A New Generation of Hamon Resistor Standards

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Introduction

• In 1954, B.V. Hamon proposed the design of a precision resistor standard

• Advances in resistor technologies, more precise calibration methods, resistor arrangements have allowed for better results

• Tolerances, temperature coefficients, and the environment can affect values

• The design of a resistance standard should account for these effects

• This presentation will discuss the efforts being undertaken at the Reliability and Failure Analysis Laboratory at the University of Alabama in Huntsville to design and construct a reliable and maintainable resistance standard
What is the Hamon Resistor?

- Proposed by B.V. Hamon in 1954
- Used to calibrate standard resistors
- Initial design consisted of eleven $10\,\Omega$ resistors
- Guard resistors are utilized to provide more accurate measurements
- Resistors may be connected in parallel or series-parallel

Fig. 1 | The parallel connections of $n$ separate four-terminal resistors.
Automated Guarded Resistor Bridge

• Previously, calibrations of standard resistors from 10 MΩ to 1 TΩ at NIST were performed manually

• New design uses a guarded Wheatstone bridge that is automated and robust

• DC voltage calibrators in two arms of the bridge have low output impedances that reduce errors

• High resistor values guard the high side of the detector and reduce leakage currents

Fig. 2 | Guarded resistor bridge with programmable sources, drive resistors, and guard resistors. The detector, D, measures difference in currents flowing through Rx and Rs.
Balancing the Resistor Bridge

• An electrometer with a resolution of +/- 3 fA in the current mode is used as the detector to measure differences in currents

• Initially, voltage sources are chosen to have the same nominal ratio as $R_x$ and $R_s$

• A linear relationship exists between applied test voltage and the current measured by the detector

Fig. 3 | Detector current vs. calibrator voltage in the guarded bridge.
Hamon-Guarded 10x100 MΩ Network

- Guarded resistor bridge developed at the National Institute of Metrological Research
- Consists of ten thick-film resistors, each with a nominal value of 100 MΩ
- Each guard resistor has a value of 10 MΩ
- Resistor network is encased in an aluminum cylinder and series to parallel connections are made through use of a mobile link

Fig. 4 | a) View of the 1 GΩ output of the Hamon network. b) View of the 10 MΩ output of the Hamon network.
Guarding System for the Hamon Network

- Consists of ten resistors with a nominal value of 10 MΩ
- Mounted on the cylindrical body of the main resistors by means of two metal rings
- The leakage resistance of each main resistor is divided into three parts by means of the two rings
- Guard resistor maintains the same potential as across the main resistor so part of the leakage resistance between points b and c is in parallel with the guard resistor

Fig. 5 | Schematic of the 100 MΩ step network, denoting main, guard, and leakage resistances.
Comparison of Resistor Technologies

Thin Film Resistors
• Manufactured through a sputtering process, provides a uniform metallic film
• Resistive element is approximately 1000 Angstroms thick
• Able to achieve much lower tolerances and temperature coefficients
• Improved characteristics and performance leads to higher cost

Thick Film Resistors
• Most widely available and are the lowest cost of any resistor technology
• Good solution if the application in question does not require low TCR or tight tolerance
• Resistive element is thousands of times thicker than thin film elements

Foil Resistors
• Best precision and stability
• Resistive element is an alloy that is several micrometers thick
• Limited by resistance value

Fig. 6 | a) A through-hole foil resistor. b) An axial thin film resistor. c) A surface mount thick film resistor.
What factors can affect resistance output?

• Temperature coefficients of resistance, or TCRs
  - TCR of thin film resistors is around 25ppm/K, TCR for thick film resistors is around 200 to 250 ppm/K
• Tolerances of resistors
• Oxidation of solder joints
• Connection points contribute impedances
• RF interference
• Thermal shock or vibration
Our Design Approach

Resistors of equal value

Trim potentiometer

Resistor of slightly greater value than parallel resistance

High value resistor
Conclusion

• Resistance standards are simple in concept, but difficult in design

• Prototype of a new resistor standard has been constructed, testing to begin soon

• The resistor standard should yield precise and stable values since circuit components possess optimal specifications

• Increase in resistance values creates concern for stability due to increases in TCR and tolerance

• The potentiometer in the circuit will need to be stabilized to prevent drift in values
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- Support from the Reliability and Failure Analysis Laboratory at the University of Alabama in Huntsville is gratefully appreciated
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