STATUS OF THE QUANTUM HALL RESISTANCE RISP

Randolph E. Elmquist
National Institute of Standards and Technology[†]
Gaithersburg, MD 20899, USA

Abstract

The NCSL Working Group that is developing a Recommended Intrinsic/Derived
Standards Practice (RISP) for a quantum Hall resistance (QHR) standard has
surveyed a group of standards laboratories to learn where a need for the
standard exists. Smaller national laboratories are actively seeking to develop
QHR facilities to support industrial needs. U.S. major industrial standards
laboratories are suitable sites for the QHR standard, but few are eager to
pursue development due to the perceived difficulty and expense of operating a
QHR facility. The development of the RISP will reduce the ambiguity in the
planning process. Initial questions about the method of measuring the
resistance standard and scaling to the decade levels are addressed.

Intrinsic Standards

Two intrinsic effects in solid state devices, the quantized Hall effect and
the Josephson effect, are used as a foundation of the U.S. and international
electrical measurement system. The value of the maintained unit is the same in
all laboratories using the intrinsic effect as the standard if measurements
are properly performed, and in addition the time dependence or drift in the
unit is removed. Fig. 1 shows the drift of the U.S. ohm since 1984 and the
1990 adjustment[1], a change made to bring the unit into agreement with the SI
definition of the QHR. Similar corrections were made in laboratories world-
wide.

Users of resistance standards require artifact standards such as wire-wound
resistors at many different levels of resistance. U.S. industrial standards
laboratories and government laboratories insure that scaling from one decade
level to another decade level, such as from 1 Ω to 10 kΩ, is accurately
achieved. The scaling from the value of the QHR to a decade level is not as
straightforward, and several methods will be covered in the QHR RISP.

National laboratories which do not now have a QHR facility must rely on
another nation's calibration and may hand-carry a set of resistance standards
once or twice a year. Mexico, South Africa, Spain, and Taiwan are among those

---

[†]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.

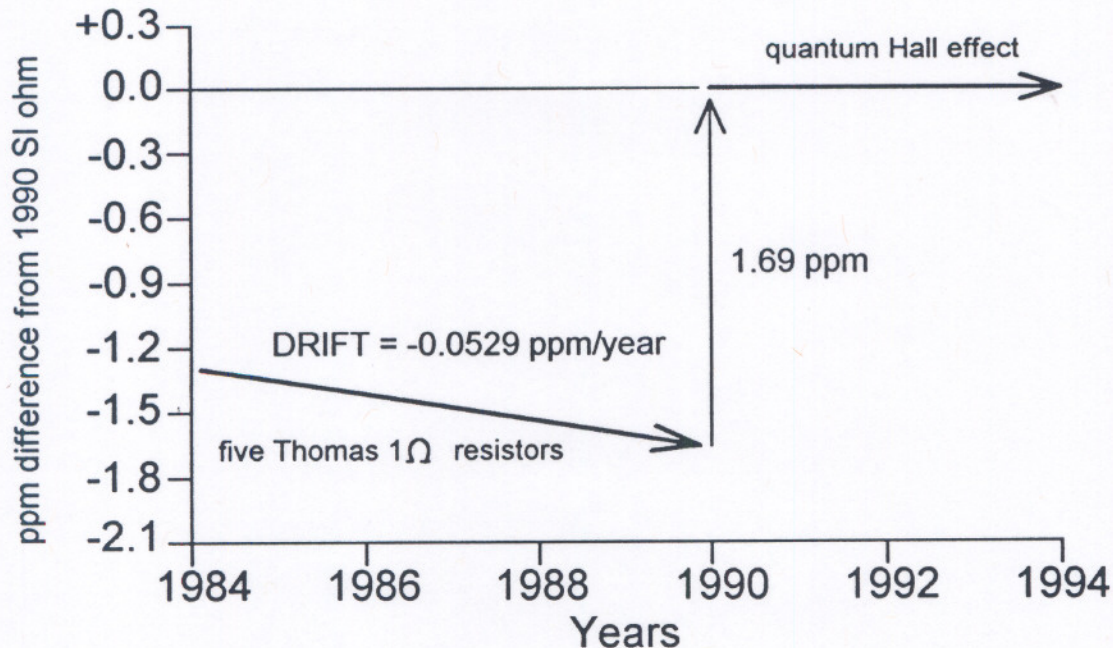## TIME DEPENDENCE OF THE U.S. OHM

Fig. 1: The January 1, 1990 adjustment to the U.S. ohm.

planning or considering development of a QHR national resistance standard.

Survey

Interviews with representatives of major standards laboratories have helped to develop the outline which the QHR RISP working group is preparing. Potential users who participated in our survey included U.S. industrial and government laboratories and non-U.S. national laboratories. Most of the participants expect to attain an accuracy of 0.1 ppm to 0.05 ppm in supporting 10 kΩ standard resistors. QHR laboratory personnel would spend about one to two months using the system each year and the total operating cost for the QHR facility would need to be less than $20 k per year. Initial costs are approximately three to four times this yearly expenditure. QHR laboratories would require fewer external quality control checks (resistor calibrations) and the accuracy of maintained resistance units would not be affected by changes in local standards due to transport. Thus, laboratories would have the potential to achieve lower overall uncertainties.

The survey also helps identify where sufficient need for the QHR standard exists. A capability to scale between 1 Ω and 10 kΩ and achieve closure with NIST calibrations to within 0.2 ppm or better indicates that the laboratory has the needed technical resources to take advantage of a QHR standard. Many of these laboratories are using or see a need for an on-site Josephson junction (JJ) array standard to improve voltage calibrations. The JJ array standard could also be used as a linearity standard, and could supply data to improve the ratio accuracy of some instruments used in QHR scaling.
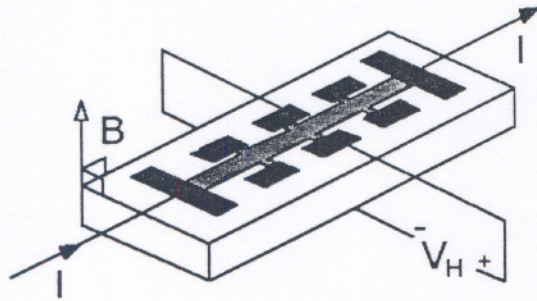
QUANTIZED HALL RESISTANCE

Some technical specifications for the QHR (Ref. 2)
Sample Material: GaAs/GaAlAs heterostructure
Contacts: Source, drain, and two or three pairs of
　　　Hall voltage pads
Source-drain current: I = 20 to 50 μA
Measurement temperature: T = 1.5 K or lower
Resistance correction due to temperature: Less
　　　than 0.03 ppm
Magnetic flux density at i = 2 step: B = 8 to 12 Tesla

Fig. 2

Measurement System

The most accurately measured QHR steps[2] have resistance values of 6453.20175 Ω and 12906.4035 Ω and are called the i=4 and i=2 quantized Hall steps. A one-to-one comparison to the step resistance requires using high quality wire-wound resistors of nominally equal value. These resistors then can be used to scale to 10 kΩ with higher measurement currents than are recommended for measurements of the QHR (see Fig. 2).

A straightforward measurement technique is called the DVM method[3,4] and can be used to scale directly to a high quality 10 kΩ resistor. The measurement apparatus consists of a very stable reversible current source and a very linear DVM. This system would require checks on the DVM linearity using a JJ array to achieve uncertainties of 0.05 ppm.

Conclusion

Intrinsic electrical standards have had an important effect on metrology by reducing the need for international comparisons and providing a basis for common international units of measurement. The local QHR standard would lower the primary laboratories' uncertainties in resistance calibrations, and the the purpose of the QHR RISP is to guide the laboratories in its application.

References

[1]　Belecki, Norman B., Dziuba, Ronald F., Field, Bruce F., and Taylor, Barry N., "Guidelines for implementing the new representations of the volt and ohm effective January 1, 1990," Natl. Inst. Stand. Technol. Technical Note 1263, June 1989.

[2]　Delahaye,F., "Technical guidelines for reliable measurements of the Quantized Hall resistance," *Metrologia*, vol. 26, pp.63-68, 1989.

[3]　Jaeger, Klaus B., Levine, Paul D., and Zack, Craig A., "Industrial experience with a quantized Hall effect system" *IEEE Trans. Instrum. Meas.*, vol. 40, no. 2, pp. 256-261, 1991. Also, Jaeger, Klaus B., "Traceability of the ohm through the quantum Hall effect," to be presented at this conference.

[4]   Cage, Marvin E., Yu, Dingyi, Jeckelmann, Beat M., Steiner, Richard L.,
and Duncan, Robert V., "Investigating the use of multimeters to measure
quantized Hall resistance standards," *IEEE Trans. Instrum. Meas.*, vol. 40, no.
2, pp. 262-266, 1991.

I_0 - 500 A/div; - 1400 A
I_1 - 500 A/div : 1350 A
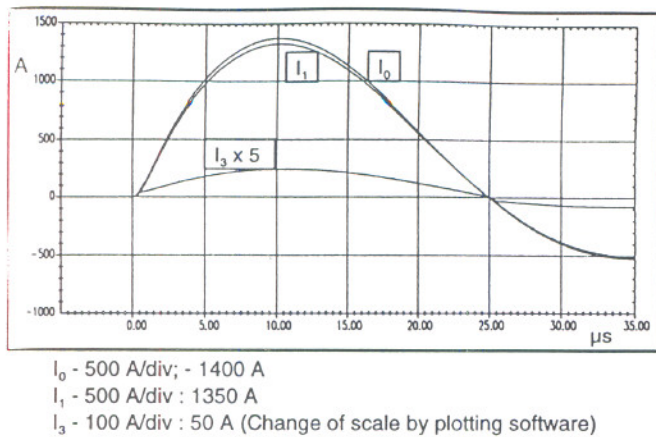I_3 - 100 A/div : 50 A (Change of scale by plotting software)

Figure 8 - Model plot of currents, for conditions similar to Figure 4

Figure 8 shows the three current traces, similar to the current traces of Figure 4. The top trace is the applied surge, 1400 A, postulated according to Eq. (1) to match the current involved in the measurement of Figure 4. Practically the same peak values are obtained for the resulting currents, respectively 1300 A for the current in the arrester, I_1, and 50 A for the current in the downstream SPD, I_3. (Note that to present the three traces on the same software-driven plot, the I_3 trace is scaled by a factor of five, to fit the 500 A/div versus 100 A/div of the respective scales of Figure 4).

4 Other important factors

The objective of this paper, as stated in the introduction, is only to show how the dilemma of cascade coordination might be resolved by recourse to a gapped arrester at the service entrance. We have shown that effective coordination becomes possible by appropriate selection of the limiting voltages of the varistors and of the gap sparkover characteristics. However, there are other factors that will need to be addressed by designers before this approach can be transitioned to viable hardware. We have not attempted at this stage to study in detail all of these factors, but suggest the following list of topics for consideration.

These are familiar to arrester manufacturers and this list is not intended to tutor them, but simply to place the idea in perspective so that no false expectations are raised that an immediate and easy solution is already at hand. We will have accomplished our purpose if the old idea is just given new consideration. Among the topics to be studied, the following are most important:

- Ability of the varistor to reduce the follow current to a level that will allow the gap to clear at the first current zero — as postulated.

- Ability of the varistor to conduct the follow current that the power system can deliver at the point of installation.

- Ability of the gap to withstand the unavoidable power-frequency overvoltages of the power system without going into conduction and yet to have an acceptable sparkover voltage.

V. THE NEW OPPORTUNITY

The results of our experimental measurements, which can be expanded by parametric modeling, show how a happy state of affairs — an effective coordination of cascaded SPDs — could be obtained by gapped arresters at the service entrance. These arresters would combine the best of the two technologies, gas tubes and metal-oxide varistors. This will not happen, however, if the decision is not made to apply such a gapped arrester. That decision must be made by utilities and installers. In contrast, the de facto situation inside the building, imposed by millions of installed appliances, is now hopelessly immovable. Typically, when these appliances include a built-in SPD or, when the end-user purchases and installs an add-on, plug-in SPD, these SPDs are of the type with low limiting voltage [5], resulting in difficult if not impossible coordination.

This very difficult coordination, however, should not be construed as a recipe for disaster. The reality of the present situation is that these low limiting voltage SPDs manage in general to survive even in the absence of a service entrance arrester. As discussed earlier, this is not a desirable situation, hence the proposals for whole-house surge protection. But if the proposed service entrance arrester were designed to use a simple varistor with ratings commensurate with utility practices, it is most likely that the internal SPDs will "protect" the service entrance arrester, which then serves no useful purpose and is a waste of resources. Furthermore, as more electronics and equipment with low logic voltages are installed, the existing practices may lose effectiveness.

Standards or regulations cannot prescribe the particular type of service entrance arrester (furthermore, the provision of a service entrance arrester is required in only a few countries), so the decision is left to the community of utilities, SPD manufacturers and end-users. The manufacturers would probably respond to the need for gapped arresters if informed system designers were to call back from retirement the 'ancient' gapped device and, with appropriate technology update, give the old idea a new lease on life.

VI. CONCLUSIONS

1. The dilemma of coordinating a cascade of surge-protective devices can be solved by providing a gapped arrester at the service entrance, that will coordinate with the de facto situation inside the building.

2. The need for a service-entrance arrester to withstand the scenario of lost neutral can be satisfied by a gapped arrester having sufficient maximum continuous operating voltage capability.

3. Experimental verification of this coordination has been demonstrated for typical branch circuit lengths and limiting voltages applicable to the 120/240-V systems used in residential applications in North America. The same principles can be applied to other power systems with appropriate adaptation of voltage ratings and careful consideration of the local grounding practices.

4. The behavior of a complex system such as the interactions between circuit impedances and the nonlinear characteristics of surge-protective devices can be successfully modeled to allow parametric studies.

5. Other factors need attention, for which good engineering practice applied by surge-protective device manufacturers can provide adequate design.

6. While the idea appears sound, it cannot be implemented by individual end-users. It will take an initiative by a centralized organization, such as the utility serving the district, to persuade manufacturers that a market opportunity exists to which they can contribute.

VII. ACKNOWLEDGMENTS

VIII. REFERENCES

1. Matsuoka, Masyama & Ida, *Supplementary Journal of Japanese Society of Applied Physics*, Vol 39, pp 94-101, 1970

2. Harnden, Martzloff, Morris, and Golden, "Metal-oxide Varistor: a New Way to Suppress Transients," *Electronics*, October 1972.

3. Sakshaug, Kresge, and Miske, "A New Concept in Station Arrester Design," IEEE Transactions-PES-96, March/April 1977.

4. Martzloff, "Transient Overvoltage Protection: The Implications of New Techniques," *Proceedings, EMC Zurich 1981*.

5. UL Standard 1449, *Transient Voltage Surge Suppressors* (1980).

6. Martzloff and Leedy, "Selecting Varistor Clamping Voltage: Lower Is Not Better!" *Proceedings, EMC Zurich 1989*.

7. Key, Mansoor, and Martzloff "No Joules for Surges: Relevant and Realistic Assessment of Surge Stress Threats," *Proceedings, 7th International Conference on Harmonics and Quality of Power*, Las Vegas, September 1996.

8. Key and Martzloff, "Surging the Upside-Down House: Looking into Upsetting Reference Voltages," *Proceedings, PQA'94*, Amsterdam, October 1994.

9. IEC Publication 664, *Insulation coordination within low-voltage systems, including clearances and creepage distances for equipment*, 1980.

10. Standler, "Coordination of Surge Arresters For Use on Low-voltage Mains," *Proceedings, EMC Zurich 1991*.

11. Lai and Martzloff, "Coordinating Cascaded Surge-protective Devices: High-Low vs. Low-High," *Conference Record, IEEE-IAS Meeting*, October 1991. Also in *IEEE Transactions, IAS 29-4 1993*.

12. Hostfet and Huse, "Coordination of Surge Protective Devices in Power Supply Systems: Needs for Protection," *Proceedings, ICLP 1992*.

13. Hasse, Wiesinger, Zahlmann and Zischank, "Principle for an Advanced Coordination of Surge Protective Devices in Low Voltage Systems," *Proceedings, ICLP 1994*.

14. Rousseau and Perche, "Coordination of Surge Arresters in the Low-Voltage Field," *Proceedings, 17th International Telecommunications Conference* (INTELEC 95), 1995.

15. *Transient Voltage Suppression Devices*, Harris Corp., 1990.

16. IEEE C62.33-1982 (Reaffirmed 1989). *IEEE Standard Test Specifications for Varistor Surge-Protective Devices*.

17. IEEE C62.41-1991, *IEEE Recommended Practice on Surge Voltages in Low-Voltage AC Power Circuits*.

18. IEEE C62.45-1992, *IEEE Guide on Surge Testing for Equipment Connected to Low-Voltage AC Power Circuits*.

19. Mansoor and Martzloff, "Driving High Surge Currents into Long Cables: More Begets Less," *IEEE Transactions PWRD 12, No.3, July 1997*.

20. Goedde, Dugan and Rowe, "Full Scale Lightning Surge Tests of Distribution Transformers and Secondary Systems," *IEEE - PES Transmission and Distribution Conference Record*, Dallas TX, September 1991.

21. Martzloff and Gauper, "Surge and High-Frequency Propagation in Industrial Power Lines," *IEEE Transactions IA-22*, July 1986.

22. EPRI, "Electromagnetic Transients Program (EMTP), Version 2.0; Volume 1; Main Program; Volume 2: Auxiliary Routines" *EPRI Report EL-6421-L*, July 1989.

23. Martzloff, Mansoor, Phipps and Grady, "Surging the Upside-Down House: Measurements and Modeling Results," *Proceedings, PQA'95 Conference*, EPRI, 1995.

Arshad Mansoor (M' 1995) is an Electrical Systems Engineer at the EPRI Power Electronics Applications Center (PEAC). He received his MS and Ph.D. in electrical engineering from the University of Texas, Austin in 1992 and 1994 respectively. His areas of interest include Power Quality, power systems transients analysis, harmonics, surge propagation and protection, and EMTP model development.

François Martzloff (M'1956, F'1983) Born and educated in France, with additional MS degrees from Georgia Tech and Union College, worked at General Electric for 29 years and now 12 years at the National Institute of Standards and Technology. He is contributing to several committees for the development of standards on EMC, surge protection and Power Quality in the IEEE and the IEC.

Kermit Phipps is in charge of testing and evaluating equipment performance in accordance with standards of ANSI, IEEE, IEC, Military, UL, and the EPRI System Compatibility Test Protocols. At PEAC, he has conducted laboratory investigations of lamp ballasts, surge-protective devices, uninterruptible power supplies, and personal computers. He is the author of test protocols and research papers on surge propagation and power quality.