AUTOMATED AC BRIDGE FOR RESISTANCE MEASUREMENTS

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Abstract

An automated, guarded ac Kelvin bridge has been developed for measuring the frequency dependence of precision resistors from the 1-Ω to the 1-MΩ level over the frequency range of 10 Hz to 10 kHz. The main ratio arms consist of two-stage 30-bit binary inductive voltage dividers. A guard inductive voltage divider drives a RC network to provide a known phase compensation to balance the quadrature component of the bridge. A bridge substitution technique is used in which the unknown is compared to a standard of known impedance. The bridge resolution is better than 0.1 ppm for the in-phase and quadrature components.

Introduction

In response to requests to provide a calibration service for ac resistance standards needed to calibrate ac resistance thermometry bridges and the new generation of impedance bridges, the National Institute of Standards and Technology (NIST) has established a program to develop the capability of measuring the frequency dependence and phase angle of precision resistors from the 1-Ω to the 1-MΩ level over the frequency range 10 Hz to 10 kHz.

The approach has been to develop an ac Kelvin bridge [1] consisting of inductive voltage dividers (IVD's) as the main and inner ratio arms. A third IVD is used to inject a current in a RC network that provides a known phase compensation [2] to balance the quadrature component of the bridge. A fourth IVD drives the inner shield of a triaxial cable that connects the outputs of the main and inner ratio guard IVDs, at a guard potential. All IVD's, along with the bridge ac source and null detector, are remotely programmable through a standard IEEE-488 interface to provide for complete automation of the measurement system. A bridge balancing algorithm is used to measure the in-phase and quadrature out of balance voltages, and then null these voltages by adjusting the appropriate IVD ratio.

AC Kelvin Bridge

The basic circuit of the ac Kelvin bridge for comparing two four-terminal resistors is shown in Fig. 1. The diagram does not show the complete shielding and guarding connections or the use of coaxial chokes [3] in various branches of the circuit that are required to reduce small but troublesome loop and ground currents to insignificant values. Main dividers IVD-1 and IVD-2 are NIST-built binary IVD's [4,5]. Divider IVD-3 is the quadrature divider which is used to inject current into the RC network to provide a known phase compensation to balance the quadrature component of the bridge circuit. Divider IVD-4 is the guard divider which reduces leakage currents from the detector to other parts of the circuit, and 2) Resistor R_1 indicates where the unknown and working standard are each measured in sequence (substitution technique). Resistor R_2 is a "dummy" resistor whose absolute value need not be known: however, it must remain stable or predictable during a measurement run.

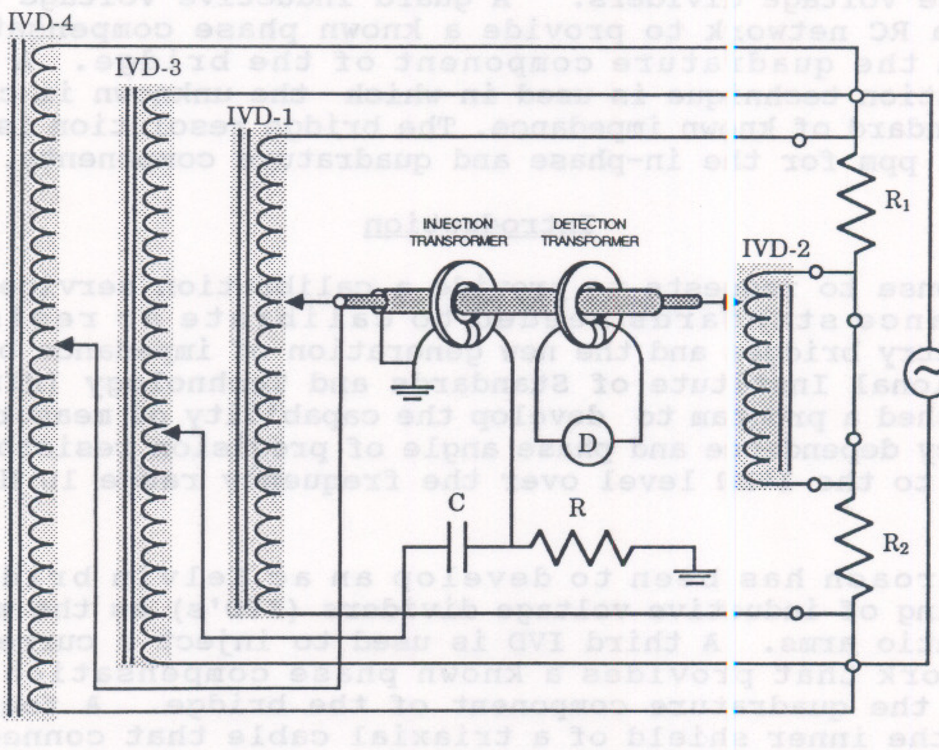

Fig. 1 AC Kelvin Bridge.

Binary IVD's The main and inner ratio arms of the ac Kelvin bridge each consist of a 30-bit binary IVD. Each binary divider is constructed with four transformer sections mounted on a printed circuit board along with shielded switching relays controlled by an IEEE-488 interface circuit. The first and second sections are two-stage transformers providing 7 bits and 8 bits, respectively. The third and fourth sections are single stage transformers providing 8 bits and 7 bits, respectively. The binary IVD is designed to operate over the frequency range 10 Hz to 10 kHz at 0.25 V/Hz.
A more detailed description of this divider is given in another paper submitted to this conference.

Bridge Balance The procedure for eliminating the effects of lead and link resistances is not as critical for the ac Kelvin bridge as for its dc analogue because of the high input impedances of the two-stage dividers IVD-1 and IVD-2 [6]. In practice, with divider input impedances > 40 kΩ and lead resistances < 1 mΩ, the bridge balance equation reduces to

$$R_1 = R_2\left(\frac{k}{1-k}\right)$$

where k is the setting of divider IVD-1. The equation is accurate to better than 1 part in 10^7; however it does not include the quadrature component or the effects of leakage currents.

The quadrature balance is achieved by adjusting the setting of quadrature divider IVD-3. The voltage difference between the outputs of IVD-1 and IVD-3 causes a current to flow through the RC network. This current generates a voltage across R to provide for a quadrature null balance. This quadrature voltage is precisely known since it is a funcion of ωCR and the settings of IVD-1 and IVD-3. From the results of the in-phase and quadrature balances, the ac resistance and phase angle of a resistor can be determined in terms of the known characteristics of a standard.

Balancing Algorithm To automate the ac kelvin bridge a balancing procedure had to be established that would allow arms of the bridge to be adjusted without overloading or damaging the detector. Both in-phase and quadrature channels are monitored as the sensitivity of the detector is increased. To avoid overloading the detector, balancing procedures are enacted when a channel is 50% off scale.

Since the voltage measured on the in-phase channel of the detector is a function of IVD-1, a zero finding algorithm is used to set IVD-1 to a ratio that will drive the in-phase channel of the detector to a null point. Likewise the voltage measured on the quadrature channel is a function of IVD-3 so the same zero finding algorithm is used to drive the quadrature channel to a null point. A variation of the Newton-Raphson method [7] iteratively calculates new ratios for the IVDs from voltages measured at previously set IVD ratios. The IVDs are set to the new ratios and voltages are measured until the bridge drives both channels of the detector to a null. Once both the in-phase and quadrature are balanced, a final sequence of measurements is performed to determine the value of the resistor. A flow chart of the balancing algorithm is shown in figure 2.

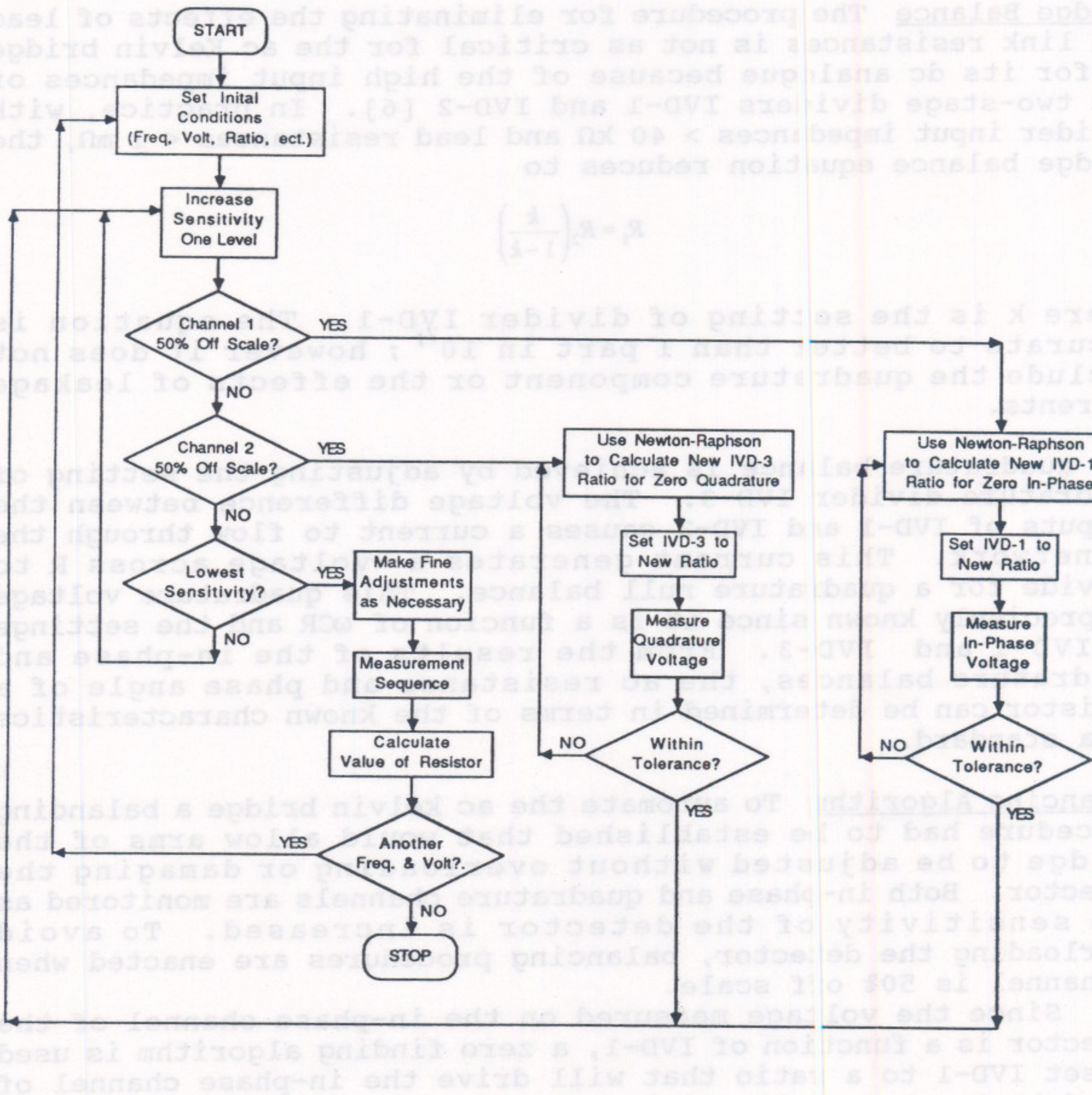

Fig. 2 Balancing Algorithm Flow Chart.

System Performance

The system is under evaluation to determine its ultimate accuracy. The resolution of the bridge is about 0.01 ppm at frequencies from 10 Hz to 1 kHz. Above 1 kHz the resolution decreases to about 0.1 ppm because the low-frequency first stage transformer sections of the binary dividers are bypassed. Over most of the frequency range, the linearity of the dividers is within 0.5 ppm. However, this does not limit the bridge accuracy since the linearity of the dividers can be determined and corrections applied to the divider settings.

An evaluation of the bridge and the measurements made with it to determine the ac resistance and phase angle of resistors will be reported at the conference.

References

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