INDUCTIVE VOLTAGE DIVIDERS AND THEIR APPLICATION TO PRECISION ELECTRICAL MEASUREMENTS

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Abstract - *In the framework of laboratory exercises for students attending lectures on metrology of electrical quantities at the Faculty of Electrical Engineering, Czech Technical University, application of inductive voltage dividers to precision coaxial bridges is demonstrated. Four terminal-pair bridges are used in comparisons of like impedances and a quadrature bridge has been realized for linking resistance and capacitance standards. A method for calibrating multi-decade inductive voltage dividers has also been developed.*

Keywords - Inductive voltage divider, calibration, four terminal-pair bridge.

1. INTRODUCTION

It is well known that when inductively coupled ratio arms are used in ac bridges, high stability and sensitivity as well as reduced susceptibility to earth admittances can be achieved [1], [2]. Such ratio arms, widely known as ratio transformers, comprise at least two windings, connected in series aiding, wound on a magnetic core of high permeability. Ratios of properly constructed transformers are not affected, at least to parts in 10^8, by aging or moderate changes in enviromental conditions (position, temperature, pressure, humidity, etc.). Moreover, if an accuracy of parts in 10^6 is satisfactory, the ratio of the transformer can be taken to be equal to the ratio of the number of turns of the windings. Of course, when lower uncertainty is required, a method of calibrating the transformer ratio is needed.

Ratio transformers may be designed and used to provide both voltage and current ratios. Adjustable inductive voltage dividers (IVDs) are undoubtedly of the greatest utility as they provide an output voltage whose magnitude is related to the source voltage by an accurate and stable ratio which can be as finely adjusted as required. In principle, IVDs are autotransformers which usually have several (up to 8) decades to provide fine resolution of the voltage ratio.

With an intention to demonstrate various ways of application of multi-decade inductive voltage dividers and to show their calibration to students attending lectures on metrology of electrical quantities at the Faculty of Electrical Engineering, Czech Technical University, the following themes have been incorporated into the programme of laboratory excercises:

a) characterization of multi-decade inductive voltage dividers,
b) realization of bridges for comparison of like impedances and
c) realization of a quadrature bridge.

2. CHARACTERIZATION OF MULTI-DECADE INDUCTIVE VOLTAGE DIVIDERS

In the framework of the divider characterization, its error characteristics are determined by a method based on

1) comparison of the multi-decade divider under test with an 11 section reference divider (Fig. 1) and
2) calibration of the reference divider utilizing an auxiliary 11:1 transformer (Fig. 2). It is not necessary to know the exact value of the transformer ratio before the experiment.

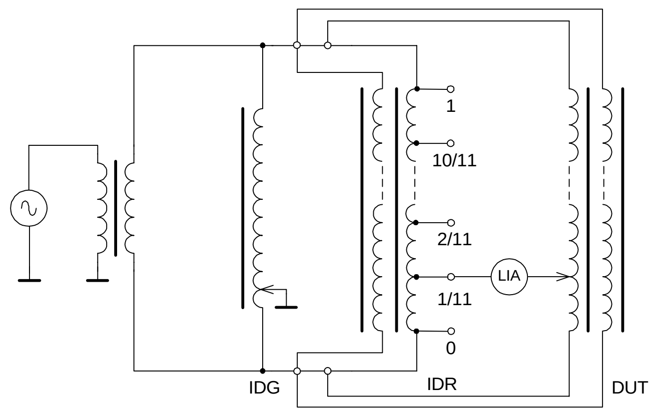

Fig. 1 - Comparison of two-stage inductive voltage dividers.

In Fig. 1, a lock-in amplifier (LIA) is used to compare the output voltage of the two-stage divider under test (DUT) with that of a 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. 2, a lock-in amplifier compares secondary voltage of an 11:1 transformer (T) with that across one section of the reference divider. The measurement is repeated for all sections of IDR.

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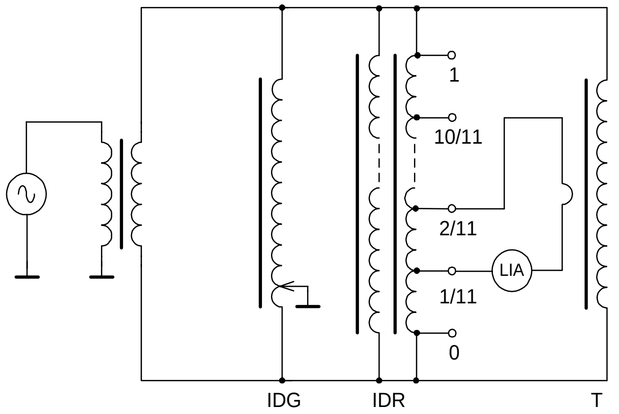

Fig. 2 - Calibration of reference divider.

The circuits of both Fig. 1 and Fig. 2 (as well as the bridges of Figs. 3, 4 and 5) 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.

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

At frequencies from 400 Hz to 5 kHz, the method enables measurement of both the in-phase and the quadrature ratio error with an uncertainty (k = 2) less than 1 part in 10^7 of input [3].

Students performing characterization of a divider by means of the circuits of Figs. 1 and 2 are instructed

a) to derive formulae for calculating both the in-phase and the quadrature errors of the DUT for ratios of i / 11, i = 1, 2, ..., 10 from the differential voltages measured by the lock-in amplifier,
b) to evaluate the change of the error characteristics in case of disconnection of the exciting winding of the two-stage DUT and
c) to measure, for one of the ratios i / 11 , the change of the output voltage of the DUT due to a defined loading of it, and to calculate the corresponding output impedance.

3. BRIDGES FOR COMPARISON OF LIKE IMPEDANCES

Two versions of a four terminal-pair bridge for comparison of like impedances are demonstrated to the students: an R-R bridge for intercomparison of resistances and a C-C bridge fo intercomparison of capacitances [4].

By means of the R-R bridge (Fig. 3), frequency characteristics of conventional resistance standards of nominal values of 10 Ω, 100 Ω and 1000 Ω are measured by their 1:1 comparisons against quadrifilar resistors with calculable frequency performance. An eight-decade two-stage divider is used for in-phase balancing of the bridge, the

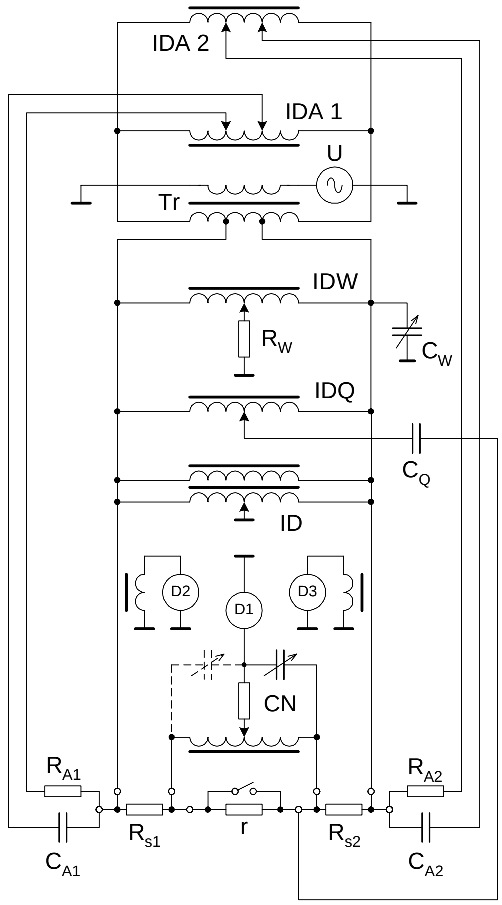

Fig. 3 - R-R bridge.

quadrature balance being obtained by means of a single stage divider IDQ connected to a low-value capacitor C_Q. To ensure zero currents in the high potential leads of resistors R_{s1} and R_{s2} to be compared, auxiliary detectors D 2 and D 3 have to be nulled by properly adjusting inductive voltage dividers IDA 1 and IDA 2.

A bridge suitable for C-C comparisons can easily be derived from the R-R bridge by properly changing the values of R_{A1}, C_{A1}, R_{A2}, C_{A2} and modifying the circuitry for quadrature balancing (Fig. 4). Employment of such a bridge in 1:10 comparisons of 10 pF and 100 pF fused-silica capacitance standards is demonstrated to the students.

As a part of presentation of the above bridges, reasons for employment of current equalizers, Wagner networks (components IDW, R_W and C_W in Figs. 3 and 4) and combining networks (CN in Figs. 3 and 4) are explained.

Principles underlying the design and construction of resistors having calculable frequency performance are described.

It is obligatory for the students to derive balance conditions of the bridges and to give full uncertainty budgets in their laboratory reports.

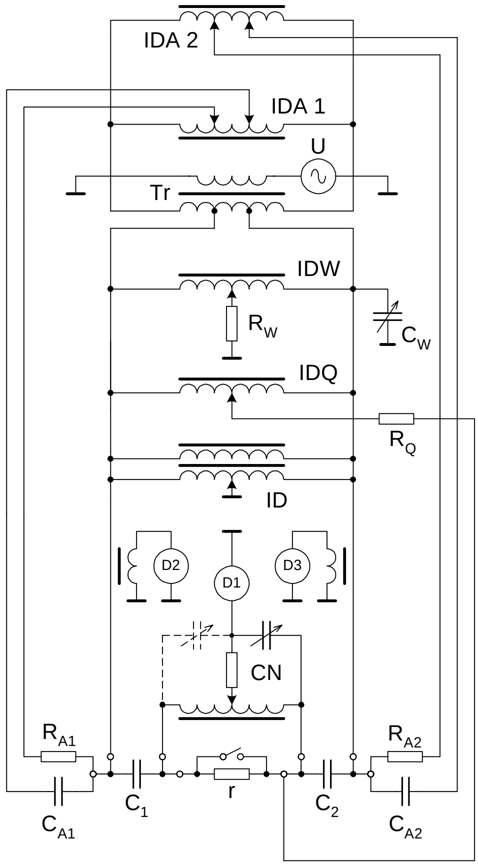

Fig. 4 - C-C bridge.

4. QUADRATURE BRIDGE

For demonstrating the principle of the quadrature bridge, a measurement system based on a commercial two-phase generator, which deliveres voltages $\boldsymbol{U}_1$ and $\boldsymbol{U}_2$ with a mutual phase shift of 90°, has been developed (Fig. 5). The bridge is used to compare 10 nF capacitors with 10 kΩ resistors and the comparison uncertainty (k = 2) is less than 5 parts in 10^5 in the frequency range from 400 Hz to 5 kHz.

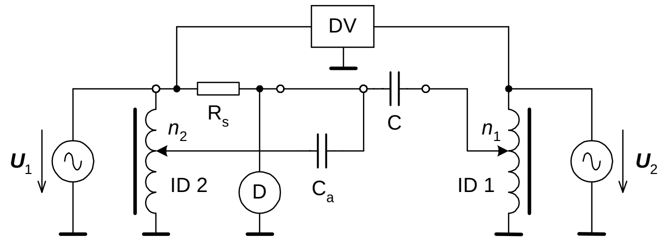

Fig. 5 - Quadrature bridge.

In case of an ideal resistor R_s and an ideal capacitor C, only one balance control (divider ID 1) would be sufficient for balancing the bridge. Of course, an additional control (divider ID 2) is necessary when the time constant of the resistor and the power factor of the capacitor are not negligible.

If nominally equal voltages U_1 and U_2 are set before balancing the bridge, voltmeter DV reads both of them with approximately the same systematic error and, very nearly, only resolution of the voltmeter affects the uncertainty of the ratio U_1/U_2 which appears in the balance condition.

Students operating the quadrature bridge have to derive its balance conditions, to evaluate the effect of possible non-observance of the phase shift of 90° between the voltages U_1 and U_2 and to evaluate the effect of load imposed on the divider ID 1 by the capacitor C.

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