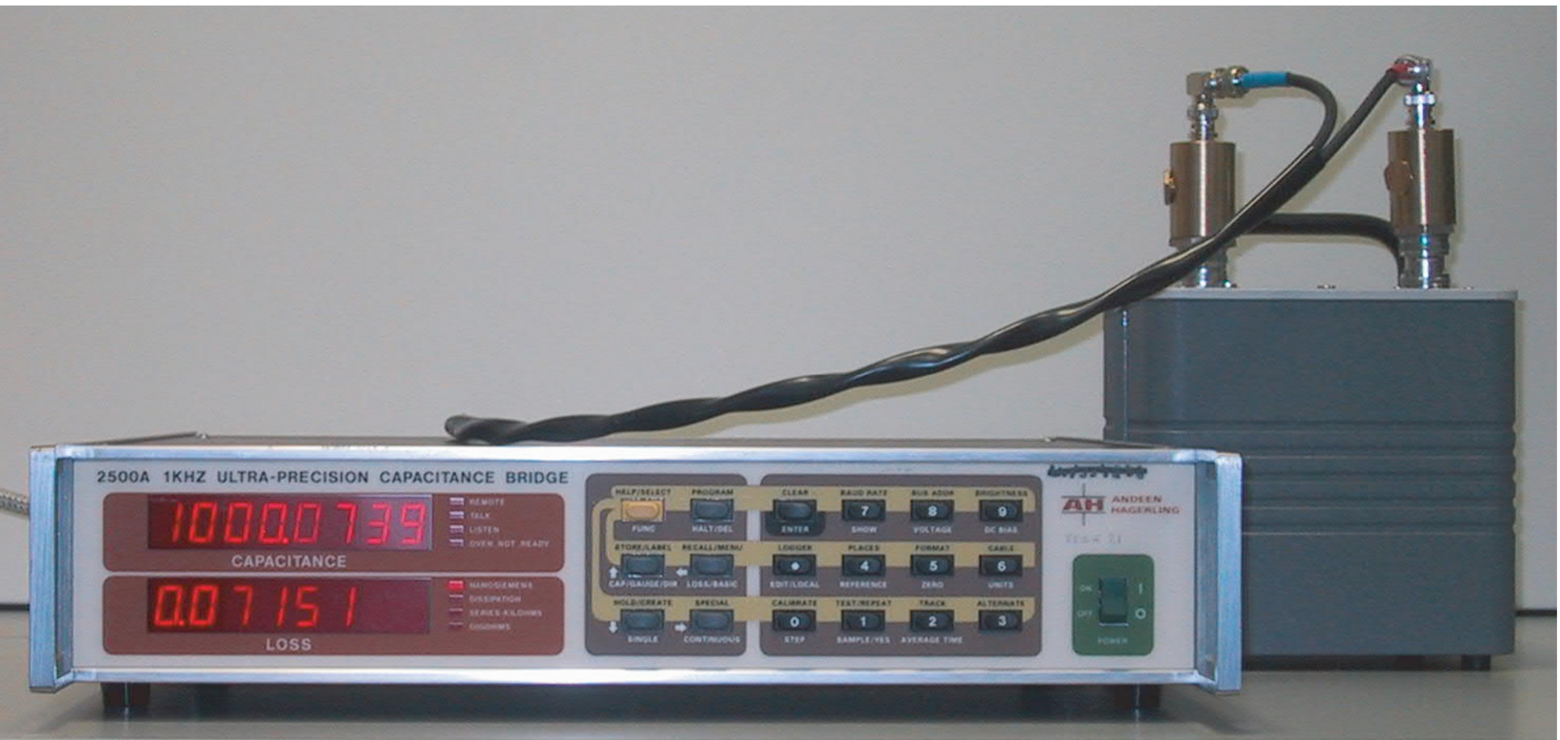
Calibration Services

Electricity, acoustics, time and frequency

VTT MIKES



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VTT MIKES

Electricity, acoustics, time and frequency

Direct voltage

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Metrological background

The accuracy of almost all electrical measuring instruments is based, in addition to resistance, on the traceability of direct voltage. VTT MIKES maintains the national standard of direct voltage Finland. The unit of direct voltage, volt, is determined very accurately (relative uncertainty even 10^{-10}) by using Josephson voltage standard. The volt from the Josephson standard is transferred to Zener working standards and from there to calibrators and multimeters. The measurement range is extended above 10 V by using a resistive voltage divider.

Figure 1. The traceability of direct current is based on a Josephson standard cooled in liquid helium.

Calibration services

The most important DC voltage calibration targets are DC voltage standards, DC and multifunction calibrators as well as precision multimeters. Moreover, DC voltage dividers and nanovoltmeters are calibrated. The standard under calibration is usually monitored for a couple of weeks by comparing it to our working standards. When lower measurement uncertainties are needed a Zener voltage standard can be calibrated directly with our Josephson standard. On request, the DC voltage ranges of multimeters and calibrators can be calibrated using Josephson and Zener standards and a resistive voltage divider. Resistive voltage dividers are calibrated by comparing them to a reference divider or a Josephson normal.

Examples of device models that we calibrate:

- Zener DC voltage standards: Fluke 732A, 732B, 732C, 7000
- Voltage dividers: Fluke 752A (high-voltage dividers see brochure for high voltage and current)
- Nanovoltmeters: Keithley 181, 182, 2182, Fluke 845, Keysight 34420A

Figure 2. Zener DC voltage standard.

Table 1. Minimum measurement uncertainties for the most common DC voltage calibrations. With special methods, it is possible to achieve significantly lower calibration uncertainties.

	Zener standard			Calibrator of multimeter		
Voltage (V)	1	1.018	10	0 ... 10	10 ... 100	100 ... 1000
Uncertainty (µV)	0.2	0.2	2	0.3 ... 20	70 ... 610	1000 ... 10000

Direct current

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Metrological background

Traceability of direct current is in practice based on direct voltage and resistance as well as Ohm's law. Accurate DC current measurements can also be made with zero flux current transducers.

Calibration services

VTT MIKES direct current calibrations cover a very wide range from 1 fA (10^{-15} A) to 500 A and cover both power supplies and current meters.

At the lowest currents (fA to nA ranges), the target devices are electrometers and low current calibrators. In addition to currents, some electrometers can also measure electrical charge.

In nA to A ranges, the most common target devices are multifunction calibrators and multimeters, which also measure other quantities than direct current and thus are described in another brochure.

Devices measuring high currents (> 20 A) are zero flux transducers, current clamps and electronic loads (see separate brochure) and devices producing high current include different current and power sources.

Examples of device models we calibrate:

- Low currents 1 fA – 100 µA
  - o Electrometers: Keithley 6517A, 6517B, 6430
  - o Low Current Sources / Calibrators: Keithley 263
- Mid-range currents 100 µA – 20 A
  - o Multimeters & calibrators (in another brochure)
- High currents 20 A – 600 A
  - o Zero flux transducers: Lem, DaniSense, PM Special Measurement Systems (formerly Hitec)
  - o Meters for calibrating welding power sources
  - o Traditional current clamps and flex probes: the most common are various Fluke models
  - o Electronic loads: Array, Tenma, Keysight, etc. (see another brochure)

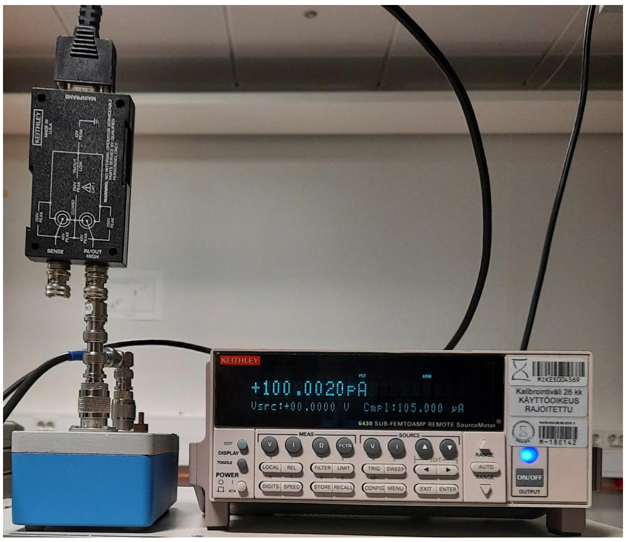

Figure 1. Electrometer measuring a small direct current of 100 pA.

Figure 2. Clamp current meter in a 50-turn calibration coil measuring a large 500 A direct current.

AC voltage and current, multimeters & calibrators

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Metrological background

The traceability of our most accurate reference multimeters and calibrators in terms of DC voltage, direct current and resistance is obtained by comparing them with our own more accurate standards (resistance standards, direct voltage standards, etc.), which usually produce a single point value.

Combining the traceability of these different quantities into individual multimeters and calibrators provides highly versatile devices for traceable measurement and generation of electrical quantities that can be used to perform large-scale computer-controlled calibrations of customers' equipment.

Figure 1. Calibrators, multimeter and other electrical measuring devices.

Calibration services

Depending on the model, multimeters and multipurpose calibrators can be used for calibration of

- direct voltage 1 mV – 1000 V
- alternating voltage 1 mV – 1000 V
- direct current 100 nA – 20 A
- alternating current 1 mA – 20 A
- resistance 1 Ω – 20 GΩ
- capacitance
- simulated temperature: resistive sensor or thermocouple
- frequency

The measurement capability also allows larger ranges for some quantities. The ranges given here are limited by the typical ranges of the target devices.

Examples of device models:

- calibrators, e.g. Keithley, Beamex, Fluke 5500 & 5700 series, also oscilloscope options
- multimeters, all 3–8 digit meters, e.g. Fluke 8508A, Keysight 3458A, Keithley 2000
- testers, e.g. Sefelec 2804, tester calibrators, e.g. Fluke 5320A
- phase meters, e.g. Clarke-Hess 6000A, North Atlantic Industries 2250A.

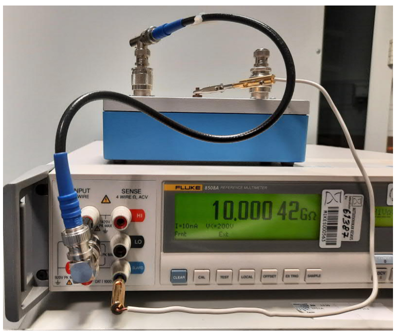

Figure 2. Calibration of a multimeter using a resistance standard.

Capacitance and inductance

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Metrological background

At VTT MIKES, traceability of capacitance is based on 10 pF – 1 µF reference capacitors calibrated at BIPM and RISE. Inductances are traceable to resistance standards of VTT MIKES.

BIPM, International Bureau of Weights and Measures
RISE, Research Institutes of Sweden

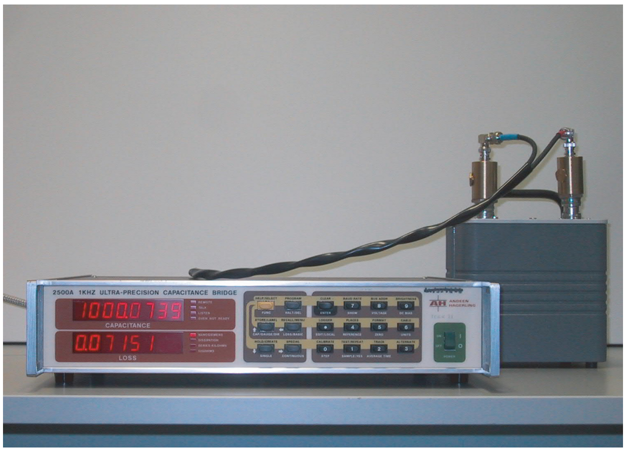

Figure 1. AH2500A measuring bridge and calibration of a 1 nF capacitance normal.

Calibration services

VTT MIKES calibrates capacitance and inductance standards and LCR-meters primarily at 1 kHz frequency, and to a limited extent at other frequencies.

Examples of device models:

- capacitance standards and capacitance decades 0.1 pF – 1 µF at frequency 1 kHz
- capacitances at voltages above 1 kV, 10 pF – 100 µF at frequencies 45 Hz – 60 Hz (see high voltage and current)
- simulated capacitances of calibrators
- inductance standards 100 µH – 100 mH at frequency 50 Hz – 1 kHz (2 kHz)
- LCR-meters at fixed points covered by the reference standards at frequency 1 kHz, at some extents at other frequencies, too.

Figure 2. Inductance decade box.

Resistance

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Metrological background

Resistance is the most important quantity of electrical measurements together with direct voltage. In addition to direct resistance calibrations, resistance standards are needed for providing traceability to other electrical quantities. VTT MIKES is the national standards laboratory of resistance. The traceability of resistance standards at VTT MIKES is based on its own quantum Hall standard, which connects the unit of resistance to the values of physical constants with a relative uncertainty of about 10^{-8}.

Figure 1. Resistance bridge comparing two 1-kΩ resistance standards.

Calibration services

The resistance calibration range at VTT MIKES is very wide, 10 µΩ – 100 TΩ (10^{14} Ω). If necessary, the measuring capacity extends even wider, depending on the object. The most accurate calibrations are performed in the middle of the scale and at powers below 10 mW. Under certain conditions high-power calibrations can also be performed up to 2 kW. The temperature and power dependencies of the resistances as well as the AC / DC differences can be measured, also.

In addition to the resistance (unit Ω), we have measured the resistivity of materials (unit Ωm).

Examples of devices to be calibrated:

- resistance standards, shunts and resistance decades 100 µΩ – 100 TΩ
- insulation testers, e.g. Fluke 1555, Megger MIT, Chroma 11210
- milliohm meters, e.g. Agilent, GW Instek
- multimeters and multipurpose calibrators (in another brochure)
- resistivity of alloys

Oscilloscopes and oscilloscope calibrators

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Metrological background

The traceability of the VTT MIKES oscilloscope calibrator is based on the measurement standards for DC voltage, AC voltage, resistance, time interval, frequency and RF power. In addition to the actual oscilloscope calibrator, some oscilloscope functions are calibrated with other reference devices such as frequency counter, multimeter, and multi-function calibrator.

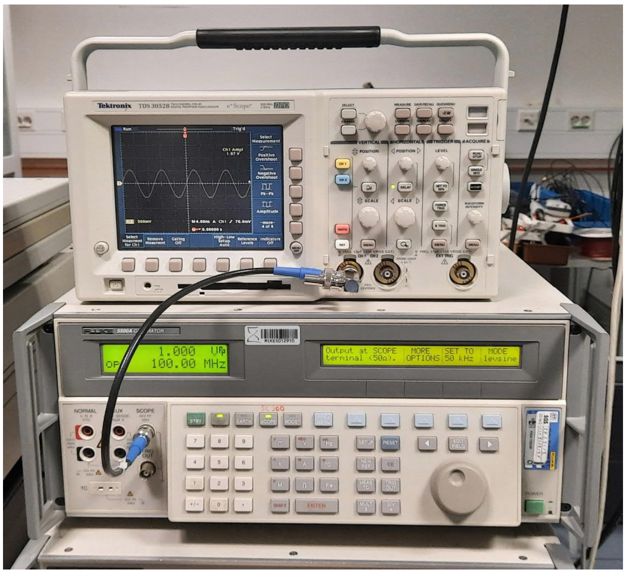

Figure 1. The oscilloscope calibrator supplies a 100 MHz signal to the oscilloscope being calibrated.

Calibration services

VTT MIKES calibrates oscilloscopes with the SC300 oscilloscope option of the Fluke 5500A multi-function calibrator up to 300 MHz. Correspondingly, we calibrate the oscilloscope options for our customers' calibrators. Depending on the device model, the features to be calibrated include:

- input impedance
- DC voltage levels
- freguency band
- frequency response of frequency band limiting functions
- frequency
- trigger sensitivity
- accuracy of horizontal delay
- signal rise time
- in addition, we perform functional tests recommended by the manufacturer.

Examples of devices to be calibrated:

- oscilloscopes up to 300 MHz, e.g. Tektronix, Keysight, Tenma
- oscilloscope options for Fluke calibrators SC300, SC600.

Power sources and electronic loads

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Metrological background

The traceability of power supply and electronic load calibrations is based on VTT MIKES measurement standards for direct current, direct voltage and resistance.

Figure 1. Power supply, load and a multimeter displaying the reference current.

Calibration services

Depending on the model, electronic loads can be set to simulate different types of electrical loads:

- constant resistance mode (CR)
- constant voltage mode (CV)
- constant power mode (CP)
- constant current mode (CC).

Power supplies can usually be used in two different modes:

- constant voltage mode (CV)
- constant current mode (CC).

In VTT MIKES, all these modes can be calibrated, i.e. the device's own reading can be compared to a value determined with reference devices.

Examples of devices to be calibrated:

- DC power sources typically up to 2 kW, e.g. Keysight, Keithley, TTi
- electronical DC loads typically up to 2 kW, e.g. Keithley, Tenma, Chroma.

Calibration of power and energy at line frequency

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The measurement of electric energy consumption has a huge economic importance. Through the development of electric energy market, the importance of measurement accuracy and traceability is further emphasised. Accurate electric power standards are required in the calibration of energy meters. At MIKES, measurements of electric power at 50 Hz are traceable to SI units through a sampling power standard. Calibrations are performed using either single-phase or three-phase measurements. Typical devices that we calibrate are electric power meters and converters.

At VTT MIKES power laboratory, the traceability of electric power at 50 Hz is based on direct voltage from a Josephson standard and resistance realised by a quantum Hall equipment. The sampling power standard consists of two 8½ digit voltmeters, which are accurately synchronised. Currents smaller than 20 A are converted to voltages using specially constructed shunt resistors, whose resistance values are traceable to the quantum Hall resistance standard. The same measurement equipment with a current sensor based on a Rogowski coil is used to measure currents and current ratios up to 8000 A. The measurement uncertainty of the VTT MIKES power reference equipment is 0.005 % at its best.

The methods and equipment of VTT MIKES power laboratory represent international top quality. The high quality of measurements is verified by taking part in international comparison measurements together with national metrology laboratories from other countries. VTT MIKES is also an active member in different expert working groups at international level and takes part in national as well as international joint research projects. Several projects are in the European Metrology Research Programmes EMRP and EMPIR.

Figure 1. Six channel sampler for power calibrations. The sampler can be used also for calibration of power harmonics, and digital measuring instruments using IEC 61850-9-2 LE and IEC 61869-9 protocols.

Calibration services

VTT MIKES calibrates especially reference standards of customers who need the best available measuring accuracy. Typical instruments are power comparators and converters. The calibrations are performed by connecting the same current and voltage to the customer's device and the reference meter of VTT MIKES. If necessary, effect of the power source used in the calibrations is minimized by accurately synchronising the meters. The reference meter used in the calibrations is either a single-phase sampling power standard or a three-phase power comparator.

In addition to power standards, we calibrate current and voltage transformers and transducers up to 200 kV voltage and 8 kA current. We carry out special assignments related to the measurement of electric power and energy, as well as power quality, and take part in research and development cooperation projects in this field. More-over, we organise educational opportunities in this field and custom-tailored training.

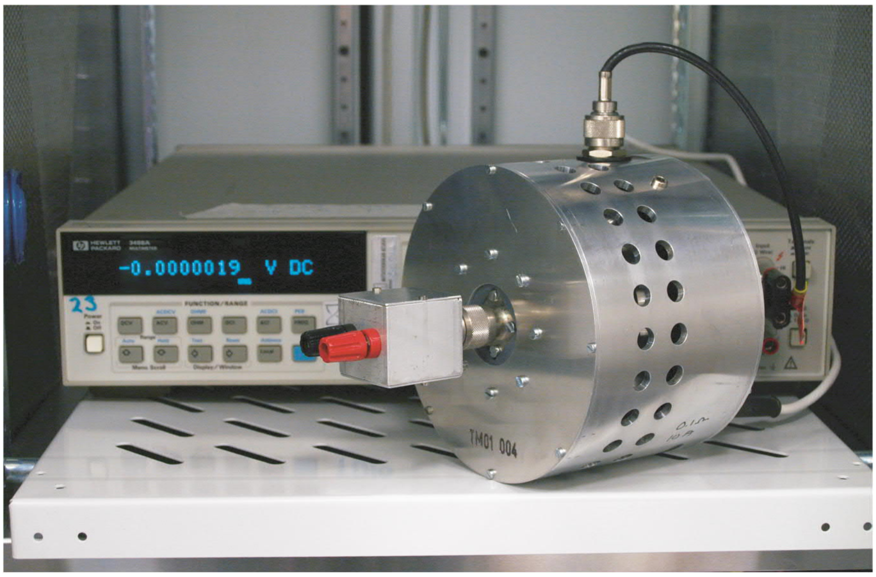

Figure 2. A coaxial shunt resistor of the sampling power standard.

Table 1. Measuring ranges and calibration uncertainties at VTT MIKES for calibrations of power and energy.

Measured quantity	Expanded relative uncertainty (*k* = 2)
Single phase, 50 Hz, 30 V – 500 V, 5 mA – 40 A	
Active power	50 µW/VA
Reactive power	100 µvar/VA
Single phase, 400 Hz – 10 kHz, 1 V – 500 V, 5 mA – 10 A	
Active power	120 - 400 µW/VA
Reactive power	120 - 400 µvar/VA
Harmonics, 50 Hz – 2.5 kHz, 1 V – 500 V, 5 mA – 10 A	
Voltage, 1 V – 500 V	100 µV/V
Current, 5 mA – 10 A	100 µA/A
3-phase, 50 Hz, 50 V – 350 V, 5 mA – 12 A	
Active power	120 µW/VA
Reactive power	250 µvar/VA
Active power	120 µWh/VAh
Reactive power	250 µvarh/VAh

RF- and microwave calibrations

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The importance of measurement reliability is emphasized along with the continuously increasing amount of applications in RF- and microwave ranges. VTT MIKES is the national metrology institute in this field and offers traceability with low uncertainty to internationally accepted measurement standards in RF and microwave power measurements and measurements of S parameter (reflection and attenuation). We calibrate power sensors and attenuators for instance.

Our calibration equipment is equipped with precision type N connectors, thus our measurement range extends to 18 GHz. The measurements and the analysis of results are mainly automated. The measurements are carried out in a controlled 23 °C temperature in an electromagnetically shielded room.

The high standard of the measurements is verified by actively taking part in international comparisons together with other national metrology institutes. The traceability is based on power and attenuation calibrations at NPL (National Physical Laboratory) in U.K. and on the primary standards at VTT MIKES.

Figure 1. Measurement of power sensors.

Calibration services

Power

The calibration coefficients of sensors are determined with measurement equipment based on a power divider. Measurement of reflection coefficient by using a vector network analyser is included in the sensor calibration. Typically, calibration takes five workdays. The calibration of the absolute power of a power reference in a power meter is performed for thermocouple and diode power sensors. The reflection coefficient of the power source is determined at the same time.

Figure 2. Measurement set-up for power sensors.

Attenuation

Attenuation calibrations are carried out by traceable vector network analyser measurements. Determination of reflection coefficient by is included in the calibration. We calibrate fixed value attenuators as well as step attenuators. The step attenuators can be controlled by using a GPIB bus, RS-232 connection or directly using the step attenuator controller Agilent 11713A.

Reflection coefficient

Traceable measurements of reflection coefficient are performed using a vector network analyser. The impedance of the impedance standards used in the measurements is determined at VTT MIKES with accurate dimensional measurements. Dimensional measurement services for N-type airlines are offered for customers, also.

Figure 3. Measurement of reference step attenuator.

Table 1. Measurement ranges and uncertainties.

Quantity	Measurement range	Measurement frequency range	Uncertainty
Calibration coefficient of power sensors	1 mW	10 MHz – 18 GHz(1)	0.4 % – 1.1 % (k=2)(2)
Absolute power	1 mW	10 MHz – 18 GHz(1)	4 mW/W – 11 mW/W (k=2)
Attenuation	0 dB – 80 dB	300 kHz – 6 GHz	0.02 dB – 0.17 dB (k=2)
Attenuation	0 dB – 60 dB	6 GHz – 18 GHz	0.05 dB – 0.18 dB (k=2)
Reflection coefficient (real and imaginary parts)	between –1 and 1	10 MHz – 18 GHz	0.013 – 0.024 (k=2.45) (3)

1) Frequencies for power calibrations: 10 MHz, 30 MHz, 50 MHz, 100 MHz, 300 MHz, 500 MHz, 1 GHz, 1,5 GHz, 2 GHz – 18 GHz in 1 GHz steps.
2) Absolute value of reflection coefficient ≤ 0,08
3) A 95 % coverage for the complex uncertainty of a complex variable is obtained when k=2.45.

High voltage and high current

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High voltage quantities

The importance of high voltage measurements has been emphasized with the opening of electricity markets. The quality of electricity, transmission losses and the sale of electricity for industry and for private households have become more important measuring and monitoring subjects. In addition to electricity, electronics and information industries, high voltage users can be found, in almost every industrial sector. High voltage metrology at VTT MIKES is internationally respected and provides services on traceability also at customers premises in Finland and globally.

Traceability

The high voltage measurements at VTT MIKES are traceable to capacitance, resistance and voltage, which in turn are based on quantum primary standards: quantum Hall resistance standard and Josephson voltage standard. We have performed well and also acted as a coordinator in international comparisons in high voltage metrology. As an example of this is the coordination of broad European and worldwide comparisons of lightning impulse voltage measuring systems.

Calibration services

VTT MIKES offers calibration services for almost all high voltage quantities and measuring systems up to 200 kV voltage. The range of alternating current calibrations extends to 8 kA. The measuring range for pulse quantities covers a voltage range from millivolts up to megavolts and currents up to tens of kiloamperes. Our expert services cover different aspects of calibration of measuring systems. If wanted, we evaluate customer's measuring systems and modify them to be more accurate and stable if needed. In future, our area of qualification will be extended to calibrations related to measurements on the quality of electricity.

The best calibration uncertain y is achieved, when calibrations are performed in a laboratory at VTT MIKES but calibrations can be carried out at customer's premises, also. Measuring systems can be calibrated on-site when the voltage level, the size of the system, grounding conditions or proximity effects necessitate it.

Calibration subjects

Devices that we calibrate include.

- voltage dividers
- voltage and current transformers
- measuring probes, voltage and current sensors and current shunts
- high voltage inductors and capacitors
- transient recorders, peak voltage meters
- surge-, EFT- and ESD- test devices
- voltage testers
- pulse calibrators
- partial discharge calibrators

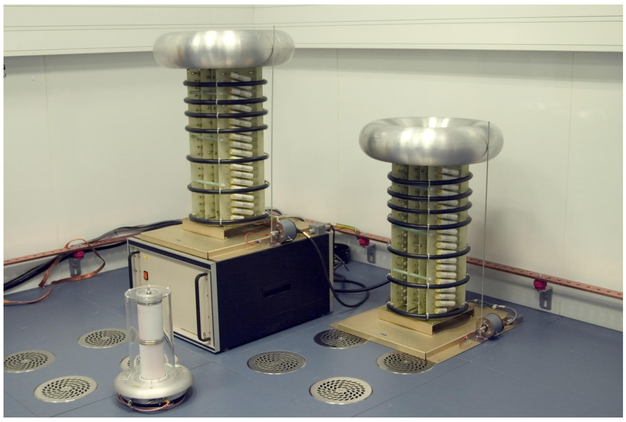

Table 1. Calibration services of high voltage.

Quantity	Measurement range	Uncertainty (*k*=2)
Direct voltage, voltage ratio	1 kV – 1000 kV	0.0005 – 0.01 %
Direct current, current ratio	100 A – 600 A	0,002 %
Alternating voltage	1 kV – 200 kV	0.005 %
– ratio error	1 kV – 200 kV	0.002 – 0.005 %
– phase displacement	0 – 100 mrad	0.02 mrad
Alternating current	1 A – 8 kA	0.005 %
– ratio error	1 A – 8 kA	0.0025 %
– phase displacement	0 – π rad	0.05 mrad
Capacitance	1 – 200 kV / 10 pF – 100 µF	0.002 – 0.02 %
– loss factor tan δ	$1 \cdot 10^{-5}$ – 2	1 % ($1 \cdot 10^{-5}$ abs)
Inductance / losses	1 µH – 10 H	0.03 % / 0.2 mrad
Lightning impulse voltage	50 mV – 400 kV	0.1 – 0.5 %
Switching impulse voltage	1 V – 400 kV	0.1 – 0.2 %
Other voltage impulses (e.g. surge)	1 V – 400 kV	0.1 – 0.5 %
Impulse current	1 A – 10 kA	3 %
ESD-pulse	1 A – 50 A	5 %
Impulse Time parameters	0.7 ns – 100 ms	0.5 – 5 %
Apparent charge of partial discharge	0.01 pC – 10 nC	1 – 5 %

Acoustic calibrations

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The need of accurate acoustic measurements is growing for instance due to regulations and legislations concerning noise emissions and exposure to vibrations. A good measurement accuracy requires, in addition to high-quality measurement devices, regular and traceable calibrations. In Finland, VTT MIKES is responsible for the traceability of the acoustic quantities: sound pressure and acceleration.

Sound pressure is transformed into an electrical signal by using accurate condenser microphones, whose primary calibration equipment is in use at VTT MIKES. Sound level calibrators are calibrated using these condenser microphones. The traceability chain of sound pressure level starts from the calibration of laboratory grade microphones by using a so-called reciprocity calibration system. This calibration gives the voltage-pressure sensitivities of the microphones. The method is described in the standard IEC 61094-2 (1992-03) and it is in use in several other national metrology institutes.

A vibration transducer produces a signal, typically a voltage or a charge, which is proportional to the acceleration of mechanical motion. Therefore, in the calibration of a vibration transducer, the sensitivity (typically mV/(m/s2) or pC/(m/s2) of the sensor is determined as a function of frequency. VTT MIKES calibrates vibration transducers by comparing their readings to a known vibration produced with a vibration exciter. The real amplitude of acceleration and frequency is simultaneously measured by using a reference sensor. The method is described in the standard ISO 16063-21:2003.

Figure 1. A reciprocity calibration of microphones is starting in the soundproof laboratory at VTT MIKES.

Calibration services

Microphones

We calibrate ½ (LS2P) and 1 (LS1P) inch condenser microphones described in the standard IEC 61094-1 (Table 1). The calibration method depends on the accuracy required by the customer. The smallest calibration uncertainties can be achieved by using the reciprocity method. In many cases, a comparison with a reference microphone by a sound level calibrator is adequate.

Table 1. Uncertainties of calibration for microphones.

Type of microphone	Frequency [kHz]	Uncertainty [dB]
LS 1	0.0315	0.06
	0.063 ... 2	0.04
	4	0.05
	5	0.06
	8	0.08
	10	0.10
LS 2	0.0315	0.08
	0.063	0.06
	0.125 ... 8	0.05
	10	0.06
	12.5	0.08
	16	0.10
	20	0.14

Sound level calibrators

Sound level calibrators and pistonphones are the most common devices calibrated at VTT MIKES acoustics laboratory. We calibrate the sound pressure levels at fixed frequency points. At the same time, the distortion and frequency of the sound source is measured.

Vibration transducers and loggers

We calibrate vibration transducers, loggers and vibration measurement devices in the frequency range 1 Hz – 10 kHz. Typical nominal acceleration is 10 m/s^2. The calibration gives the magnitude and the phase of the sensitivity of the vibration transducer. The uncertainty of the calibration depends on the transducer under calibration. Typical uncertainties for the magnitude are 1–3 % and for the phase 1–2° depending on the frequency (Table 3).

Table 3. The measurement ranges and typical uncertainties of vibration calibrations. (*) Frequency range is not included in the CMC table of VTT MIKES.

Calibrated instrument	Frequency [kHz]	Typical uncertainty [%]
Vibration transducer	10 – 10 000	0.8 – 2
Vibration transducer	1 – 100 (*)	0.5 – 1
Vibration calibrator	10 – 10 000	1.5
Vibration logger	10 – 10 000	1.5

Table 2. Calibration ranges and uncertainties for sound level calibrators. The type of the measurement.

Type of calibrator	Frequency (Hz)	Sound level [dB re 20 µPa]	Uncertainty [dB]
Single-frequency	125 – 1000	70 – 130	0.08
Multi-frequency	31.5	94 – 114	0.15
	63 – 4000	94 – 114	0.15
	8000 – 12500	94 – 114	0.15

Calibration of time, time interval and frequency

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Measurements of frequency and time interval are needed in various direct and indirect measurements, e.g., in telecommunication; therefore, precise and traceable frequency and time interval measurements are important nationally. The importance of absolute time is increasing, too (e.g. NTP service and time stamps).

VTT MIKES is responsible for the traceability of time, time interval, and frequency in Finland. VTT MIKES time laboratory maintains the official time in Finland with an uncertainty of 10 ns in relation to the coordinated universal time (UTC) and national frequency with a $1{\bullet}10^{-13}$ relative uncertainty. The reference standards for time and frequency are one caesium atomic clock, four hydrogen masers and several GPS receivers. Finland participates in maintaining of the UTC with its five reference standards through GPS based time comparison.

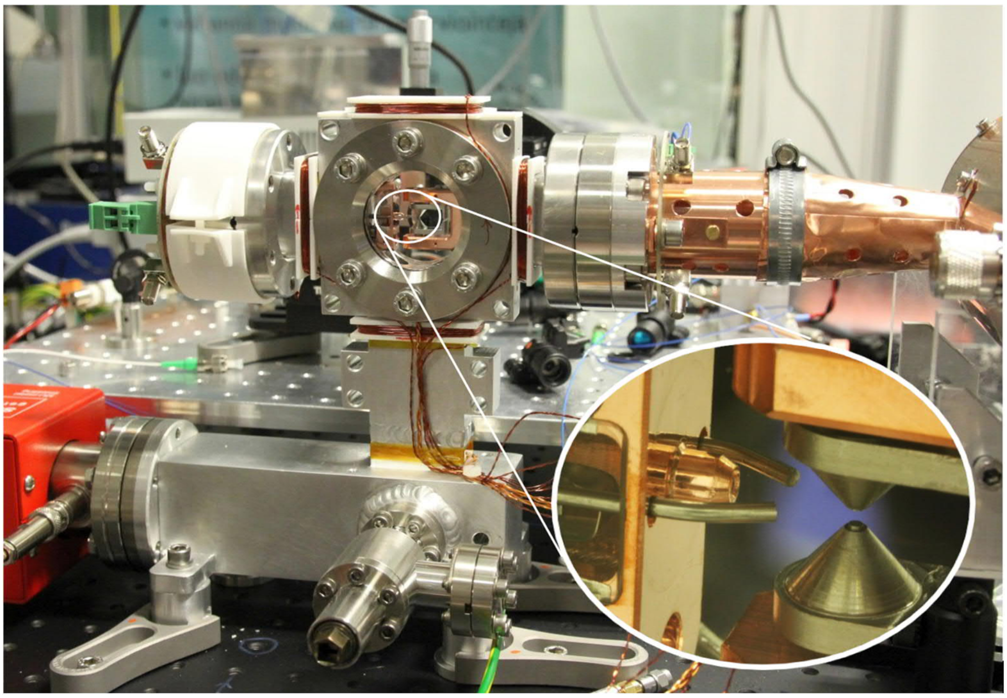

Figure 1. VTT MIKES is developing an optical primary frequency standard based on the 445 THz quadrupole-transition in a laser-cooled $^{88}Sr^{+}$ ion. It is likely that a future re-definition of the SI-second will be based on a similar type of optical atomic clock.

Calibration services

We calibrate e.g. GPS receivers (time, frequency), oscillators, time interval counters, stopwatches, stroboscopes, and optical tachometers. The frequency range is 1 mHz to 5 GHz. We make time interval measurements according to customer's need, with a lower limit of approximately one nanosecond. Furthermore, VTT MIKES has a transmitter for time code and precise 25 MHz frequency for those near the Helsinki metropolitan area who need precise time and frequency.

In addition to calibration, we carry out special assignments related to time and frequency measurements and participate in research and development collaboration projects in this field.

NTP - network time service

Computer clocks can be synchronised with the national time in Finland maintained by VTT MIKES by using Network Time Protocol, NTP. The achievable uncertainty depends on network connections, but it is around one millisecond at its best. VTT MIKES maintains NTP servers subject to charge for institutions and companies. Public Stratum-2 NTP servers are available free of charge for public use.

https://www.vttresearch.com/en/ourservices/time-finland-ntp-network-time-service

PTP – precision time service

VTT MIKES provides PTP time services for customers that need accurate and reliable time. This service is typically provided over a dedicated optical fibre between VTT MIKES and the customer. Uncertainty can be below 10 ns depending on the implementation and length of the optical fibre.

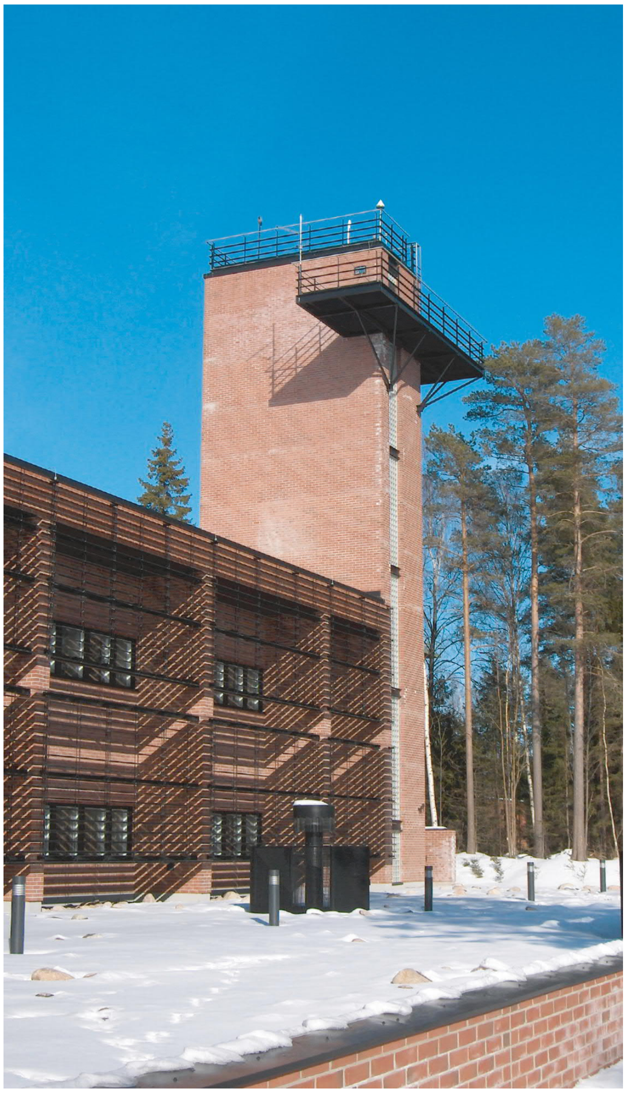

Figure 2. VTT MIKES participates in maintaining of the UTC through GPS-based time comparison.

VTT

beyond
the obvious

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