DC HIGH-VOLTAGE DIVIDER EVALUATION USING THE BINARY STEP-UP METHOD

Sang Hwa Lee, *Kwang Min Yu,* *Jeon Hong Kang and *Seok Myeong Jang*

Korea Research Institute of Standards and Science (KRISS), *Chung-Nam National University
shlee@kriss.re.kr

Abstract: An evaluation technique and traceability for a DC-resistive high-voltage divider was established based on 1 kV, which was traceable to a Josephson voltage standard at the Korea Research Institute of Standards and Science. To do this, the binary step-up method was used to evaluate the voltage-dividing ratio and the voltage coefficient of the divider up to 100 kV. The expanded relative uncertainty for the dividing ratio up to 100 kV was 16×10^{-6} level. To confirm the validity of the method, the ratio at 1 kV was compared with the resistance ratio of the divider, and the two results agreed to within 5.3×10^{-6}.

Keywords: Josephson voltage standard, Binary step-up, DC high-voltage ratio, DC-resistive high-voltage divider, voltage coefficient.

1. INTRODUCTION

The most common method used to evaluate the dividing ratio is to measure the resistance on the high-voltage and low-voltage arms of the divider [1]. However, our goal was to establish a traceability that would be based on a national voltage standard, the Josephson voltage standard, and to use a technique to evaluate the dividing ratio precisely using the binary step-up method. In this paper, we present our results of our experiments for accurately determining the voltage coefficient and voltage-dividing ratio, as well as discussing the effect of temperature on the DC high-voltage dividers up to 100 kV using the method.

2. MEASUREMENT METHOD AND APPARATUS

To determine the voltage-dividing ratio and voltage co efficient of a high-voltage divider that is traceable to a Josephson voltage standard using the binary step-up method[2], two high-voltage resistors with the same nominal value, R_1 and R_2, and a single voltage resistor, r, are required, as shown in Fig. 1. A sequence of steps that combine and separate the two dividers is used, as shown in Fig. 1, and the voltage across the resistors on the low-voltage arm is measured at each step. In this process, the voltage, V_2, that is applied at the combined divider is nearly equal to $2V_1$, and the applied voltages at the divider are: 1, 2, 4, 8, 16 (12.5), 25, 50, and 100 kV in that order. To measure up to 100 kV, a dividing ratio at 12.5 kV is used instead of
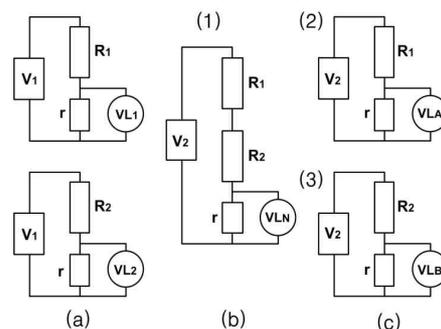

Fig. 1. Binary step-up method for determining the voltage-dividing ratio and voltage coefficient.

16 kV, because the ratio change between 8 kV and 25 kV is agreed within measurement uncertainty and the dividing voltage corresponding to the applied voltage is measured on the low-voltage arm. The calibrator, which is traceable to a Josephson voltage standard, is used to produce 1 kV, and Model CA150 high-voltage dividers (NMIA) are used. The high-voltage supply has a maximum output of 200 kV DC and a specified output stability of 0.01% per hour.

We used the following method to obtain improved output stability. First, we set up our measurement system as shown in Step (1) of Fig. 1(b), and we measured the voltage across the resistors on the low-voltage arms. Then, we measured the same voltage when the system was set up as shown in Step (2) of Fig. 1(c), Step (1) of Fig. 1(b), Step (3) of Fig. 1(c), and Step (1) of Fig. 1(b) successively. To simplify our measurement procedure, we carried out our experiments according to Steps (1)–(2)–(1)–(3)–(1) in Fig. 1.

3. RESULTS AND DISCUSSION

4.1. Determination of the voltage coefficients

The graphs shown in Fig 3 show the measurement of the voltage coefficients of dividing ratios described in Section 3. The voltage coefficients were determined by extrapolation of the gradient of linear fits of Γ_A and Γ_B versus the applied voltage. The calculated values of the data shown in Fig. 3 are -0.001×10^{-6}/kV and 0.012×10^{-6}/kV. In the graphs shown in Fig. 3, the error bars denote the mean measurement uncertainties for a given voltage coefficient.

The uncertainties of Γ_A and Γ_B shown in Fig. 3 are 4.19×10^{-6} and 3.67×10^{-6}, respectively.
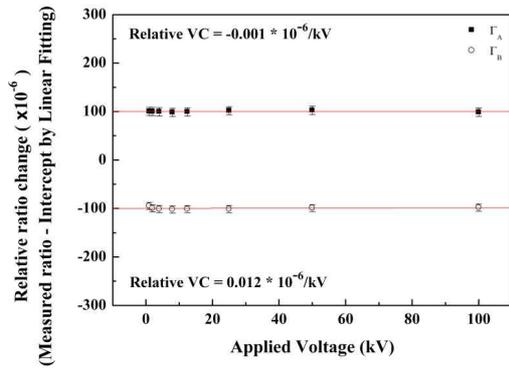
(Offsets of $+120 \times 10^{-6}$ and -90×10^{-6} are applied to them, respectively, to discriminate between Γ_A and Γ_B results)

Fig. 3. Voltage coefficients of the high-voltage dividers determined using the binary step-up method.

In the graphs shown in Fig. 3, the error bars denote the mean measurement uncertainties for a given voltage coefficient. The uncertainties of Γ_A and Γ_B shown in Fig. 3 are 4.19×10^{-6} and 3.67×10^{-6}, respectively.

4.2. Estimation of the uncertainty

The measurement model for determining the dividing ratios is given as follows.
$$\Gamma_A(V_2)=V_2/VL_A=VL_N(\Gamma_A(V_1) + \Gamma_B(V_1) - 1)/VL_A \qquad (1)$$
According to the Law of Propagation of Uncertainty in the ISO GUM Guide [4], the relative combined standard uncertainty for the model is given in a linear approximation by

$$u^2\{\Gamma_A(V_2)\}/\{\Gamma_A(V_2)\}^2 \fallingdotseq u^2(VL_A)/(VL_A)^2+(VL_N)/(VL_N)^2+$$
$$1/4 \times u^2(V_1)/(V_1)^2+1/4 \times u^2(VL_1)/(VL_1)^2+1/4 \times u^2(V_1)/(V_1)^2+$$
$$1/4 \times u^2(VL_2)/(VL_2)^2+1/2 \times u^2(V_1)/(V_1)^2 \qquad (2)$$

The first two terms and the last two terms mean the uncertainties for the DMM measurements and the other two terms mean the calibration uncertainties for the applied voltage. The parameters represented in equation (2) correspond to Figure 1 and the estimated uncertainty at the previous step influences on the uncertainty at the next step. Therefore, the DMM uncertainties for all steps were estimated based on equation (2) and among them, the DMM uncertainty in the range of 4 kV which has the largest uncertainty was shown in Table 1.

Table 1 Uncertainty budget for the voltage-dividing ratio measurements using the binary step-up method.

Uncertainty components	Standard uncertainty
V_L (1 kV ~ 100 kV, A) and V_L (1 kV ~ 100 kV, B) uncertainty:	
-Type A Uncertainty of the V_L (4 kV)	1.13×10^{-6}
-Calibration and stability(24 hours) of the DMM(200 mV ~ 20 V range) and the meter calibrator @ 1 kV (estimated by equation (12))	4.90×10^{-6}

Voltage coefficient of the high-voltage divider:	Γ_A	Γ_B
- Mean standard deviation of Γ_A, Γ_B	3.91×10^{-6},	2.79×10^{-6}
- Error from the gradient of linear fits of Γ_A, Γ_B	0.016×10^{-6},	0.026×10^{-6}
- Standard deviation of linear fits of Γ_A, Γ_B	1.50×10^{-6},	2.38×10^{-6}
Combined standard uncertainty (voltage coeff.)	4.19×10^{-6},	3.67×10^{-6}
Effect of temperature on the dividing ratio	1.15×10^{-6}	
Stability of the high-voltage supply	4.54×10^{-6}	
Combined standard uncertainty. divider A, divider B	8.05×10^{-6},	7.79×10^{-6}
Expanded uncertainty. (k = 2, confidence level of 95 %)	16.10×10^{-6},	15.58×10^{-6}

(Note: The uncertainty of V_L is taken from the range of 4 kV which has the largest uncertainty in the range from 1 kV to 100 kV)

5. CONCLUSIONS

The voltage-dividing ratio and voltage coefficient of a DC high-voltage divider up to 100 kV were accurately evaluated using a binary step-up method. The advantage of this method is that it is always traceable to a national voltage standard, the Josephson voltage standard, in contrast to existing methods. The expanded uncertainty of these dividers up to 100 kV was estimated to be 16×10^{-6} level. To validate the method of using the dividing ratios given by 1 kV, which is a reference voltage, the results were compared with the resistance ratios given by resistance measurements on the high-voltage and low-voltage arms, and it was confirmed that they agreed to within 5.3×10^{-6}. In addition, the stability of the high-voltage supply improved from 0.01% per hour to 4.54×10^{-6} up to 100 kV. The largest factors influencing the uncertainty were considered to be the uncertainty in the calibration in the DC 200 mV range of the DMM and the stability of the high-voltage supply. However, it is expected that these factors can be improved on using a direct calibration from a programmable Josephson voltage standard, which is under development, and by using a more stable high-voltage supply.

6. REFERENCES

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