AC Resistance Thermometry Bridges and their Advantages
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What is at the heart of the AC bridge concept? And what makes it so special?

The Ratio Transformer
The ratio transformer is sometimes referred to as an IVD, an Inductive Voltage Divider. As suggested by its name the 'simple' task of the ratio transformer is to divide the voltage across the resistance thermometer $R_t$ and a reference resistor $Rs$, which carry a common current, and therefore measure the ratio $V_t / V_s$, which is the same as the ratio $R_t / Rs$.

So the heart of an ASL AC bridge is a super accurate voltage divider

Direct Current (DC)
A traditional method for measuring resistance accurately in this way is the Wheatstone bridge, this is made of two resistance elements, one of which is fixed $R_f$ and one is variable $R_v$. As with an AC bridge, the other half of the bridge is the resistance thermometer $R_t$ and the standard resistor $Rs$. In the Wheatstone bridge, adjustment of the variable resistor $R_v$ allows the voltage across the galvanometer to be adjusted to zero. In this condition, when the bridge is said to be balanced, the ratio $R_v / R_f$, is the same as $R_t / Rs$.

For our purposes we know $Rs$, so we can calculate $R_t$ from $R_v / R_f \times Rs$
However, to help us understand the equivalent AC bridge principles, it might be easier to picture the Wheatstone bridge using a decade resistor box to obtain a balance as shown below,

Here, Rv is shown as a decade resistor box.

Alternating Current (AC)
A simplified diagram of an AC bridge is shown below, the voltage across the standard Rs is measured by the fixed primary winding (P) of the ratio transformer. The secondary winding (S), or the variable, can be adjusted so the voltage division is equal to that of Rt to Rs.

The secondary winding (S) is far from a simple secondary and can be shown to take the form of cascaded ‘decades’, which can be considered similar in principle to that of the decade resistor box.

In effect, one tapping of the ‘unity ratio’ decade has ten tappings which represent ‘0.1’ ratio each. So the AC voltage across the one unity tapping is also across all ten ‘0.1’ ratio tappings, hence a division of 10 is available on this AC voltage. Each ‘0.1’ ratio tapping has ten tappings representing ‘0.01’ etc. In this way the ratio of the thermometer Rt and the standard resistor Rs may be read directly.
A representation of this arrangement is shown below,

What are the disadvantages of the DC measurement technique?

- Voltmeter offset and linearity errors
- Noise on the sense current and voltmeter
- Sequential measurement temperature change
- Thermal EMFs
- Slower to achieve the correct measurement.

These all lead directly to the measurement uncertainty.

What are the advantages of the Ratio transformer and therefore ASL AC Bridges?

- High Accuracy
  Accuracy is inherent in the design of ASL bridges; ASL use AC measurement techniques in its bridges because the AC ratio technique is the best ratio standard able to provide higher precision.

- Long term stability
  The Ratio transformer (Inductive Voltage Divider) does not drift with time and has proven to have long term stability providing consistent measurement results.

- Elimination of DC circuit drifts
  By using AC the amplifier drifts associated with DC instruments are not a problem, therefore providing good stability and fast measurements.
• Low temperature coefficient
The ratio transformer is insensitive to ambient temperature changes and therefore requires little or no warm-up time providing less waiting time and no need for ambient temperature control.

• 4 wire measurement
To provide the highest possible accuracy and eliminates the effects of lead resistance within the measurement, even with the addition of Multiplexers and long cables.

• Elimination of thermal and electrochemical EMFs
These effects are cancelled by using AC current, in an attempt to cancel these errors, DC instruments reverse their measuring current but at the expense of measurement time and level of accuracy.
DC instruments have to reverse their measurement current periodically in an attempt to match the AC bridge performance and in doing so extend the measurement time. In effect, DC measurements are sequential, whereas AC bridge measurement is concurrent, or overlapping, so there are no errors caused by conditions changing while the actual measurement is taking place. In addition these current reversals in DC instruments generate heating and cooling due to the Peltier effect at all the connections in the measurement circuit. This heating and cooling effect then caused thermal EMFs to be created and will be added to the thermometer voltage, even when reversed the measure resistance will be higher than the true ohmic value. By contrast the low frequency AC measurement technique will not allow time for significant heating and cooling to take place, so the true ohmic value of the thermometer is measured.

• Active input circuitry
Input ‘guarding’ techniques increase the input impedance of the ratio transformer so as not affect the current and maintain the measurement accuracy from leakage currents.
This allows the ASL AC bridges to be used in a wide range of applications without affecting the performance.

• Low Frequency carrier
The use of 25 – 75Hz almost completely eliminates the ‘1/F noise’ generated within DC instruments, this provides a measurement that is more precise, has lower noise, a high resolution and in a fast time.

The ‘1/F noise’ or ‘flicker noise’ is basically the tendency of the offset voltage of many meters and amplifiers to vary erratically in a way which is inversely proportional to frequency. With the CTR9000(ASL F900/F18) a matching transformer is part of the design that optimally matches the Thermometer resistance that also reduces the effects of noise at this level of measurement.
This measurement frequency also provides an inherent rejection of line/supply frequency interference and harmonics, while reducing reactive effects with a quadrature servo enabling the correct resistance values being obtained in the measurement.
Traceability of AC bridges to National Standards

There are 3 commonly used techniques for checking/calibrating the bridges or instruments used in resistance thermometry. All of these can be used with AC bridges; only 2 are available for DC instruments, using calibrated resistors and the Resistance Bridge Calibrator (RBC).

Nearly every national laboratory in the world uses AC resistance bridges to establish the ITS-90 temperature scale in their country and uses some, or all of these to confirm measurements being made and traceability.

1. Calibrated reference resistors
These can be used (with AC or DC instruments) to check calibration. The calibration uncertainty available (from NMIs) on these resistors is typically 0.05 ppm DC and 0.5 ppm AC. It appears therefore that this technique will not work as well with AC instruments as their DC counterparts. However, the standards used are typically Wilkins resistance standards (CER6000-RW) or equivalents and these have stabilities of 2 ppm per year so that the measurement uncertainty associated with the reference resistor is dominated not by the initial calibration uncertainty but by the long-term stability. The RMS combination of uncertainties means that for calibrations in which the standard is calibrated annually by a national standards laboratory the contribution of the reference resistor to the total measurement uncertainty is:

- DC: uncertainty, \( u_R = 2^2 + 0.05^2 = 2.0 \text{ ppm} \)
- AC: uncertainty, \( u_R = 2^2 + 0.5^2 = 2.1 \text{ ppm} \)

There is therefore very little difference between the uncertainty that can be achieved for AC and DC instruments using this technique.

2. Ratio Test Unit (RTU)
This can be used only on AC bridges to check the accuracy and linearity of a resistance bridge. This device is produced by ASL and simulates the reference and thermometer resistances using an inductive voltage divider (transformer) to generate ratios of AC voltages. Effectively this technique compares the measurement made by the bridge’s ratio transformer with a more accurate external ratio transformer. The advantage of this technology is that the voltage ratio generated by the Inductive Voltage divider (IVD) depends only on the turns ratio, which is stable with time & temperature (you cannot lose or gain turns). Also, the uncertainty of these ratios and therefore of the RTU calibration is calculable and again is stable with time and temperature. IVD techniques are used in national standard laboratories as inherent standards, not requiring calibration. The RTU used by ASL to calibrate its products is returned periodically to the national standards laboratory of Germany (PTB) for checking against their own IVDs so we do have traceability of the calibrations at ASL back to a leading national standards laboratory.

The uncertainty offered ranges from 0.09 to 0.13 ppm across the operating range and is limited by the uncertainty of the PTB standards.
3. The Resistance Bridge Calibrator (RBC)
This can be used (with AC or DC instruments) to check the linearity of a bridge by generating a set of resistance values that exercise the bridge over its working range. The RBC contains 4 precision resistors, which can be connected in various series and/or parallel combinations. Although the actual value of each resistor is not known to more than a few ppms, it is possible to determine the linearity of the instrument to much better uncertainty. The resistors are used to generate 35 discrete resistance values from the 4 base resistors. These are measured using the instrument under test and although there will be uncertainty in the measured value due to the instrument; this generates 35 simultaneous equations with just 4 unknowns (the 4 resistor values). It is then possible to derive a best-fit determination of the 4 resistor values and from this to derive the 35 resistances (as a proportion of the maximum resistance) used to check the bridge. This enables the linearity (but not the scale accuracy) to be checked. The scale accuracy of an AC bridge can be checked using the internal unit check function. Using this technique it is possible to check a CTR9000 (ASL F18) bridge (0.1ppm accuracy) with residual linearity errors of less than 0.03ppm.