

Comité consultatif d'électricité (CCE)

Consultative Committee
for Electricity (CCE)

Rapport de
la 21^e session
(juin 1997)
Report of
the 21st Meeting
(June 1997)

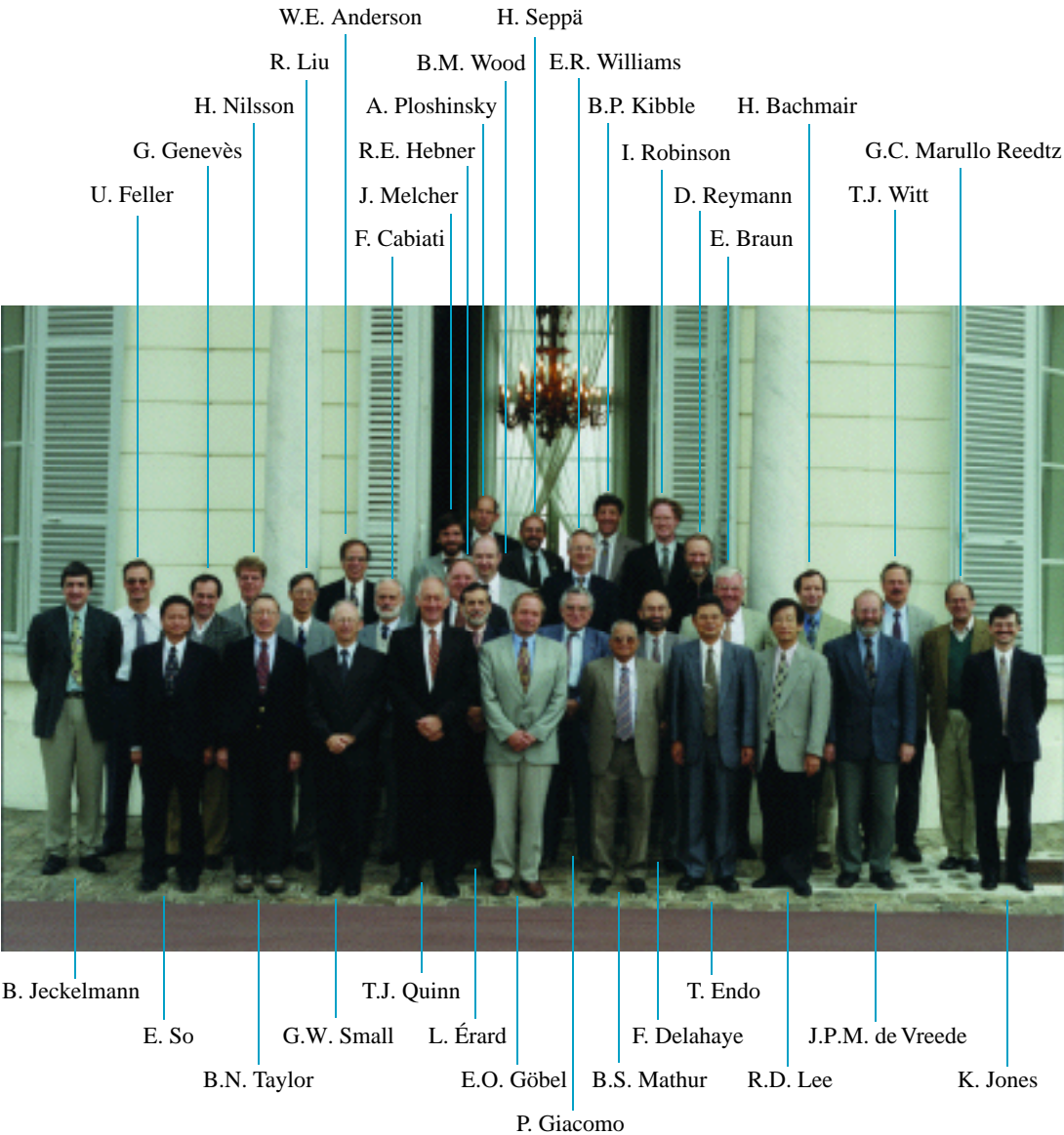


Bureau
international
des poids
et mesures

Organisation
intergouvernementale
de la Convention
du Mètre

Comité consultatif d'électricité ■ 21^e session (juin 1997)
Consultative Committee for Electricity ■ 21st Meeting (June 1997)

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Bureau International des Poids et Mesures

Consultative Committee for Electricity (CCE)

21st Meeting (June 1997)

Note on the use of the English text

To make its work more widely accessible the Comité International des Poids et Mesures publishes an English version of its reports.

Readers should note that the official record is always that of the French text. This must be used when an authoritative reference is required or when there is doubt about the interpretation of the text.

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MEMBER STATES OF THE METRE CONVENTION

Argentina	Japan
Australia	Korea (Dem. People's Rep. of)
Austria	Korea (Rep. of)
Belgium	Mexico
Brazil	Netherlands
Bulgaria	New Zealand
Cameroon	Norway
Canada	Pakistan
Chile	Poland
China	Portugal
Czech Republic	Romania
Denmark	Russian Federation
Dominican Republic	Singapore
Egypt	Slovakia
Finland	South Africa
France	Spain
Germany	Sweden
Hungary	Switzerland
India	Thailand
Indonesia	Turkey
Iran (Islamic Rep. of)	United Kingdom
Ireland	United States
Israel	Uruguay
Italy	Venezuela

THE BIPM AND THE METRE CONVENTION

The Bureau International des Poids et Mesures (BIPM) was set up by the Metre Convention signed in Paris on 20 May 1875 by seventeen States during the final session of the diplomatic Conference of the Metre. This Convention was amended in 1921.

The BIPM has its headquarters near Paris, in the grounds (43 520 m²) of the Pavillon de Breteuil (Parc de Saint-Cloud) placed at its disposal by the French Government; its upkeep is financed jointly by the Member States of the Metre Convention.

The task of the BIPM is to ensure worldwide unification of physical measurements; its function is thus to:

- establish fundamental standards and scales for the measurement of the principal physical quantities and maintain the international prototypes;
- carry out comparisons of national and international standards;
- ensure the co-ordination of corresponding measurement techniques;
- carry out and co-ordinate measurements of the fundamental physical constants relevant to these activities.

The BIPM operates under the exclusive supervision of the Comité International des Poids et Mesures (CIPM) which itself comes under the authority of the Conférence Générale des Poids et Mesures (CGPM) and reports to it on the work accomplished by the BIPM.

Delegates from all Member States of the Metre Convention attend the General Conference which, at present, meets every four years. The function of these meetings is to:

- discuss and initiate the arrangements required to ensure the propagation and improvement of the International System of Units (SI), which is the modern form of the metric system;

- confirm the results of new fundamental metrological determinations and various scientific resolutions of international scope;
- take all major decisions concerning the finance, organization and development of the BIPM.

The CIPM has eighteen members each from a different State: at present, it meets every year. The officers of this committee present an annual report on the administrative and financial position of the BIPM to the Governments of the Member States of the Metre Convention. The principal task of the CIPM is to ensure worldwide uniformity in units of measurement. It does this by direct action or by submitting proposals to the CGPM.

The activities of the BIPM, which in the beginning were limited to measurements of length and mass, and to metrological studies in relation to these quantities, have been extended to standards of measurement of electricity (1927), photometry and radiometry (1937), ionizing radiation (1960) and to time scales (1988). To this end the original laboratories, built in 1876-1878, were enlarged in 1929; new buildings were constructed in 1963-1964 for the ionizing radiation laboratories and in 1984 for the laser work. In 1988 a new building for a library and offices was opened.

Some forty-five physicists and technicians work in the BIPM laboratories. They mainly conduct metrological research, international comparisons of realizations of units and calibrations of standards. An annual report, published in the *Procès-Verbaux des Séances du Comité International des Poids et Mesures*, gives details of the work in progress.

Following the extension of the work entrusted to the BIPM in 1927, the CIPM has set up bodies, known as Consultative Committees, whose function is to provide it with information on matters that it refers to them for study and advice. These Consultative Committees, which may form temporary or permanent working groups to study special topics, are responsible for coordinating the international work carried out in their respective fields and for proposing recommendations to the CIPM concerning units.

The Consultative Committees have common regulations (*BIPM Proc.-Verb. Com. Int. Poids et Mesures*, 1963, **31**, 97). They meet at irregular intervals. The chairman of each Consultative Committee is designated by the CIPM and is normally a member of the CIPM. The members of the Consultative Committees are metrology laboratories and specialized institutes, approved by the CIPM, which send delegates of their choice. In addition, there are individual members appointed by the CIPM, and a representative of the BIPM

(Criteria for membership of Consultative Committees, *BIPM Proc.-Verb. Com. Int. Poids et Mesures*, 1996, **64**, 124). At present, there are nine such committees:

1. The Consultative Committee for Electricity and Magnetism (CCEM), new name given in 1997 to the Consultative Committee for Electricity (CCE) set up in 1927;
2. The Consultative Committee for Photometry and Radiometry (CCPR), new name given in 1971 to the Consultative Committee for Photometry (CCP) set up in 1933 (between 1930 and 1933 the CCE dealt with matters concerning photometry);
3. The Consultative Committee for Thermometry (CCT), set up in 1937;
4. The Consultative Committee for Length (CCL), new name given in 1997 to the Consultative Committee for the Definition of the Metre (CCDM), set up in 1952;
5. The Consultative Committee for Time and Frequency (CCTF), new name given in 1997 to the Consultative Committee for the Definition of the Second (CCDS) set up in 1956;
6. The Consultative Committee for Ionizing Radiation (CCRI), new name given in 1997 to the Consultative Committee for Standards of Ionizing Radiation (CCEMRI) set up in 1958 (in 1969 this committee established four sections: Section I (X- and γ -rays, electrons), Section II (Measurement of radionuclides), Section III (Neutron measurements), Section IV (α -energy standards); in 1975 this last section was dissolved and Section II was made responsible for its field of activity);
7. The Consultative Committee for Units (CCU), set up in 1964 (this committee replaced the “Commission for the System of Units” set up by the CIPM in 1954);
8. The Consultative Committee for Mass and Related Quantities (CCM), set up in 1980;
9. The Consultative Committee for Amount of Substance (CCQM), set up in 1993.

The proceedings of the General Conference, the CIPM and the Consultative Committees are published by the BIPM in the following series:

- *Comptes Rendus des Séances de la Conférence Générale des Poids et Mesures*;
- *Procès-Verbaux des Séances du Comité International des Poids et Mesures*;
- *Reports of Meetings of Consultative Committees*.

The BIPM also publishes monographs on special metrological subjects and, under the title *Le Système International d’Unités (SI)*, a brochure, periodically

updated, in which are collected all the decisions and recommendations concerning units.

The collection of the *Travaux et Mémoires du Bureau International des Poids et Mesures* (22 volumes published between 1881 and 1966) and the *Recueil de Travaux du Bureau International des Poids et Mesures* (11 volumes published between 1966 and 1988) ceased by a decision of the CIPM.

The scientific work of the BIPM is published in the open scientific literature and an annual list of publications appears in the *Procès-Verbaux* of the CIPM.

Since 1965 *Metrologia*, an international journal published under the auspices of the CIPM, has printed articles dealing with scientific metrology, improvements in methods of measurement, work on standards and units, as well as reports concerning the activities, decisions and recommendations of the various bodies created under the Metre Convention.

LIST OF MEMBERS OF THE CONSULTATIVE COMMITTEE FOR ELECTRICITY

as of 24 June 1997

President

E.O. Göbel, member of the Comité International des Poids et Mesures,
Physikalisch-Technische Bundesanstalt, Braunschweig.

Executive secretary

Dr T.J. Witt, Bureau International des Poids et Mesures [BIPM], Sèvres.

Members

Bureau National de Métrologie: Laboratoire Central des Industries Électriques
[BNM-LCIE], Paris.

CSIR, Division of Production Technology [DPT], Pretoria.

CSIRO, Division of Applied Physics [CSIRO], Lindfield.

Electrotechnical Laboratory [ETL], Tsukuba.

D.I. Mendeleyev Institute for Metrology [VNIIM], St Petersburg.

Istituto Elettrotecnico Galileo Ferraris [IEN], Turin.

Korea Research Institute of Standards and Science [KRISS], Taejon.

National Institute of Metrology [NIM], Beijing.

National Institute of Standards and Technology [NIST], Gaithersburg.

National Physical Laboratory [NPL], Teddington.

National Physical Laboratory of India [NPLI], New Delhi.

National Research Council of Canada [NRC], Ottawa.

Nederlands Meetinstituut: Van Swinden Laboratorium [NMI-VSL], Delft.

Office Fédéral de Métrologie [OFMET], Wabern.

Physikalisch-Technische Bundesanstalt [PTB], Braunschweig.

The Director of the Bureau International des Poids et Mesures [BIPM],
Sèvres.

CONSULTATIVE COMMITTEE
FOR ELECTRICITY

REPORT
OF THE 21st MEETING

(24-25 June 1997)

TO THE COMITÉ INTERNATIONAL
DES POIDS ET MESURES

Agenda

- 1 Opening of the meeting; designation of a rapporteur.
- 2 Matters related to fundamental constants and the SI:
 - 2.1 Report of the working group on electrical methods to monitor the stability of the international prototype of the kilogram;
 - 2.2 Report on the status of least-squares adjustment of fundamental constants;
 - 2.3 Advances in realizations of SI electrical units and improvements in our knowledge of K_J and R_K ; prospects for metrological use of single electron tunnelling devices.
- 3 Progress in and prospects of carrying out accurate measurements of quantized Hall resistance at frequencies in the kilohertz range.
- 4 Availability of arrays of Josephson junctions and quantum Hall effect samples.
- 5 Key comparisons of electrical quantities:
 - 5.1 Report of the working group on international comparisons;
 - 5.2 Discussion of proposed key comparisons;
 - 5.3 Progress or final reports on ongoing international comparisons (at DC or low-frequency AC) organized by the CCE;
 - 5.4 Progress on the organization of new comparisons.
- 6 Report on the meeting of the working group on radiofrequency quantities.
- 7 Activities of the Electricity section of the BIPM.
- 8 Future activities of the CCE.
- 9 Other business.
- 10 Date of next meeting.

1 OPENING OF THE MEETING; DESIGNATION OF A RAPPORTEUR

The Consultative Committee for Electricity (CCE) held its twenty-first meeting on 24 and 25 June 1997 at the Bureau International des Poids et Mesures (BIPM), Pavillon de Breteuil, at Sèvres.

The following were present: W.E. Anderson (NIST), H. Bachmair (PTB), E. Braun (PTB), F. Cabiati (IEN), J.P.M. de Vreede (NMI-VSL), T. Endo (ETL), L. Énard (BNM-LCIE), U. Feller (OFMET), G. Genève (BNM-LCIE), E.O. Göbel (President of the CCE), R.E. Hebner (NIST), B. Jeckelmann (OFMET), B.P. Kibble (NPL), R.D. Lee (KRISS), R. Liu (NIM), G.C. Marullo Reedtz (IEN), B.S. Mathur (NPLI), A. Ploshinsky (VNIIM), T.J. Quinn (Director of the BIPM), I. Robinson (NPL), G.W. Small (CSIRO), E. So (NRC), B.N. Taylor (NIST), E.R. Williams (NIST), B.M. Wood (NRC).

Invited: K. Jones (DSIR-MSL), H. Nilsson (SP), H. Seppä (VTT).

Also present: P. Giacomo (Director Emeritus of the BIPM); F. Delahaye, J. Melcher, D. Reymann, T.J. Witt (BIPM).

The President of the CCE, Prof. Göbel, and the Director of the BIPM welcomed participants. Dr Wood was appointed rapporteur. A total of forty-five documents was presented to the meeting for consideration by the CCE. A list is given in Annexe E 1 (page 63). The draft agenda was considered and approved.

2 MATTERS RELATED TO FUNDAMENTAL CONSTANTS AND THE SI

2.1 Report of the working group on electrical methods to monitor the stability of the international prototype of the kilogram

The President asked delegates to report on current work concerning fundamental constants and SI units in national laboratories.

Dr Kibble reported on progress of the working group on electrical methods to monitor the stability of the international prototype of the kilogram by summarizing the status of different measurements (CCE/97-14). The relative uncertainty in the NRLM mass levitation experiment is presently about 2 parts in 10^6 and it is hoped that future improvements can reduce this to the level of 1 part in 10^7 . In the experiment to measure the Avogadro constant using a silicon artefact, a relative discrepancy of about 3 parts in 10^6 , possibly due to voids in silicon, had yet to be resolved. Future improvements could perhaps decrease the relative uncertainty to about 5 parts in 10^8 . This project will be reviewed in more detail by the CCM working group on the Avogadro constant. The PTB is conducting an experiment using a mass spectrometer to accumulate an accurately measurable mass of gold. The low current level of 0.1 mA presently limits accuracy. The current will have to be increased by at least a factor of ten to achieve a relative uncertainty below 1 part in 10^6 .

Dr Kibble then described the status of different watt balance experiments. He noted that the NIST moving coil watt measurement (CCE/97-5d) had achieved a relative uncertainty of about 1.5×10^{-7} during the previous six months. Results are consistent with those obtained in 1988 by the NPL. However, for reasons that are not yet identified, the distribution of the NIST results does not seem to be completely random. Systematic evaluations of field profile, electrical leakage, electromagnetic interference, DC voltage reference and alignment errors have been completed and all are now believed to be

adequately evaluated. Remaining systematic evaluation deals with effects related to the refractive index of air: this is providing some unexpected results. When this final evaluation is complete the results will be published and the experiment will be modified to be performed in vacuum.

Dr Kibble then reviewed the NPL watt balance experiment. The apparatus is now operating in vacuum. When results of measurements taken in the course of one day are compared and fitted to a fifth-order polynomial the resultant relative scatter is well below 1 part in 10^8 . However, the electrical determination of an unknown mass disagrees with that obtained from the NPL mass standards by about 1 part in 10^6 of the nominal value. He and Dr Robinson are actively seeking the cause of this discrepancy.

Dr Kibble briefly described several new experiments. The OFMET is constructing a new type of watt balance (CCE/97-4) which uses a 100 g test mass. In this design, the moving part of the experiment is separated from the weighing part. The permanent magnet is suspended from the balance, which is a modified commercial instrument. The coil is moved in the magnetic field by an independent mechanism. The apparatus should be assembled by the year 2000.

Another new approach mentioned by Dr Kibble is the suggestion of Dr Cabiati that mechanical and electrical energy can be linked using electric forces applied to a moving electrode rather than magnetic forces applied to a coil. (Details are given in the first two publications cited in CCE/97-34.) Dr Cabiati is studying arrangements in which the electrode would move in the horizontal plane so that no measurement of g would be necessary.

Dr Kibble concluded his presentation by saying that he expects both the NPL and NIST watt balances to achieve relative uncertainties of some parts in 10^8 by mid-1998.

2.2 Report on the status of least-squares adjustment of fundamental constants

Dr Taylor discussed the next CODATA least-squares adjustment of values of fundamental constants. He noted that his goal is to complete the adjustment early in 1998. He reviewed values of K_J (CCE/97-40) including direct results from the CSIRO-NML (1988) electrometer measurements and PTB volt balance (1990), revised values of K_J arising from a recent recalculation of the fine structure constant by Kinoshita (1996) combined with results of various determinations of constants available in 1988, new determinations of the

Avogadro constant by the IRMM and NRLM, IMGCC and PTB, and gyromagnetic ratio measurements by the NIM (1995). Resulting values of K_J indicate that the adopted value K_{J-90} is in excellent agreement with present experimental data and that the assigned uncertainty is still consistent with the data set.

Dr Taylor then described present values of R_K . New data include the revised value of the fine structure constant mentioned above, new determinations of R_K at the NIST (1996) and CSIRO-NML(1996) via calculable capacitors, and a new determination of the low-field gyromagnetic ratio of the proton at the KRISS (1997) combined with other fundamental constants. The adopted value of R_{K-90} is still in excellent agreement with experimental data. Dr Taylor remarked that the uncertainty assigned to R_{K-90} is perhaps slightly too large, but took the view that there was no compelling evidence or need to reduce the assigned uncertainty.

2.3 Advances in realizations of SI electrical units and improvements in our knowledge of K_J and R_K ; prospects for metrological use of single electron tunnelling devices

Following Dr Taylor's summary of improvements in values assigned to K_J and R_K (Section 2.2), discussion turned towards other aspects of realizations of SI units and to the metrological use of single electron tunnelling devices.

Dr Jeckelmann summarized joint work by the OFMET and NRC (CCE/97-4) in which QHR reproducibility was studied as a function of device material, QHR plateau number and sample geometry. In this, the QHR was observed to be independent of these parameters within a relative precision of 3.5×10^{-10} . He also described studies of contact resistance, and recommended that, for work of the highest accuracy, contact resistance should be below 10Ω for the $i = 2$ plateau and 2Ω for $i = 4$. He concluded by saying that the CCE guidelines for QHR measurements still apply at the highest levels of accuracy.

Dr Williams described studies at the NIST (CCE/97-5g) concerning degradation with time of contact resistance in QHR samples from the LEP.

Dr Williams then described NIST experiments on SET pump design (CCE/97-5e) and on charging cryogenic capacitors. He mentioned that capacitance measurements had encountered some difficulties because of noise and high capacitance (of the order of 1 pF) of the shield.

Dr Kibble mentioned recent experiments by Dr Pepper in which a single electron per cycle is transported across a device by surface acoustic waves

(SAW) operating at 2 GHz. This frequency is 1000 times that of conventional SET devices, so the SAW device delivers that much more current. Higher currents could bring the problem of measuring SET currents more squarely into the domain of high-precision measurements with a cryogenic current comparator.

Dr Bachmair described SET measurements (CCE/97-24) at the PTB. These studies concentrated on the noise behavior of SET devices. Spectral analysis showed that all devices have $1/f$ noise characterized by a roll-off frequency of 100 Hz to 1000 Hz and an intensity (at 10 Hz) of $10^{-3} e/\sqrt{\text{Hz}}$ to $10^{-4} e/\sqrt{\text{Hz}}$, one to two orders of magnitude above the estimated intrinsic noise level. The noise in SET transistors was studied as a function of temperature (strong dependence) and current. The noise was found to be independent of substrate material. By observing correlations between noise spectra of adjacent devices they were able to conclude that only a fraction of the observed noise originates from offset (background) charge in the dielectric surroundings. They suspect that offset charge fluctuations in barriers may be the most important source of enhanced noise.

Dr Wood described SET measurements (CCE/97-35) at the NRC. A number of devices, mostly electrometers, have been fabricated and tested at 0.3 K. Coulomb blockade and SET operation have clearly been observed. Offset charges are a problem and bi-stable fluctuations of individual offset charges have been observed. Noise measurements of these devices have given values as low as $3.5 \times 10^{-3} e/\sqrt{\text{Hz}}$ or about one electron in several hours.

Dr Lee indicated that SET studies (CCE/97-8) have begun at the KRISS.

Dr Endo described the SET project (CCE/97-10) at the ETL. Charge pumps have been fabricated and Coulomb blockade has been observed with a three-gate pump.

Mr Énard briefly described the BNM-LCIE project (CCE/97-9) to use a Josephson array to measure the Hall voltage of a QHR device supplied with current from a SET device via a 10 000:1 ratio CCC. SET devices are being produced at the Commissariat à l'Énergie Atomique, Saclay (France).

3 PROGRESS IN AND PROSPECTS OF CARRYING OUT ACCURATE MEASUREMENTS OF QUANTIZED HALL RESISTANCE AT FREQUENCIES IN THE KILOHERTZ RANGE

Dr Anderson described theoretical calculations by the NIST (CCE/97-5f) of intrinsic capacitance and inductance in AC QHR measurements. The conclusion is that no intrinsic frequency dependence of QHR should be observable at present levels of precision.

Dr Marullo Reedtz of the IEN described measurements of longitudinal resistance R_{xx} versus frequency (CCE/97-32) and distortion of the R_{xx} minimum versus frequency. Since distortion occurs at low frequencies some low energy mechanism, conduction by variable range hopping, may be limiting the accuracy of AC QHR measurements.

Mr Delahaye described the AC QHR bridge at the BIPM (CCE/97-2). Measurements at ratios of 1:1 and 1:2 at 1541 Hz have been performed on five samples on the $i = 2$ and $i = 4$ plateaus. Both polarities of magnetic flux density were used. The results were extrapolated to zero current to compensate for a small current dependence. Near 1.6 kHz, relative differences of 1 or 2 parts in 10^7 were observed for different samples and different plateaus. The shapes of the plateaus vary with frequency, but AC plateaus are not as flat as the DC plateaus. Mr Delahaye also showed results of measurements on a special sample with a window etched into the centre to provide a type of internal guarding. For the case of AC, plateaus in this sample were less deformed than those of other samples, but the AC plateau was still unlike that obtained for DC measurements.

Dr Braun told the committee about the meeting of EUROMET QHR experts in Lisbon (Portugal) and his proposal that laboratories should co-operate in studying AC QHR.

Dr Kibble briefly reviewed the NPL work on AC QHR. A linear frequency dependence having a relative value of $1 \times 10^{-7}/\text{kHz}$ can be observed in the

QHR results. He added that AC/DC characteristics were being recalculated for some resistors, particularly those of the Gibbings type.

Dr Wood discussed the NRC AC QHR results (CCE/97-35), which include studies of the dependence of the QHR of several samples on current, frequency and polarity of magnetic flux density. Results for AC measurements of QHR differ in relative value by about 1×10^{-7} from those carried out at DC. However, for AC the plateau resistance versus flux density is markedly different. He also described a new coaxial sample probe for use at 0.3 K which can be used with interchangeable samples.

Dr Jeckelmann indicated that AC QHR measurements have also begun at the OFMET.

Dr Quinn suggested that the CCE create a working group on AC measurements of QHR to foster co-operation among researchers and with the objective, eventually, of developing a set of guidelines for accurate measurement of AC QHR. This was agreed and Dr Braun was chosen as chairman of the working group. Those interested in becoming members included the BIPM, BNM-LCIE, CSIRO, IEN, NIST, NPL, NRC, OFMET, PTB, VNIIM, and VTT. This working group held a short meeting in which three items were resolved:

- It was premature to recommend guidelines for accurate measurements of AC QHR.
- The most immediate goal of the working group should be to establish an exchange programme of QHR samples for AC measurements. (To achieve this, Dr Kibble and Dr Wood offered to recommend a suitable interchangeable sample system.)
- To improve regular communications between members an Internet website should be created to disseminate information to the working group. Its URL is <http://barry.m36sci.nrc.ca:80/acqhr/>.

Note: Dr Wood offered to create the website and this is now in operation.

4 AVAILABILITY OF ARRAYS OF JOSEPHSON JUNCTIONS AND QUANTUM HALL EFFECT SAMPLES

Dr Genève described progress in the fabrication (CCE/97-8) of a new set of QHR samples by the LEP(France). For this project the LEP had already made three batches of QHR wafers and a fourth was being prepared. The first batch had high contact resistances, the second batch had high R_{xx} values and the third batch had lower mobility (19 T^{-1}) than requested. The fourth batch was scheduled for distribution late in 1997.

Dr Braun discussed the production of QHR samples (CCE/97-21) at the PTB. Samples have been fabricated with the $i = 2$ plateau at flux densities varying from 6 T to 12 T. Precision measurements show good agreement with results from LEP samples at 2.2 K. Samples will be available from the PTB on a collaborative basis.

Dr Wood stated that the NRC has now successfully fabricated QHR samples (CCE/97-35). They have moderate carrier concentrations, good current carrying capability and low contact resistances. At the time of the meeting, however, only a few such samples had been tested.

Dr Lee described Josephson array developments at the KRISS. A new wafer design has been created for fabrication of four 10 V arrays and two 1 V arrays on a single wafer. He also mentioned that a superconductor/normal/superconductor Josephson array system with an integrated oscillator is under development (CCE/97-15).

Dr Bachmair discussed progress in the design and optimization of Josephson devices (CCE/97-22) at the PTB. The problem of flux trapping has been resolved. The PTB arrays require frequencies in the range 70 GHz to 75 GHz and powers of 10 mW at 10 V and 1 mW at 1 V. A technology transfer programme has begun with a German company. A project has also begun to develop a resistively shunted, programmable Josephson device.

Dr Endo indicated that while 1 V arrays were still available, the ETL had found it difficult to produce 10 V Josephson arrays (CCE/97-10), so the laboratory was encouraging a commercial firm to produce them.

Dr Hebner stated that while the NIST still had the capability to produce Josephson arrays, it had transferred that technology to the firm Hypres with which it would not compete.

5 KEY COMPARISONS OF ELECTRICAL QUANTITIES

Dr Quinn reviewed document CCE/97-1 and summarized views put at the meeting of directors of national metrology institutes in February 1997. In particular, he mentioned progress in achieving acceptance of an equivalence agreement among member laboratories of the Metre Convention. He noted that in this context “equivalence” does not imply identity, but has the usual dictionary meaning of equality of value, significance or meaning. He made the following points:

- There is a need to have visible, documented equivalence amongst national laboratories.
- The World Trade Organization cannot accept requirement for multiple calibrations of measuring instruments as this is an impediment to trade. Key comparisons are thus a necessary tool to test principal measurement techniques and to achieve this equivalence.
- We need metrological links amongst CCE members, other laboratories and regional metrology organizations.
- Ideally, at least two laboratories from each regional metrology organization should participate in each key comparison organized by the CCE.
- Ideally, key comparisons should be between independent realizations of quantities but, if not, correlation must be taken into account. Bilateral comparisons are still required.
- Results of key comparisons are best evaluated by the appropriate Consultative Committee. Thus the CCE may need to have a working group to provide an initial assessment of principal components to be considered in each key comparison.
- Final acceptance of equivalence is likely to require a quality system, such as ISO *Guide 25*, in each laboratory.

- The eventual goal is to establish equivalence of all calibration services, i.e. to have international recognition of the validity of calibration certificates.

An active discussion followed, and most members expressed strong opinions. At the end of the meeting the committee accepted three statements of principle.

- CCE members agree to reconfirm the list of key comparisons as a basis for establishing equivalence of national electrical standards and measurements.
- Key comparisons in this list are those used to establish the equivalence of national measurement standards. However, key comparisons and their periodicity may not be sufficient to fulfill the requirement of traceability; from time to time other comparisons may be necessary.
- For the purposes of this agreement, metrological equivalence of measurement standards is taken to mean the degree to which these standards are consistent with reference values determined from key comparisons. In this context the reference value is referred to as the key comparison reference value. It can be considered to represent the SI value and is a close, but not necessarily the best, approximation to the SI value. Metrological equivalence of national measurement standards is expressed quantitatively in terms of an equivalence uncertainty defined as the uncertainty of the standard declared by the participating institute (with a coverage factor $k = 2$) increased as necessary for its value to be consistent with the key comparison reference value.

The committee expressed its hope that this last statement, in particular, would become the means to quantify equivalence amongst national laboratories. Dr Hebner stated that he would ask statisticians at the NIST to review and comment on the last statement to ensure that it is statistically justifiable.

Note added in preparing final report of the meeting: The situation concerning equivalence and mutual recognition of standards has evolved quickly since the CCE met. The present authoritative statement of the agreement “Mutual recognition of national measurement standards and calibration certificates issued by national institutes” was initialled by 38 directors of national metrology institutes of member States of the Metre Convention at their meeting in Sèvres on 23-25 February 1998.

5.1 Report of the working group on international comparisons

Dr Hebner discussed reports of the working group on international comparisons (CCE/97-16 and 17) and reviewed both progress (CCE/97-18

and 19) and final reports of international comparisons at DC or low frequency organized by the CCE. (Individual comparisons are detailed in Section 5.3.)

Dr Quinn, on behalf of the Consultative Committee, asked the working group to continue its work and to oversee the selection and periodicity of key comparisons under a new title: the working group on key comparisons. Dr Hebner agreed on behalf of the working group and accepted an invitation to continue as chairman.

5.2 Discussion of proposed key comparisons

Although no additional key comparisons were proposed, several participants suggested possible topics for consideration by the committee.

Dr Kibble presented preliminary results from a EUROMET comparison of 10 pF and 100 pF capacitance standards. The results suggest that in some laboratories the 10:1 scaling of capacitance used is in error by perhaps as much as one part in 10^6 . The AC voltage ratio comparison proposed in document CCE/97-31 may test part of this discrepancy, but he expressed the view that if the discrepancy is not resolved the CCE should consider a 10 pF and 100 pF comparison. This comparison was agreed and has become comparison 97-1 (Section 5.4.1).

Dr Ploshinsky discussed document CCE/97-39, which is a proposal for a comparison of capacitance standards in the range 1nF to 100nF using ceramic capacitors as travelling standards.

Dr Ploshinsky also presented the results (CCE/97-38) of a study of characteristics of resistors manufactured by Krasnodar plant ZIP for use as maintenance and travelling standards of resistance.

It was decided to refer all these proposals to the working group on key comparisons.

Mr Nilsson pointed out that document CCE/97-29 lists current and proposed EUROMET comparisons in electricity.

5.3 Progress or final reports on ongoing international comparisons (at DC or low-frequency AC) organized by the CCE

5.3.1 Comparison 92-1 of 10 pF capacitors (pilot laboratory: NIST)

Dr Anderson described progress with comparison 92-1 on 10 pF capacitors (CCE/97-5a). This comparison began in February 1996 and four laboratories have carried out measurements on travelling standards. The comparison may take longer than anticipated because an extended settling time is required for the travelling standards.

A comparison of 10 pF capacitance standards at 1 kHz was organized by the regional metrology organization COOMET and involved nine laboratories. The results reflect correlations among laboratories that based their capacitance standards on previous comparisons with the VNIIM. A more detailed description is given in document CCE/97-42.

Dr Kibble described a current EUROMET comparison of 10 pF and 100 pF capacitance standards which has already been linked to the CCE comparison. He said that a rather large difference, of the order of 1×10^{-6} , in the 10:1 ratio assigned to 10 pF and 100 pF travelling standards has been uncovered.

5.3.2 Comparison 92-2 of AC power and energy, 50 Hz-60 Hz (pilot laboratory: NIST)

Comparison 92-2 of AC power and energy in the range 50 Hz-60 Hz began in June 1996 (CCE/97-5c). Six laboratories have measured travelling standards and the comparison is about half over. A good link has been established to a EUROMET power comparison piloted by the PTB.

5.3.3 Comparison 92-3 of multi-junction AC/DC transfer devices (pilot laboratory: PTB)

Comparison 92-3 of multi-junction AC/DC transfer devices has been completed (CCE/97-25) and shows excellent agreement among participants. A summary report of this comparison has appeared in *Metrologia* (1997, **34**, 3).

5.3.4 Comparison 92-4 of single junction thermal voltage converters, 50 kHz-100 kHz (pilot laboratory: BNM-LCIE)

Comparison 92-4 of single junction thermal voltage converters, 50 kHz-100 kHz is linked with a EUROMET comparison for which measurements were completed in April 1997 (CCE/97-7). The non-European loop of the CCE comparison began in July 1997.

5.3.5 Comparison 92-5 of single junction thermal voltage converters, 1 MHz-50 MHz (pilot laboratory: NMI-VSL)

Comparison 92-5 of single junction thermal voltage converters in the range 1 MHz-50 MHz is linked to a EUROMET comparison of which the last European loop was completed in January 1997 (CCE/97-12). The non-European loop began in March 1997 and completion is expected by the end of 1997.

5.3.6 Comparison 95-1 of DC resistances of 10 M Ω and 1 G Ω (pilot laboratory: NIST)

Comparison 95-1 of DC resistances of 10 M Ω and 1 G Ω began in September 1996 (CCE/97-5b). There are fourteen participants and the comparison is divided into five loops. It is scheduled to be completed by October 1999.

5.3.7 Extension of comparison 88-1 of inductance at 10 mH (pilot laboratory: PTB)

Dr Bachmair described a comparison of 10 mH inductance at 1 kHz (CCE/97-41), for which the PTB was pilot laboratory. This was an extension of comparison 88-1. Participants were the PTB and three additional laboratories from the regional metrology group COOMET.

5.3.8 Guidelines for comparisons

Dr Quinn presented document CCE/97-20, which is a draft of a EUROMET document outlining guidelines for the organization of comparisons. There was some discussion about criteria for the removal of data after results have been made known to participants. The committee took the view that such a document was useful, but that this particular document is not appropriate for the CCE. The working group on key comparisons was asked to consider this document at its next meeting. Dr Quinn remarked that there is a clear need to circulate a guidance document on Consultative Committee key comparisons and that it was his intention to develop one.

Dr Witt described document CCE/97-26, which summarizes shipping and customs procedures for conducting worldwide comparisons of standards. He recommended that all pilot laboratories review this information before beginning a new international comparison. The document advocates using an ATA Carnet when possible. It also proposes that in cases where customs and shipping seem to be unsatisfactory, pilot laboratories seek the help and support of Consultative Committees to find acceptable alternatives.

5.4 Progress on the organization of new comparisons

Two proposals for CCE comparisons were discussed at the 1995 CCE meeting. Progress in organizing them was reported to the meeting.

5.4.1 Comparison 97-1 of AC voltage ratios (pilot laboratory: NPL)

The NPL presented a detailed proposal (CCE 97-31) for a comparison of AC voltage ratios at an rms energization voltage of 10 V and a frequency of

1000 Hz. Participants have the option of making measurements at five other frequencies ranging from 40 Hz to 5000 Hz. The NPL has offered to be the pilot laboratory, to furnish an 8-dial inductive voltage divider travelling standard and to compile a list of principal uncertainty components. Laboratories interested in participating were requested to contact the NPL. Preliminary interest was expressed by the BNM-LCIE, CSIRO, ETL, IEN, KRISS, NIM, NIST, NPL, NPLI, NRC, PTB, SP, NMI-VSL and VNIIM.

5.4.2 Comparison 97-2 of DC voltage ratios (pilot laboratory: IEN)

Following discussion at the 1995 CCE meeting, Dr de Vreede prepared and circulated a questionnaire with a view to assessing interest in a CCE comparison of DC voltage ratios of 1000 V:10 V and 100 V:1 V and provision of a suitable travelling standard. He said that only five laboratories had responded to the questionnaire (CCE/97-14). Furthermore, no suitable travelling standard seemed to be available.

Dr Marullo Reedtz described the IEN experience with a Datron 4902S divider (CCE/97-33). This has desirable characteristics for a high voltage transfer device, but the IEN has only one of them. Furthermore, it is no longer manufactured. Under these circumstances, at the time of the CCE meeting, Dr Marullo Reedtz could not recommend that a comparison be undertaken using this device.

Dr Hebner then said that he would discuss the problem with colleagues at the NIST, and ask them to try to find a suitable travelling standard.

Note: The IEN subsequently conducted an evaluation of its 4909S instrument and used it for a comparison in Italy. On this basis, the IEN concluded that the instrument would be suitable for a CCE comparison. Furthermore, the SP offered a second such instrument for use as a travelling standard. After the CCE meeting it was agreed by letter that the comparison could begin in 1998 under the designation CCE 97-2.

5.4.3 List of key comparisons of DC and low-frequency AC quantities

Dr Taylor suggested that the CCE list its key comparisons of DC and low-frequency AC quantities: this list is presented in Table 1. He also suggested that the table should include comparisons of DC voltage standards based on Zener diodes.

Note: After the meeting, Dr deVreede expressed the view that a ten-year periodicity of AC/DC transfer comparisons should apply to the full range of parameters. A comparison involving one of the three ranges listed in Table 1 should begin, on average, once every three years.

Table 1. Key DC and low frequency AC quantities, suggested intervals between comparisons and present status of BIPM and CCE comparisons

Quantity	Years between comparisons	Start and finish dates	Identification
DC voltage: comparison of Josephson standards	10	continuous	BIPM
DC voltage: comparison of Zener diode standards	10	continuous	BIPM
Resistance: comparison of quantum Hall resistance standards	10	continuous	BIPM
Resistance: comparison of 1 Ω and 10 k Ω resistance standards	10	continuous	BIPM
Resistance at other appropriate values: 10 M Ω and 1 G Ω	5	Sept. 1996-Oct. 1999	CCE 95-1
Capacitance: 10 pF to 100 pF	10	Feb. 1996-early 1999	CCE 92-1
Inductance: 10 mH at 1000 Hz	12	1989-1994	CCE 88-1
DC voltage ratio: 1000 V:10 V and 100 V:1 V	10	to begin in 1998	CCE 97-2
AC voltage ratio: up to 100 V	10	Nov. 1997–Nov. 2000	CCE 97-1
AC/DC transfer at appropriate voltages and frequencies:	10		
3 V, 1 kHz and 3 optional frequencies		Jan. 1994-May 1996	CCE 92-3
500 V and 1000 V, 1 kHz to 100 kHz		Apr. 1995-Dec. 1997	CCE 92-4
3 V and 4 V, above 1 MHz		Aug. 1995-June 1998	CCE 92-5
AC power: 50 Hz to 60 Hz	10	June 1996–June 1999	CCE 92-2

6 REPORT ON THE MEETING OF THE WORKING GROUP ON RADIOFREQUENCY QUANTITIES

Mr Érard, chairman of the working group on radiofrequency quantities (GT-RF), presented a summary of the group's meeting held at the BIPM on 23 June 1997. The text of the group report is given at the end of this report (page 111). Key comparisons relating to radiofrequency quantities were reviewed.

7 ACTIVITIES OF THE ELECTRICITY SECTION OF THE BIPM

Dr Witt reviewed recent work (CCE/97-2) of the Electricity section of the BIPM. Dr Reymann described on-site comparisons of Josephson array voltage standards with the CSIRO-NML, IEN, KRISS, MSL, NIM and SP. Mr Delahaye noted that on-site comparisons of QHR systems have been carried out with the OFMET and PTB. As in previous comparisons, agreement is good and uncertainties are extremely small.

Dr Witt described studies of humidity and noise in Zener reference standards and spectral analyses of nanovoltmeters. He also mentioned temperature and pressure coefficient studies on Zener standards and resistors.

It was noted that Mr Delahaye had already described BIPM studies of AC QHR (Section 3). Dr Melcher outlined progress on linking capacitance standards to QHR.

Finally, Dr Witt described bilateral comparisons that have been carried out by the BIPM and routine calibration services that it has provided. He noted that, since the 1995 meeting of the CCE, the BIPM had measured characteristics of six Zener diode standards (732B). These are now available for use in bilateral comparisons with any interested national metrology institute. For the same programme, six 10 k Ω resistance standards (SR104) have been purchased and are now being characterized; plans to acquire six first-rate one ohm standards are under way.

8 FUTURE ACTIVITIES OF THE CCE

The name of the working group on international comparisons was changed to working group on key comparisons in accordance with the usage of other Consultative Committees. It was agreed that the working group on key comparisons should continue to oversee the status of international comparisons used for the purpose of establishing equivalence of national standards and calibration systems.

Dr Hebner noted that the working group would meet at the CPEM'98 to refine the list of key comparisons in an attempt to clarify the interpretation of comparison results.

Mr Énard remarked that the GT-RF is also planning to meet at the CPEM'98.

9 OTHER BUSINESS

Dr Feller gave a presentation (CCE/97-3) in which he outlined a constructional approach to the International System of Units (SI). He reviewed the functional dependence of SI base units with one another and their essential, but unstated, dependence on certain fundamental constants. He criticized some terms such as “base units” and “derived units” as misleading. He also showed that where a functional dependence exists between quantities, this dependence is identical when expressed in the SI, MKSA or CGS unit systems.

10 DATE OF NEXT MEETING

It was agreed that the next meeting of the CCE should be held in June 1999.

In closing, the President thanked delegates and BIPM staff for their participation in the meeting. He also expressed his thanks to all members for their co-operation and consideration in making his first CCE meeting a productive experience. He adjourned the meeting and wished everyone continuing success in their activities.

B.M. Wood, Rapporteur

August 1997

revised April 1998

REPORT
OF THE WORKING GROUP
ON RADIOFREQUENCY QUANTITIES
(23 June 1997)
TO THE CONSULTATIVE COMMITTEE
FOR ELECTRICITY

Agenda

- 1 Opening of the meeting; designation of a rapporteur.
- 2 Comparisons completed since the last meeting of the working group (June 1995).
- 3 Comparisons almost completed.
- 4 Progress on continuing comparisons.
- 5 New comparisons.
- 6 Information on EUROMET comparisons.
- 7 Report of the sub-group on key comparisons.
- 8 Future comparisons.
- 9 Guidelines for the organization of comparisons.
- 10 New developments in different laboratories of the GT-RF.
- 11 Date of next meeting.

1 OPENING OF THE MEETING; DESIGNATION OF A RAPPORTEUR

The working group on radiofrequency quantities (GT-RF) met at the Bureau International des Poids et Mesures (BIPM), in Sèvres, on 23 June 1997.

The following were present: J. Achkar (BNM-LCIE), L. Brunetti (IEN), J.P.M. de Vreede (NMi-VSL), L. Érard (Chairman), R.M. Judish (NIST), R.D. Lee (KRISS), A. Ploshinsky (VNIIM), T.J. Quinn (Director of the BIPM), G.W. Small (CSIRO), U. Stumper (PTB), B.M. Wood (NRC), H. Yajima (ETL), R.W. Yell (NPL).

Also present at the meeting: P. Giacomo (Director Emeritus of the BIPM), T.J. Witt (BIPM).

The Chairman, Mr Érard, welcomed participants and opened the meeting.

The Director of the BIPM, Dr T.J. Quinn, welcomed participants and wished them a successful meeting.

The agenda was considered and approved.

Dr J. Achkar was appointed rapporteur.

2 COMPARISONS COMPLETED SINCE THE LAST MEETING OF THE WORKING GROUP (JUNE 1995)

Results of the four comparisons completed since the last meeting were discussed. Details are given in Table 1.

3 COMPARISONS ALMOST COMPLETED

Participants discussed the three comparisons that were completed but for preparation of the final reports (Table 2). Mr Yell and Mr Judish, representatives of the pilot laboratories for the comparisons, affirmed that final reports would be sent to the Chairman and the BIPM before the end of 1997.

4 PROGRESS ON CONTINUING COMPARISONS

Table 3 summarizes the progress of ongoing comparisons organized in 1986, 1992 and 1995. Some of them are scheduled for completion before the end of 1997 so that results may be presented at the CPEM'98.

5 NEW COMPARISONS

In discussing proposals for new comparisons, the working group took into account ongoing and recently completed comparisons. Thus when a power comparison at 94 GHz was proposed, Mr Énard reminded the group that comparison GT-RF/83-3 (published in *IEEE Trans. Instrum. Meas.*, 1989, **38**, 927-929) concerned power at 94 GHz. Messrs Yell and Judish replied that, since completion of comparison GT-RF/83-3, significant improvements have been made in apparatus in their laboratories. Dr Achkar added that the BNM-LCIE intends to rebuild its microcalorimeter, so they too were interested in this comparison.

After further discussion, three new comparisons were approved. They concern S parameters with 3.5 mm connectors, and power at 45 GHz and 94 GHz. Details are given in Table 4.

6 INFORMATION ON EUROMET COMPARISONS

Mr Énard informed the group that a summary of the final report of the EUROMETcomparison 341 had been submitted for publication to *Metrologia* (1997, **34**, 443-444). This was a comparison of power measured in a 50 Ω coaxial line at frequencies between 50 MHz and 18 GHz. Participants were the BNM-LCIE and NMi-VSL.

7 REPORT OF THE SUB-GROUP ON KEY COMPARISONS

Mr Énard presented the report of the sub-group formed at the last GT-RF meeting in June 1995. This group is charged with proposing a list of key comparisons of radiofrequency quantities. The sub-group met during the CPEM'96 in Braunschweig.

This was followed by a discussion of key comparisons. The list of key comparisons of radiofrequency quantities is given in Table 5a for quantities measured in waveguides and in Table 5b for quantities measured in coaxial transmission lines. The discussion eventually turned to the question of whether all radiofrequency quantities of metrological concern should be the subject of key comparisons. Prof. Giacomo pointed out that this was not necessary; key comparisons serve to demonstrate general competence in microwave metrology.

8 FUTURE COMPARISONS

The group proposed possible topics for future comparisons and assigned levels of priority to them. These topics and priorities are summarized in Table 6.

9 GUIDELINES FOR THE ORGANIZATION OF COMPARISONS

Mr Érard presented a draft proposal to EUROMET outlining guidelines for the organization of international comparisons. This was followed by a discussion of the guidelines. It was noted that the BIPM had also drafted a set of guidelines for comparisons organized by Consultative Committees.

10 NEW DEVELOPMENTS IN DIFFERENT LABORATORIES OF THE GT-RF

Participants were invited to describe some of the new developments in their laboratories. Dr Achkar mentioned noise, power, S parameters, loop and horn antennas at the BNM-LCIE. Mr Small mentioned new work in radiophysics and antennas at the CSIRO. Dr Wood described the NRC work on rebuilding air-supply lines. Dr Brunetti mentioned work at the IEN on superconductors at frequencies between 35 MHz and 50 GHz. Dr Ploshinsky said that the VNIIM was working on solutions to problems arising from incompatibility of their connectors with those from other laboratories. Dr de Vreede said that the NMi-VSL was extending its rf metrology work up to 40 GHz in all areas except noise. Mr Judish mentioned that the NIST now has a world wide web site for high-frequency metrology. He also spoke of recent NIST work on non-linear network analyzers. Mr Yell described the NPL work on a special probe for very near fields and technical work on dielectric measurements. He also mentioned the formation of a dielectric metrology club in the United Kingdom that now has fifty members. Dr Stumper mentioned the PTB's new temperature-controlled room and described future work on 3.5 mm and K connectors, on-wafer measurements, coplanar structures and various measurements in the range 75 GHz-110 GHz.

11 DATE OF NEXT MEETING

It was agreed that Mr Érard would try to organize an informal meeting of the GT-RF during the CPEM'98 in Washington DC in July 1998. The next formal GT-RF meeting will be held just before the next CCE meeting.

J. Achkar, Rapporteur
June 1997

Table 1. Comparisons completed since the last meeting of the working group (June 1995)

- 78-5 Horn gain and transverse polarization ratio between 8 GHz and 12 GHz.
(Pilot laboratory: NIST; participants: CNET, CSIRO, FTZ, NMi-VSL, NPL, TUD).
The results were published in *IEEE Trans. Ant. Prop.*, 1996, **44**, 1367-1374.
- 78-13 Noise power in waveguide R 100.
(Pilot laboratory: NPL; participants: BNM-LCIE, CSIRO, NIM, NIST, PTB).
The report is complete and has been distributed to participants who should send their comments to the NPL, the pilot laboratory, before October 1997. The NPL will prepare a communication for the CPEM'98, a paper for *IEEE Trans. Instrum. Meas.* and a summary report for *Metrologia*.
- 86-2 Q-factor at frequencies up to 30 MHz.
(Pilot laboratory: NIST; participants: BNM-LCIE, PTB, SESC).
The final report is complete and has been distributed to participants. The results have been analyzed and the working group has decided not to publish them.
- 86-3 Complex reflection coefficient in waveguide R 320 at 27 GHz, 35 GHz and 40 GHz.
(Pilot laboratory: NPL; participants: BNM-LCIE, CSIRO, NIM, NIST, PTB).
The final report is complete and has been distributed to participants. The BNM-LCIE has yet to check its results and send possible corrections to the NPL, the pilot laboratory, before October 1997. The NPL will prepare a communication for the CPEM'98, a paper for *IEEE Trans. Instrum. Meas.* and a summary report for *Metrologia*.

Table 2. Comparisons nearly completed

- 83-4 Measurements of scattering coefficients (*S* parameters) by broadband methods over the band 2 GHz-18 GHz.
(Pilot laboratory: NPL; participants: BNM-LCIE, CSIRO, FFV, NIST, NMi-VSL, PTB, SPTT).

The BNM-LCIE will send its uncertainty statements to the NPL, the pilot laboratory, before the end of July 1997. The NPL must send the report to participants before the end of August 1997. Comments on the report should be sent to the NPL before the end of October 1997. The NPL will prepare a communication for the CPEM'98, a paper for *IEEE Trans. Instrum. Meas.* and a summary report for *Metrologia*.

- 92-2 Noise power in 50 Ω coaxial line (type N connector) at 30 MHz and 4 GHz.

(Pilot laboratory: NIST; participants: BNM-LCIE, NPL, PTB; KRISS also joined this comparison).

The NIST, as pilot laboratory, is scheduled to send the report to participants by the end of July 1997. Comments should be sent to the NIST before the end of September 1997. The final report will be available in December 1997. So that the comparison could remain on schedule, the NIST and KRISS agreed that, after the meeting, they would carry out a bilateral comparison at some future date.

- 92-4 Power in waveguide R 320: effective efficiency of bolometer mounts at 33 GHz.

(Pilot laboratory: BNM-LCIE; participants: CSIRO, KRISS, NIST, NMI-VSL, NPL, NRC, PTB; IEN withdrew).

The BNM-LCIE, as pilot laboratory, will send results to participants before the end of July 1997. The BNM-LCIE will prepare the report and send it to participants before the end of September 1997. Comments on the report are to be sent to the BNM-LCIE before the end of November 1997. The BNM-LCIE will prepare a communication for the CPEM'98, a paper for *IEEE Trans. Instrum. Meas.* and a summary report for *Metrologia*.

Table 3. Comparisons in progress

- 86-1 Power flux density at 2.45 GHz and 10 GHz.

Electric field strength between 300 MHz and 1000 MHz.

(Pilot laboratory: NIST; participants: ARCS, BNM-LCIE, CRL, ETL, IEN, JQA, KEC, KRISS, NMI-VSL, NPL, PTB).

Travelling standards are now in Poland and will shortly be sent to the PTB, the last participant. The PTB measurement results will be sent to the NIST, the pilot laboratory, before the end of September 1997. The comparison is scheduled for completion by the end of 1997. The NIST will prepare the report before June 1998 and it will be distributed to participants during the CPEM'98.

- 92-1 Horn antenna gain in IEC R 320 at 26.5 GHz, 33 GHz and 40 GHz.
(Pilot laboratory: NPL; participants: BNM-LCIE, CSIRO*, KRIS, NIST, NMi-VSL).

The comparison will begin at the end of 1997. The NPL will send a technical protocol to participants.
- 92-3 Measurement of scattering coefficient (S parameters) by broad-band 2 GHz-18 GHz (type N connector).
(Pilot laboratory: NPL; participants in EUROMETloop: BNM-LCIE, IEN*, NMi-VSL, NML, PTB, SPTT; participants in the GT-RF loop: BNM-LCIE, CSIRO*, KRIS*, NIST, NRC*, PTB).

The EUROMET loop of the comparison will begin in November 1997. The GT-RF loop will begin when the EUROMET loop is finished.
- 92-6 Voltage (1 V) in 50 Ω coaxial line at frequencies between 1 MHz and 300 MHz (option up to 1000 MHz).
(Pilot laboratory: NMi-VSL; participants: AREPA*, BNM-LCIE, CEM or INTA, CMI, CSIRO, IEN, KRIS, NIST, NRC, PTB, SMU, SPTT, VNIIM).

A preliminary comparison was carried out in 1996 between the PTB and NRC. Interim results are available from the NMi-VSL, the pilot laboratory. The full comparison will begin in October 1997. Each laboratory is expected to complete its measurements within one month.
- 92-7 Antenna factor at 10 kHz, 100 kHz, 1 MHz and 30 MHz.
(Pilot laboratory: NPL; participants: BNM-LCIE, CSIRO*, ETL*, IEN, KRIS, NIST*, NMi-VSL, PTB).

The NPL will send a proposal to participants in November 1997. The comparison will begin in April 1998. Two antennas will be used as travelling standards; an active one (from the EMCO) and a passive one (from the NPL).
- 92-8 Antenna factor at frequencies between 30 MHz and 1000 MHz.
(Pilot laboratory: NPL; participants: CSIRO*, ETL*, IEN*, KRIS, NIST*, NMi-VSL*, PTB*).

* to be confirmed.

The chairman proposed that this comparison be deleted because no laboratory has agreed to participate. No decision was made to continue or cancel it.

- 95-1 Power in waveguide R 620: effective efficiency of bolometer mounts at 62 GHz.

(Pilot laboratory: BNM-LCIE; participants: NIST, NPL, SSIA).

The NPL has finished its measurements. The travelling standard is now at the BNM-LCIE. It will be sent to the SSIA at the end of June 1997 and to the NIST in the autumn of 1997. The BNM-LCIE will prepare the report in the spring of 1998 and this will be discussed at the CPEM'98. The comparison at 45 GHz mentioned in the original protocol will now be classified as comparison GT-RF/97-2.

Table 4. New comparisons

- 97-1 *S* parameters in PC-3.5 between 50 MHz and 26.5 GHz.

(Pilot laboratory: BNM-LCIE; participants in GT-RF loop: CSIRO*, KRISS*, NIST, NPL, NRC*; participants in EUROMET loop: CMI, FFV, GUM*, IEN, INTA, NMi-VSL, NML, NPL, PTB, SPTT, TF).

The comparison will begin with the GT-RF loop and end with EUROMET loop. The BNM-LCIE will send a technical protocol to the participants by the end of October 1997. Frequencies to be included in the final report are: 50 MHz, 500 MHz, 3 GHz, 15 GHz and 25 GHz.

- 97-2 Power in waveguide R 400: effective efficiency of bolometer mounts at 45 GHz.

(Pilot laboratory: NIST; participants: BNM-LCIE*, ETL*, IEN, KRISS*, NPL, NRC*, VNIIM).

The NIST will send a proposal to participants before the end of 1997.

- 97-3 Power in waveguide R 900: effective efficiency of bolometer mounts at 94 GHz.

(Pilot laboratory: NPL; participants: BNM-LCIE, ETL*, IEN*, KRISS*, NIST, NRC*, PTB, VNIIM*).

The NPL will prepare a proposal and send it to participants in the spring of 1998. This will be discussed during the CPEM'98.

Table 5. Key comparisons recommended by the working group on radiofrequency quantities (radiofrequency and microwaves: 1 MHz to 100 GHz)

a) Quantities measured in waveguide

Quantity	Years between comparisons	Start and finish dates	Identification
Power in appropriate waveguide size	3	April 1994-end 1997 1996-1998 1997-1999 1998-2000	GT-RF 92-4 GT-RF 95-1 GT-RF 97-2 GT-RF 97-3
Attenuation at appropriate values (3 dB, 50 dB)	3		
Noise power	10	Sept. 1985-Dec. 1997	GT-RF 78-13
Power flux density	10		
Antenna gain	10	end 1997-end 1999	GT-RF 92-1

b) Quantities measured in coaxial line

Quantity	Years between comparisons	Start and finish dates	Identification
Power with a suitable connector	5		
Attenuation at appropriate values (100 dB, 10 dB step)	10		
Voltage at appropriate values and frequencies	10	Oct. 1997-1999	GT-RF 92-6
Reflection coefficient/S parameters (with suitable connectors)	10	May 1991-Oct. 1997 Nov. 1997-1999 1997-1999	GT-RF 83-4 GT-RF 92-3 GT-RF 97-1
Noise power	10	Jan. 1996-end 1997	GT-RF 92-2
Impedance	to be defined		
Electromagnetic field/antenna	10	1991-1997 Nov. 1997-1999	GT-RF 86-1 GT-RF 92-7

Table 6. Possible topics for future comparisons**Priority 1**

- T1 Impedance in the frequency range 1 MHz-100 MHz.
 The NPL can serve as pilot laboratory.
- T2 Power in 50 Ω coaxial line: effective efficiency of bolometer mounts
 (type N connector).
 The NMi-VSL can serve as pilot laboratory.
- T3 Noise in waveguide for frequencies above 18 GHz.
 The BNM-LCIE can serve as pilot laboratory.
- T4 Noise in 50 Ω coaxial line for frequencies below 100 MHz.
 The NPL can serve as pilot laboratory.

Priority 2

- T5 Power in 50 Ω coaxial line: efficiency of bolometers (3.5 mm
 connector).
- T6 Reflection coefficient in 75 Ω coaxial line.

APPENDIX E 1.

Working documents submitted to the CCE at its 21st meeting

(see the list of documents on page 63)

ANNEXE E 1.

Documents de travail présentés à la 21^e session du CCE

Ces documents de travail peuvent être obtenus dans leur langue originale sur demande adressée au BIPM.

Document

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- 97-1 BIPM. — Note on equivalence of national measurement standards together with an enclosed document, T.J. Quinn, 8 p.
- 97-2 BIPM. — Work of the electricity section of the BIPM for the period June 1995-June 1997, 20 p.
- 97-3 OFMET (Suisse). — A constructional approach to the International System of Units (SI), U. Feller, 17 p.
- 97-4 OFMET (Suisse). — Progress in the representation of the electrical quantities at OFMET, U. Feller, M. Flüeli, B. Jeanne-ret, B. Jeckelmann, 6 p.
- 97-5 NIST (États-Unis). — Reports to the CCE from NIST:
 - a. Report on international comparison of 10 pF capacitors, 1 p.
 - b. Report on the international comparison 95-1 of DC resistance of 10 M Ω and 1 G Ω , 1 p.
 - c. Report on international comparison of 50/60 Hz power, 1 p.
 - d. Report on the NIST SI watt determination, 2 p.
 - e. Report on prospects for the metrological use of single electron tunneling (SET) devices, 1 p.
 - f. Report on corrections to the AC quantized Hall resistance, 1p.
 - g. Report on quantized Hall resistance devices, 1 p.

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- 97-6 BNM-LCIE (France). — Liste de documents présentés à la 21^e session du CCE, 1 p.
- 97-7 BNM-LCIE (France). — Status of the CCE 92-4 comparison: AC/DC transfer difference at 500 V and 1000 V (1 kHz-50 kHz and 100 kHz), A. Poletaëff, 2 p.
- 97-8 BNM-LCIE (France). — Production of QHE samples LEP and BNM-LCIE, M. Chambon, J. Blanchet, F. Piquemal, G. Genevès, 3 p.
- 97-9 BNM-LCIE (France). — Progress in fundamental and applied low frequency and DC electrical metrology at BNM-LCIE, G. Genevès, G. Trapon, F. Piquemal, J. Blanchet, J.P. Lo-Hive, A. Poletaëff, P. Gournay, M. Bellon, 14 p.
- 97-10 ETL (Japon). — Progress in DC/LF electrical standards during the period June 1995-June 1997 at ETL, T. Endo, 8 p.
- 97-11 NMi-VSL(Pays-Bas). — General progress report of VSL during 1995-1997, J.P.M. de Vreede, 3 p.
- 97-12 NMi-VSL (Pays-Bas). — Status report on CCE comparison 92-5, C.J. van Mullem, J.P.M. de Vreede, 1 p.
- 97-13 NMi-VSL (Pays-Bas). — Status report on GT-RF comparison 92-6, J.P.M. de Vreede, 1 p.
- 97-14 NMi-VSL (Pays-Bas). — Status report on CCE comparison 95-3, J.P.M. de Vreede, 1 p.
- 97-15 KRISS (Rép. de Corée). — List of working documents submitted to the CCE by the KRISS, 1 p:
1. KRISS (Rép. de Corée), VNIIM (Féd. de Russie). — A traceability of loss angle standards at KRISS, R.D. Lee, H.J. Kim, Yu.P. Semyonov, 7 p.
 2. KRISS (Rép. de Corée), VNIIM (Féd. de Russie). — Fabrication of main electrodes of a calculable capacitor, R.D. Lee, H.J. Kim, G.Y. Kim, Yu.P. Semyonov, 8 p.
 3. KRISS (Rép. de Corée), NML-CSIRO (Australie). — Recognition of the equivalence of the national standards of Korea and Australia, R.D. Lee, 3 p.

4. KRISS (Rép. de Corée). — Absolute-ratio Hamon divider with superconducting contact, K.-T. Kim, 4 p.
 5. KRISS (Rép. de Corée). — Annual changes of Zener voltage standards in Korean industries, K.-T. Kim, 5 p.
 6. KRISS (Rép. de Corée). — Fabrication of planar multi-junction thermal converters, S.W. Kwon, S.I. Park, 1 p.
 7. KRISS (Rép. de Corée), VNIIM (Féd. de Russie). — A new low-field determination of the proton gyromagnetic ratio in water, V.Ya. Shifrin, P.G. Park, V.N. Khorev, C.H. Choi, C.S. Kim, 12 p.
 8. KRISS (Rép. de Corée). — Other activities at KRISS, K.-H. Yoo, K.-T. Kim, K.W. Yeom, 2 p.
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- 97-16 Report of the CCE working group on international comparisons, 1st Meeting (1995), T.J. Witt, 4 p.
 - 97-17 Report of the CCE working group on international comparisons, 2nd Meeting (1996), T.J. Witt, 5 p.
 - 97-18 NIST (États-Unis). — Contribution of Alan Cookson, 2 p.
 - 97-19 Report on international comparisons (at DC or low frequency AC) organized by the CCE, 3 p.
 - 97-20 EUROMET. — Guidelines for the organization of comparisons. EUROMET guidance document n° 3, 6 p.
 - 97-21 PTB (Allemagne). — Precision quantum Hall effect devices with tailor-made electron densities, K. Pierz, B. Schumacher, 4 p.
 - 97-22 PTB (Allemagne). — Availability of 10-V arrays of Josephson junctions, F. Müller, J. Niemeyer, 2 p.
 - 97-23 PTB (Allemagne). — Progress toward monitoring the international prototype of the kilogram – State in 1996, M. Gläser, 13 p.
(also submitted as document CCM/96-14).
 - 97-24 PTB (Allemagne), Université de Moscou (Féd. de Russie). — Noise measurements in metallic single electron tunneling devices, H. Wolf, H. Scherer, T. Weimann, A.B. Zorin, V.A. Krupenin, S.V. Lotkhov, J. Niemeyer, 7 p.

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- 97-25 PTB (Allemagne). — CCE comparison of AC-DC voltage transfer standards at the lowest attainable level of uncertainty, M. Klonz, 9 p.
- 97-26 BIPM. — A note on customs and shipping procedures used in Consultative Committee comparisons, T.J. Witt, 7 p.
- 97-27 BIPM. — Key comparisons in electricity carried out by the BIPM on a continuous basis, 1 p.
- 97-28 VNIIM (Féd. de Russie). — Systems of electrical units and the fundamental constants, V.S. Tuninsky, 8 p.
- 97-29 EUROMET, SP (Suède). — Report on EUROMET comparison measurements in the field of electricity, H. Nilsson, 2 p.
- 97-30 SP (Suède). — Progress report from the Swedish National Testing and Research Institute, SP, within electrical metrology, H. Nilsson, 4 p.
- 97-31 NPL (Royaume-Uni). — Proposed international comparison of AC voltage ratio using an inductive voltage divider draft, I. Robinson, 2 p.
- 97-32 IEN (Italie). — Effect of the frequency on the longitudinal resistance of a GaAs-AlGaAs heterostructure, F. Cabiati, L. Callegaro, C. Cassiago, V. D'Elia, G. Marullo Reedtz, 5 p.
- 97-33 IEN (Italie). — Experience on the calibration and use of a 4902S voltage divider, R. Cerri, V. Lacquaniti, G. Marullo Reedtz, G. La Paglia, A. Sosso, 2 p.
- 97-34 IEN (Italie). — List of publications submitted to the CCE by IEN (Turin, Italy), 2 p.
- 97-35 NRC (Canada). — Progress in electrical standards during the period June 1995-June 1997, B. Wood, 3 p.
- 97-36 VNIIM (Féd. de Russie). — Adjusted values of the fundamental constants in the modified systems of units, V.S. Tuninsky, 2 p.

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- 97-37 VNIIM (Féd. de Russie). — Basic design of the quantum standard of AC voltage, A.S. Katkov, E.D. Koltik, V.I. Krzhimovsky, G.P. Telitchenko, 2 p.
- 97-38 VNIIM (Féd. de Russie). — Development and investigation of “base” and transportable resistance standards, B. Litvinov, A. Ploshinsky, Yu. Semyonov, 3 p.
- 97-39 VNIIM (Féd. de Russie). — About international comparison of capacitance standards, Yu. Semyonov, 1 p.
- 97-40 NIST (États-Unis). — Present status of SI values of K_J and R_K , B.N. Taylor, P.J. Mohr, 4 p.
- 97-41 PTB (Allemagne). — International comparison of 10 mH inductance standards – The COOMET loop, H. Eckardt, 3 p.
- 97-42 PTB (Allemagne). — 10 pF capacitance comparison within the scope of the COOMET metrology organization, H. Eckardt, 5 p.
- 97-43 NIM (Chine). — The modified Maxwell-wien bridge at NIM, Lu Wenfuz, Din Cheng, Shao Fang, He Xiaobing, 2 p.
- 97-44 NIM (Chine). — General progress report in DC and low frequency electrical and magnetic standards of NIM during 1995-1997, Liu Ruimin, 6 p.
- 97-45 IRL (Nouvelle-Zélande). — The MSLNZ mains frequency power bridge, A.C. Corney, 4 p.

LIST OF ACRONYMS USED IN THE PRESENT VOLUME

1 Acronyms for laboratories and committees*

AREPA	AREPA Test and Kalibrering A/S, Silkeborg (Denmark)
ARCS	Austrian Research Centre, Seibersdorf (Austria)
BIPM	Bureau International des Poids et Mesures
BNM-LCIE	Bureau National de Métrologie: Laboratoire Central des Industries Électriques, Fontenay-aux-Roses (France)
CCE	Consultative Committee for Electricity
CCM	Consultative Committee for Mass and Related Quantities
CEM	Centro Español de Metrologia, Madrid (Spain)
CIPM	Comité International des Poids et Mesures
CMI	Český Metrologický Institut/Czech Metrological Institute, Prague and Brno (Czech Rep.)
CNET	Centre National d'Études des Télécommunications, Issy-les-Moulineaux (France)
CODATA	Committee on Data for Science and Technology
COOMET	Cooperation in Metrology among the Central European Countries
CPEM	Conference on Precision Electromagnetic Measurements
CRL	Communications Research Laboratory, Tokyo (Japan)
CSIR-DPT	(former NPRL) Council for Scientific and Industrial Research, Division of Production Technology, Pretoria (South Africa)
CSIRO	(former NML) Commonwealth Scientific and Industrial Research Organization, Division of Applied Physics, Lindfield (Australia)

* Organizations marked with an asterisk either no longer exist or operate under a different acronym.

*CSMU	Československý Metrologický Ústav, Bratislava and Prague (former Czechoslovakia), see SMU
*DSIR	Department of Scientific and Industrial Research, Lower Hutt (New Zealand), see MSL
EMCO	Electro-Mechanics COmpany InterTest Inc., Flanders NJ (United States)
ETL	Electrotechnical Laboratory, Tsukuba (Japan)
EUROMET	European Collaboration on Measurement Standards
FFV	Maintenance Division, National Industries Corporation, Arboga (Sweden)
FTZ	Fernmeldetechnisches Zentralamt, Darmstadt (Germany)
GT-RF	Working group on radiofrequency quantities
GUM	Główny Urząd Miar/Central Office of Measures, Warsaw (Poland)
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IEN	Istituto Elettrotecnico Nazionale Galileo Ferraris, Turin (Italy)
IMGC	Istituto di Metrologia G. Colonnetti, Turin (Italy)
INTA	Instituto Nacional de Técnica Aeroespacial, Madrid (Spain)
IRL	Industrial Research Limited, Lower Hutt (New Zealand)
IRMM	Institute for Reference Materials and Measurements, European Commission
ISO	International Organization for Standardization
JQA	Japan Quality Assurance Organization (Japan)
KEC	Kansai Electronic Industry Development Center (Japan)
KRISS	Korea Research Institute of Standards and Science, Taejon (Rep. of Korea)
LCIE	Laboratoire Central des Industries Électriques, Fontenay-aux-Roses (France), see BNM
LEP	Laboratoire d'Électronique Philips, Limeil-Brévannes (France)
MSL/MSLNZ	(former DSIR) Measurement Standards Laboratory of New Zealand, Lower Hutt (New Zealand)
NIM	National Institute of Metrology, Beijing (China)
NIST	National Institute of Standards and Technology, Boulder and Gaithersburg (United States)
NMi-VSL	Nederlands Meetinstituut: Van Swinden Laboratorium, Delft (Netherlands)
*NML	National Measurement Laboratory, Lindfield (Australia), see CSIRO

NPL	National Physical Laboratory, Teddington (United Kingdom)
NPLI	National Physical Laboratory of India, New Delhi (India)
*NPRL	National Physical Research Laboratory, Pretoria (South Africa), see CSIR
NRC	National Research Council of Canada, Ottawa (Canada)
NRLM	National Research Laboratory of Metrology, Tsukuba (Japan)
OFMET	Office Fédéral de Métrologie/Eidgenössisches Amt für Messwesen, Wabern (Switzerland)
PTB	Physikalisch-Technische Bundesanstalt, Berlin and Braunschweig (Germany)
SESC	Service Electrical Standards Centre, Bromley (United Kingdom)
SMU	(former CSMU) Slovenský Metrologický Ústav/Slovak Institute of Metrology, Bratislava (Slovakia)
SP	(former Statens Provningsanstalt) Sveriges Provnings- och Forskningsinstitut/Swedish National Testing and Research Institute, Borås (Sweden)
SPTT	Swiss PTT General Directorate, Research and Development Technical Centre, Bern (Switzerland)
SSIA	State Scientific Industrial Association “Metrology”, Kharkov (Ukraine)
TF	Telecom Finland, Helsinki (Finland)
TUD	Technical University of Denmark, Lyngby (Denmark)
VNIIM	D.I. Mendeleyev Institute for Metrology, St Petersburg (Russian Fed.)
*VSL	Van Swinden Laboratorium, Delft (Netherlands), see NMi
VTT	Centre for Metrology and Accreditation, Technical Research Centre of Finland, Espoo (Finland)

2 Acronyms for scientific terms

CCC	Cryogenic current comparator
CGS	System of units based on three base units: centimetre, gram, second
MKSA	System of units based on four base units: metre, kilogram, second, ampere
QHE	Quantum Hall Effect
QHR	Quantum Hall resistance
SET	Single electron tunnelling
SAW	Surface acoustic wave
SI	International System of Units

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