A MULTI-FREQUENCY 4-TERMINAL-PAIR AC BRIDGE

A. Jeffery, J. Q. Shields and S. H. Shields
National Institute of Standards and Technology[1]
Gaithersburg, MD 20899-8112

Abstract

A 4-terminal-pair ac bridge, capable of a relative uncertainty of 2×10^{-9}, has been constructed at NIST. The bridge is a multi-ratio bridge (10:1, 2:1 and 1:1) and operates in the range from 100 Hz to 2000 Hz. The design and initial testing of this bridge is described.

Introduction

Our motivation for building a new bridge was to expand our measurement frequencies, which have so far been limited to 1592 Hz. This is critical for our capacitance calibration services, which at present must increase their measurement uncertainty to provide measurements at frequencies besides 1592 Hz. Other frequencies would also be required for ac quantum Hall resistance (QHR) measurements, which may provide an alternative means to obtain a capacitance standard.

At present, there exist two bridges used for capacitance measurements. One is a 4-terminal-pair (4TP) bridge 10:1 ratio [1] which is optimized to work at 1592 Hz but can also be used a frequencies between 159 Hz and 15920 Hz. This bridge is mainly used in the series of measurements linking the calculable capacitor to the dc QHR (See Fig. 1). It is a complex bridge and difficult to use and although it can be used at 400 Hz and below, its capabilities at those frequencies are unsatisfactory. The second bridge is a multi-ratio 2-terminal-pair (2TP) bridge that is used for the transfer of the capacitance unit to the calibration laboratory (See Fig. 1) as well as for weekly monitoring of our 10 pF bank of capacitors. The multi-ratio capability is needed for the voltage dependence measurements. However, active electronics in the quadrature adjustment limit this bridge to measurements at 1592 Hz. Both of these bridges are direct reading ratio sets [2].

We require a 4TP bridge that operates between 100 Hz and 2000 Hz to replace the present 4TP 10:1 ratio bridge. Ratios of 2:1 and 1:1 are needed since the QHR would be compared to reference resistance standards of 12 906 Ω and 6 453 Ω. We also need bridges to measure the ac QHR in terms of the calculable capacitor. This would require making that series of measurements at 1233 Hz. Fig. 1 shows how the new bridge would be used in our measurement chain. We also require a new two-terminal-pair multi-ratio bridge for weekly monitoring of our 10 pF bank of capacitors and for voltage dependence measurements.

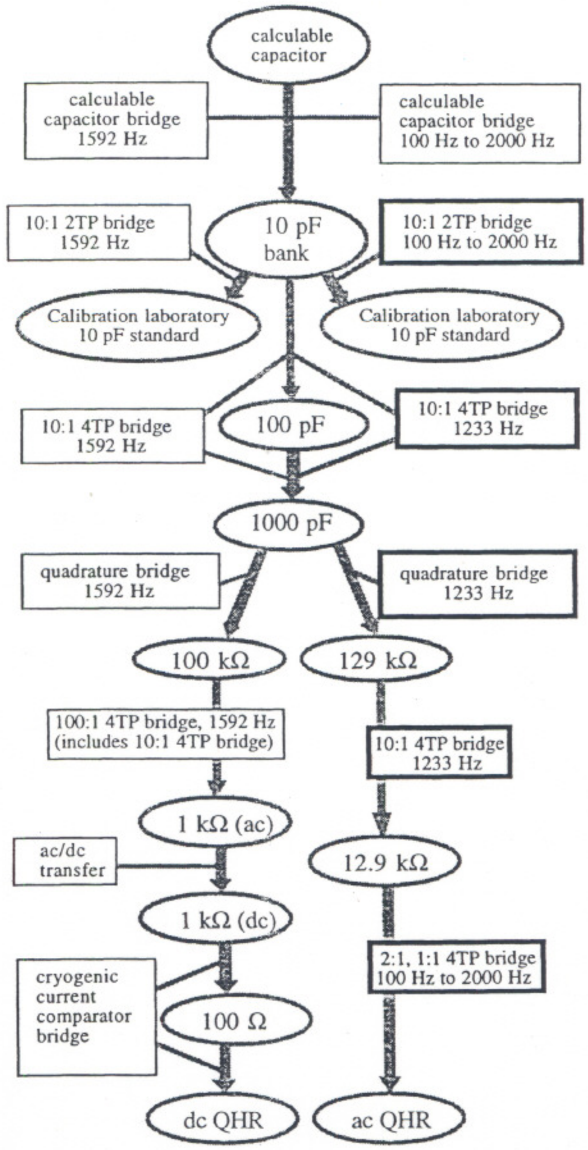

Figure 1. Series of measurements which connect the calculable capacitor with the capacitance calibration laboratory and the dc and ac QHR. The standards are represented by ovals and the bridges by rectangles. The bold rectangles represent the new bridges. Note that the 1233 Hz quadrature bridge has not yet been constructed.

[1] Electricity Division, Electronics and Electrical Engineering Laboratory, Technology Administration, U.S. Department of Commerce. Official contribution of the National Institute of Standards and Technology, not subject to copyright in the United States.

Instead of building two bridges, one to replace the 2TP bridge at different frequencies and a 4TP bridge with multi-ratios, the thought has been to start with one multi-purpose bridge that could fulfill all these needs. This bridge would not have the required uncertainty for all applications but would work well enough to gain experience with multi-frequency measurements. Other bridges specific to the ac QHR measurements or the 10:1 capacitance ratio measurements could then be built at a later time.

Design

The new bridge is a 4TP bridge with ratios of 1:1, 2:1 and 10:1 designed to work from 100 Hz to 2000 Hz. The 4TP definition and 4TP bridges are described in [1]. The new 4TP is much easier to operate than the present 4TP bridge. The present 4TP bridge requires six auxiliary balances even with the use of combining networks whereas the new 4TP bridge only requires three.

The new bridge is essentially a 2TP bridge that has been converted into a 4TP bridge by using an auxiliary transformer to provide the voltage supply for the additional terminal-pairs required for 4TP measurements. Previous work where the existing 2TP bridge was converted to a 4TP bridge and compared with the existing 4TP bridge at 1592 Hz has shown that the bridges are equivalent to within a relative standard uncertainty of 2×10^{-9} [3].

The design of the 2TP part of the new bridge is based on the existing multi-ratio 2TP bridge. The main difference in the design is the increase in the number of turns on the transformer to ensure sufficient impedance at low frequencies. The quadrature adjustment was also changed and is no longer a direct reading ratio set. The quadrature adjustment is achieved instead by injecting a voltage through a conductance standard at the detector. A few smaller changes were also made and these will be described.

One of the design issues encountered was whether or not to use a 2-stage multi-ratio transformer for the bridge. Two-staging a transformer is generally recommended since it improves the range and accuracy of a bridge. However, it would have been difficult to build a 2-stage, multi-ratio bridge transformer that could be used for a wide range of impedances and it was decided not to 2-stage the main transformer. The existing multi-ratio 2TP bridge is not 2-staged and has a transformer ratio that has been stable over 20 years. Also, the excellent agreement between the existing 2TP bridge converted to a 4TP bridge and the existing 4TP bridge have given us confidence that without 2-staging, this transformer will still perform well enough to be used in this general purpose bridge.

Measurements

Initial measurements with the new 4TP bridge have shown promising agreement with the present 4TP bridge. The two bridges have been compared for the measurement of 10:1 capacitance ratios at 1592 Hz and 1000 Hz.

The calibration of the new bridge will require the three following steps [1]: (1) a check on the linearity of the bridge dials, (2) determination of the actual magnitude and phase angle that correspond to the changes on the real and quadrature dials of the bridge, and (3) determination of the main transformer ratio. The phase defect of the bridge should also be checked. These measurements must be evaluated at 1592 Hz, 1000 Hz, 400 Hz and 100 Hz. The performance of the bridge with a range of impedances will also be investigated. The results of these measurements will be presented.

References

[1] R. D. Cutkosky, "Techniques for Comparing Four-Terminal-Pair Admittance Standards", in J. of Res. of the Nat. Bur. Stand., Vol. 74C, Nos. 3 and 4, pp. 63-78, July-December 1970.

[2] R. D. Cutkosky, "Active and Passive Direct Reading Ratio Sets for the Comparison of Audio-Frequency Admittances", in J. of Res. of the Nat. Bur. Stand., Vol. 68C, No. 4, pp. 227-236, October-December 1964.

[3] A. Jeffery, J. Q. Shields and L. H. Lee, "An Easy-To-Use Combination Four-Terminal-Pair / Two-Terminal-Pair Ac Transformer Bridge", in J. Res. Natl. Inst. Stand. Technol. Vol. 103, No. 2, pp. 163-166, March-April 1998.