

HIGH RESISTANCE MEASUREMENT AT NIM

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Abstract

An automatic ratio bridge based on BVD is used to take measurement up to $1\text{G}\Omega$ at NIM. Adopting a “Virtual Null” mode efficiently reduces effects of insulation of bridge and offset current of detector. The measurement of a $100\text{M}\Omega$ Hamon resistor shows an agreement of 1 parts in 10^6 at ratio $1\text{G}\Omega:100\text{M}\Omega$.

Introduction

Standard resistors from $100\text{k}\Omega$ to $1\text{G}\Omega$ are manually calibrated at NIM on a guarded Wheatstone bridge fabricated by NIM-self. It is noise sensitive and time exhaustive, so higher uncertainty. Automatic Ratio Bridge [1] based on a 13-bits Binary Voltage Divider (BVD [2]) from MI is commercially available. As the BVD have an full linearity of approximately 1 part in 10^8 after its self-calibration combining with a DVM, it is possible to measure the ratio of two resistance to within a few ppm in the range from $10\text{k}\Omega$ to $100\text{M}\Omega$. The constraints that limit the bridge range to higher resistance are mainly insulation of bridge terminals and DVM’s basis offset currents, etc. A procedure called “Virtual Null” reduces these effects and extends resistance measurement to $1\text{G}\Omega$ within a few ppm uncertainty. An $11 \times 100\text{M}\Omega$ Hamon resistor with equal-potential-guard is developed to verify that.

Principle

The circuit of automatic bridge based on BVD is shown in Fig.1.

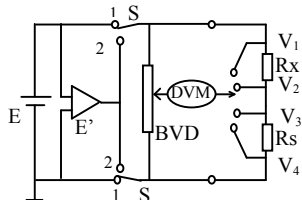


Fig. 1 Automatic Ratio Bridge Based on BVD

After the four measurements V_1, V_2, V_3, V_4 are down, the ratio of R_X and R_S is given by

$$R = \frac{R_x}{R_s} = \frac{V_1 - V_2}{V_3 - V_4} = \frac{V_1/E - V_2/E}{V_3/E - V_4/E} = \frac{r_1 - r_2}{r_3 - r_4}$$

Here, $r_i = V_i / E = k_i + v_i / E$. k_i represents the settings of BVD at V_i , v_i the DVM’s reading. The error of r_i is

$$\partial r_i = \partial k_i + \frac{\partial v_i}{E} + \frac{v_i}{E} \cdot \frac{\partial E}{E} \approx \partial k_i + \frac{\partial v_i}{E}$$

In case of $100\text{M}\Omega$ and above, the leakage resistor R_L between terminals V_2, V_3 or cable’s insulation and ground will considerably shunt R_S to limit the lowest uncertainty. The offset current of DVM, typically a few pA, which flow through the higher equivalent output resistance of bridge also superposes a few microvolts on DVM readings.

These defects are greatly improved by following “Virtual Null” measurement mode. That is doing two measurements for either of V_2 and V_3 . Firstly switch S to 1 in Fig. 1, then to 2 with all other settings unvaried. The difference of DVM’s two readings removes greatly effects of insulation and offset current.

1. Insulation Effect of Terminals V_2 and V_3

Concerning $S=1, V_+^I$, which means the high side’s potential of DVM or one of V_2 and V_3 in Fig.2, and V_-^I , the low side’s potential of DVM or BVD’s output, can be expressed as followings

$$V_+^I = \frac{R_S // R_L}{R_X + R_S // R_L} E \approx \frac{R_S}{R_S + R_X} \left(1 - \frac{R_S}{R_S + R_X} \frac{R_X}{R_L} \right) E$$

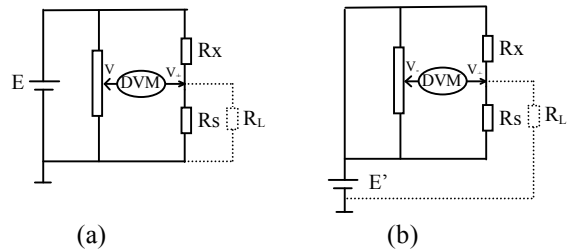


Fig. 2a Equivalent circuit of S to position 1

Fig. 2b Equivalent circuit of S to position 2

Here R_L indicates the leakage resistance from terminal v_2 to bridge ground. E' referring output voltage of active guard

proximately equals V_+^I , viz. $E' = \frac{R_S}{R_S + R_X} E(1 + \alpha) \approx V_+^I$.

For $S = 2$,

$$V_+^2 = \frac{R_L}{R_L + R_S // R_X} E' \approx \left(1 - \frac{R_S R_X}{R_L (R_S + R_X)}\right) E'$$

$$V_-^2 = E'$$

The difference of DVM's two readings, D_{DVM} , could be

$$D_{DVM} = (V_+^1 - V_-^1) - (V_+^2 - V_-^2) \\ = \left(\frac{R_S}{R_S + R_X} E - V_-^1\right) + \frac{R_S}{R_S + R_X} \left(-\frac{R_S}{R_S + R_X} \cdot \frac{R_X}{R_L} E + \frac{R_X}{R_L} E'\right)$$

Considering, $E' = \frac{R_S}{R_S + R_X} E(1 + \alpha)$

$$D_{DVM} = \left(\frac{R_S}{R_S + R_X} E - V_-^1\right) + \frac{R_X}{R_L} \cdot \frac{R_S^2}{(R_S + R_X)^2} E \alpha$$

The relative error induced by R_L

$$\frac{R_S}{R_L} \cdot \frac{R_X}{R_S + R_X} \alpha < \frac{R_S}{R_L} \alpha$$

Generally, $\alpha < 10^{-3}$. For $R_X:R_S=1G\Omega:100M\Omega$ and $R_L \geq 10^{12}\Omega$, the error induced by R_L would be less than 10^{-7} .

2. Effect of DVM's performance, as Input Resistance R_i , offset current I_o and offset voltage e_o .

An equivalent circuit of a DVM is shown as in Fig. 3a. Leakage resistance R_H , R_L and bias current I_o shunt an ideal voltmeter in series with the offset e_o . It is simplified as Fig. 3b if G is guarded with V_- .

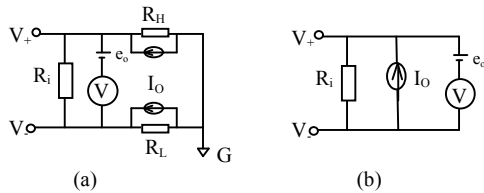


Fig. 3a Equivalent circuit of DVM

Fig. 3b Equivalent circuit of DVM with G guarded by V_- .

In case of $S=1$ and $S=2$, Equivalent circuits of bridge are shown in Fig. 4a and Fig. 4b respectively.

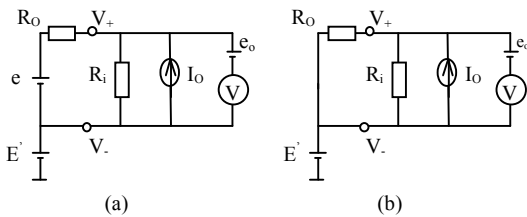


Fig. 4 Equivalent circuits of bridge with $S=1$ and $S=2$. R_o and e refer the output resistance and voltage of bridge.

From Fig. 4, the readings of ideal voltmeter, V_1 and V_2 ,

should be

$$V_1 = e_o + (R_o // R_i) I_o + \frac{R_i}{R_i + R_o} e$$

$$V_2 = e_o + (R_o // R_i) I_o$$

$$V_1 - V_2 = \frac{R_i}{R_i + R_o} e \approx \left(1 - \frac{R_o}{R_i}\right) e$$

It is clear that offset voltage and current, e_o and I_o , have no effect on the difference of DVM's two readings if they are unvaried. Input resistance will result in an error to E' as

$$\frac{R_o}{R_i} \cdot \frac{e}{E'}$$

Normally e/E' is less than 1×10^{-3} . $R_X:R_S=1G\Omega:100M\Omega$, $R_i \geq 100G\Omega$ results in error 1×10^{-6} .

Experiments

For verifying the ratio uncertainty of bridge in "Virtual Null" mode, a $100M\Omega$ Hamon wirewound resistor, with auxiliary equal-potential-guard is fabricated and calibrated by this way.

$R_x (\Omega)$	$R_s (\Omega)$	$R_x : R_s$
$R_2 = 100M$	$R_1 = 10M$	10.000747
$R_{HP} = 10M$	$R_1 = 10M$	1.0000601
$R_{HS} = 1G$	$R_2 = 100M$	9.999846

The results, $R_{HS} : R_{HP} = 100(1 - 0.8 \times 10^{-6})$, give an agreement of 1 parts in 10^6 with $100M\Omega$ Hamon Resistor at the ratio of $1G\Omega:100M\Omega$.

Conclusions

An "Virtual Null" mode is adopted on MI Automatic Ratio Bridge. The uncertainty is improved at ratio $1G\Omega:100M\Omega$. This is principally suitable for the resistance calibration above $1G\Omega$.

Reference

- [1] A.F.Dunn, "Measurement of Resistance Ratios in the Range to 100 Megohms." *IEEE Trans. Instrum. Meas.*, vol. 40, No.2, pp278-280, 1991.
- [2] R. D. Cutkosky, "A New Switching Technique for Binary Resistive Dividers." *IEEE Trans. Instrum. Meas.*, vol. IM-27, No.4, pp421-422, 1978.
- [3] S. H. Tsao, "An Accurate, Automatic 10-V Measurement System." *IEEE Trans. Instrum. Meas.*, vol. 38, pp321-323, 1989.

