Apex level Standards and Industrial Metrology
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Sh Harish Kumar  
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**D 05.02 Standards of Dimension**  
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Sh Arif Sanjid  
Sh Vinod Kumar  
Sh Sandeep Kumar  
Sh Abhishek Singh  
Sh Virendra Babu  
Sh Ravi Khanna  
Sh Mukesh Kumar  

**D 05.03 Temperature and Humidity Standards**  
Dr Yesh Pal Singh  
Dr Dilip Dhondiram Shivagan  
Sh Jagannath Prasad  
Sh Rasika Behari Sibal  

**D 05.04 Optical Radiation Standard**  
Dr H C Kandpal  
Dr (Ms) Ranjana Mehrotra  
Sh Virendra Kumar Jaiswal  
Dr Parag Sharma  
Sh K N Basavaraju  
Sh Sudama  
Dr Bharat Kumar Yadav  

**D 05.05 Force and Hardness Standards**  
Dr Sushil Kumar Jain  
Dr S Seela Kumar Titus  
Sh Rajesh Kumar  
Sh Harish Kumar  
Sh Vikram  

**D 05.06 Pressure and Vacuum Standards**  
Dr Ashis Kumar Bandyopadhyay  
Sh D Arun Vijayakumar  
Dr Sanjay Yadav  

**D 05.07 Acoustics, Ultrasonic, & Vibration Standards**  
Dr Ashok Kumar  
Dr Mahavir Singh  
Sh Naveen Garg  
Dr P K Dubey  
Dr Kiriti Soni  
Sh Gurbir Singh  
Ms Reeta Gupta  
Dr Yudhisthier Kumar Yadav  

**D 05.08 Fluid Flow Measurement Standards**  
Sh Shiv Kumar Jaiswal  
Sh Ishwar Singh Taak  

**D 05.09 LF & HF Impedance & DC Standards**  
Sh Anil Kishore Saxena  
Dr Sher Singh Rajput  
Sh Ajeeet Singh  
Sh Rajbeer Singh  
Sh M A Ansari  
Sh Satish  
Sh Kul Bhushan Ravat  
Sh Mohammad Saleem  
Sh Avdhesh Kumar Goel  

**D 05.10 LF & HF Voltage, Current & Microwave Standards**  
Sh Anil Kumar Govil  
Sh Pramendra Singh Negi  
Sh Saood Ahmed  
Sh Bijendra Pal  

**D 05.11 AC High Voltage and AC High Current Standards**  
Sh Mukesh Kumar Mittal  
Sh Sridhar Lingam  

**D 05.12 AC Power & Energy Standards**  
Sh Mukesh Kumar Mittal  
Sh Joges Chandra Biswas  
Sh Anoop Singh Yadav
Apex Level Standards and Industrial Metrology

Apex Level Standards and Industrial Metrology (ALSIM) division of CSIR-NPL is responsible for establishing, maintaining and upgrading the national standards and providing traceability to other accredited laboratories in the field of physico-mechanical and electrical and electronics standards. It comprises of twelve sub-divisions, their ‘Calibration and Measurement Capabilities (CMCs) are peer reviewed at regular intervals, to maintain equivalence in measurements and calibrations at the international levels. The activities of the ALSIM are funded by CSIR-Network project entitled: Measurement Innovations in Science and Technology (MIST).

During this period many new activities have been undertaken, in brief, these are as follow:

(i). CSIR-NPL also has started preliminary investigations for development of a Watt Balance.

(ii). In India, facility for determination of metrological characterization of high capacity weights is only available at CSIR-NPL, New Delhi. The group provides calibration facilities at the apex level for high capacity weights like 100 kgs, 200 kgs and up to 2000 kgs. The characterization work has been carried out for ISRO, Sriharikota for their research and development related activities.

(iii). Similarly, very high capacity volumetric vessels of 1000 l and 2000 l are calibrated for M/s Rockwin Flow Meters Pvt. Ltd., Faridabad. The metrological investigations help the manufacturer to fabricate and develop high precision volumetric vessels for further traceability of volumetric measurements in higher range.

(iv). Secondary hardness standardizing machines of Brinell, Rockwell (including superficial Rockwell), Vickers and micro-Vickers hardness were established. This enables us to provide traceability in hardness measurement including a newly introduced micro-Vickers scale.

(v). A peak to peak measurement module has been successfully designed and its functionality realized with a view to minimize the error in voltage measurement in the ultrasonic power evaluation. It has been found to be better and more accurate than measuring the rf voltage directly.

(vi). The range of AC-DC current transfer measurement facility at NPL has been extended from existing 20A to 80A using ingeniously developed current TEE. Now CSIR-NPL is capable of providing traceability to user organizations by calibrating the AC-DC current shunts of 30A, 50A, and 80A along with the thermal current converters or thermal transfer standard in the frequency range 40 Hz - 10 kHz.

(vii). To establish Standards for Radiated Power Density, a GTEM have been indigenously developed based on Crawford concept. The proposed GTEM is applicable for frequency range 0.7 - 2.5 GHz.

(viii). A new facility for the calibration of Transformer Loss Measuring System (TLMS) up to 100kV/2000Amps has been established and calibration services as well as traceability is provided to power corporations and manufacturers.
Besides, ALSIM division is actively involved in the intercomparison activities namely:

(i). An inter-laboratory comparison has been conducted on mass parameter with three standard weights of nominal values of 100 mg, 20 g and 1 kg. The inter-laboratory comparison has been aimed to evaluate the competence and the compatibility of the measurement results reported by the SAARC NMIs (BSTI, Bangladesh; NPSL, Pakistan; NBSM, Nepal and MUSSD, Sri Lanka). CSIR – National Physical Laboratory, India (NPLI) was the pilot laboratory of this program.

(ii). Participating in international inter-comparison (NPLI as pilot laboratory in length, parameters) with BSTI- Bangladesh, MUSSD-Sri Lanka and NPSL-Pakistan.

(iii). APMP-T-S7: Comparison of Pt/Pd thermocouple at Cobalt-carbon (Co-C) eutectic fixed point (1324 °C), which has been developed in the laboratory.

(iv). APMP-T-S8: APMP TCT/DEC: Comparison of Liquid-in-glass thermometers against SPRTs covering a range from -41 °C to 250 °C using high precision alcohol, water and oil baths. The measurement results after analysis shall be submitted to SIRIM, Malaysia.

(v). An Inter-laboratory comparison in LIGT (0-100 °C) and Type-S thermocouple (0-1000 °C) was organized by our group among the NMIs of four SAARC countries namely Bangladesh, Nepal, Sri Lanka and Pakistan.

(vi). Participated in the APMP Key Comparison of Luminous Intensity (APMP. PR-K3.a) and have finished the measurements. Final report of the measurements was submitted to NMI, Japan- the Pilot Laboratory in March 2014.

(vii). APMP.M-P-K13 (piloted by NMJ, Japan) is under draft stage, draft A is being circulated to the participating laboratories. The main objective of this key comparison is to compare the performance of hydraulic pressure standards of participating institutes, in the pressure range 50 MPa to 500 MPa in gauge mode to essentially support the objective evidence for high pressure CMGs of the participating institutes.

(viii). A bilateral comparison of 10 k & 1 & 1 between BIPM and NPLI was carried out. Measurement analysis is in progress.

(ix). NPL is a Pilot Lab and coordinating the inter-comparison (P1-APMP.EM-S8) of 6½ Digit Multimeter (DMM) under Asia Pacific Metrology Programme (APMP), in which 16 countries are participating.

The results are communicated to NMI-Australia for consultation. The individual results will be communicated to participating labs for their comments, etc. Thereafter it will be submitted as draft A report to APMP.

Also taking active part in the NABL proficiency testing programme as follow:

(i). NPL-NABL-PT-Program, NABL-Temp-006 has been completed for Type-S thermocouple in the range from 0 to 1200 °C. 12-Calibration laboratories participated in the program.

(ii). Under NPL-NABL-PT-Program, two Proficiency Testing (PT) Programmes for Capacitance Measurements are being carried out:
Apex Level Standards and Industrial Metrology

(a) 1 µF (NABL - E - Capacitance - 003)
(b) 10 pF & 100 pF (NABL - E - Capacitance - 004)

The ALSIM division is conducting large numbers of training programme, in various parameters, for industries, legal metrology officers and for SAARC countries.
Mass Standards

Mass Standard has been mandated to provide apex level traceability and dissemination of standards to the calibration laboratories and user industries in the area of mass, volume, density and viscosity. Except viscosity, volume and density are the derived units from mass. Mass plays very vital role and the National Prototype Kilogram No. 57 (NPK-57) is the primary standard of mass in India. NPK-57 is used to calibrate the transfer mass standards and these transfer mass standards are further used in maintaining the unbroken chain of traceability.

Development of model of Watt Balance principle

CSIR–NPL also has started preliminary investigations for development of a Watt Balance. The investigations are done for static and dynamic phases of the Watt Balance. An experimental set up has been established. A wheel of diameter 300 mm, and thickness 10 mm has been fabricated, which is made of Aluminum. The wheel is fitted with knife edge made of gun metal and placed over the suitably flattened aluminum plate fixed to wooden base. The wheel is provided with two pans of diameter 40 mm attached to each other by a string.

The group provides calibration facilities at the apex level for high capacity weights like 100 kgs, 200 kgs and up to 2000 kgs. The characterization work has been carried out for ISRO, Sriharikota for their research and development related activities.

![Fig. 5.2: High Capacity Weights of ISRO, Sriharikota](image1)

Metrological investigations of high capacity volumetric vessels of Rockwin Flow Meters.

Similarly, very high capacity volumetric vessels of 1000 l and 2000 l are calibrated for M/s Rockwin Flow Meters Pvt. Ltd., Faridabad. The

![Fig. 5.3: A Typical High Capacity Volumetric Vessel](image2)

metrological investigations help the manufacturer to fabricate and develop high precision volumetric vessels for further traceability of volumetric measurements in higher range.

Metrological characterization of balance of 1.5 t of Shankar Wires, Deoghar

Though the balances of varying capacity up to 100 kg may be calibrated by some of NABL accredited laboratories, but in higher capacity, only
CSIR–NPL has the facilities. A 1.5 t balance of M/s Shankar Wires Pvt. Ltd, Deoghar has been recently investigated for its metrological capability at site and the report has been prepared.

b. A two days on site training program (April 26-27, 2013) was conducted at NPSL, Pakistan for better understanding of the mass measurement, uncertainty of measurement and calibration of balances etc.

c. Assistance in assessment through NABL to NBSM, Nepal & SQCA, Bhutan accreditation in mass parameter by CSIR – NPL assessors.


e. An inter-laboratory comparison has been conducted on mass parameter with three standard weights of nominal values of 100 mg, 20 g and 1 kg. The inter-laboratory comparison has been aimed to evaluate the competence and the compatibility of the measurement results reported by the SAARC NMIs (BSTI, Bangladesh; NPSL, Pakistan; NBSM, Nepal.

Fig. 5.4: 1.5 t Balance of M/s Shankar Wires Pvt. Ltd. at Deoghar

**Metrological investigations of Reference Grade Hydrometers**

The reference grade hydrometers play a very vital role in maintaining the traceability of density from the primary solid density standard to the working hydrometers. The reference grade hydrometers are used to calibrate the laboratory grade hydrometers or secondary reference grade hydrometers, which in turn calibrates working hydrometers. The working hydrometers are used for density measurement of the liquids directly. Hence, correction of the reference grade hydrometers is very important.

The observations of the investigations have been published in International Journal of Modern Physics: Conference Series, Vol. 24, 2013.

**CSIR NPLI – PTB – SAARC Program**

Under CSIR NPLI – PTB – SAARC program, the following activities took place:

- Attended the Second Co-ordination meeting on Regional Cooperation Metrology at Islamabad, Pakistan during April 22-25, 2013.

Fig. 5.5: Preliminary Results of SAARC-PTB Inter-laboratory comparison for 1000 g

and MUSSD, Sri Lanka). CSIR – National Physical Laboratory, India (NPLI) was the pilot laboratory of this program.

**Density measurement of special alloy developed by Heavy Alloy Penetration Plant, Trichy.**

Some special purpose materials have been developed and fabricated by Heavy Alloy Penetration Plant, Tiruchirappalli under Ministry of Defense for their specific requirement. The density of such samples has been measured very precisely.

**Metrological characterization of Dead weights for Dead Weight Tester, Dead Weight Force Machine & Fluid Flow Standards.**

Dead weights from in-house activities as well as from calibration laboratories and organizations like ERTL are regularly received for calibration of their dead weights in N. The calibration of such
dead weights is very pivotal in maintaining traceability of pressure, force, torque, fluid flow etc. from apex level to user industries as well as in CSIR-NPL too.

**STANDARDS OF DIMENSION**

Participating in international inter-comparison (NPLI as pilot laboratory in length, parameters) with BSTI- Bangladesh, MUSSD-Sri Lanka and NPSL-Pakistan.

1. **Procurement of 3D Coordinate Measuring Machine (Make: Mitutoyo):**

![Image](Fig. 5.6: Experimental setup for electronic level calibration)

2. **Improving uncertainty of measurement in the calibration of electronic level by minimising various systematic errors:**

Engineering levels with typical resolutions of 1μm/m are very often used for inspecting flatness of surface plates, straightness of machine guides and inclinations of machine parts, surfaces etc. Measurement laboratories calibrate these engineering levels using small angle generating instruments viz. sine bar, tilting table. For the engineering level and small angle generators many national measurement institutes have their best calibration capability of an uncertainty in the range of ±1μm/m to ±4μm/m at a 95% confidence level. At NPL-India, an experimental setup is established to investigate various systematic errors. The imperfections are a) misalignment of line of measurement b) flatness, levelling of working platform c) force balancing/weight distribution along the cantilever d) pivoting of tilting table. These imperfections are minimized to improve the repeatability. Further, Laser interferometer is used to calibrate the engineering levels on a tilting table. Uncertainty of measurement for each experiment improved up to ±0.8 μm/m.

**TEMPERATURE AND HUMIDITY STANDARDS**

Temperature standards at NPL are established in accordance with the International Temperature Scale of 1990 (ITS-90) by realizing and maintaining the equilibrium states called fixed points of high purity substances. Ar, Hg, H₂O, Ga, In, Sn, Zn, Al and Ag measured by the platinum resistance thermometers covering the range from 84K to 1234K and realizing Ag and Cu points in blackbody cavities by spectral photoelectric radiation pyrometer, LP4 and thus extends the temperature range from 1234 K to 3500 K.

The humidity standard is maintained through a temperature-pressure humidity generator, Thunder Scientific, USA made, and capable of generating humidity in the range from 10%Rh to 95% RH with a precision of 0.1% RH. The temperature and pressure indicators used in the Chamber are traceable to NPL.

This Section is providing **apex level calibration** to a large number of NABL accredited laboratories, govt. departments and user industries for all types of temperature measuring standards and instruments in the range from -200 °C to 3000 °C and humidity measuring instruments in the range from 10%RH to 95%RH. A significant amount of ECF was generated through these calibration services.

**APMP key comparisons**

This year the Group has completed two major APMP comparisons.

**APMP-T-S7:** Comparison of Pt/Pd thermocouple at Cobalt-carbon (Co-C) eutectic fixed point (1324 °C), which has been developed in the laboratory. The results submitted to NMI, Korea.

**APMP-T-S8:** APMP TCT/DEC: Comparison of Liquid-in-glass thermometers against SPRTs covering a range from -41  °C to 250  °C using high precision alcohol, water and oil baths. The measurement results after analysis shall be submitted to NIMT Thailand.

Temperature & Humidity Standards Group has initiated an innovative project on Boltzmann constant entitled “Determination and realization of thermodynamic temperature by acoustic gas thermometry” for redefinition of unit, kelvin. Work is in progress on the preliminary experimental
requirements. Fixed point of silver with new set-up installed this year has been utilized to calibrate HTPRTs. The results on experimental runs taken on the fixed point have improved the precision and uncertainty in the measurement of the Ag-point. The facility has been utilized for calibration of SPRTs and HTPRTs of in-house and international standards. One such calibration requirement has been received from Sri Lanka Standards Institution (SLSI), Sri Lanka.

**National & International Collaboration**

NPL-NABL-PT-Program, NABL-T-Temp-006 has been completed for Type-S thermocouple in the range from 0 to 1200 C. 12-Calibration laboratories participated in the program. Expertise was provided to NABL for Core Accreditation Committee decisions and in the assessment of calibration laboratories in the field of thermal calibration.

The Group is associated as one of the teams in the NPL-PTB SAARC project. An Inter-laboratory comparison in LIGT (0-100 °C) and Type-S thermocouple (0-1000 °C) was organized by our group among the NMIs of four SAARC countries namely Bangladesh, Nepal, Sri Lanka and Pakistan. The Group provided expertise for peer review of calibration laboratory namely Shri Lanka Standards Institution (SLSI), under the Sri Lanka Accreditation Board (SLAB) during 20-24 Jan, 2013.

**OPTICAL RADIATION STANDARDS**

Dissemination and maintenance of the units of optical radiation of standards have direct impact on societal needs as lighting is one of the largest industrial sectors in the country. We have participated in the APMP Key Comparison of Luminous Intensity (APMP. PR-K3.a) and have finished the measurements. Final report of the measurements was submitted to NMI, Japan- the Pilot Laboratory in March 2014. The report of the Key Comparison is expected after all the measurements at other NMIs are finished. This will help continuation of the CMCs of the Optical Radiation Standards section of NPL. Measurements of luminous intensity were performed on three intensity lamps for preparing artifacts for APMP Key Comparison for Luminous Intensity.

**Measurement results of APMP Key Comparison for Luminous Intensity (APMP. PR-K3.a)**

**Table 5.1 1st Round Measurement (2013)**

<table>
<thead>
<tr>
<th>Lamp No.</th>
<th>Current(A)</th>
<th>Voltage(V)</th>
<th>Distribution Temperature or CCT (K)</th>
<th>Luminous Intensity (cd)</th>
</tr>
</thead>
<tbody>
<tr>
<td>OSRAM Wi41/G: 60</td>
<td>5.862</td>
<td>30.42</td>
<td>2856±20</td>
<td>280.8</td>
</tr>
<tr>
<td>OSRAM Wi41/G: 67</td>
<td>5.856</td>
<td>30.36</td>
<td>2856±20</td>
<td>276.3</td>
</tr>
<tr>
<td>OSRAM Wi41/G: 87</td>
<td>5.880</td>
<td>30.41</td>
<td>2856±20</td>
<td>276.6</td>
</tr>
</tbody>
</table>

**Table 5.2 2nd Round Measurement (2014)**

<table>
<thead>
<tr>
<th>Lamp No.</th>
<th>Current(A)</th>
<th>Voltage(V)</th>
<th>Distribution Temperature or CCT (K)</th>
<th>Luminous Intensity (cd)</th>
</tr>
</thead>
<tbody>
<tr>
<td>OSRAM Wi41/G: 60</td>
<td>5.862</td>
<td>30.42</td>
<td>2856±20</td>
<td>280.4</td>
</tr>
<tr>
<td>OSRAM Wi41/G: 67</td>
<td>5.856</td>
<td>30.36</td>
<td>2856±20</td>
<td>276.6</td>
</tr>
<tr>
<td>OSRAM Wi41/G: 87</td>
<td>5.880</td>
<td>30.41</td>
<td>2856±20</td>
<td>276.3</td>
</tr>
</tbody>
</table>
The final report of key comparison will be published soon by the Pilot laboratory after compilation of results obtained from all the participating laboratories.

Calibration and Testing services: A good amount (about 80 lakhs) of ECF was generated in the year 2013-14 through the initiative taken for calibration of new generation energy saving lamps.

FORCE AND HARDNESS STANDARDS

Force, torque and hardness measurements play a vital role in several industries and research in stress measurement and analysis of materials, products and processes for safety, reliability, stability, efficiency, etc. This group has been engaged in establishing primary standards in all these areas for providing the necessary traceability to the user industries across the county. This group is constantly involved in research and developmental activity for augmenting and upgrading the standards at par with other leading National Metrology Institutes (NMIs) to establish equivalence to the international system of measurements.

Recently, static piezoelectric actuation has been deployed in low force measurement as it exhibits a good stiffness compared to other actuators. An attempt has been made to investigate the feasibility of developing a piezoelectric actuator to exert a desired force on a load cell and to study the observed force versus displacement characteristics. A piezoelectric stack is developed comprising of 14 units of PZT-4 piezo ceramic elements each having a thickness of about 5mm. They are joined together with alternative polarity and the elements are electrically connected in parallel. The stack is appropriately mounted inside the diamond shaped frame using a proper stopper and bolt arrangement as depicted in fig 5.7. Hence the stack is pre-stressed in tension. On the application of the external excitation voltage to the stack elements, they undergo either contraction or expansion depending upon the polarity of the applied voltage. The corresponding transvers or longitudinal displacement of the piezoactuator can be utilized for further application on any desired module as applicable.

Fig. 5.7: Experimental Set-up

The Figure 5.8 shows a typical behaviour of the 1000N force transducer with the increase in the applied voltage, indicating that a force of about 1N is attained in the range of the measurements performed. The Repeatability of the measurement is found to be within 1% which indicates that such piezo actuators can be used for the realization, generation and measurement of small forces.

Fig. 5.8: The variation of measured force on the 1000N force transducer output with Excitation Voltage

The Calibration Measurement capability (CMC) of a torque generating system in the range of 1Nm to 20Nm, using a simple circular pulley as schematically illustrated in Fig.5.9, is reaffirmed.
A fine metallic strip is properly attached at the periphery of the circular section as shown in the figure to support a loading hanger. The circular disc is separately calibrated from the NPL dimension standard for its diameter (radial arm), also the masses used are calibrated from the NPL Mass standard and the calibration and measurement capability (CMC) of this system was theoretically estimated by considering the uncertainty associated with them. A precision flange type torque transducer of capacity 20Nm was used as torque transfer standard to reaffirm the calibration and measurement capability of this system. The CMC of the torque generating system was determined considering the contributions of various uncertainty components including the uncertainty associated with the mean values obtained from the primary machine using the standard procedure. In this way the CMC of the torque machine in the 1-20Nm was reaffirmed and this gives us confidence about the performance of the machine.

Secondary hardness standardizing machines of Brinell, Rockwell (including superficial Rockwell), Vickers and micro-Vickers hardness were established. These machines were calibrated for the applied forces for the different hardness scales possible in the machine. The evaluated forces were found to conform to the requirement of the international standards ISO 6506/7/8 and the calibration measurement capability of the machines were also evaluated. By using these facilities, hardness blocks calibration are provided for the user industries and other calibration laboratories. This enables us to provide traceability in hardness measurement including a newly introduced micro-Vickers scale which is shown in Figure 5.10.

![Micro Vickers Hardness Machine](image)

The group is actively involved in large scale dissemination of the standards of Force, Torque and Hardness to the user industries and calibration laboratories by providing the necessary measurement traceability for these parameters. About 700 calibration reports were issued to the customers all over the county in force, hardness and torque parameters during the last year and the ECF realized in this process was approximately Rs 75 lakh. The group also provides training to the metrologists working in different sectors like NABL accredited laboratories, legal metrology divisions, industries, etc.

**VACUUM AND PRESSURE STANDARDS**

The Pressure Standards group has the mandate to establish, maintain and upgrade the national pressure standards and provide national traceability via apex level calibration and consultancy services for reference and pressure measuring instruments received from industries and other users in the pressure range starting from atmospheric pressure to 1.0 GPa.

The pneumatic pressure section primarily establishes, maintains and upgrades the standards for pneumatic pressures in the pressure range 0.04
to 40 MPa. The primary as well as the secondary standards are dead weight testers which are characterized against each other as well as are traceable through a continuous chain of overlapping pressures to the ultrasonic interferometer manometer. The measurements made are world class and traceable to the international standards.

In addition to the above mentioned activities, the group is also engaged in basic research which includes investigation of materials under high pressure as well phonon behavior at liquid N₂ temperatures using state of the art Raman spectrometer. The group also collaborates with researchers within and outside NPL for Raman characterization of strategic materials, temperature dependent Raman studies and assists in the analysis of the data. The results have been published in reputed international journals.

**PRESSURE STANDARDS**

**Raman studies**

In continuation of our research on high pressure behavior of rare earth oxides, data analysis was completed for PrO₂ and Ho₂O₃ and results of phase progression of lanthanide dioxides (CeO₂ and PrO₂) have been published. The detailed analysis of results of Er₂O₃, Tb₂O₃ is underway.

At ambient, Raman spectra were recorded for a number of samples in collaboration with various groups of NPL as well as other organizations e.g., Delhi University, DTU etc. These include samples like CZTS, ZnO, Fe₂O₃, Bi₂Te₃, GaN, Graphene, Cu₂SbSe₃, LaInO₃, TiO₂, Ir₂O₃, GeTe, FeCNT etc. etc.

**High Pressure Raman study of Lanthanide dioxides (CeO₂ & PrO₂)**

The phase progression in nano-crystalline oxides PrO₂ and CeO₂ up to pressures of 49 GPa and 35 GPa, respectively, were investigated via in situ Raman spectroscopy at room temperature. With an increase in applied pressure the Raman modes due to the cubic phase were seen to steadily shift to higher wavenumbers for both the samples. However, we observed the appearance of a number of new peaks around a pressure of about 34.7 GPa in CeO₂ and 33 GPa in PrO₂ which were characteristic of an orthorhombic α-PbCl₂ type structure. The mode Gruneisen parameters for both the phases were obtained from the pressure.

![High pressure Raman spectra of PrO₂](image)

**Fig. 5.11:** High pressure Raman spectra of PrO₂
dependence of frequency shifts. On decompression, the high pressure phase existed down to a total release of pressure. Although the high pressure Raman data for PrO₂ has not been reported so far, nevertheless, the Gruneisen parameters for the orthorhombic modes obtained after extrapolation to the atmospheric pressure gave values comparable to those of CeO₂.

Draft A Results of APMP KEY COMPARISON

Draft A report of this comparison, identified as APMP.M.P-K13, piloted by NMJ, Japan, is received. The main objective of the key comparison is to compare the performance of hydraulic pressure standards of participating institutes, in the pressure range 50 MPa to 500 MPa in gauge mode to essentially support the objective evidence for high pressure CMCs of the participating institutes. The total participating institutes were 10 including NMJ/AIST, Japan; NPLI, India; NMC/A*S, Singapore; NIM, Thailand; NMIA, Australia; NIM, China; CMS/ITRI, Chinese Taipei; KIM-LIPI, Indonesia; KazInMetr, Kazakhstan and KRISS, Korea. In this comparison, a set of pressure balance utilizing 3 piston-cylinder assemblies of 2 mm² nominal effective area was circulated as the transfer standard (TS). As per draft report, NPLI results are in excellent agreement with pilot laboratory (having relative deviations better than 9 ppm) and also with other participating institutes as shown in the Fig. 5.13. In the Draft A report, the results of the respective participating institutes are compared in terms of the deviations from the pilot institute’s result. The results of this comparison will be linked to the corresponding CCM key comparison, CCM.P-K13 in which NPLI was also a successful participating institute.

Fig. 5.13: Relative deviations of the participating institutes’ results from the pilot institute’s results

Comparison of National and Industrial Hydraulic Pressure Standards in the Pressure Range up to 500 MPa

An in-house comparison of several pressure standards maintained by NPL and other Indian pressure measurement laboratories was carried out using a transfer standard (TS), designated as NPL500MPN, in the pressure range 50-500 MPa, having nominal effective [A’] as 1.96 mm². The objective of the comparison is to determine the values of the A’ₚ of TS and their uncertainties at specified pressures. The comparison was carried out at pressure points of 50, 100, 150, 200, 250, 300, 350, 400, 450 and 500 MPa. The TS was cross-floating against the NPL secondary and primary pressure standards, (NPL500MPA and NPL-H1) and 2 industrial pressure standards (CMERI and YANTRIKA). The comparison data thus obtained are analyzed in terms of A’ₚ(mm²) as a function pressure p (MPa). The values of the A’ₚ and λ thus obtained are also compared with the values of the TS deduced from
recently completed CCM intercomparison exercise. Finally, the consistency of the results in the whole pressure range (50 to 500) MPa is compared with median of $A'_p$ (mm$^2$) values against all laboratory standards (LSs) and found that the results are compatible, uniform and traceable to each other (Fig. 5.14). The degree of equivalence has also been estimated and it is observed that all the standards agree well within the standard measurement uncertainty of the respective LS.

**VACUUM STANDARDS**

- Barometric Pressure Standards activity
  - Ultrasonic Interferometer Manometer (UIM), Force Balanced Piston Gauge (FPG) and Air Piston Gauge (APG), all primary pressure standards are being maintained in good working condition. The

<table>
<thead>
<tr>
<th>STANDARD</th>
<th>RANGE</th>
<th>EXPANDED UNCERTAINTY (at k = 2)</th>
<th>DATE OF COMMISSION</th>
</tr>
</thead>
<tbody>
<tr>
<td>UIM</td>
<td>1.0 Pa to 130.0 kPa (abs)</td>
<td>Q(0.0092 Pa, 0.00072% of rdg)</td>
<td>1982</td>
</tr>
<tr>
<td></td>
<td>1.0 Pa to 130.0 kPa (gauge)</td>
<td>Q(0.0092 Pa, 0.00072% of rdg)</td>
<td></td>
</tr>
<tr>
<td>APG</td>
<td>20.0 kPa to 360.0 kPa (g)</td>
<td>± 0.0012% of rdg</td>
<td>2001</td>
</tr>
<tr>
<td></td>
<td>6.5 kPa to 360.0 kPa (abs)</td>
<td>Q(0.14 Pa, 0.0012% of rdg)</td>
<td></td>
</tr>
<tr>
<td>FPG</td>
<td>1.0 Pa to 15.0 kPa (abs)</td>
<td>Q(0.012 Pa, 0.0025 % of rdg)</td>
<td>2010</td>
</tr>
<tr>
<td></td>
<td>1.0 Pa to 15.0 kPa (gauge)</td>
<td>Q(0.012 Pa, 0.0025 % of rdg)</td>
<td></td>
</tr>
</tbody>
</table>

A

<table>
<thead>
<tr>
<th>STANDARD</th>
<th>RANGE</th>
<th>EXPANDED UNCERTAINTY (at k = 2)</th>
<th>YEAR OF COMMISSION</th>
</tr>
</thead>
<tbody>
<tr>
<td>DPI 145 (01)</td>
<td>0.01 hPa to 1000.0 hPa (abs)</td>
<td>Q(0.006 hPa, 0.012% of rdg)</td>
<td>1997</td>
</tr>
<tr>
<td></td>
<td>35.0 hPa to 1300.0 hPa (abs)</td>
<td>Q(0.006 hPa, 0.01% of rdg)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-1000.0 hPa to 0 to +4000.0 hPa (g)</td>
<td>Q(0.006 hPa, 0.014% of rdg)</td>
<td></td>
</tr>
<tr>
<td>DPI 145 (02)</td>
<td>0.0 hPa to 2600.0 hPa (abs)</td>
<td>Q(0.006 hPa, 0.015% of rdg)</td>
<td>2011</td>
</tr>
<tr>
<td></td>
<td>-200.0 hPa to 0 to +200.0 hPa (g)</td>
<td>Q(0.006 hPa, 0.6% of rdg)</td>
<td></td>
</tr>
</tbody>
</table>

Several secondary pressure standards are also being maintained in good condition for R&D and calibration work. Traceability of all these secondary standards is maintained through calibration of the same against the National Primary Pressure Standards. The measurement uncertainty details of these standards are given in the above table 5.3.

**Fig. 5.14:** Relative deviation of $A'_p$ from median values measurement uncertainty of UIM and APG in both absolute and gauge pressure regions are twice notified in BIPM KCDB as Calibration Measurement Capabilities (CMC) of NPL, India, during 2004 and 2009 through Peer Review conducted in every 5 year duration.
Vacuum Standards activity

CMCs:

- Static Expansion System ~ Range: 10 Pa to 0.05 Pa (Exp Uncertainty: ± 4.0E-03 Pa, coverage factor ~2, confidence level ~ 95%)
- Continuous Expansion (Dynamic Expansion) System ~ Range: 10⁻³ Pa to 10⁴ Pa (Exp Uncertainty: ± 2.0E-02 Pa, coverage factor ~2, confidence level ~ 95%)

**ACOUSTICS, ULTRASONIC AND VIBRATION STANDARDS**

The Acoustics and Vibration standard of NPL is at present maintaining the standards of sound pressure and vibration amplitude in compliance with ISO 17025 & relevant IEC Standards with measurement uncertainties at par with other NMLs. The traceability to regional laboratories and public sector undertakings is provided by the calibrations of electro-acoustic equipments traceable to the national standards. The division is focusing on reducing the measurement uncertainties to an extent at par with some of the reputed NMLs and extension of sound and vibration facilities to shock calibration and free field calibration of microphones. The division is also focused on upgradation of sound transmission loss and sound absorption measurement facility with an objective of reducing measurement uncertainty in sound transmission loss and sound absorption and development of acoustical materials for noise control and abatement. The division is focused to upgrade the measurement standards not only to establish a strong traceability chain throughout the country, but also to help public sector and govt. undertakings, industries and society for noise and vibration abatement and control. The Ultrasound standard of NPL, India is focused on realizing the primary standard of Ultrasound power and provides calibration and testing services in the area of ultrasonic metrology, thus providing traceability to both the industrial and public sector undertakings. The division is responsible for upgradation and maintenance of primary standard of ultrasonic power with an objective of reducing the measurement uncertainty primarily due to rf voltage measurements. A new differential peak to peak measurement approach to reduce the ac voltage measurement error has been investigated.

**Maintenance and up-gradation of National standards of sound, pressure and vibration amplitude**

The Acoustics and Vibration Standard are responsible for maintenance and upgradation of two primary standards viz., Standard of Sound Pressure and Standard of Vibration Amplitude. The division is responsible to establish, maintain and continually upgrade the national standards of measurements of sound and vibration and disseminates the standards by providing the apex level calibration services to the industry and institutions of the country. The primary standard of sound pressure is maintained through absolute calibration of standard condenser microphones in the coupler cavity by the reciprocity technique in the frequency range 31.5 Hz to 25 kHz. The primary standard of vibration amplitude is maintained through absolute calibration of standard reference

<table>
<thead>
<tr>
<th></th>
<th>-1000.0 hPa to 0 to +1000.0 hPa (g)</th>
<th>Q(0.006 hPa, 0.03% of rdg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CDG</td>
<td>0.0 Pa to 133.0 Pa (abs)</td>
<td>Q(0.01 Pa, + 0.22% of rdg)</td>
</tr>
<tr>
<td>CDG</td>
<td>0.0 Pa to 13.3 kPa (abs)</td>
<td>Q(0.011 Pa, + 0.11% of rdg)</td>
</tr>
<tr>
<td>CDG</td>
<td>-1.33 kPa to 0 to +1.33 kPa (g)</td>
<td>Q(0.012 Pa, + 0.3% of rdg)</td>
</tr>
<tr>
<td>RSG (01)</td>
<td>-1.0 kPa to 0 to +1.0 kPa (g)</td>
<td>Q(0.014 Pa, + 0.8% of rdg)</td>
</tr>
<tr>
<td>RSG (02)</td>
<td>-10.0 kPa to 0 to +10.0 kPa (g)</td>
<td>Q(0.059 Pa, + 0.1% of rdg)</td>
</tr>
</tbody>
</table>
accelerometers using the Laser interferometer in the range 5 Hz to 10 kHz. The accuracy of primary standards is verified periodically through participation in key comparison exercises with leading NMIS of the world.

The division is focused on reducing the measurement uncertainties in realizing the primary standards of sound and vibration. The measurement uncertainty calculated in calibration of reference accelerometer is calculated to be 0.3% at 160 Hz at par with other NMIs in APMP region, while for the extended frequency range it varies between 0.3 to 1.25 % (k=2, 95 % confidence level). Efforts are in progress to reduce the measurement uncertainties in the low frequency range (0.1 Hz to 5 Hz) and high frequency range (≥ 10 Hz).

**Study of Atmospheric Boundary Layer (ABL) for Air pollution application.**

SODAR (Sonic Detection And Ranging) is an acoustic remote sensing technique for monitoring the dynamics of the lower atmospheric boundary layer (ABL) thermal structures in real time. SODAR has capabilities to provide a direct pictorial view of the prevailing meteorological processes such as onset/dissipation of free convection, inversion, and fumigation considered useful for air quality assessment studies. Use of site specific SODAR data pertaining to inversion/mixing height is often recommended for environment protection agencies for environment impact assessment (EIA) and planning strategies for disaster management under the accidental release of pollutants.

![National Primary Standard of vibration realized at CSIR-NPL, India](image)

**Fig. 5.15:** National Primary Standard of vibration realized at CSIR-NPL, India

Continuous efforts are targeted towards reducing the measurement uncertainties in realization of primary standard of sound pressure using the well known reciprocity method. The dimensional characterization of microphones has lead to reaffirmation of measurement uncertainty in pressure sensitivity determination to 0.04 to 0.15 dB in the frequency range 31.5 Hz to 25 kHz. The use of the optical method for measuring the front cavity volume has refined the measurement methodology followed by adaptation of a self reliant, traceable and systematic measurement procedure in comparison to the earlier use of nominal values for the sensitivity fitting exercise.

National Physical Laboratory, New Delhi has designed, developed & fabricated a mono-static SODAR. The SODAR system is capable of monitoring the ABL up to a height of 1 km. High power acoustic burst, of 100 ms duration, at 2 KHz is repeatedly transmitted vertically, every 6 sec. using an acoustic antenna. The antenna comprises of 4’ parabolic dish with a transducer placed at its focus. The backscattered signals from atmospheric turbulent regions occurring along the propagation path are received by the same antenna and processed to produce echogram of the prevailing meteorological phenomenon.

![Echograms of Atmospheric Boundary layer height observed for Delhi in December, 2013](image)

**Fig. 5.16:** Echograms of Atmospheric Boundary layer height observed for Delhi in December, 2013
measurement in the ultrasonic power evaluation. It has been found to be better and more accurate than measuring the rf voltage directly. As the circuit employs a very fast diode and peak detector, it has fast dynamic response. It holds the dc voltage within one complete rf cycle. Such fast technique is necessarily needed too the automation. The dc output obtained from the developed module needs to be measured with higher accuracy. This ultimately increases the measurement accuracy of rf voltage.

![Block diagram showing the parts of radiation force balance setup at NPL, India used to measure total ultrasonic power of a transducer](image)

**FLUID FLOW MEASUREMENTS STANDARDS**

The Fluid Flow Measurement Standards group has the mandate to provide apex level testing and calibration services for the different types of domestic and industrial water flowmeters. The group has a Water Flow Calibration Facility (i.e. Primary Standard of Flow) for calibration of different types of water flowmeters as per ISO 4185 standard. Since the present facility is obsolete now, therefore, its upgradation using latest instrumentation and controls was planned. For this purpose, Rs. 1.65 Crores has been sanctioned in XII-Five Year Plan (2012-17) under MIST project.

The group also has a Water Meter Testing Facility (i.e. Secondary Standard of Flow), for testing of domestic/ industrial water meters of sizes 15 mm to 50 mm as per IS 779, IS 6784 and ISO 4064 standards.

The Gas Flow Calibration System in the flow range 10 sccm to 1000 slm with expanded uncertainty of 0.2% (at k=2) is being installed. This system would be used for calibration of mass flow controllers, mass flow meters and rotameters.

An automatic Water Flow Calibration Standard (i.e. Primary Standard of Flow) of size...
DN100 was developed in technical collaboration with M/s Bharti Automation Pvt. Ltd., New Delhi. The traceability of this system was established using various standards instruments traceable to national standards. The uncertainty of this system for volume flow rate is 0.03% (at $\kappa=2$) for collected mass of 2000 kg (Table 5.4).

Table 5.4: Uncertainty of New Water Flow Calibration System of size DN100

<table>
<thead>
<tr>
<th>Sources of uncertainty for volume flow rate</th>
<th>Standard uncertainty At 2000 kg At 1000 kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collected Mass in Weighing Tank</td>
<td>0.01% 0.02%</td>
</tr>
<tr>
<td>Collection Time (including diverter timing error)</td>
<td>0.01% 0.01%</td>
</tr>
<tr>
<td>Water Density</td>
<td>0.05% 0.005%</td>
</tr>
<tr>
<td>Combined uncertainty ($\mu_\nu$)</td>
<td>0.015% 0.023%</td>
</tr>
<tr>
<td>Expanded uncertainty ($U$) at $\kappa=2$</td>
<td>0.03% 0.05%</td>
</tr>
</tbody>
</table>

**LF, HF IMPEDANCE AND DC STANDARDS**

This activity is maintaining the LF & HF impedance standards, DC standards and DC High Voltage standards.

**LF & HF Impedance Standard:** This activity is maintaining the primary standards of capacitance, inductance and ac resistance. Value to the 10 pF capacitor is assigned through primary standard, a calculable cross capacitor, with an uncertainty of 0.6 ppm using precision ac bridges. Scale of capacitance is built up from 10 pF to 1 F using transformer ratio arm bridges. The unit of ac resistance, Ohm, is also realized from capacitance standard, using Quadrature Bridge and other precision ac bridges at 1kΩ. The scale of resistance from 1 Ω to 1 MΩ builds up with Kelvin double arm ac bridge. The unit of inductance, Henry, is realized from capacitance and resistance using Maxwell-Wien bridge. Value to 100 μH to 10 H is assigned through this bridge.

The Precision Coaxial air-lines are taken as the primary standard of HF capacitance standard, traceable to length standards. The capacitance values of these air lines at high frequencies have been evaluated from their dimensions by using the transmission line theory and taking into account the distributive effects associated with the coaxial lines. A set of seven air-lines of different lengths from 3 cm to 30 cm exhibit capacitance values which vary from 2 pF to 20 pF respectively and has been employed in the frequency range of 10 kHz to 100 MHz. Transfer standards of capacitance at high frequency include a set of four coaxial capacitors (1 pF to 20 pF) and four 4-TP (Terminal Pair) air dielectric capacitors (1 pF to 1000 pF) which are calibrated against the primary standard. These transfer standards are then used to calibrate the LCR meters and Impedance analyzer in the range of 1 pF to 1000 pF from 10 kHz to 10 MHz and 1 pF to 20 pF from 10 MHz to 100 MHz respectively.

**DC standards:** This activity is maintaining National Standards of DC voltage, DC current and DC resistance. The apex level calibration facilities have been provided to the ERRLs, ETDCs, Defence and other government organizations for dissemination of traceability.

**DC High Voltage Standards:** This group is providing calibration facility for High Voltage DC equipments i.e. DC High Voltage probe, DC High Voltage divider, DC High Voltage Power Supplies and DC Volt meter, upto 100 kV. Primary standard of DC High Voltage is the Resistive Divider, which is traceable to Josephson voltage standard.

**Bilateral comparison of 10 kΩ & 1Ω Standards between NPL & BIPM (BIPM.EM-K13.a and b)**

A bilateral comparison of 10 kΩ & 1Ω between BIPM and NPL was carried out.

The traveling standards were kept at 23°C for about two weeks to recover the temporal behavior following transportation. Then the measurements were taken for over 2-3 weeks. The measurements were carried out using DCC bridge with a 50 mA dc current for 1Ω resistors and 100mA for 10 kΩ resistors. After measurements in this group and QHR Group, the standards were returned to the BIPM. Measurement analysis is in progress.

**Re-establishment of High Value Capacitor calibration facility (100 mF to 1F)**

This Facility was established at NPL in year 1986. However this facility was discontinued in Year 2008 due to no demand from the customers. Now many organizations are demanding calibration of capacitors from value 100 mF to 1 F.
Hence, this has now been re-established for calibration of 100 mF and 1 F at a frequency of 60 Hz.

**APMP Comparison of 6½ Digit Multimeter (DMM)**

NPL is a Pilot Lab and coordinating the inter-comparison (P1-APMP.EM-S8) of 6½ Digit Multimeter (DMM) under Asia Pacific Metrology Programme (APMP), in which 16 countries are participating. The participating countries are Australia, Hong Kong, Sri Lanka, Kazakhstan, Egypt, South Africa, Thailand, New Papua Guinea, Vietnam, Jordan, Mongolia, Philippines, Malaysia, Indonesia, Syria and India (Pilot Lab).

The circulation of artifact completed in April 2013.

The DC measurements are carried by our group and ac measurement by D#5.10. Measurements, data consolidation and analysis were carried out. The results are communicated to NMI-Australia for consultation. The individual results will be communicated to participating labs for their comments, etc. Thereafter it will be submitted as draft A report to APMP.

**To Conduct Inter-Laboratory Proficiency Testing amongst the NABL Accredited Laboratories in India (CLP 003732)**

Under this Project, our group is co-ordinating two Proficiency Testing (PT) Programmes for Capacitance Measurements:

(i) 1 µF (NABL - E - Capacitance - 003)
(ii) 10 pF & 100 pF (NABL - E - Capacitance - 004)

The first circulation loop completed in the month of July 2012. The eight participating labs in first loop are ERTL (N), ETDC - Mohali, C & I Systems- Rajasthan, ETDC - Jaipur, IDEMI - Mumbai, EQDC - Vadodara, EQDC - Gandhinagar, NQCC - Ahmedabad.

The second circulation loop started from Sep. 2012 and completed in Jan 2013. This circulation scheme includes nine participating labs viz. PMMPL - Noida, ECIL - Hyderabad, BDL - Hyderabad, BEL - Bangalore, Transcal - Bangalore, ETDC-Bangalore, ERTL (E), ERTL (S) and Karandikar Lab-Mumbai.

Interim report submitted to NABL in May 2013. NABL communicated the En values to the respective labs. Final report is under preparation.

**Evaluation of Four-Terminal-Pair Air Capacitance Standards**

At low frequency, the most precise standard of capacitance is a three terminal capacitor popularly known as cross calculable capacitor. The reference standards of capacitance at high frequency include the set of four-terminal-pair (4TP) capacitance standards with nominal values of 1 pF, 10 pF, 100 pF and 1000 pF. Recently CSIR-NPL has initiated the process for the establishment of traceability of high frequency capacitance standards. The evaluation of 4TP capacitance standard consists of three parts; measurement of reference capacitance and capacitive components at 1 kHz, determination of inductive components using resonance technique and computation of capacitance of 4TP standard ($C_{4TP}$) using extrapolation.

The concept of 4TP has been introduced by Cutkosky in 1964 and he defined 4TP standards as the most precision admittance and impedance standards. Cutkosky expressed the impedance of 4TP linear network as

\[ Z_{4TP} = \frac{z_{12} + z_{13} + z_{14}}{z_{11}} \] (1)

Jones extrapolates the 4TP capacitance standard from 1 kHz to higher frequencies using resonance technique. 4TP standards of Agilent 16380A set can be represented as an electrical equivalent circuit model (EECM) described by Yonekura and Wakasugi, consisting of low value inductors and resistors, leakage capacitances and common mode inductance shown in Fig. 5.21. Suzuki evaluated 4TP capacitance standard using single port RF network analyzer and computed its $Z_{4TP}$ mathematically. But single port measurements cannot be sufficiently accurate for a calculation of $Z_{4TP}$ at each frequency of interest. To overcome the limitations of Suzuki method, a method based on four-port scattering matrix, S is proposed by Callegaro and Durbiano using EECM. The s-parameters of 4TP impedance standards could be measured using two-port-network analyzer by connecting two terminal pair at a time and
terminating other two with characteristic impedance.

![Image](image)

**Fig. 5.21. Electrical Equivalent Circuit Model (EECM) of Agilent 16580A set air capacitance standard**

**Measurement Procedure**

The technique proposed for the evaluation of 4TP capacitance standard involves the use of the relation between S and Z given as

\[ z_{22} = z_{12} - (s - z_{22})^{-1} (s + z_{22})^{-1} \]  

(2)

Where \( I \) is unit matrix \([4 \times 4]\) and \( z_{22} \) is the characteristic impedance, 50  \( \Omega \).

The s-parameters are measured using two-port vector network analyzer with impedance analysis option (Agilent E5061B). The nine s-parameters \((s_{12}, s_{22}, s_{23}, s_{24}, s_{31}, s_{34}, s_{41}, s_{42}, \text{and } s_{44})\) are measured from 10 MHz to 500 MHz for each value of 1 pF, 10 pF, 100 pF and 1000 pF and then converted into impedance parameters using (2).

**A. Determination of Series and Parallel Resonance Frequencies**

The parallel resonance frequency (fp) of capacitance standard is determined from zero crossing of imaginary part of 4TP impedance \((\text{Im}(Z_{4TP}))\) versus frequency graph. The series resonance frequency (fs) of capacitance standard is determined from the zero crossing obtained from imaginary part of 4TP admittance \((\text{Im}(Y_{4TP}))\) versus frequency graph. Table 5.5 shows fp and fs thus obtained for each nominal value of capacitance standard.

<table>
<thead>
<tr>
<th></th>
<th>1 pF</th>
<th>10 pF</th>
<th>100 pF</th>
<th>1000 pF</th>
</tr>
</thead>
<tbody>
<tr>
<td>fs, MHz</td>
<td>393.12</td>
<td>327.88</td>
<td>180.58</td>
<td>61.75</td>
</tr>
<tr>
<td>fp, MHz</td>
<td>89.62</td>
<td>244.89</td>
<td>262.96</td>
<td>251.02</td>
</tr>
</tbody>
</table>

**B. Measurement of Capacitive and Inductive Components of Electrical Equivalent Circuit Model (EECM)**

To evaluate 4TP capacitance standards, it is required to determine the capacitive and inductive components of EECM. The reference capacitance \((C_{ref})\) at 1 kHz is measured using AH2700 ultra precision capacitance bridge from Andeen Hagerling while high-to-ground \((C_{hig})\) and low-to-ground leakage capacitances \((C_{lbg})\) are measured using GR 1615 capacitance bridge from General Radio. Table 5.6 shows the capacitive components measured using capacitance bridge at 1 kHz.

<table>
<thead>
<tr>
<th></th>
<th>1 pF</th>
<th>10 pF</th>
<th>100 pF</th>
<th>1000 pF</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECMM components</td>
<td>(C_{ref}, pF)</td>
<td>0.9999</td>
<td>9.998</td>
<td>99.99</td>
</tr>
<tr>
<td></td>
<td>(C_{hig}, pF)</td>
<td>17.4</td>
<td>25.5</td>
<td>31.2</td>
</tr>
<tr>
<td></td>
<td>(C_{lbg}, pF)</td>
<td>49.2</td>
<td>29.5</td>
<td>32.4</td>
</tr>
</tbody>
</table>

The fs and fp are used to compute the inductive components of the equivalent model. In the reported technique \(L_{cm}, L_{h}, \text{and } L_{l}\) are computed by solving (3) for the resonance conditions.

**C. Computation of Four-Terminal-Pair Capacitance**

\(C_{4TP}\) has been computed using (3) for 4TP air dielectric capacitance standards from 1 kHz to 30 MHz as shown in Table 5.7. The sensitivity coefficients have been determined using the partial differentiation to compute the expanded uncertainty (Ue) of capacitance standards with the help of measurement automation program. The
measurement uncertainty due to capacitance bridge, network analyzer and resonance frequency have been included in the uncertainty budget.

**Summary and Results**

The $C_{atp}$ and $Ue$ have been computed for 1 pF, 10 pF, 100 pF and 1000 pF up to 30 MHz. The computed capacitance and expanded uncertainty are comparable with the results reported by other NMIs. The results are further compared and validated with the high frequency LCR Meter (Agilent 4285A). The accuracy of the network analyzer has less effect on the uncertainty budget because it provides only series and parallel resonance frequencies. The measurement automation programs have been developed to ease the process of measurement and for the computation of resonance frequencies & measurement uncertainty.

**Table 5.7: Computed $C_{atp}$ and $Ue$**

<table>
<thead>
<tr>
<th>Frequency, MHz</th>
<th>1 pF</th>
<th>10 pF</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$C_{atp}$ pF</td>
<td>$Ue$, %</td>
</tr>
<tr>
<td>0.001</td>
<td>1.000</td>
<td>± 0.50</td>
</tr>
<tr>
<td>0.01</td>
<td>1.000</td>
<td>± 0.50</td>
</tr>
<tr>
<td>0.1</td>
<td>1.000</td>
<td>± 0.50</td>
</tr>
<tr>
<td>1</td>
<td>1.000</td>
<td>± 0.50</td>
</tr>
<tr>
<td>10</td>
<td>0.988</td>
<td>± 0.57</td>
</tr>
<tr>
<td>30</td>
<td>0.895</td>
<td>± 1.44</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Frequency, MHz</th>
<th>100 pF</th>
<th>1000 pF</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$C_{atp}$ pF</td>
<td>$Ue$, %</td>
</tr>
<tr>
<td>0.001</td>
<td>100.0</td>
<td>± 0.05</td>
</tr>
<tr>
<td>0.01</td>
<td>100.0</td>
<td>± 0.05</td>
</tr>
<tr>
<td>0.1</td>
<td>100.0</td>
<td>± 0.05</td>
</tr>
<tr>
<td>1</td>
<td>100.0</td>
<td>± 0.05</td>
</tr>
<tr>
<td>10</td>
<td>100.4</td>
<td>± 0.16</td>
</tr>
<tr>
<td>30</td>
<td>103.7</td>
<td>± 1.09</td>
</tr>
</tbody>
</table>

**Charge Measurement:**

To provide calibration and traceability for low level electrical charge down to 200 pC:

Several modifications have been made in the previous design of the charge generation and measurement set up using the constant voltage method which resulted in achieving measurement of charges down to 100 pC with very good accuracy. The lowest measurement range achieved improves upon the targeted value of 200 pC. The operation of the set up has been automated with GPIB control using software developed in LabVIEW for instrument control and data acquisition. Table 5.8 illustrates the measurement results.

**Table 5.8: Measurement Results**

<table>
<thead>
<tr>
<th>Charge Range</th>
<th>Uncertainty Achieved</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 nC - 1 nC</td>
<td>0.1% to 0.5%</td>
</tr>
<tr>
<td>1 nC - 100 pC</td>
<td>0.5%</td>
</tr>
</tbody>
</table>

**Automation of Calibration**

The dc parameter calibrations of reference DMM and multifunction calibrator have been automated with PC control using calibration automation software developed in LabVIEW. The calibration automation software performs all necessary instrument controls as well as acquisition, processing, recording, reporting and storage of the test and calibration data. Separate software modules have been created for voltage, current and resistance calibrations. Calibration of any one parameter can be done for a complete range of values in a single run of the program with the calibration result saved in an excel file at the end. Automation reduces considerably the calibration time and avoids possible mistakes in recording the measured data and calculations. Automation programs for other commonly used instruments are also under development.

**LF & HF VOLTAGE, CURRENT AND MICROWAVE STANDARDS**

CSIR-NPL has the responsibility to upgrade the present apex level calibration facility and to provide traceability to user organizations. We are providing national traceability in the LF voltage,
current, HF voltage and Microwave attenuation, impedance, power parameters through apex level calibration to ISRO, DRDO, Naval Dockyard, Air Force, BEL, STQC labs, regional laboratories and the other user organizations.

Traceability of National microwave power standard has been re-established from 10 MHz to 18 GHz with an uncertainty ranging from 0.2 % to 0.8 %. Dissemination of transfer standards for maintaining the traceability of measurements is under progress. The established VNA traceability has been used in assigning VSWR/ reflection coefficient mismatch uncertainty for the coaxial thermistor mount, primary standard of microwave power. At present, NPLI has a coaxial microcalorimeter in 7 mm line working upto 18 GHz. With the advancement in metrology most of the NMLs of the world have the calibration facility upto 50 GHz. Development of NPLI 2.4 mm coaxial microcalorimeter is under progress at LNE France, which will help in fulfilling the demand of high frequency and microwave power calibration to keep pace with international level.

We have participated in an international APMP key comparison (July-August 2013) APMP.EM.RF-K8.CL “Microwave Power in 50 ohm coaxial line; frequency 10 MHz to 18 GHz” to establish a close degree of equivalence in measurements among the participating NMLs. In this Key Comparison NMI-Japan is the Pilot laboratory along with thirteen participating laboratories of APMP including NPL India. The travelling standards consist of two thermocouple power sensors and a power meter.

Thermal current converters (TCC) or thermal transfer standard (TTS) with AC-DC current shunts are used as reference standards for LF current in the frequency range from 40 Hz to 10 kHz. These standards provide accurate and precision measurement for LF current. The range of AC-DC current transfer measurement facility at NPL has been extended from existing 20A to 80A using indigenously developed current TEE. Now CSIR-NPL is capable of providing traceability to user organizations by calibrating the AC-DC current shunts of 30A, 50A, and 80A along with the thermal current converters or thermal transfer standard in the frequency range 40 Hz - 10 kHz.

Fig. 5.23. AC-DC current transfer measurement facility upto 80A

Progress under the establishment of Standards for Radiated Power Density:

A handheld spectrum analyzer (FSH8, R&S Germany) along with two isotropic probes have been procured. To calibrate the procured probe inside a GTEM cell, a GTEM cell have been indigenously developed based on Crawford concept. The proposed GTEM is applicable for frequency range 0.7 - 2.5 GHz.

Fig. 5.22. Direct Comparison Technique used in APMP Intercomparison

Fig. 5.24. Setup for E-field probe calibration and measured VSWR
Utilizing the BSNL base station situated at New Rajinder Nagar (28°37’42.5"N 77°10’25.0"E), radiated power density at 1.8 GHz and 2.4 GHz frequencies was measured at distances varying from 1 to 30 m. The radiated power density measurements were repeated using the VSNL tower located at Dasghara (28°37’29.4"N 77°09’48.6"E) for the same frequency points and varying distances. An E-Field probe along with Spectrum Analyzer is used as receiver to measure the signal strength, electric field strength and radiated power density. Radiated power density measurements (W/m²) at above two locations were performed with the help of E-field probe and spectrum analyzer with embedded software for different frequencies. Equipment used for these measurements are traceable to Microwave Attenuation, Impedance, Power Standards and Dimensional Metrology at CSIR-NPL, India.

![Fig. 5.25. Radiated power density measurement with results (1.8 GHz and 2.4 GHz)](image)

**AC POWER AND ENERGY STANDARDS**

The activity is maintaining the primary standard of AC Power & Energy (PPCS) traceable to voltage, resistance and time. Working range is 10V to 480V/10mA to 100A/ PF:1 to 0.01(lag/lead) at frequency range 40 Hz to 400 Hz.

The single phase and three phase reference standards are calibrated against this PPCS and then used in our calibration benches for providing traceability to all power sector organizations, other laboratories and energy meter manufacturers in India and in SAARC countries.

Calibration of three phase class 0.01 and single phase class 0.005 reference standards are now being done in NPL which were earlier being sent to other NMIs.

The new CMCs of AC Power & Energy Standard has been uploaded on BIPM website in March 2014. The best uncertainties in active power are ± 0.005% in reactive power ± 0.009% and in apparent power ± 0.008%.

The Isolation transformer has been calibrated using two comparators.

By conventional method we could calibrate from 120A to 1 A at UPF and at 0.8 lag PF only but
by this new method we could calibrate the Isolation Transformer from 120A to 0.01A and at every power factor, i.e., 1 – 0.01(j/c).

Primary Power Calibration System (PPCS) is set up and is being used for disseminating traceability in India and in SAARC countries and the results of Isolation transformer will be traceable to PPCS through the current values and phase between voltage and currents.