HIGH RESISTANCE MEASUREMENT AT NIM

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Abstract

An automatic ratio bridge based on BVD is used to take measurement up to 1GΩ at NIM. Adopting a "Virtual Null" mode efficiently reduces effects of insulation of bridge and offset current of detector. The measurement of a 100MΩ Hamon resistor shows an agreement of 1 parts in 10^6 at ratio 1GΩ:100MΩ.

Introduction

Standard resistors from 100kΩ to 1GΩ 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 10kΩ to 100MΩ. 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 1GΩ within a few ppm uncertainty. An 11 × 100MΩ 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.

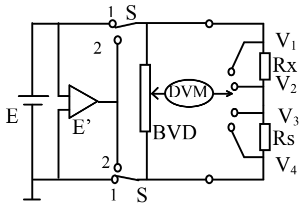


Fig. 1 Automatic Ratio Bridge Based on BVD

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

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

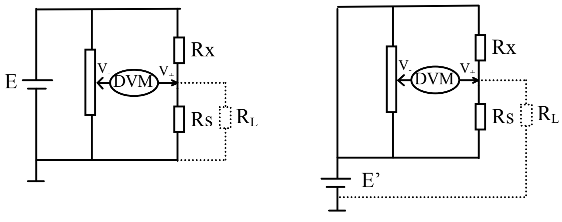
In case of 100MΩ and above, the leakage resistor R_L between terminals V_2, V_3 or cable's insulation and ground will considerably shunt R_S to limit the lowest uncertainty. The offset current of DVM, typically a few pA, which flow through the higher equivalent output resistance of bridge also superposes 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_+^1, which means the high side's potential of DVM or one of V_2 and V_3 in Fig.2, and V_-^1, the low side's potential of DVM or BVD's output, can be expressed as followings

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



(a) (b)

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

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

$$D_{DVM} = \left(V_+^1 - V_-^1\right) - \left(V_+^2 - V_-^2\right)$$

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

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

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

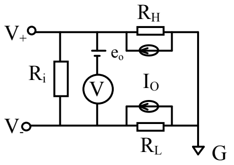
The relative error induced by R_L

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

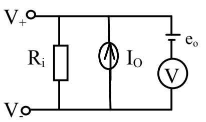
Generally, $\alpha < 10^{-3}$. For Rx:Rs=1GΩ:100MΩ and $R_L \geqslant 10^{12}$Ω, the error induced by R_L would be less than 10^{-7}.

2. Effect of DVM's performance, as Input Resistance R_i, offset current I_0 and offset voltage e_0

An equivalent circuit of a DVM is shown as in Fig. 3a. Leakage resistance R_H, R_L and bias current I_0 shunt an ideal voltmeter in series with the offset e_0. It is simplified as Fig. 3b if G is guarded with V_-.



(a)

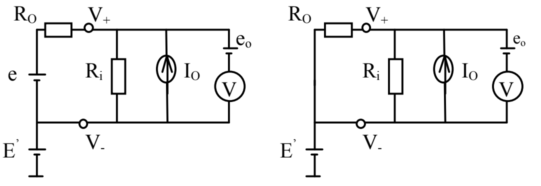


(b)

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.



(a) (b)

Fig. 4 Equivalent circuits of bridge with S=1and 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

$$V_1 = e_0 + (R_o // R_i) I_0 + \frac{R_i}{R_i + R_o} e$$

$$V_2 = e_0 + (R_o // R_i) I_0$$

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

It is clear that offset voltage and current, e_0 and I_0, 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 =1GΩ:100MΩ, $R_i \geqslant$ 100GΩ results in error 1 × 10^{-6}.

Experiments

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

R_x (Ω)	R_s(Ω)	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 × 10^{-6}), give an agreement of 1 parts in 10^6 with 100MΩ Hamon Resistor at the ratio of 1GΩ:100MΩ.

Conclusions

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

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.