Improving length and scale traceability in local geodynamical measurements

Jorma Jokela, Pasi Häkli, Markku Poutanen, Ulla Kallio and Joel Ahola

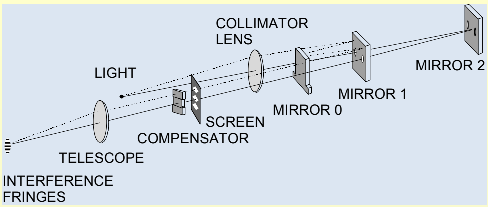
Finnish Geodetic Institute

Traceability of GPS measurements is uncontrollable in the viewpoint of metrology because the scale of a GPS measurement cannot be unambiguously conducted from the definition of metre. We bring the traceable scale to our networks using electronic distance measurement (EDM) instruments, the scales of which are corrected and validated at the Nummela Standard Baseline. Local geodynamical measurements will profit from the reduced measurement uncertainty, and therefore we seek further innovations to improve the traceability. We present latest results of the measurements of the Nummela Standard Baseline and examples of calibrations and recent scale transfers to other baselines.

Nummela Standard Baseline

The *Nummela Standard Baseline* (NSB) of the Finnish Geodetic Institute is widely known as the longest, most accurate and stable measurement standard in the world for traceable geodetic length measurements. It serves in national and international scale transfer measurements for other national or accredited calibration services for EDM instruments, as well as for scientific purposes. The accuracy of the NSB, in terms of standard uncertainty is better than 10^{-7} (0.1 ppm) from Väisälä interference measurements.

The importance of the Väisälä interference method was recognized already in an IAG motion in 1951 and IUGG resolution in 1954, recommending the use of similar methods for assuring the uniform scale in geodetic networks.



Interference measurements of the NSB are performed with the classical *Väisälä white light interference comparator*. Even today the method is superior to modern techniques in terms of accuracy for outdoor baselines up to a few kilometres. The scale is traceable to the definition of metre through the quartz gauge system. The length of a 1-m-long quartz metre is known from comparisons and absolute calibrations with better than 40 nm standard uncertainty.

Results of the latest interference measurements in 2005 and 2007 confirm the excellent stability of the NSB. The difference between the first interference measurement in 1947 and the latest one in 2007 for the full length of 864 m is only 0.08 mm. This proves the location on a forested non-freezing sandy ridge excellent. The standard uncertainties of the lengths from 24 m to 864 m are from 0.02 mm to 0.07 mm in the 2007 measurements.

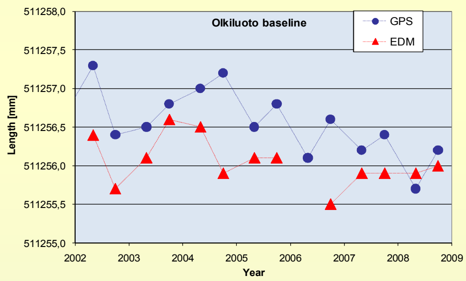
Traceable scale and calibration

The length of the NSB is preserved in stable underground markers with projection measurements where the distances between the markers on the observation pillars are projected to the distances between the underground markers.

For calibration of EDM instruments reverse projections are later performed to obtain known distances between forced-centring plates. A combination of EDM instrument and one or more prism reflectors is calibrated (e.g.) by measuring all available baseline distances to both directions. Air temperature, pressure and humidity observations for velocity correction are applied to the distance measurements.

The NSB has been used for calibration and scale transfer for several domestic and international baselines. Proper metrological traceability is achieved through a documented unbroken chain of calibrations and internationally approved standards. The traceable scale can be applied e.g. in GPS measurements.

Scale in geodynamical measurements



A 511-m EDM baseline was established at the Olkiluoto nuclear power station, Finland, to monitor the scale and scale variation of GPS measurements. Since mid-1990s a local micro network has been measured with GPS to detect and monitor possible crustal deformation in the area. Since 2002 the baseline has been measured in connection to the GPS measurements semi-annually with an EDM instrument (Kern Mekometer ME5000) calibrated at the NSB. The standard uncertainty (1-σ) of the Olkiluoto baseline from the Mekometer measurement is about 0.3 mm.

Olkiluoto baseline has shown that the distance measured with GPS differs approximately 0.5 mm (1 ppm) from the traceable EDM results. This shows the need for control of the scale in such measurements. We study techniques to more reliably determine the scale of GPS with traceable EDM results. Research for GPS metrology utilizing EDM baselines is reported in another paper in this Assembly.

Absolute distance measurement

The importance of the NSB and the interference method is again increasing. The FGI with eight other European institutes participate a Joint Research Project "*Absolute long distance measurement in air*" under the European Metrology Research Programme (EMRP). It is financially supported by the European Union. The goal is to develop and validate new techniques and instruments for long distance measurements in air beyond the state-of-the-art with targeted accuracy of 10^{-7} or better. The NSB is used in testing and validation of new techniques and absolute distance measurement (ADM) instruments.

Scale transfer

- **1997, 2001, 2007, 2008** Kyviškės, Lithuania, 1320 m
- **1997** Hsinchu, Taiwan, 432 m
- **1998** Otaniemi, 75 m; **2002–2009** Olkiluoto 511 m
- **1998** Chengdu, China, 1488 m; **2009** Beijing & Zhengzhou
- **1999** Gödöllő, Hungary, 864 m
- **2000, 2008** Väänа, Estonia, 1728 m, 1344 m
- **2002** Eggemoen, Norway, 960 m
- **2002** Novobërdë, Serbia (Kosovo), 1831 m
- **2003** Tsukuba, Japan, 6–204 m
- **2006** Daejeon, South Korea, 20–280 m
- **2008** Innsbruck, Austria, 1080 m

Recent scale transfers using the quartz gauge system or instrument calibration at the Nummela Standard Baseline.

Examples of baselines where the scale of the NSB is applied: (from top to bottom) Kyviškės, Innsbruck, Vääna and Olkiluoto.

Results of the NSB interference measurements

Baseline lengths at the Nummela Standard Baseline from the 15 interference measurements in 1947–2007 with standard uncertainties (1-σ). The results show the excellent stability of the NSB; maximum difference of the 864-m distance in 15 interference measurements has been approximately 0.6 mm in 60 years.

Epoch	0 – 24 mm + 24 m	0 – 72 mm + 72 m	0 – 216 mm + 216 m	0 – 432 mm + 432 m	0 – 864 mm + 864 m
1947.7	—	—	—	95.46 ±0.04	122.78 ±0.07
1952.8	—	—	—	95.39 ±0.05	122.47 ±0.08
1955.4	—	—	—	95.31 ±0.05	122.41 ±0.09
1958.8	—	—	—	95.19 ±0.04	122.25 ±0.08
1961.8	—	—	—	95.21 ±0.04	122.33 ±0.08
1966.8	—	—	—	95.16 ±0.04	122.31 ±0.06
1968.8	—	—	—	95.18 ±0.04	122.37 ±0.07
1975.9	—	—	—	94.94 ±0.04	122.33 ±0.07
1977.8	33.28 ±0.02	15.78 ±0.02	54.31 ±0.02	95.10 ±0.05	122.70 ±0.08
1983.8	33.50 ±0.02	15.16 ±0.02	53.66 ±0.04	95.03 ±0.06	—
1984.8	33.29 ±0.03	15.01 ±0.03	53.58 ±0.05	94.93 ±0.06	122.40 ±0.09
1991.8	33.36 ±0.04	14.88 ±0.04	53.24 ±0.06	95.02 ±0.05	122.32 ±0.08
1996.9	33.41 ±0.03	14.87 ±0.04	53.21 ±0.04	95.23 ±0.04	122.75 ±0.07
2005.8	33.23 ±0.04	14.98 ±0.04	53.20 ±0.04	95.36 ±0.05	—
2007.8	33.22 ±0.03	14.95 ±0.02	53.13 ±0.03	95.28 ±0.04	122.86 ±0.07

Calibration and projection measurements at the NSB.