Progress report on Electrical Metrology at VSL (2015 – 2017)

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Subfield DC

DC voltage and Josephson

Within the JRPs “Q-wave” (finished in 2016) and its successor “QuADC” (started in 2016) VSL is working on the practical and theoretical aspects of quantum waveform metrology, including generation of arbitrary Josephson signals, the deviation problem of voltage leads at higher frequencies, a Josephson delta-sigma converter, voltage scaling and uncertainty calculations. After initial work on changing the inductance of the voltage leads, the MHz resonance was treated theoretically as a reflected wave problem [1]. A new solution is proposed and the practical details have been simulated, showing that uncertainties on the order of 10 ppm are within reach for frequencies up to 1 MHz [2]. Measurements were performed at PTB in a small cryostat to reduce the deviation significantly [3]. Further work has been performed on the electronics for a Josephson delta-sigma converter [4].

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Resistance

A study was made on the calibration of teraohmmeters. The influence of several setting parameters, including the triggering, was evaluated. This has significantly lowered the achievable uncertainty in calibration of these meters.

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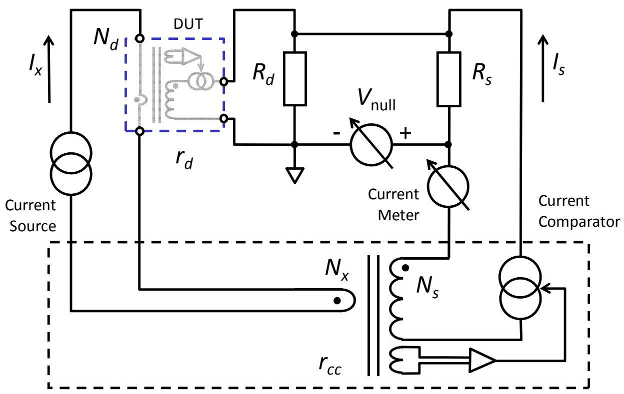
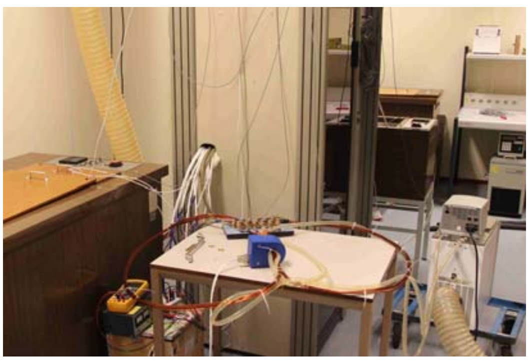
DC current

The measurement range of the previously developed system for calibration of DC current ratios has been extended from 600 A to 1200 A. The uncertainty that can be achieved with the VSL DC current ratio system is around 0.5 ppm [5]. In the case of the Euramet.EM-S35 comparison, the final uncertainty was 1 ppm, due to limitations in the behaviour of the travelling standard (stability, current conductor position sensitivity). We are waiting for the results of the EM-S35 comparison to become available.





The VSL system has been used to verify the linearity of a new commercial device to the level of 1 ppm.

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Subfield LF

Impedance

Experiments have been performed to bridge the traceability gap for impedance measurements in the frequency range between 10 kHz and 1 GHz at impedance levels close to 50 Ω. At the low frequency end, traceability is derived from the Quantum Hall Effect, calculable AC-DC resistors and capacitance for the phase angle. At the high frequency end, traceability is derived from microwave air-lines. In the intermediate frequency range, a comparison was made between the two approaches using coaxial 50 Ω standards with low frequency dependence in this range. A good agreement was found between the two approaches [6].

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AC/DC Transfer

VSL results in the Euramet AC/DC current comparison, as made available in 2016, confirmed the CMC.

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Power Quality

In 2015, the PQ calibration setup has been ISO 17025 accredited both for calibrations of a variety of parameters and for conformity assessment tests with respect to the IEC 61000-4-30 using the IEC 62586-2 (in collaboration with NMi Certin, a sister organization of VSL and notified body in the Netherlands). Several calibrations and conformity assessment tests have been performed since then.

Within the framework of the European EMRP SmartGrid-II project [7], work has been performed in collaboration with TU Eindhoven on the analysis of propagation of harmonics in a real distribution grid from Enduris. From the measurements and calculations the harmonic impedance of the LV side of the distribution grid was determined [8].

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Wideband Power

Within the JRP MESaIL, "Metrology for Efficient and Safe Innovative Lighting", VSL is working on two tasks relevant to electrical measurement.

In the preceding project JRP ENG05, it was established that the source impedance and the presence of harmonics in the AC power supply prevented repeatable measurements of the RMS current, power factor and electrical power consumed by SSL devices at different laboratories. A document is prepared to describe the design considerations, materials and methods to be used in the development of the Impedance Stabilisation Network (ISN). The ISN is used in electrical parameters measurement of Solid State Lighting (SSL) products. The purpose of the device is to reduce the effect of source impedance of AC voltage source, at the same time, the ISN allows the SSL under test working in the same condition.

The aim of the second task is to develop an electronic load with similar electrical behaviour as SSL devices in this project. Key features of the electronic load are rapid stabilization and switchable impedance to simulate typical SSL topologies. Two designs will be implemented. The first one is a dummy load and the second one is an electrical load with thermal stabilizer.

New uncertainty sources with respect to conventional lighting sources are determined and their effects are quantified in [9]. An online tool is created using Google app engine and hosted in http://uncertainty100.appspot.com/. It provides the possibility to do practical uncertainty evaluation for the SSL industry.

Within the JRP PhotoLED, "Future photometry based on solid-state lighting products", which started in 2016, VSL is developing AC-driven luminous flux transfer standards for laboratories where no DC power supplies are available for routine calibrations.

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Phasor measurement units (PMUs)

In the EMRP JRP "Smart Grid II" project, VSL is actively involved in research on PMUs [10]. Last year, the VSL system for testing PMUs has been further developed, with a focus on characterising the time delays in the system in order to allow for accurate phase calibrations. The preliminary results have been presented at CPEM2016 [11].

A second major line of research concerns applications of PMUs in on-site measurements in electricity grids, for example with the aim to accurately determine line impedances or fault location. Together with IMBIH an improved algorithm for determining line impedance using PMU data has been developed and evaluated. For the evaluation a laboratory model grid has been developed.

The joint project with Enduris, one of the Dutch distribution system operators, on the application of PMUs in distribution grids was continued. Six PMUs have been installed in a 50 kV ring that is heavily loaded by renewable energy sources (wind, CHP). The resulting PMU data has been used within the EMRP "Smart Grid II" and "GridSens" projects. In the latter project, also the aggregation of smart meter data has been analysed as input for state estimation algorithms, as PMUs will also be used [12].

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Non-conventional Transducers and Instrument Transformers

The EMRP JRP on "Future grids" started in May 2014. Part of the project aims at adjusting the current measurements setups to accept signals from non-conventional transformers having non-conventional voltage/current/digital outputs. A second part of the VSL involvement in this project is the calibration of commercial transformer test sets suitable for testing non-conventional transformers. A Set of two digital controlled current transformers with binairy winding ratios has been developed which enable to comparison of two currents in phase and ratio/magnitude. Both CT's show errors in the order of a few ppm. Also a set of two voltage dividers have been made based on a R2R divider topology. Results from these dividers have to be evaluated.

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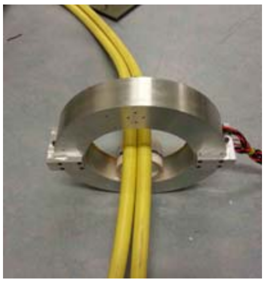
High voltage and high current

Within the ELPOW EMPIR project, VSL has continued its work on the non-invasive measurement system for on-site accurate measurement of AC currents. An improved design for openable core CT (OCCT) is presently under development. Several options for remote readout of the OCCT have been evaluated and a start has been made with the implementation of the most promising option.



VSL results in the Euramet CT comparison [13], as made available in draft A in 2016, confirmed the CMC, showing VSL to have one of the lowest uncertainties worldwide for currents up to 8 kA [14].

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Transformer Load Loss

Significant progress has been made in the realisation of a setup for on-site system calibration of commercial Power Transformer Loss Measurement Systems (TLMS). This work is part of the new European research project "Metrology for the Electrical Power industry" (ELPOW), where the goal is to realize a transportable power loss reference setup for calibration at voltages up to 100 kV and currents up to 2 kA, with uncertainty better than 50 μW/VA [15],[16].
In the past year, the complete system was built up and the components of the setup were calibrated (voltage channel, current channel, power meter). Subsequently, a large series of tests have been performed on the realisation and verification of the feedback loop designed to generate the 2 kA test current with a stable and known phase with respect to the applied 100 kV test voltage. The results achieved so far indicate that under laboratory conditions, with relatively stable voltage signal frequency, a noise in the measurements of better than 10 μW/VA (10 μrad) can be achieved. A first actual on-site test showed a significantly larger noise of around 30 μW/VA. Present work concentrates on refining the feedback loop.

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Subfield RF&MW including EM fields

RF & MW

Traceable characterization of precision coaxial air line standard

A number of facilities are clustered together for traceable characterization of precision coaxial air line standards. The following facilities are currently development:

- Coaxial air line diameter measurements based on air-gauging

  This fully automated measurement system is currently under development and will be used for coaxial air line diameter measurements over entire length of the line section with minimum step size resolution of 10 µm. The system is suitable for characterization of air lines with 2.4 mm, 2.92 mm, 3.5 mm and 7 mm connectors.

- Coaxial connector parameterization
  A set of calibrated metrology grade screw-on connector gauges and high-end digital microscopes are used for parameterization of coaxial connectors. The parameterization results are used to calculate Scattering parameters (**S** parameters) of the connector.

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Primary standard for attenuation measurements up to 50 GHz

A primary standard for attenuation measurements is under development. The system is suitable for frequencies from 2.5 MHz up to 50 GHz. The attenuation measurements are based on the IF-substitution method and will be traceable through calibrated low frequency IVD standards. The system is currently validated for frequencies up to 18 GHz [6] and is expected to be extended up to 50 GHz in the next year.

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Scattering parameters measurement

S parameter measurements related activities at VSL concentrate on realization of state-of-the-art measurement accuracy for frequencies from 1 kHz up to 50 GHz of devices with precision coaxial connectors.

VNA measurement & uncertainty software

VSL is extending the S parameter measurement capability with advanced S parameter measurement software. The measurement software is suitable for extraction of uncorrected measurement data from the VNA and included wide range of calibration techniques. The software includes automated algorithms for assessment of systems uncertainty contributions and subsequently automatically calculates total measurement uncertainty as well.

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Power measurements

A fully automated power sensor calibration facility is developed. The measurement method is based on the direct-comparison technique and covers frequencies from 1 kHz to 50 GHz in a single sweep. The measurement system is supported by advanced measurement and uncertainty calculation software, capable of calculating the calibration factor and the corresponding uncertainty values instantaneously during the measurement.

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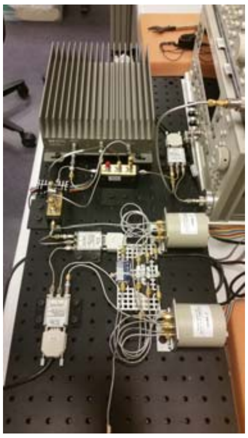

14IND02-PlanarCal

A European joint research project (JRP) is dedicated towards development of traceability chain for planar S-parameter measurements and extension towards nanoscale devices.

VSL will extend S-parameter measurements to highly mismatched nano-scale devices. VSL and Delft University of Technology have developed an interferometric based VNA measurement system suitable for high-gamma measurements.

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EM-fields

JRP IND60-EMC Industry

The project ended on July 2016.

The consortium has organized three dissemination activities in 2016:

- APEMC (Asia-Pacific International Symposium on Electromagnetic Compatibility & Signal Integrity), 19-21 May 2016, Senzhen, China
- Final workshop of the EMRP IND60 EMC Project, 3 June 2016, Delft, The Netherlands
- EMC EUROPE 2016, Wroclaw, Poland, September 5-9, 2016

In these three workshops, VSL presented the achievements obtained in the project.

In APEMC, VSL presented a paper [17]. A "parallel LISN" alternative test method is used as a case study to analyze how to calculate the uncertainty for the conducted emission ATM (Alternative test method). The dominant uncertainty comes from the unknown grid impedance. This item is analyzed for three conditions: without decoupling, with additional inductance and with correction using impedance measurement. The second solution is the simplest and third solution can bring the lowest uncertainty.

A conducted emission reference source with variable emission level is developed in VSL. It is used for round-robin tests. After circulating around Europe, totally eleven test labs have evaluated their conducted emission test capabilities using this round-robin test device. The report is prepared and a paper has been written [18].

VSL has also participated the development and evaluation of the harmonic round-robin test devices and conducted immunity round-robin test device in this project.

Project website: www.emc-industry.com

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Participation in comparisons

- CCEM-K2.2012, Comparison of resistance standards at 10 MΩ and 1 GΩ. VSL measurements performed June – July 2014.
- EURAMET.EM-K12, AC/DC current transfer, finished in 2016.
- EURAMET.EM-S33, High voltage AC, finished in 2016.
- EURAMET.EM-S35, Comparison of High-DC Current Ratio Standard. VSL measurements Feb – Mar 2013. Draft A report expected in 2017.
- EURAMET.EM-S37, Comparison of AC current ratio. VSL measurements 2014. Draft A circulated in 2016.
- CCEM.RF-K5c comparison on S-parameter measurements in coaxial 3.5 mm connectors. The VSL measurement results are submitted.
- CCEM.RF-K26 High frequency attenuation below 40 GHz, VSL will perform measurements end of 2016

List of publications

[1] H.E. van den Brom, D. Zhao, and E. Houtzager, “Voltage Lead Errors in an AC Josephson Voltage Standard: Explanation in Terms of Standing Waves”, in Proc. Conference on Precision Electromagnetic Measurements (CPEM 2016), 10-15 July 2016, Ottawa, Canada

[2] D. Zhao, H.E. van den Brom, and E. Houtzager, “Mitigating Voltage Lead Errors of an AC Josephson Voltage Standard by Impedance Matching”, submitted for publication

[3] Helko E. van den Brom, Oliver F.O. Kieler, Stephan Bauer, and Ernest Houtzager, “AC-DC Calibrations With a Pulse-driven AC Josephson Voltage Standard Operated in a Small Cryostat”, accepted for publication in IEEE Trans. Instrum. Meas., DOI 10.1109/TIM.2017.2662381

[4] Jane Ireland, Alice Cryer, Jonathan M. Williams, Ernest Houtzager, Ralph Hornecker, and Helko E. van den Brom, “Design of delta-sigma feedback loop for quantum voltage digitizer”, CPEM 2016 Conference Digest, Ottawa, Canada, 10-15 July 2016

[5] Gert Rietveld, Jan H. N. van der Beek, and Ernest Houtzager, “Accurate DC Current Ratio Measurements for Primary Currents up to 600 A”, IEEE Transactions on Instrumentation and Measurement 64, No. 11, pp. 3055 – 3061 (2015).

[6] Faisal Mubarak, Erik Dierikx and Gert Rietveld, “Traceable DC – 18 GHz Characterization of Coaxial 50 Ω Impedance Standards”, CPEM 2016 Conference Digest, Ottawa, Canada, 10-15 July 2016

[7] P.S. Wright, G. Rietveld, H.E. van den Brom, G. Crotti and J.P. Braun, “Smart Grid Power Quality and Stability Measurements in Europe”, CPEM 2016 Conference Digest, Ottawa, Canada, 10-15 July 2016

[8] V. Ćuk, F. Ni, W. Jin, A. Jongepier, H.E. van den Brom, G. Rietveld, M. Ačanski, and J.F.G. Cobben, “Measurement of the Harmonic Impedance of the Aggregated Distribution Network”, ICHQP conference digest, Belo Horizonte, Brazil, 16-19 October 2016.

[9] D. Zhao, G.Rietveld, J.-P.Braun, F.Overney, T. Lippert and A.Christensen, "Traceable measurements of the electrical parameters of solid-state lighting products", Metrologia 53, pp. 1384–1394 (2016).

[10] Gert Rietveld, Arjen Jongepier, Joeri van Seters, Marco Visser, Pei Liu, Milos Acanski, Dennis Hoogenboom, and Helko E. van den Brom, “Application of PMUs for monitoring a 50 kV distribution grid,” Proceedings of the 23rd International Conference and Exhibition on Electricity Distribution (CIRED), Lyon, France, pp. 1 – 5 (2015)

[11] Milos Acanski, Gert Rietveld, and Dennis Hoogenboom, “Accurate Phase Calibration of PMUs and PMU Calibrators”, Proceedings of the 2016 Conference on Precision Electromagnetic Measurements (CPEM 2016), Ottawa, Canada, pp. 1 – 2 (2016).

[12] F.Ni, P.H.Nguyen, J.F.G.Cobben, H.E.van den Brom, D. Zhao, "Uncertainty Analysis of Aggregated Smart Meter Data for State Estimation", in Proc. 2016 IEEE International Workshop on Applied Measurements for Power Systems (AMPS 2016), 28-30, Sept. 2016, Aachen, Germany

[13] K. Draxler, R. Styblíková, G. Rietveld, H. van den Brom, M. Schnaitt, W. Waldmann, E. Dimitrov, T. Cincar-Vujovic, B. Pączek, G. Sadkowski, G. Crotti, R. Martín, F. Garnacho, I. Blanc, R. Kämpfer, C. Mester, A. Wheaton, E. Mohns, A. Bergman, M. Hammarquist, H. Çayci, J. Hällström, E-P. Suomalainen, “International Comparison of

Instrument Current Transformers up to 10 kA at 50 Hz Frequency", Proceedings of the 2016 Conference on Precision Electromagnetic Measurements (CPEM 2016), Ottawa, Canada, pp. 1 – 2 (2016).

[14] Helko E. van den Brom, Gert Rietveld, and Eddy So, "Sampling Current Ratio Measurement System for Calibration of Current Transducers up to 10 kA with $5 \cdot 10^{-6}$ Uncertainty", IEEE Transactions on Instrumentation and Measurement 64, No. 6, pp. 1685 – 1691 (2015).

[15] E. Houtzager, M. Acanski, and G. Rietveld, "Reference setup for the calibration of power transformer loss measurement systems", Proceedings of the 2016 Conference on Precision Electromagnetic Measurements (CPEM 2016), Ottawa, Canada, pp. 1 – 2 (2016).

[16] Gert Rietveld, Ernest Houtzager, and Dongsheng Zhao, "Impact of the Ecodesign Directive on Traceability in Power Transformer Loss Measurements", Proceedings of the 23rd International Conference and Exhibition on Electricity Distribution (CIRED), Lyon, France, pp. 1 – 5 (2015).

[17] D. Zhao, S.Cakir and O. Sen, "Uncertainty Evaluation of an Alternative Conducted Emission Test Method" in Proc. of APEMC (Asia-Pacific International Symposium on Electromagnetic Compatibility & Signal Integrity and Technical Exhibiton), pp912—915, 19-21 May 2016, Senzhen, China

[18] E.Tas, S.Cakir, M.Cetintas, P.Hamouz, T.Isbring, M.Kokalj, D.Lopez, U.Lundgren, D.Mandaris, B.Pinter, M.Pořiz, M.Pous, F.Pythoud, O.Sen, F.Silva, M.Svoboda, B.Trincaz, and D. Zhao, "Proficiency Testing for Conducted Immunity with a new Round Robin Test Device" in Proc. of the 2016 International Symposium on Electromagnetic Compatibility - EMC EUROPE 2016, pp. 274—279, Wroclaw, Poland, September 5-9, 2016

[19] Gert Rietveld, Jean-Pierre Braun, Ricardo Martin, Paul S. Wright, Wiebke Heins, Nikola Ell, Paul Clarkson, and Norbert Zisky, "Measurement Infrastructure to Support the Reliable Operation of Smart Electrical Grids", IEEE Transactions on Instrumentation and Measurement 64, No. 6, pp. 1355 - 1363 (2015).