AUTOMATED AC BRIDGE FOR THE MEASUREMENT OF RESISTORS OVER THE FREQUENCY RANGE 10 Hz TO 10 kHz

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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 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. The bridge is guarded with an additional IVD which is also used to inject a current in a RC network to provide a known phase compensation [2] to balance the quadrature component of the bridge. 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.

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 in reducing 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 guard divider which serves two functions; namely, 1) to reduce leakage currents from the detector to other parts of the circuit, and 2) to inject current into the RC network to provide a known phase compensation to balance the quadrature component of the bridge circuit. 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.

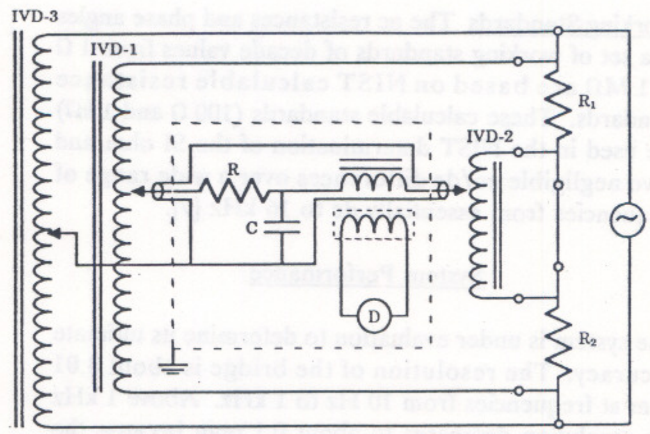

Fig. 1 AC Kelvin Bridge.

Binary IVD's The main and inner ratio arms of the ac Kelvin bridge consist of 30-bit binary IVD's. 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 to its dc analogue because of the high input impedances of the two-staged 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 guard 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.

Working Standards The ac resistances and phase angles of a set of working standards of decade values from 1 Ω to 1 MΩ are based on NIST calculable resistance standards. These calculable standards (100 Ω and 1 kΩ) are used in the NIST determination of the SI ohm and have negligible ac/dc differences over a wide range of frequencies from essentially dc to 16 kHz [7].

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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