# CONVERSION OF A 2-TERMINAL-PAIR BRIDGE TO A 4-TERMINAL-PAIR BRIDGE FOR INCREASED RANGE AND PRECISION IN IMPEDANCE MEASUREMENTS

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## Abstract

A new 4-terminal-pair bridge, capable of a relative uncertainty of 1 in  $10^9$ , has been constructed at NIST by converting a 2-terminal pair bridge. The conversion requires only addition of components which are easily removed if 2-pair measurements are to be made. The design and testing of this bridge will be described.

#### Introduction

Four-terminal-pair measurements can be made with a high degree of accuracy for a wide range of impedance values. To achieve the same results with two-pair bridges, extrapolation techniques must be used, and even then the equivalent precision can only be attained for large impedances, e.g. 10 pF to 1000 pF at 1592 Hz [1]. Four-terminal-pair measurements have the advantages of reducing the effects of parasitic impedances and diminishing the sensitivity to variations in series impedances and shunt admittances in the leads. This is especially important when measuring small impedances.

Each 4-terminal-pair standard has four terminal pairs where certain conditions must be met. This creates a well-defined standard which can be moved between different bridges and still give the same value. Four-terminal-pair bridges required a complex sequence of auxiliary balances [2] in order to meet the required conditions at the four terminals of each standard. A 4pair standard and the conditions to be met at each terminal pair are shown in Fig.1.



Figure 1. Diagram of a 4-terminal-pair standard.

#### Design

The 2-terminal pair bridge that has been converted is a direct reading ratio set built by Cutkosky at NIST and is similar to those described in Ref. [3]. It has half taps and tenth taps and therefore can be used as a 10:1, 2:1 or 1:1 bridge. A simplified version of a two-pair 10:1 bridge is shown in Fig. 2.



Figure 2. Simplified version of a 10:1 2-pair bridge. 't' represents the turns of the transformer. The standards are enclosed in dashed ovals. The coaxial chokes and components for voltage adjustment are not shown.

The conversion to a 4-terminal-pair bridge is achieved by providing two additional terminals (1 and 4) for each standard and by satisfying certain conditions at each terminal-pair. The converted 2-pair bridge is shown in Figure 3.

Connections for the drive terminals (terminals 1) are created by the addition of leads which supply current to these terminals. These leads supply current to the standard and associated cables so that there is zero current at terminal 2, the potential terminal. The drive terminals are supplied by an auxiliary transformer. The added leads are at a slightly higher potential than the potential leads for the 2-pair bridge to provide adjustment of the supplied current The auxiliary transformer is built with taps such that it can also be used in a 10:1, 2:1 or 1:1 ratio and shares the same power supply as the transformer for the 2-pair bridge.

The condition for zero current at the potential terminals (terminals 2) is met by the insertion of defining transformers, T1 and T2, at these terminals. Defining transformers are used to ensure that there is zero current at that point in the circuit and are used with detectors (D1 and D2 in this case). A complete description of defining transformers is given in Ref. [2]. This auxiliary balance is made by adjusting T3 and T4 for a null at D1 and T5 and T6 for a null at D2 which satisfies the condition of zero current at terminal 2 of the standards. The transformers, T3, T4, T5, and T6, are commercial decade ratio transformers. In practice, the 100 turn detector winding of the defining transformer is shorted and the detector is connected only during the adjustment of the auxiliary balance.

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Figure 3. Diagram of a 10:1 ratio 4-terminal-pair bridge converted from a 2-pair bridge. The terminals for the four-terminal-pair standards, which are enclosed in the dashed ovals, are labeled 1, 2, 3 and 4. 'T' refers to a transformer, 'D' to a detector and 't' represents the turns of a transformer. The coaxial chokes and components for voltage adjustment are not shown.

The connections for terminals 4 ( $I_{0 \text{ u} \text{ t}}$  terminals) and 3 (detector terminals) of the standards are the same as described in Cutkosky's 4-terminal-pair bridge [2]. The 100 turn detector winding of the defining transformer, T8, is kept shorted except during the adjustment of this auxiliary balance. Y and T7 are adjusted so that no change is observed at the main detector, D, when a voltage is injected at the 100 turn winding of T8.

## Measurements

The new 4-terminal-pair bridge requires fewer auxiliary balances than the present 4-terminal-pair bridge which makes it much easier to use. As for any direct reading ratio set, the calibration will require the three following steps [2], a check on the linearity of the bridge dials, determination of the actual magnitude and phase angle which correspond to the changes on the real and quadrature dials of the bridge, and determination of the main transformer ratio. These will be performed and reported on.

The bridge will also be compared against our present 4-pair bridge by making measurements with both bridges on a range of impedance standards.

#### Conclusions

The converted 4-terminal-pair bridge is much simpler to use and construct than the previous 4-

terminal-pair bridge [2]. It requires only three auxiliary balances and can be constructed with only additional external connections to a previously existing 2-pair bridge Two-terminal-pair standards can easily be converted to four-terminal-pair standards by the addition of two coaxial tees.

This bridge will be used as a check of the present 4-terminal-pair bridge used at NIST in the SI ohm determination. The bridge will also be used in quantum Hall effect ac measurements.

### References

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