}} - R_{K-VDC} + R_{K-drop\ Cable} + R_{K-emf} + R_{K-res} \quad \text{.....(15)}$$

where:

R_{K-VDC}	=	the calibration ratio between the first and second standard DC voltages
ΔR_{K-drop}	=	the calibration ratio between the FRONT and REAR cable voltage drops
ΔR_{K-emf}	=	the ratio between the FRONT and REAR emf voltages
ΔR_{K-res}	=	the calibration ratio for RMM reading resolution

The combined uncertainty can be obtained by combining all individual uncertainties and an RMM reading resolution. The individual uncertainties come from the DC voltage standard, the cable voltage drops, the emf voltages, and the RMM reading resolution. This combination can be formed in the following equation (*JCGM 200-2008*, *2012)*.

$$U_{Combination} = \sqrt{c^2_{VDC-F}\cdot u^2_{VDC-F} + c^2_{VDC-R}\cdot u^2_{VDC-R} + c^2_{\Delta drop-F}\cdot u^2_{\Delta drop-F} + c^2_{\Delta drop-R}\cdot u^2_{\Delta drop-R} + c^2_{\Delta emf-F}\cdot u^2_{\Delta emf-F} + c^2_{\Delta emf-R}\cdot u^2_{\Delta emf-R} + c^2_{\Delta res}\cdot u^2_{\Delta res}} \quad \text{.......} \ (16)$$

where:

u_{VDC-F}	=	the uncertainty for DC voltage standard at FRONT terminal
u_{VDC-R}	=	the uncertainty for DC voltage standard at REAR terminal
$u_{\Delta drop-F}$	=	the uncertainty for cable voltage drops at FRONT terminal
$u_{\Delta drop-R}$	=	the uncertainty for cable voltage drops at REAR terminal
$u_{\Delta emf-F}$	=	the uncertainty for emf voltage at FRONT terminal
$u_{\Delta emf-R}$	=	the uncertainty for emf voltage at REAR terminal
$u_{\Delta res}$	=	the uncertainty for RMM reading resolution
c_{VDC-F}	=	the uncertainty coefficient for standard DC voltage at FRONT terminal
c_{VDC-R}	=	the uncertainty coefficient for standard DC voltage at REAR terminal
$c_{\Delta drop-F}$	=	the uncertainty coefficient for cable voltage drop at FRONT terminal
$c_{\Delta drop-R}$	=	the uncertainty coefficient for

cable voltage drop at REAR terminal

$c_{\Delta emf-F}$ = the uncertainty coefficient for emf voltage at FRONT terminals

$c_{\Delta emf-R}$ = the uncertainty coefficient for emf voltage at REAR terminal

$c_{\Delta res}$ = the uncertainty coefficient for RMM reading resolution

Every uncertainty coefficient can be obtained from the following differential equation.

$$c_{VDC-F} = \frac{\partial R_K}{\partial (V_{DC-F})} = \frac{1}{V_{DC-R}}$$

$$c_{VDC-R} = \frac{\partial R_K}{\partial (V_{DC-R})} = \frac{-V_{DC-F}}{V_{DC-R}^2}$$

$$c_{\Delta drop-F} = \frac{\partial R_K}{\partial (V_{\Delta drop-F})} = \frac{1}{V_{\Delta drop-R}}$$

$$c_{\Delta drop-R} = \frac{\partial R_K}{\partial (V_{\Delta drop-R})} = \frac{-V_{\Delta drop-F}}{V_{\Delta drop-R}^2}$$

$$c_{\Delta emf-F} = \frac{\partial R_K}{\partial (V_{\Delta emf-F})} = \frac{1}{V_{\Delta emf-R}}$$

$$c_{\Delta emf-R} = \frac{\partial R_K}{\partial (V_{\Delta emf-R})} = \frac{-V_{\Delta emf-F}}{V_{\Delta emf-R}^2}$$

$$c_{\Delta res} = 1$$

The uncertainty budget for ratio using calibration method was presented on Table 7 (see APPENDIX).

The DC voltage ratio of RMM obtained from this study was validated using the error factor principle of -1> En> 1. Some related variables to the En (Table 8) were the nominal value for the calculation (R_A), the nominal value for calibration (R_K), the uncertainty for the indirect measurement method (U_{RA}) and the uncertainty for the calibration method (U_{RK}).

Table 8 Calibration validation values for RMM ratios.

Ratio	R_A	U_{RA}	R_K	U_{RK}	E_n
1.018:1.018	1.0001560	0.0000116	1.0001420	0.0000110	0.87
1.018:10	9.823179	0.000416	9.823148	0.000385	0.05
1.018:100	98.23197	0.08521	98.23696	0.08520	-0.041

CONCLUSION

The dissemination process for DC voltages from three single range secondary standards to one multi range tertiary standard has been successfully conducted utilizing an RMM equipment and ratio method. From this research, three measurement ratio namely 1.018:1.018, 1.018:10, and 1.018:100 with errors of -0.000014, -0.000031, and 0.00499 respectively were validated to support a calibration procedure. The results can be used to build a self supporting traceability chart in the Laboratory of EML, RCM-LIPI for DC voltages from 1.018 V up to 1000 V.

To optimize the result, it is suggested that the follow up of this study should be carried using the same kind of measurement cables and the equal number of connections to the FRONT and REAR terminals. This action will reduce errors due to imbalance loads.

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