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CALIBRATION OF MULTI-DECADE INDUCTIVE VOLTAGE DIVIDERS

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Abstract: A method for calibrating multi-decade inductive voltage dividers has been developed which makes it possible to determine both the inphase and the quadrature error for ratios of i /11, i = 1, 2, ..., 10 in the frequency range from 400 Hz to 5 kHz. Calibration is made by comparing the divider under test against a reference two-stage divider having a ratio winding with 11 identical sections. In calibration of the reference divider itself, an auxiliary 11:1 transformer is used.
Keywords: inductive voltage divider, calibration, ratio error

1 INTRODUCTION

Multi-decade inductive voltage dividers proved to be useful tools for precision AC ratio measurements. At the Department of Measurements, Faculty of Electrical Engineering, Czech Technical University, these dividers are mainly used as balance controls in a number of impedance bridges, included those developed for AC quantum-Hall-effect-based calibration of resistance and capacitance standards [1], [2]. As an example, a transformer bridge for comparison of four terminal-pair resistance standards is shown in Fig.1. An eight-decade two-stage inductive voltage divider ID is used for inphase balancing of the bridge, the quadrature one being secured by means of a single-stage divider IDQ connected to a low-value capacitor C_Q . By properly adjusting dividers IDA 1 and IDA 2, auxiliary detectors D 2 and D 3 have to be nulled to ensure zero currents in the high potential leads of resistors R_{s1} and R_{s2} to be compared. Divider IDW being one of the Wagner balancing components, another multi-decade divider is used in the combining network CN to eliminate the effect of unwanted potential difference between low potential terminals of R_{s1} and R_{s2} .

In addition to employment as bridge components, we also use multi-decade inductive voltage dividers as reference ratio devices in calibration of precision transformer bridges for resistance thermometry, as well as for calibration of precision measuring amplifiers for strain gauge transducers [3].

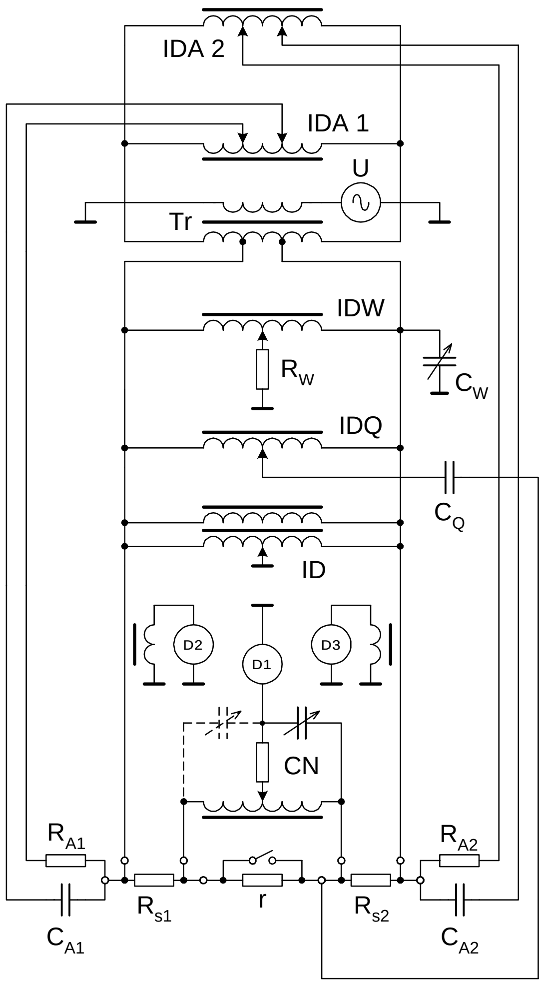

Figure 1. Four terminal-pair transformer bridge

Inductive voltage dividers are exceedingly accurate ratio devices and great attention has been paid to development of procedures for their calibration (see e.g. [4] for a review). The number of all available settings of a multi-decade divider being extremely high, a complete calibration of such a divider is hardly possible and, usually, inphase and quadrature errors corresponding only to a limited number of ratios of values uniformly distributed in the range from 0 to 1 are determined in course of the calibration. Selection of ratios of *i* /11, *i* = 1, 2, ..., 10, i.e.

0.090 909 09
0.181 818 18
0.272 727 27
etc.

seems to be advisable as every digit of every decade of the divider has to be set just once to obtain all above ratios.

2 CALIBRATION PROCEDURE

The proposed calibration procedure consists of

1) comparing of the multi-frequency divider under test against an 11 section reference divider (Fig. 2) and
2) calibration of the reference divider based on employment of an auxiliary 11:1 transformer (Fig. 3). It is not necessary to know the exact value of the transformer ratio before the experiment.

The calibration devices of both Fig. 2 and Fig. 3 are of coaxial design but, for simplicity of drawing, the circuits of outer coaxial conductors are not shown and connections to them are drawn as earth connection symbols.

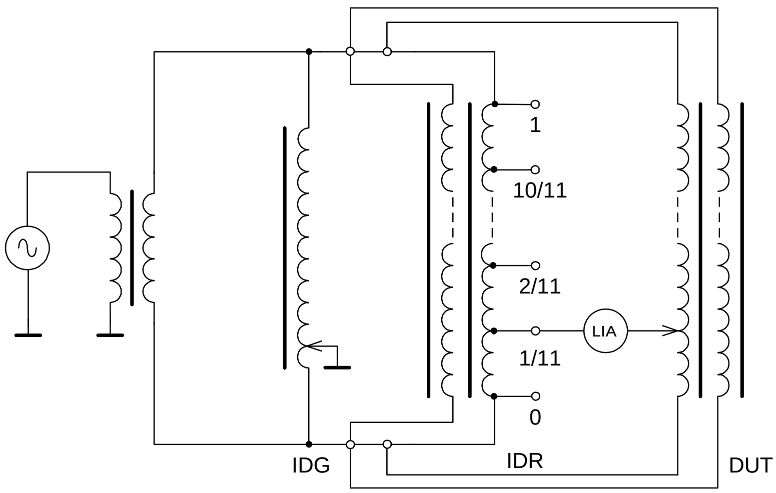

Figure 2. Comparison of two-stage inductive voltage dividers

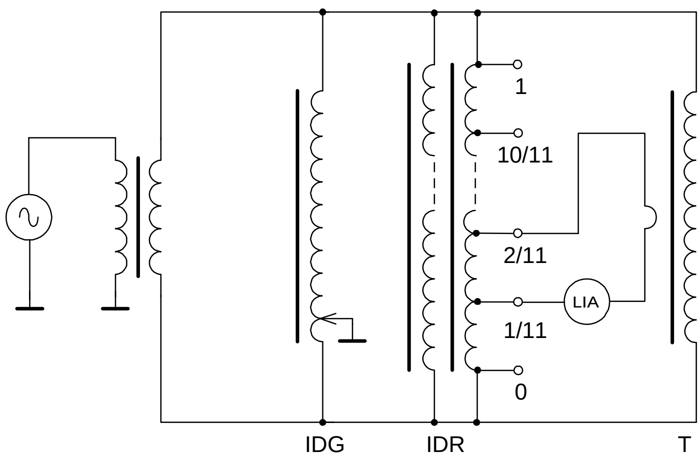

Figure 3. Calibration of reference divider

In Fig. 2, a lock-in amplifier (LIA) is used to compare the output voltage of the two-stage divider under test (DUT) with that of the two-stage reference divider (IDR), both dividers being set to the same nominal ratio. The measurement is repeated for all taps of IDR.

In Fig. 3, the lock-in amplifier compares secondary voltage of the 11:1 transformer (T) with that across one section of the reference divider. The measurement is repeated for all sections of IDR.

A guard divider IDG is used in both calibration devices. In case that setting of this divider is made the same as that of IDR, the effect of leakage currents through stray impedances of the amplifier branch is eliminated.

3 EVALUATION OF ERROR CHARACTERISTICS OF THE DIVIDERS

From differential voltages $\boldsymbol{u}_0$, $\boldsymbol{u}_{1/11}$, …, $\boldsymbol{u}_1$ (Fig. 4) obtained as result of comparison of IDR and DUT

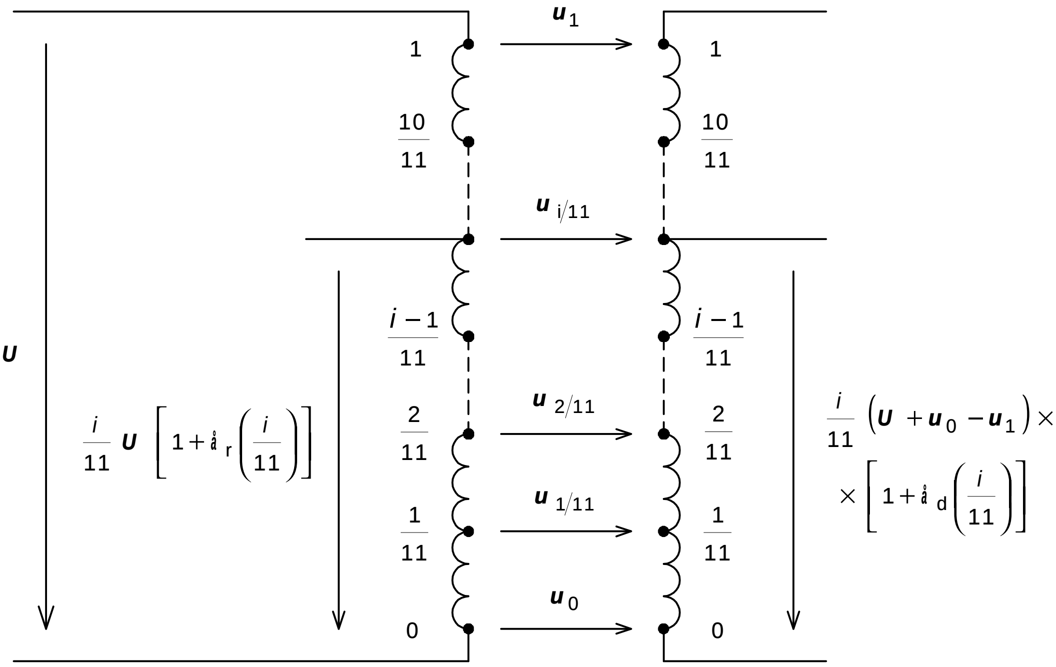

Figure 4. Voltages used in evaluating difference of ratio errors of IDR and DUT

by means of the device of Fig. 2, difference of relative ratio errors e_r and e_d of these dividers can be calculated for ratios i /11, i = 1, 2, …, 10. From Fig. 4 we have

$$\boldsymbol{\varepsilon}_r\left(\frac{i}{11}\right)-\boldsymbol{\varepsilon}_d\left(\frac{i}{11}\right)=\frac{1}{\mathbf{U}}\left(-\frac{11-i}{i}\mathbf{u}_0-\mathbf{u}_1+\frac{11}{i}\mathbf{u}_{i/11}\right) \tag{1}$$

Difference of inphase ratio errorrs related to the input is

$$\alpha_r\left(\frac{i}{11}\right)-\alpha_d\left(\frac{i}{11}\right)=\frac{i}{11}\,\mathrm{Re}\left[\boldsymbol{\varepsilon}_r\left(\frac{i}{11}\right)-\boldsymbol{\varepsilon}_d\left(\frac{i}{11}\right)\right] \tag{2}$$

difference of quadrature ratio errors related to the input being

$$\beta_r\left(\frac{i}{11}\right)-\beta_d\left(\frac{i}{11}\right)=\frac{i}{11}\,\mathrm{Im}\left[\boldsymbol{\varepsilon}_r\left(\frac{i}{11}\right)-\boldsymbol{\varepsilon}_d\left(\frac{i}{11}\right)\right] \tag{3}$$

Similarly, sectional errors e_{ri} of the reference divider (Fig. 5) can be calculated from differential voltages $\boldsymbol{u}_{r1}$, $\boldsymbol{u}_{r2}$, …, $\boldsymbol{u}_{r\,11}$ obtained as result of comparison of sectional voltages $\boldsymbol{U}_1$, $\boldsymbol{U}_2$, …, $\boldsymbol{U}_{11}$ against secondary voltage $\boldsymbol{U}_{sT}$ of the auxiliary transformer T (for simplicity of drawing, only differential voltage $\boldsymbol{u}_{r1}$ is shown in Fig. 5). We obtain

$$\boldsymbol{\varepsilon}_{ri}=\frac{1}{\boldsymbol{U}}\left(\sum_{j=1}^{i}\boldsymbol{u}_j-11\,\boldsymbol{u}_i\right)\quad,\quad i=1,2,\ldots,11 \tag{4}$$

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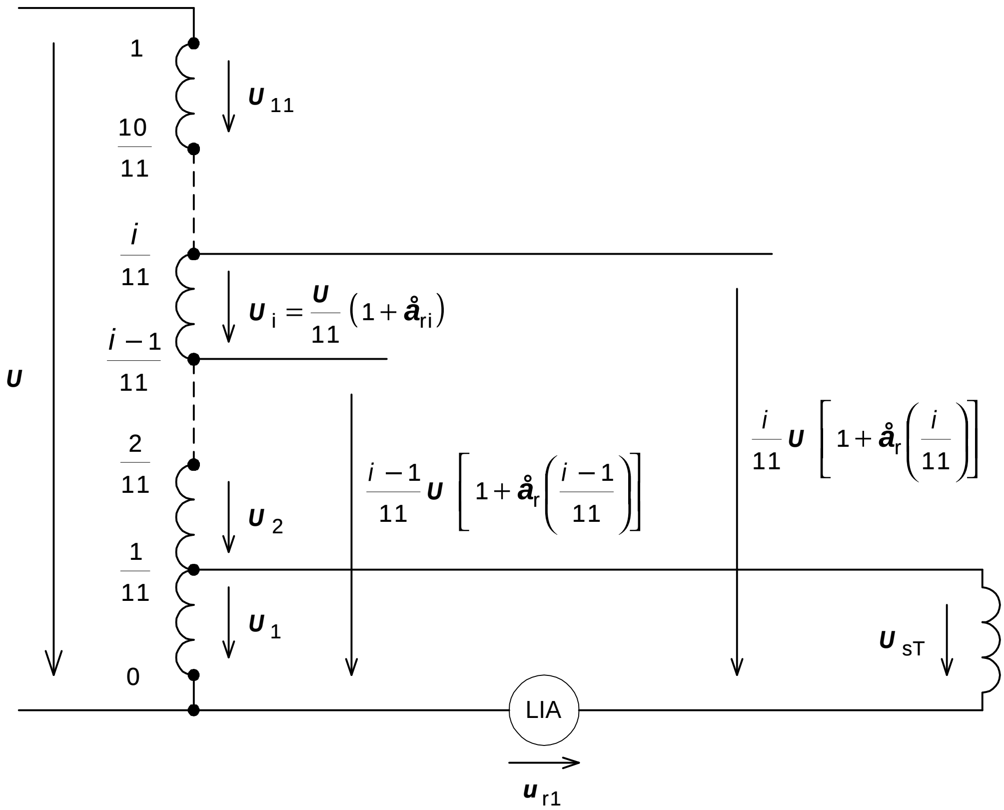

Figure 5. Voltages used in evaluating ratio errors of IDR

and the relative ratio error for the ratio of *i* /11 is given by

$$\mathring{a}_{r} = \frac{1}{i} \sum_{j=1}^{i} \mathring{a}_{rj} \qquad (5)$$

Inphase and quadrature ratio errors related to the input are, respectively,

$$\acute{a}_{r} = \frac{i}{11} \mathrm{Re}\left(\mathbf{\mathring{a}}_{r} \right) \qquad (6)$$

and

$$\hat{a}_{r} = \frac{i}{11} \mathrm{Im}\left(\mathbf{\mathring{a}}_{r} \right) \qquad (7)$$

By introducing (5)-(7) into (1)-(3), equations for ratio errors of DUT can be obtained.

4 REFERENCE DIVIDER AND AUXILIARY 11:1 TRANSFORMER

Two identical mumetal toroidal cores with outer diameter of 140 mm, inner diameter of 100 mm and height of 20 mm are used in our two-stage reference divider. Both the exciting and the ratio winding of the divider have 110 turns, ratio winding being devided into 11 sections.

In the auxiliary 11:1 transformer, a primary winding of 330 turns and a secondary winding of 30 turns are separated by two electrial shields and wound around a mumetal core having outer diameter of 140 mm, inner diameter of 80 mm and height of 20 mm.

Some of the error characterisitics of the reference divider are shown in Fig. 6.

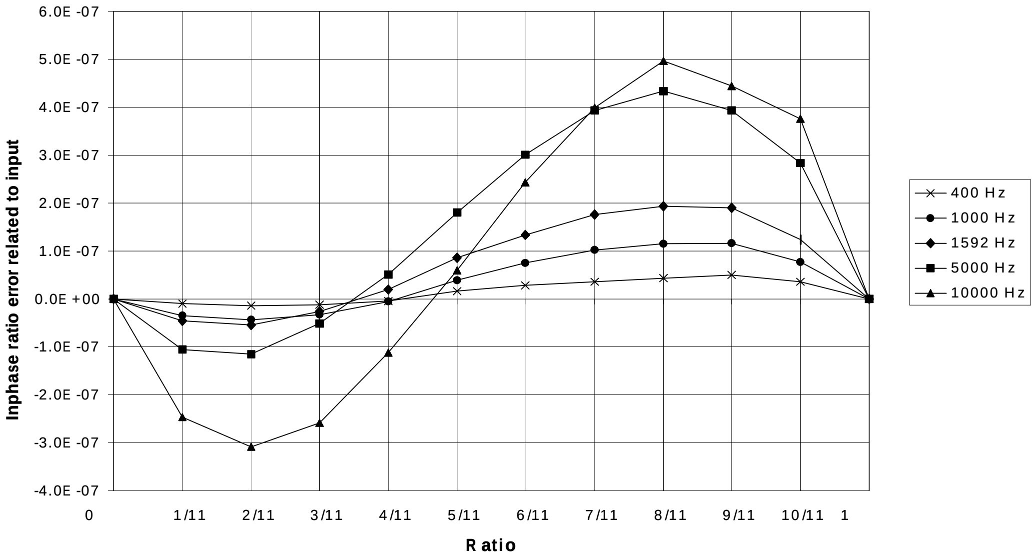

Figure 6. Error characteristics of the reference divider

5 CONCLUSION

The method described here is mainly used for calibration of seven- and eight- decade inductive voltage dividers of both single- and two-stage design in the frequency range from 400 Hz to 5 kHz. For these frequencies, the method enables measurement of both the inphase and quadrature ratio error with an combined uncertainty (k = 2) less than 1 part in 10^7 of input.

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