MEETING THE CHALLENGE TO KEEP ELECTRICAL MEASUREMENTS CONSISTENT GLOBALLY

By:

R.E. Hebner

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Center for Electromechanics
The University of Texas at Austin
PRC, Mail Code R7000
Austin, TX 78712
(512) 471-4496

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Robert Hebner
The University of Texas at Austin
Mail Code R7000
Austin, Texas 78712

Abstract

The system for assuring the consistency of electrical measurements is being expanded through key comparisons. The initial process to select key comparisons is consensus by experts. With experience, the process should become more rigorous. Advances in commerce, computing, and analysis as well as market forces may influence future key comparisons.

Introduction

The world's nations have come together voluntarily, largely under the auspices of the Treaty of the Meter, to assure that it is possible to make consistent measurements at different locations around the globe. A key historical step was the adoption, in 1960, of the International System of Units or the "SI" as it is conventionally called.

The physical realization of SI measurement capability is a challenge because of the broad range of measurements that can be made. Not only is there a range of fields of measurements, but each field is also huge. In chemical measurements, for example, there are multiple concentrations of multiple chemicals in multiple matrices to be measured requiring a multitude of techniques.

In electrical measurements, the task is equally daunting. Take, for example, the task of determining that, in more than 100 countries, resistance can be measured consistently. This seemingly simple task is complex because for modern science and commerce, the resistances of interest may range from fractions of microohms to tens of gigaohms. But the complexity is not one-dimensional. The frequencies of interest range from dc to terahertz and the voltages of interest may range for nanovolts to megavolts. It has never been possible, or necessary, to compare every laboratory at all combinations of all parameters. Over the past few years, however, changing technology has stimulated a change in the philosophy of how best to assure consistency is possible.

Evolving Measurement Philosophy

It is impossible to characterize the individual approaches and motivations of all metrologists worldwide. To guide future work, however, it is useful to examine large changes in shared philosophies. This examination is particularly important today because we are passing through one of those large changes. A useful way to think about that change is that we are augmenting a rigorously deterministic system with a targeted sampling process.

The existing system was based on the very reasonable premise that with limited funds and a range of needs, one should concentrate resources on the most accurate possible measurements of the most fundamental quantities. We also developed rigorous uncertainty models that allowed comparison of results of measurements of the same quantity across laboratories. We are successful, for example, at comparing 10-volt Josephson junction arrays around the world with a high degree of confidence that the differences among laboratories are within a part in 10^9. We then use thermal converters to compare alternating with direct voltages and ratios of known impedances to scale magnitudes. We have developed methods to determine the uncertainty of each of these processes. When the uncertainties of all of these processes are very small compared to the needs of science or commerce, there is a high degree of confidence that consistent measurements could be made. Brian Petley [1] summarized this situation in a report given to a conference of the International Measurement Confederation.

A challenge to this philosophy has been raised within the past decade. The challenge is that, in too many areas, commerce needs such accuracy that confidence in the system is brought into question. The accreditation community brought this situation to the attention of the metrology community.

To assure confidence, the various nations decided to augment the previous system with targeted sampling. This sampling process is commonly referred to as "key comparisons". In this approach, each nation supports accurate basic measurements and appropriate scaling to meet national needs. It then reports publicly the quantities that it supports, with the appropriate uncertainty. Committees of the CIPM review the situation and choose the most important comparisons to demonstrate the validity of national claims. The initial set of comparisons that the Consultative Committee for Electricity and Magnetism selected are summarized in Table 1.

Table 1. Summary of Electrical Key Comparisons

Parameter	Range
DC Voltage	1 V and 10 V
Resistance Ratios	$R_H(2)/100\ \Omega$; 10 kΩ/100 Ω; 100 Ω/ 1 Ω
Resistance	1Ω, 10 kΩ, 10 MΩ, 1 GΩ
Inductance	10 mH at 1000 Hz
Capacitance	10 pF
AC/DC Transfer	1 kHz to 50 MHz, selected frequencies
AC Voltage Ratio (Inductive)	40 Hz to 5 kHz, selected frequencies
DC Voltage Ratio (Resistive)	1000 V to 10 V; 100 V to 10 V
AC Power and Energy	50 Hz and 60 Hz
Power	33, 45, 62, 94 GHz, in waveguide; selected frequencies 10 MHz to 26 GHz in coaxial cable
Noise Power	In waveguide and in coaxial cable
Antenna Gain	26.5, 33, 40 GHz
RF Voltage	1 V; 1 MHz to 300 MHz, 1 GHz
S Parameters	2 GHz to 18 GHz, 50 MHz to 26.5 GHz
Antenna Fields	Power Flux Density: 2.45 to 10 GHz E-Field Strength: 300 to 1000 MHz
Excess Noise Ratio	12.4, 13.5, 15, 17.5, 18 GHz

The fundamental logic of this list is obvious. The voltage comparisons rest on the Josephson effect, which has the temporal and spatial consistency needed to underpin a global system. This is supplemented by comparisons of key techniques to realize impedence, and thus current, and to scale them in both magnitude and frequency. Because the power industry, the computer industry and the telecommunications industry are both stimulating economic growth worldwide and pushing the limits of measurement capability, special attention is paid to key parameters of interest to these industries.

This list is expected to change with time as technology and the needs of commerce change. In fact, a challenge is to complete a sufficient number of comparisons in time to support rather than hinder trade.

The internet is key support for this process to work. With today's computer technology, the capabilities of all nations are being gathered into a single database long with the results of comparisons. This data will help target areas for needed comparisons. More importantly it is accessible to science, governments, and industries worldwide, providing them with information on the state of measurement technology.

Future Changes

As the key comparison process is being launched, it is also important to recognize that the process used to permit global measurement consistency is based on technology and the current era is one of rapid technological change. So an accelerating rate of change should be expected.

Factors that are likely to affect the processes used to achieve global measurement consistency include:

- Globalization of trade

  As trade becomes increasingly global, the need for consistency increases. With air travel, few places on the globe are more than 24 hours apart. Global measurement consistency must be supported on this time scale.
- Globalization of the instrumentation industry

  One consequence of our global economy is the emergence of a few global instrumentation companies. They will increasingly, in ways that are not yet understood, share with governments the responsibility to assure measurement consistency.
- Telepresense

  The internet will increasingly give us the capability to participate in work at other laboratories without leaving our own. This may reduce the number of artifacts that must be exchanged to assure consistency.
- Better statistical analysis

  A good database may stimulate research that will permit more confidence with less data once the global process is better modeled.

Finally, in the midst of all this actual and possible change, it is important to emphasize that the changes are of process, not content. The key assumptions that accuracy is important and that improvement in the accuracy of fundamental quantities pays great benefits remain the foundation on which the future is built.

References

[1] B. Petley, "Measurement past, present, and future," Proceedings of IMEKO XI, International Measurement Confederation, pp. 9-24, 1988.