GNSS CORS
Calibration and Testing

Outline

- A brief introduction to the European Synchrotron Radiation Facility (ESRF),
- ISO 17123 part 8,
- Calibration and Traceability,
- GNSS calibration,
- Summary.

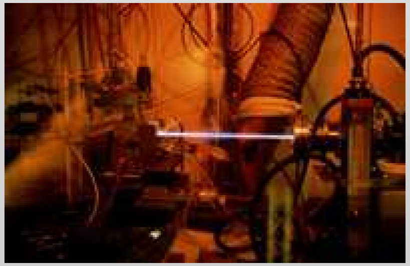
The ESRF

- The European Synchrotron Radiation Facility (ESRF) is located in Grenoble, France.
- It is a joint facility supported and shared by 18 European countries.
- It operates the most powerful synchrotron radiation light source in Europe.

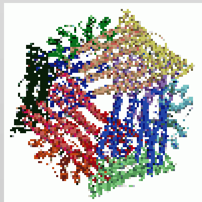
Science at the ESRF

Many important questions in modern science cannot be answered without a profound knowledge of the intimate details of the structure of matter.

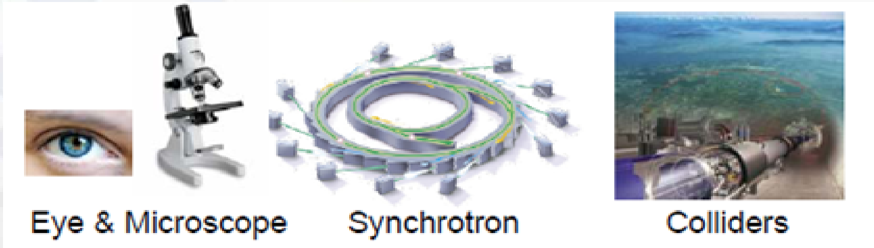
Synchrotron radiation sources can be compared to "super microscopes" revealing invaluable information in numerous fields of research.

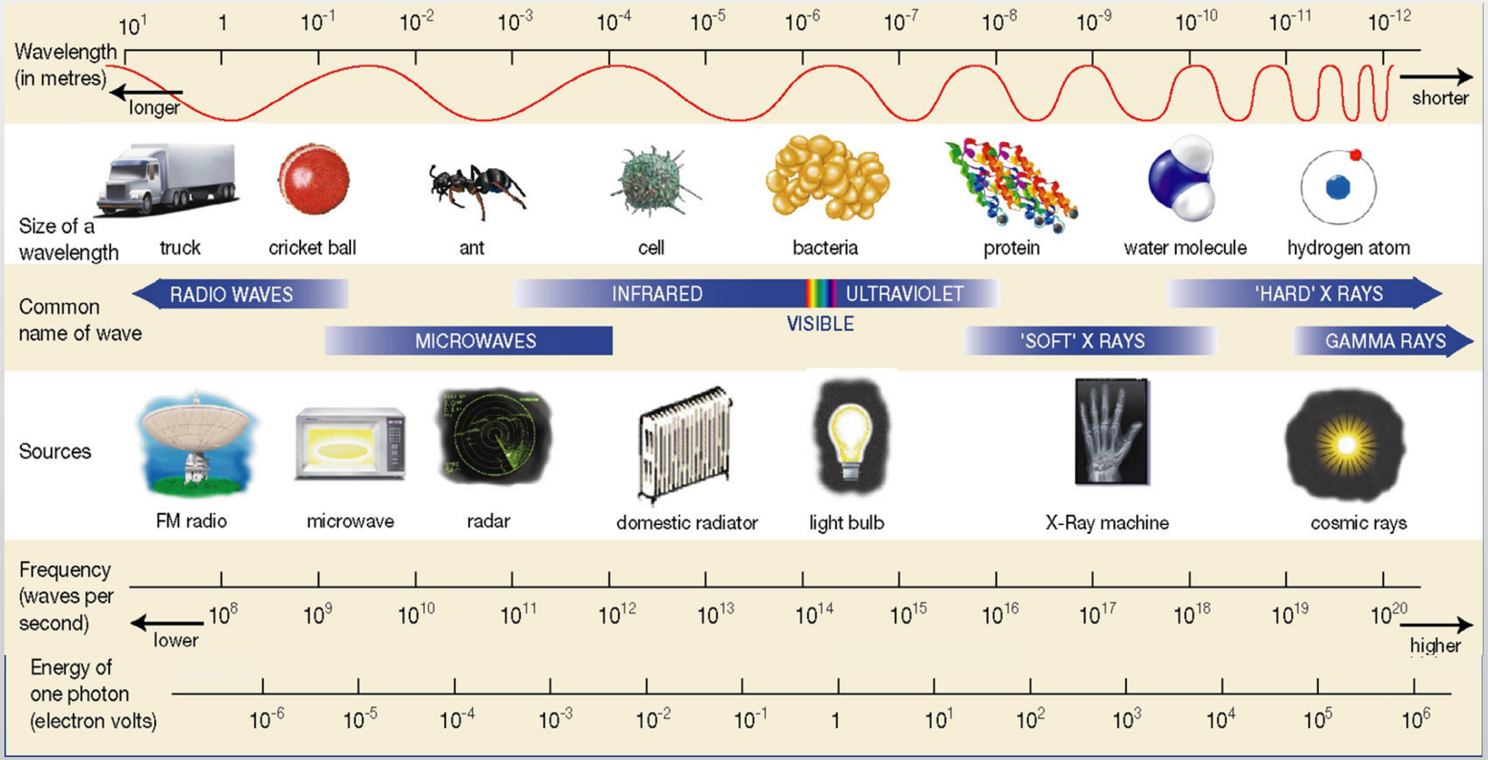


Biology, Concentrating on proteins
Chemistry, Ultra-rapid reactions
Medicine, The inside story
Earth science, Our mysterious planet
Physics, Small is especially beautiful
Materials, Smart stuff
Environment, Maintaining a natural balance
Industry, Tomorrow's technology

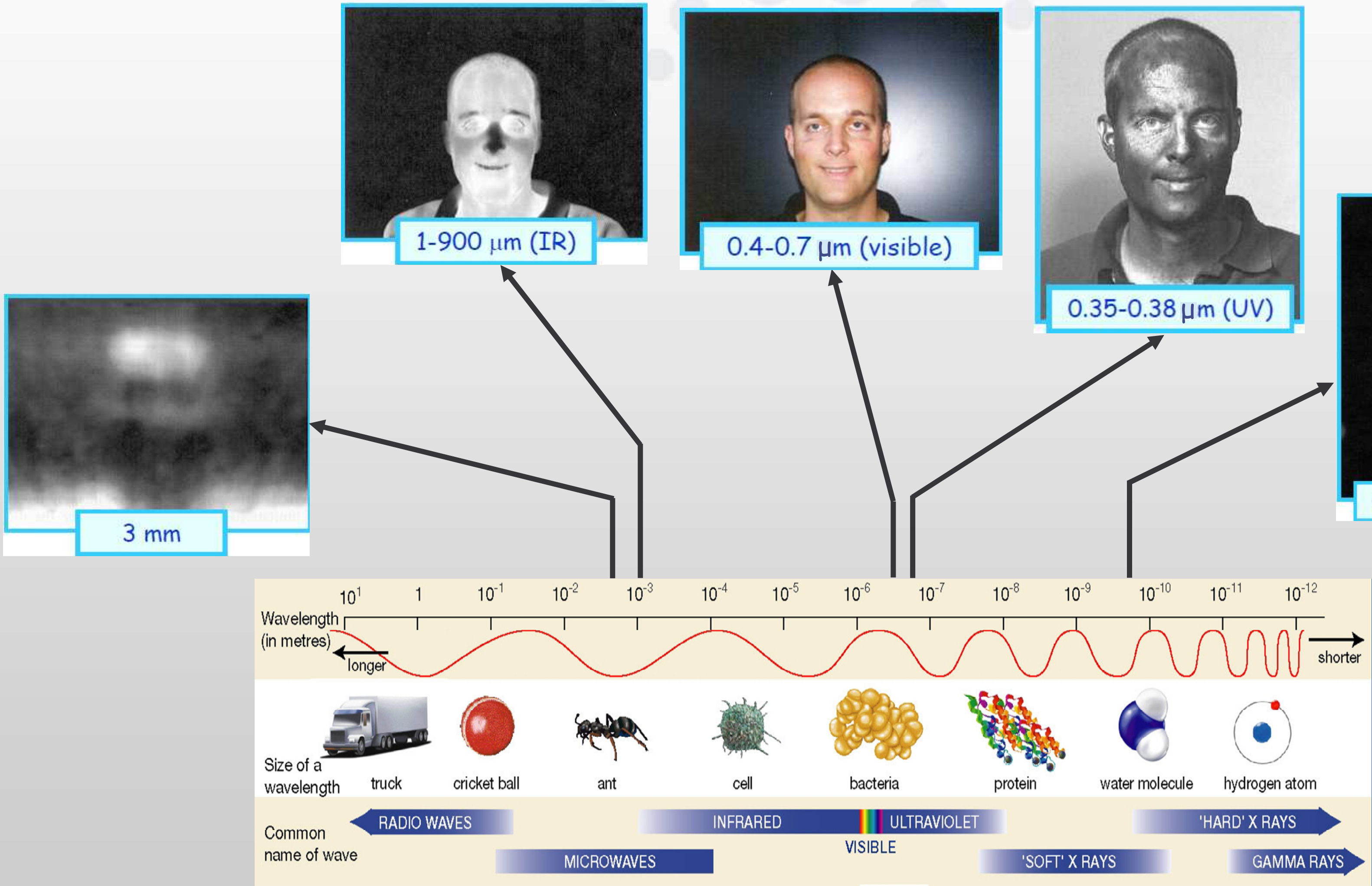


Science at the ESRF

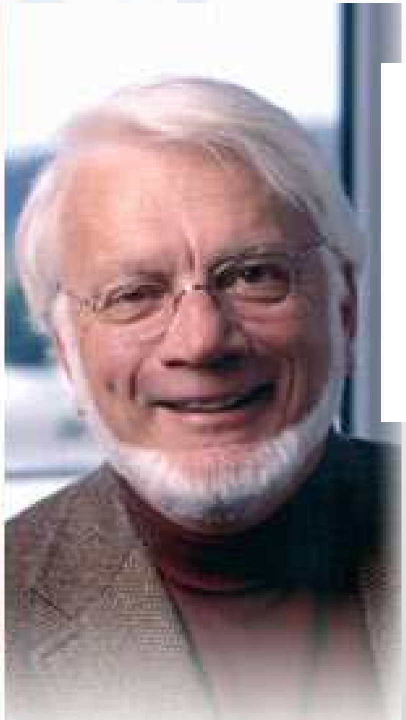


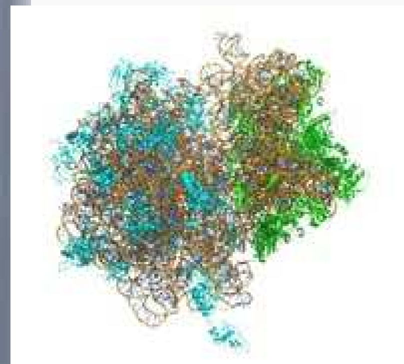


Science at the ESRF



Science at the ESRF





Ada Yonath, from the Weizmann Institute (Israel) and Venkatraman Ramakrishnan, of the MRC Laboratory of Molecular Biology in Cambridge (UK), both ESRF long-term users, have been awarded the Nobel Prize of Chemistry 2009. The award is given for the study of the structure and function of the ribosome, the protein factory in the cell. They will share the prize with Thomas Steitz, from Yale University (US).

ISO17123 part 8

GNSS field measurement systems in real time kinematic (RTK)

INTERNATIONAL STANDARD

ISO 17123-8

First edition
2007-09-15

Optics and optical instruments — Field procedures for testing geodetic and surveying instruments —

Part 8:
GNSS field measurement systems in real-time kinematic (RTK)

Optique et instruments d'optique — Méthodes d'essai sur site des instruments géodésiques et d'observation —

Partie 8: Systèmes de mesure GNSS sur site en temps réel cinématique

Reference number
ISO 17123-8:2007(E)

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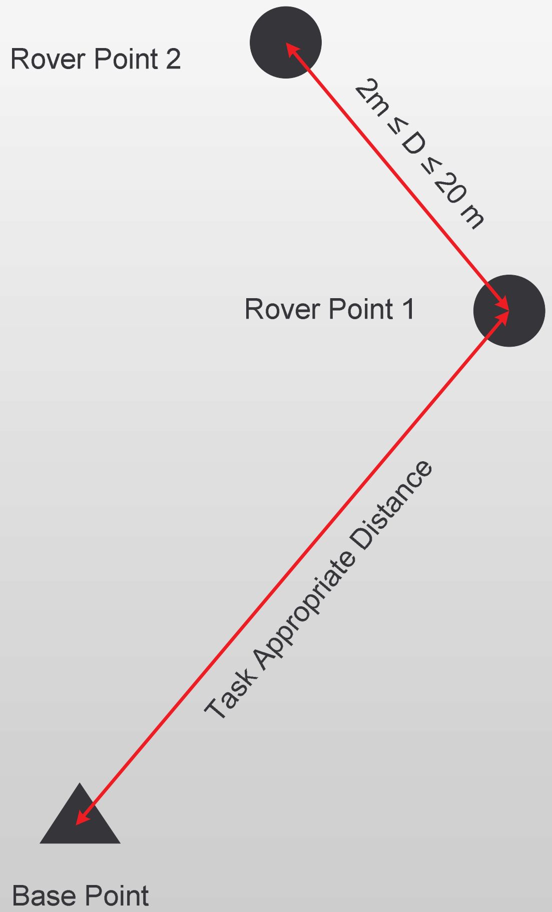
- This standard specifies field procedures for evaluating the precision (repeatability) of Global Navigation Satellite System (GNSS) field measurement systems in real-time kinematic (GNSS RTK).
- These tests are primarily intended to be field verifications of the suitability of an instrument for the application at hand, and/or to satisfy the requirements of other standards.

ISO17123 part 8

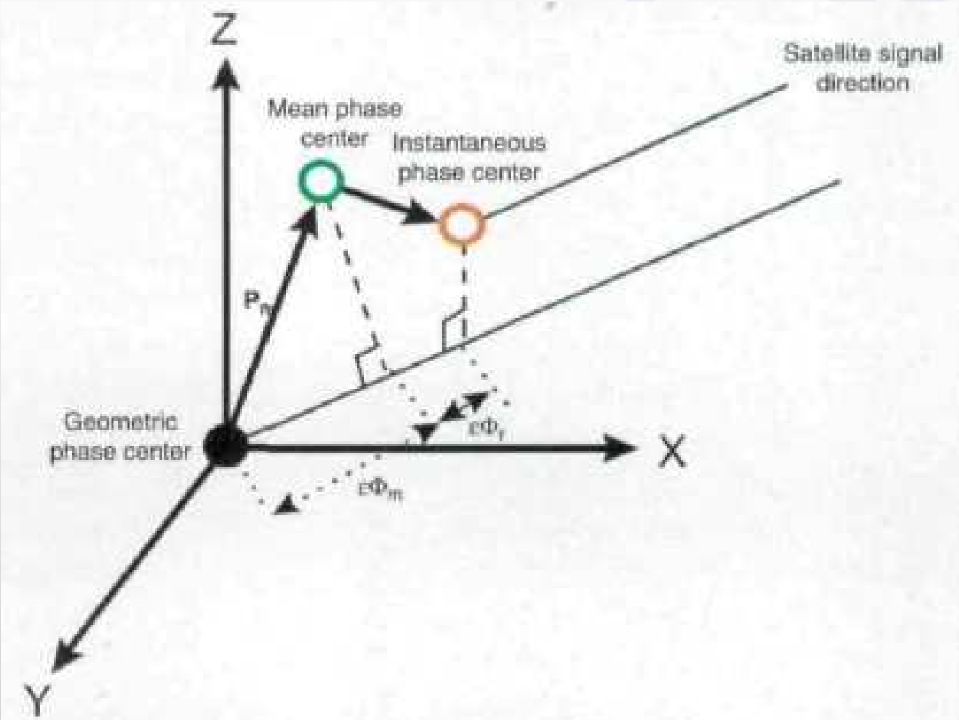
GNSS field measurement systems in real time kinematic (RTK)



- Measure the distances and height differences between the two rover points are measured by independent methods to a precision of better that 3 mm.
- Five sets of x, y and h coordinate measurements are made.
- Distances and height differences are calculated from the measured x, y and h values.
- The difference between these measured distances ε_D and heights ε_h and those determined independently must satisfy:
  - $|\varepsilon_D| \leq 2.5 \times \sqrt{2} \times s_{xy}$
  - $|\varepsilon_h| \leq 2.5 \times \sqrt{2} \times s_h$
- s_{xy} and s_h are a priori uncertainties
- The full test is essentially the simplified test repeated three times each separated by a minimum 90 minute time interval.
- However, the analysis is considerably more involved using statistical tests.

GNSS calibration

Antenna phase centre variation (PCV) calibration

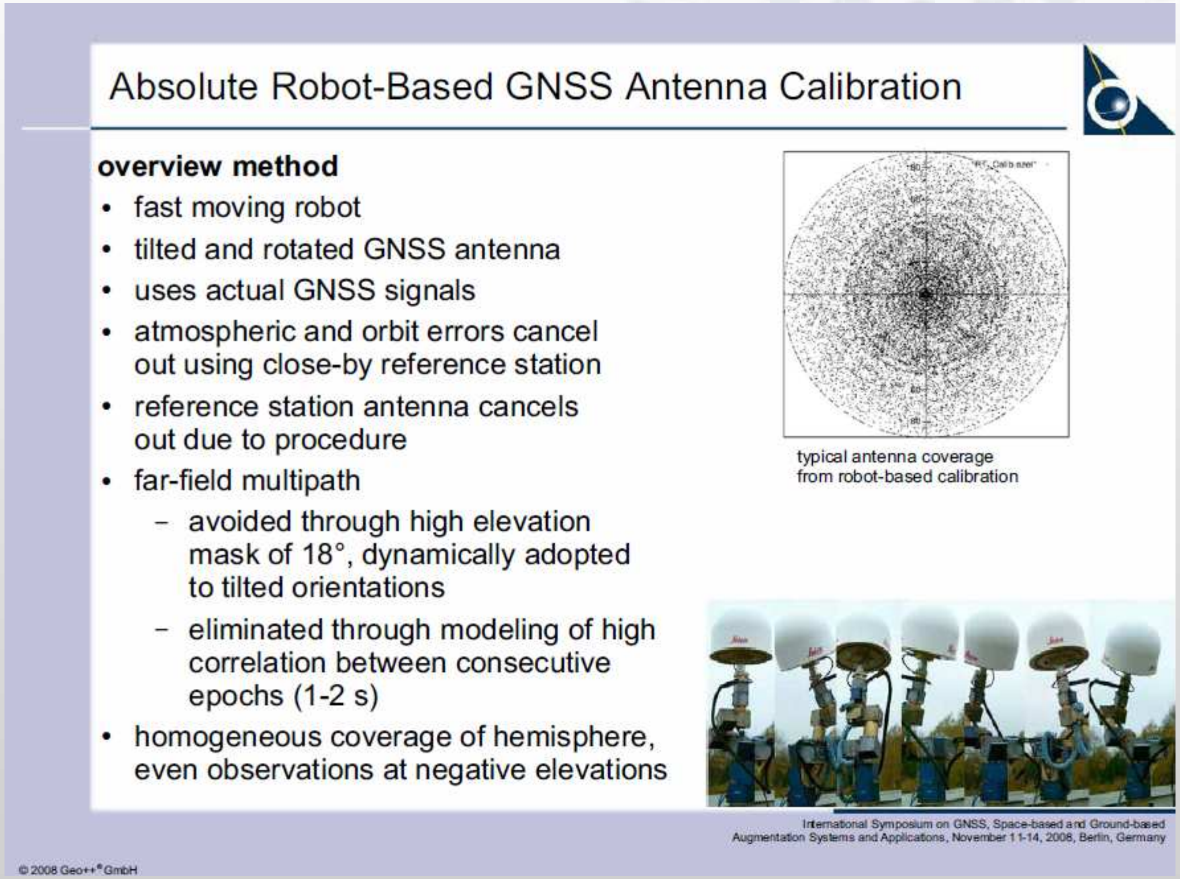


- The job of the GNSS antenna is to convert energy received from the satellite into electrical current that can be processed by the receiver.
- The receiver then determines the coordinates of the antenna – or, more precisely it determines the coordinates of the electrical phase centre (PC) of the antenna.
- Antenna PC variation calibration establishes an error map which is a function of elevation and azimuth angles of the electromagnetic wave incident at the satellite.

Graphic Akrour B., Santerre R.,Geiger A., *Calibrating Antenna Phase Centers- A Tale of Two Methods,* February 2005, GPS World.

GNSS calibration

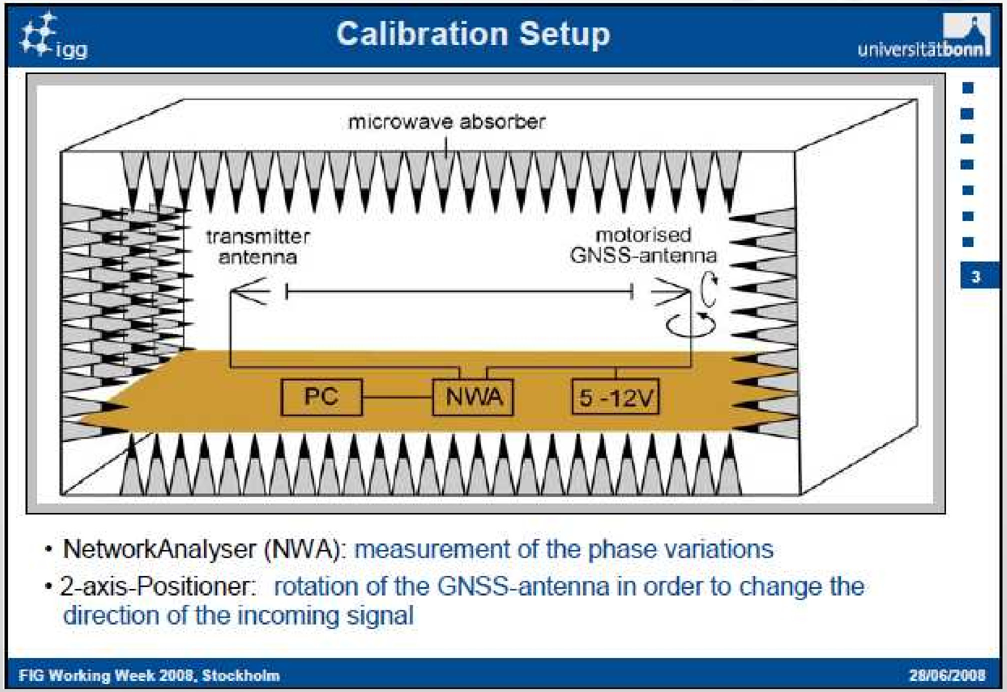
Absolute antenna PCV variation calibration with a robot

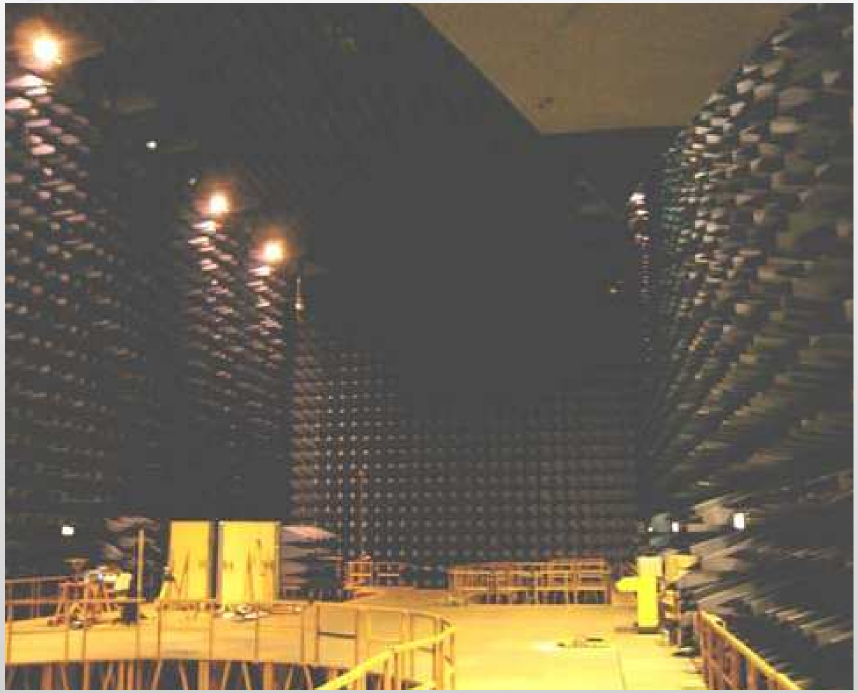


Smitz M., Wubenna G., Propp M., *Absolute Robot-Based GNSS Antenna Calibration –Features and Findings, Geo++® GmbH, 30827 Garbsen Germany,* in *International Symposium on GNSS, Space Based and Ground Based Augmentation Systems and Applications, November 11-14, 2008,* Berlin, Germany.

GNSS calibration

Absolute antenna PCV calibration with an anechoic chamber

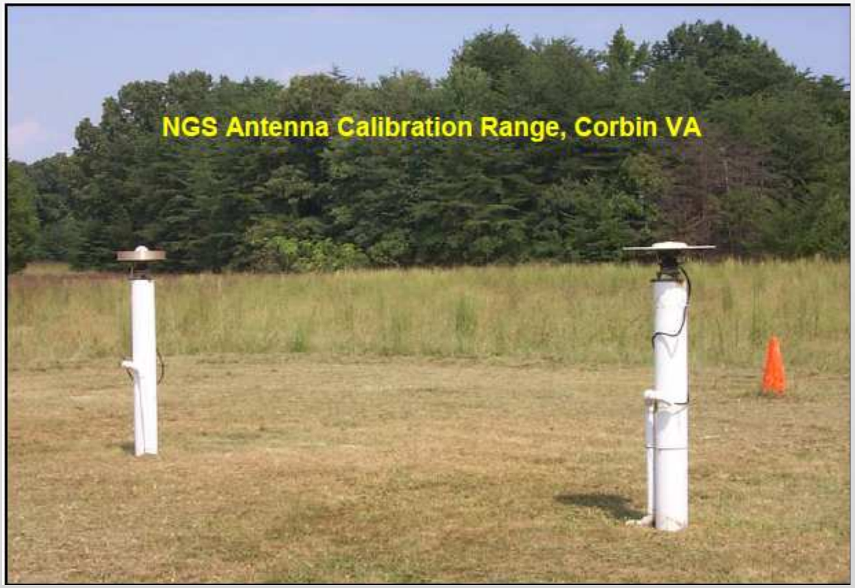


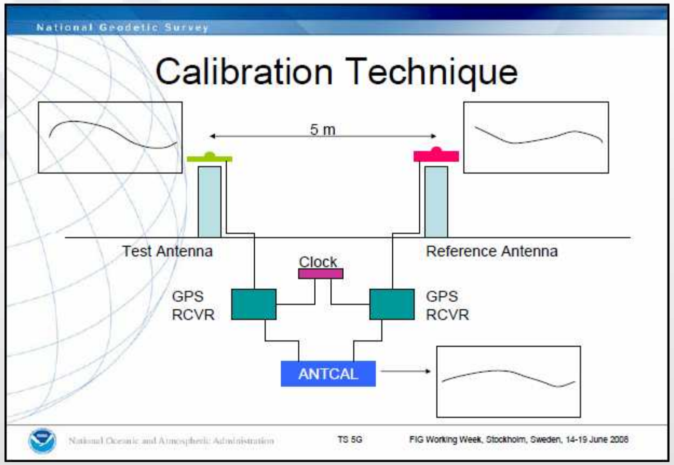


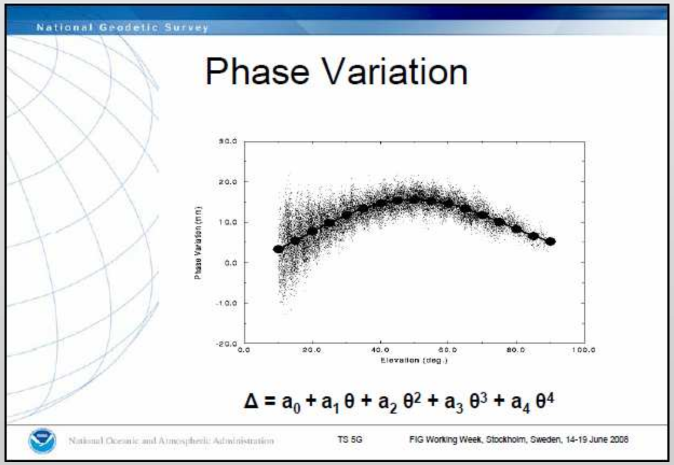
Zeimetz, P. and Kuhlmann H.. *On the Accuracy of Absolute GNSS Antenna Calibration and the Conception of a New Anechoic Chamber* in *FIG Working Week 2008* 2008. Stockholm: FIG.

GNSS calibration

Field PCV Calibration at the NGS





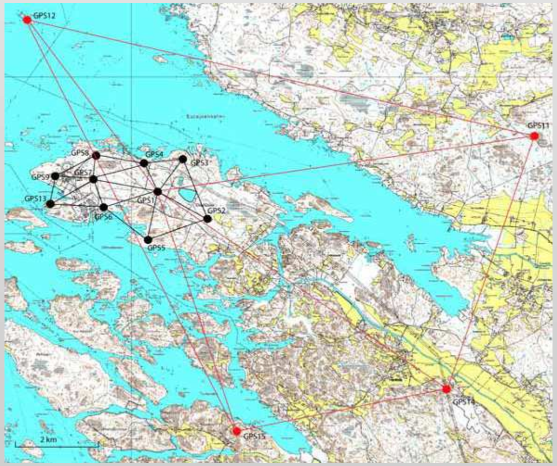


Comparison to a *reference* antenna to determine the PCV.

Mader G. and Weston N., GPS *Antenna Calibration at the National Geodetic Survey* in *FIG Working Week 2008* 2008. Stockholm: FIG.

GNSS calibration

Field GNSS Calibration Finland (MIKES and Finnish Geodetic Institute)



Ahola J., Koivula H., Jokela J., *GPS Operations at Olkiluoto, Kivetty and Romuvaara in 2007,* Finnish Geodetic Institute May 2008.
Jokela J. et al, *On Traceability of Long Distances ,* XIX IMEKO World Congress, Lisbon Portugal, September 6-11, 2009.

GNSS calibration
Field GNSS Calibration Malaysia

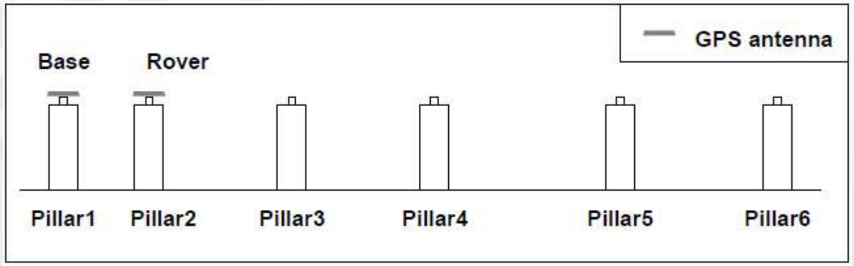
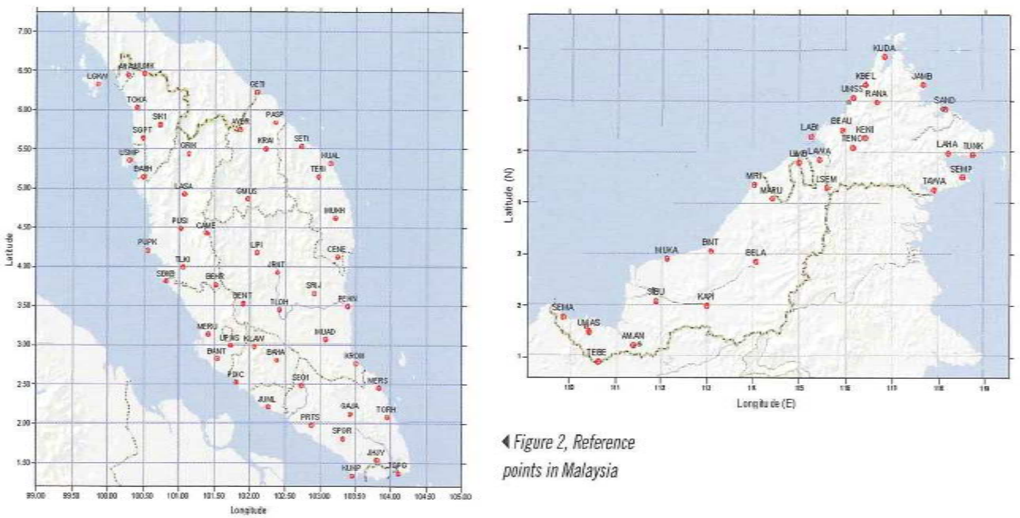


Figure 1: UTM EDM baseline test site



◀ Figure 2, Reference points in Malaysia

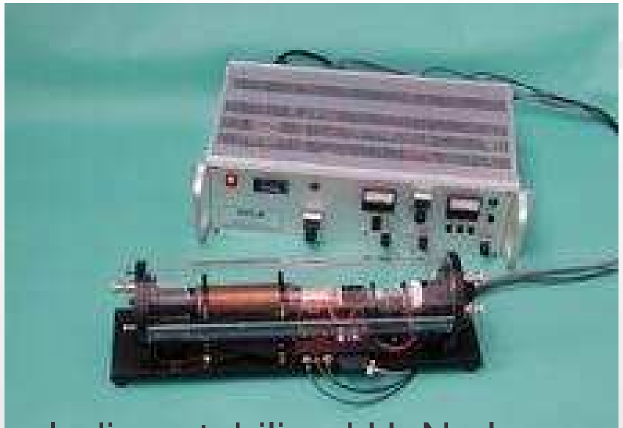
Ses, S., et al., *Potential use of GPS for cadastral surveys in Malaysia*, in *40th Aust. & 6th S.E.Asian Surveyors Congress*. 1999: Fremantle, Australia.
Zhang Y., et al., *Cadastral System in Malaysia RTK in Updating Coordinate System*, in GIM International. April 2009.

Calibration and Testing

- Testing is intended to verify the suitability of a particular instrument for the required application at hand, and to satisfy the requirements of best practice standards.
- The instrument uses its own measurements to qualify and quantify its performance.

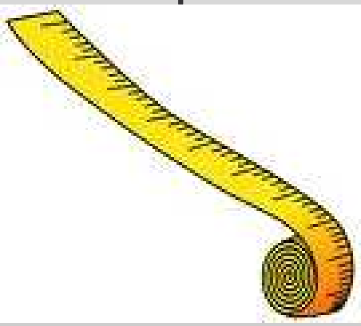
- Calibration links the instrument by comparison directly to international reference standards and ensures traceability.

Traceability



Iodine-stabilised HeNe laser

Traceability

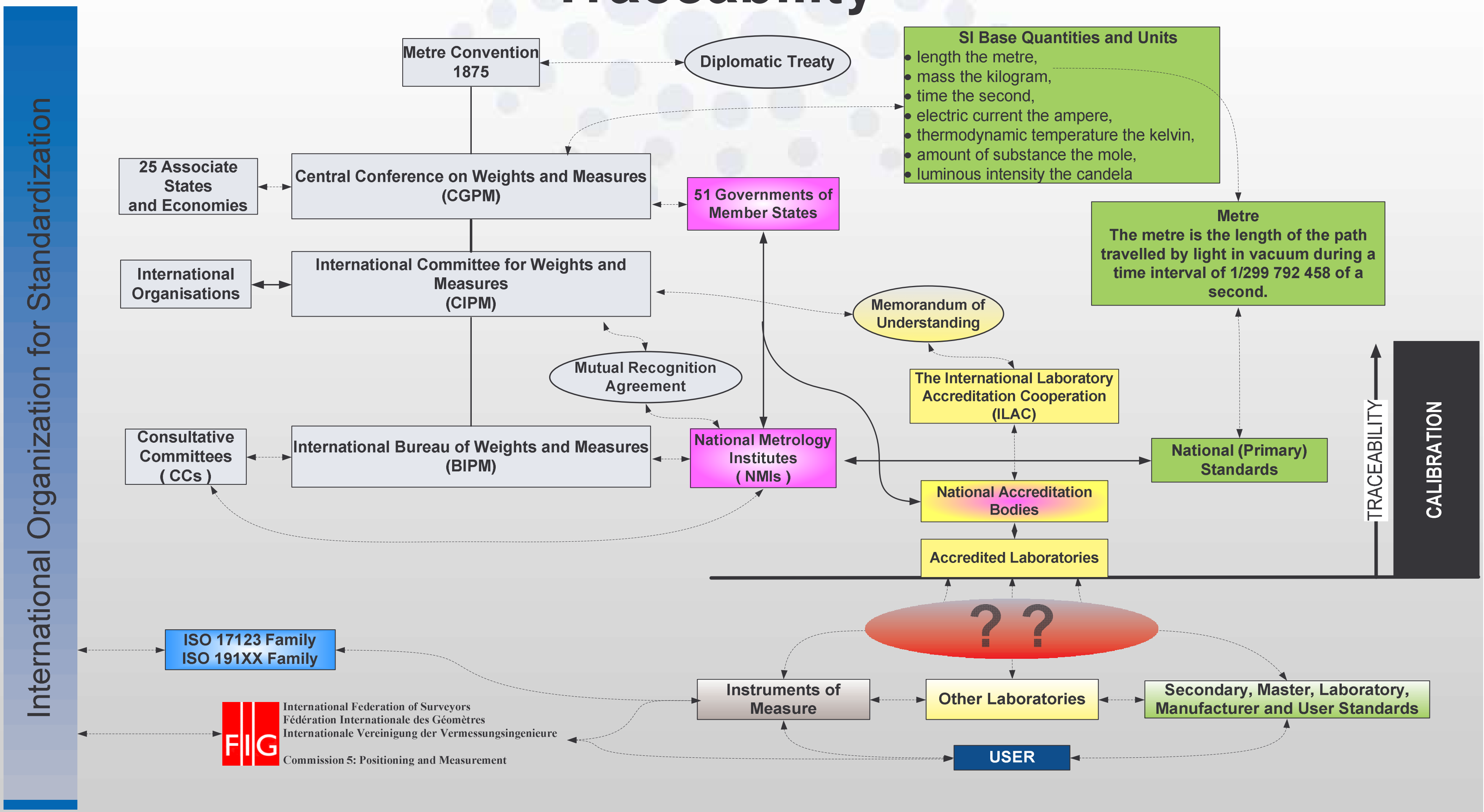


One of the pillars of instrument calibration and all legal metrology is the notion of traceability.

Traceability is a method of ensuring that a measurement (even with its uncertainties) is an accurate representation of what it is trying to measure.

With traceability, it is possible to demonstrate an unbroken chain of comparisons that ends at a national metrology institute (NMI).

Traceability

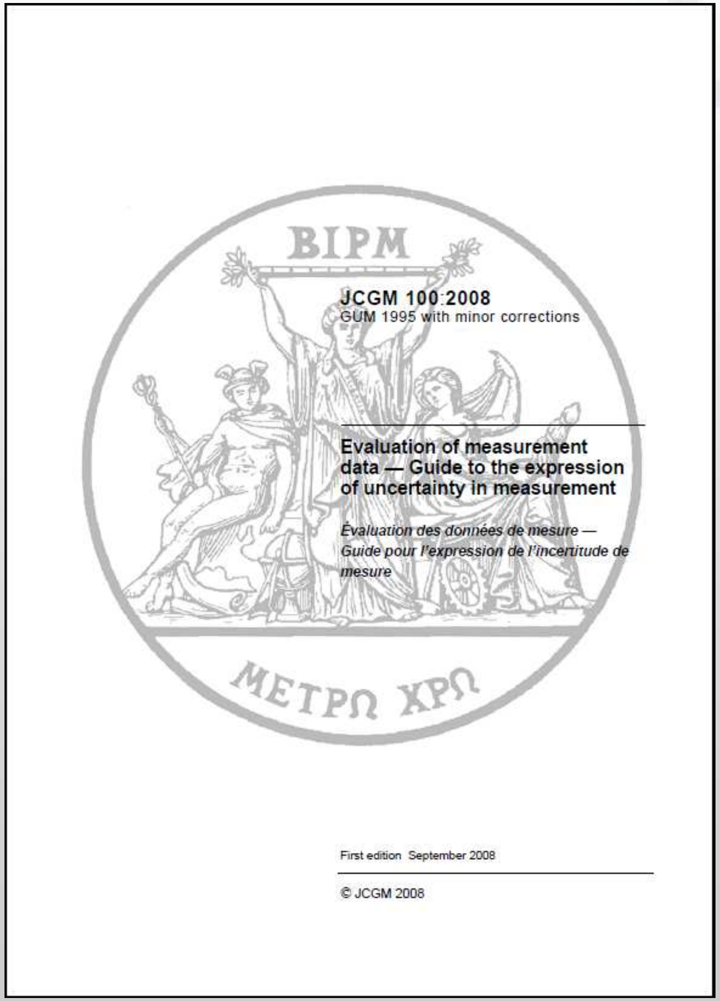


Traceability in GNSS calibration

- Traceability is the “property of a measurement result whereby the result can be related to a reference through a documented unbroken chain of calibrations, each contributing to the measurement uncertainty” (VIM)
- Traceability establishes a link between the measurement and one of the base SI units.
  - length (metre),
  - mass (kilogram),
  - time (second),
  - electric current (ampere),
  - thermodynamic temperature (kelvin),
  - amount of substance (mole),
  - luminous intensity (candela).

Traceability and Uncertainty

The GUM


BIPM

JCGM 100:2008
GUM 1995 with minor corrections

Evaluation of measurement data — Guide to the expression of uncertainty in measurement

Évaluation des données de mesure — Guide pour l'expression de l'incertitude de mesure

ΜΕΤΡΩ ΧΡΩ

First edition September 2008

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- Traceability is ensured through the concept of uncertainty in measurement,
- The mechanism whereby uncertainty is established in traceable measurements is outlined in the 'Guide to the expression of uncertainty in measurement' (GUM).
- The GUM provides general rules that are intended to be applicable to a wide range of measurements for use within standardization, calibration, laboratory accreditation and measurement services.

Evaluation of measurement data — Guide to the expression of uncertainty in measurement. ed. Joint Committee for Guides in Metrology. 2008, BIPM: Sèvres.

GUM and Uncertainty

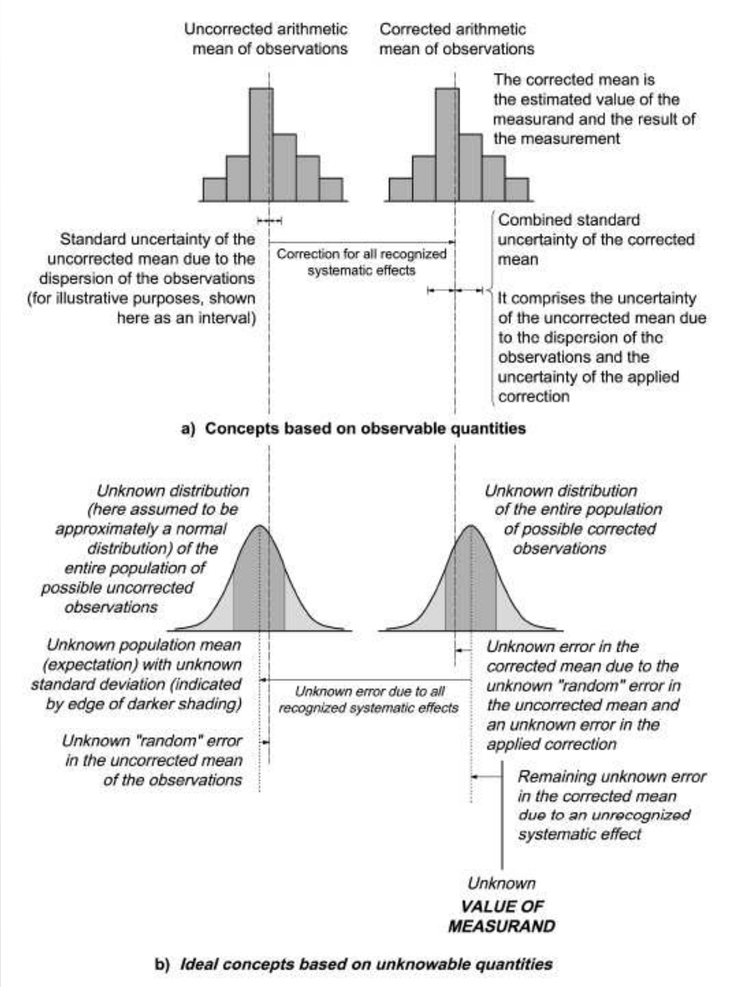


Figure D.1 — Graphical illustration of value, error, and uncertainty

The exact values of the error contributions to a measurement are unknown and unknowable.

However, the uncertainties associated with the random and systematic effects that give rise to the error can be evaluated.

Evaluation of measurement data — Guide to the expression of uncertainty in measurement. ed. Joint Committee for Guides in Metrology. 2008, BIPM: Sèvres.

GUM and Uncertainty

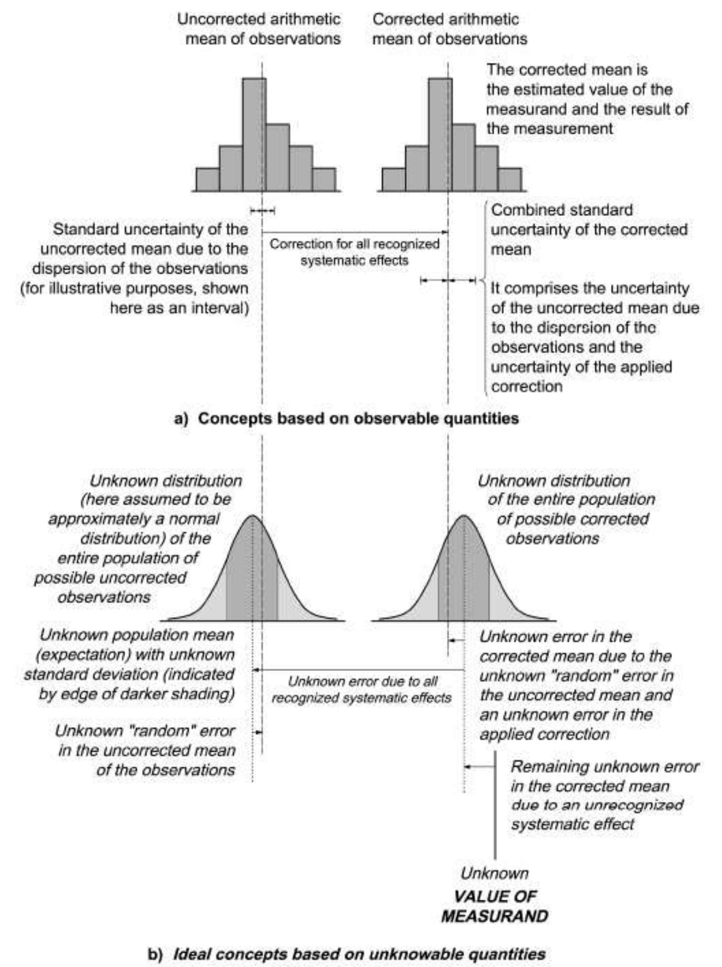


Figure D.1 — Graphical illustration of value, error, and uncertainty

Nevertheless, even if the uncertainties are small, there is still no guarantee that the error in the measurement is small.

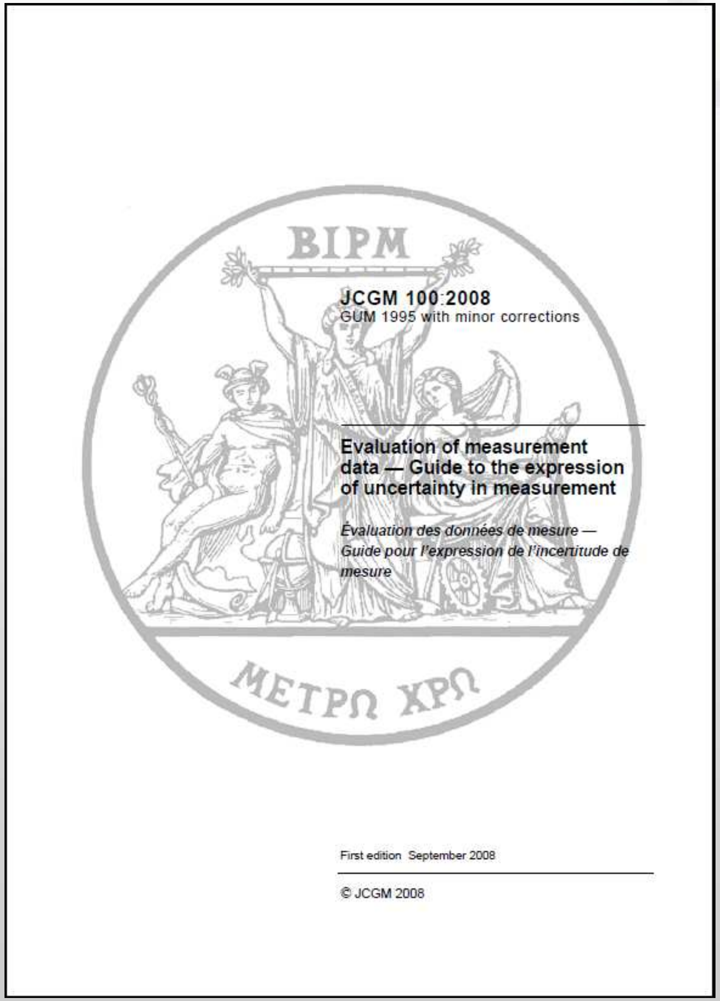
For example, an unrecognized systematic effect may have been overlooked.

Thus the uncertainty in a measurement is an estimate of the likelihood of its nearness to the value of the measurand.

Evaluation of measurement data — Guide to the expression of uncertainty in measurement. ed. Joint Committee for Guides in Metrology. 2008, BIPM: Sèvres.

The Measurand

the quantity to be measured


BIPM

JCGM 100:2008
GUM 1995 with minor corrections

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- The first step in making a measurement is to specify the measurand.
- The measurand can only be specified by a description of a quantity.
- In principle, it cannot be completely described without an infinite amount of information.
- Thus, to the extent that it leaves room for interpretation, incomplete definition of the measurand introduces a component of uncertainty into the result of a measurement that may be significant relative to the required accuracy.

Evaluation of measurement data — Guide to the expression of uncertainty in measurement. ed. Joint Committee for Guides in Metrology. 2008, BIPM: Sèvres.

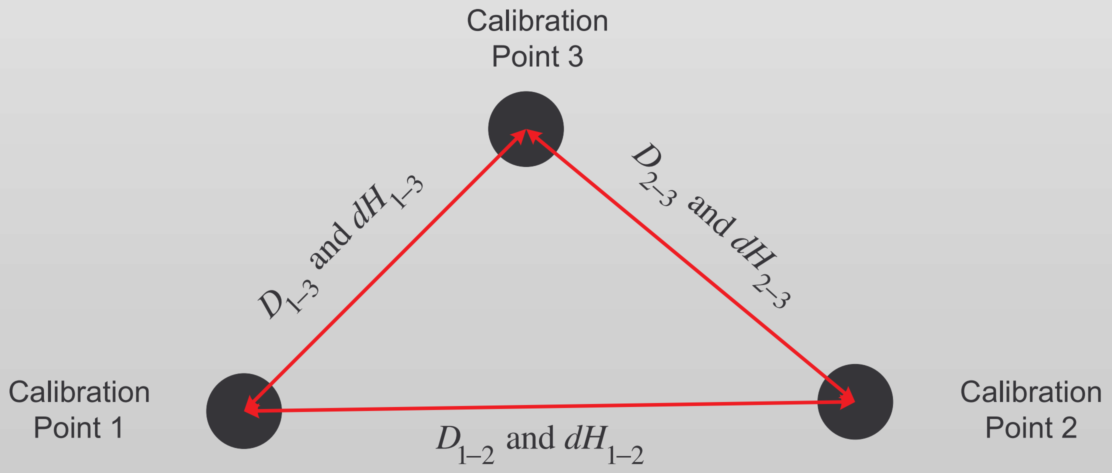
Traceability in GNSS calibration

In GNSS CORS, what is the mesurand?

- In GNSS CORS, what is the mesurand?
- The GNSS measurement system involves several satellites each with clocks transmitting time and the latest orbital parameters through a variable medium to a receiver.
- Add into this mixture reference stations (CORS) with their own intrinsic errors.
- What is the measurand?
- Perhaps start with something simpler: when a GNSS receiver is installed on two points, what is the measurand?
- In the ISO 17123 part 8, the measurand is unambiguously defined to be the horizontal distance and height difference between the two points upon which the GNSS receiver has been positioned.

Possible prototype GNSS calibration scenario

- Build upon the ISO 17123 part 8 standard.
- It is an internationally accepted framework for determining and evaluating the precision of GNSS RTK measurement systems.
- It is based on easily traceable height difference and distance measurements.



Possible prototype GNSS calibration scenario

Uncertainty

Type A Uncertainty

Type A uncertainty components come from the repeated measurements of the instrument being calibrated (i.e. the analysis of a series of observations).

Type B Uncertainty

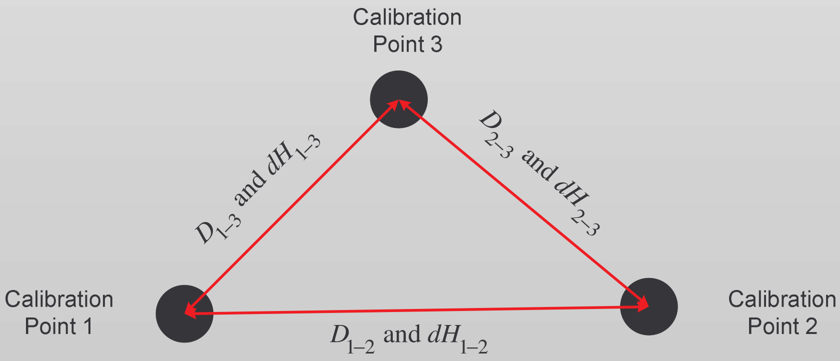
The Type B uncertainty components are those that come by means other than the analysis of a series of observations.
Generally the Type B uncertainty components, are a function of the uncertainty of the standard(s) used to calibrate the instrument.

$$u = \sqrt{(\text{Type A})^2 + (\text{Type B})^2}$$

Possible prototype GNSS calibration scenario

Type A

- Repeat the following measurements a minimum of 10 times at different times of the day and over several days
  - Measure the three distances D_{REF} and three height differences dH_{REF}
  - Measure the three calibration points with the GNSS antenna and determine D_{GNSS} and three height differences dH_{GNSS}
- Calculate the standard deviation in the differences between the distances and height differences determined by the two methods.

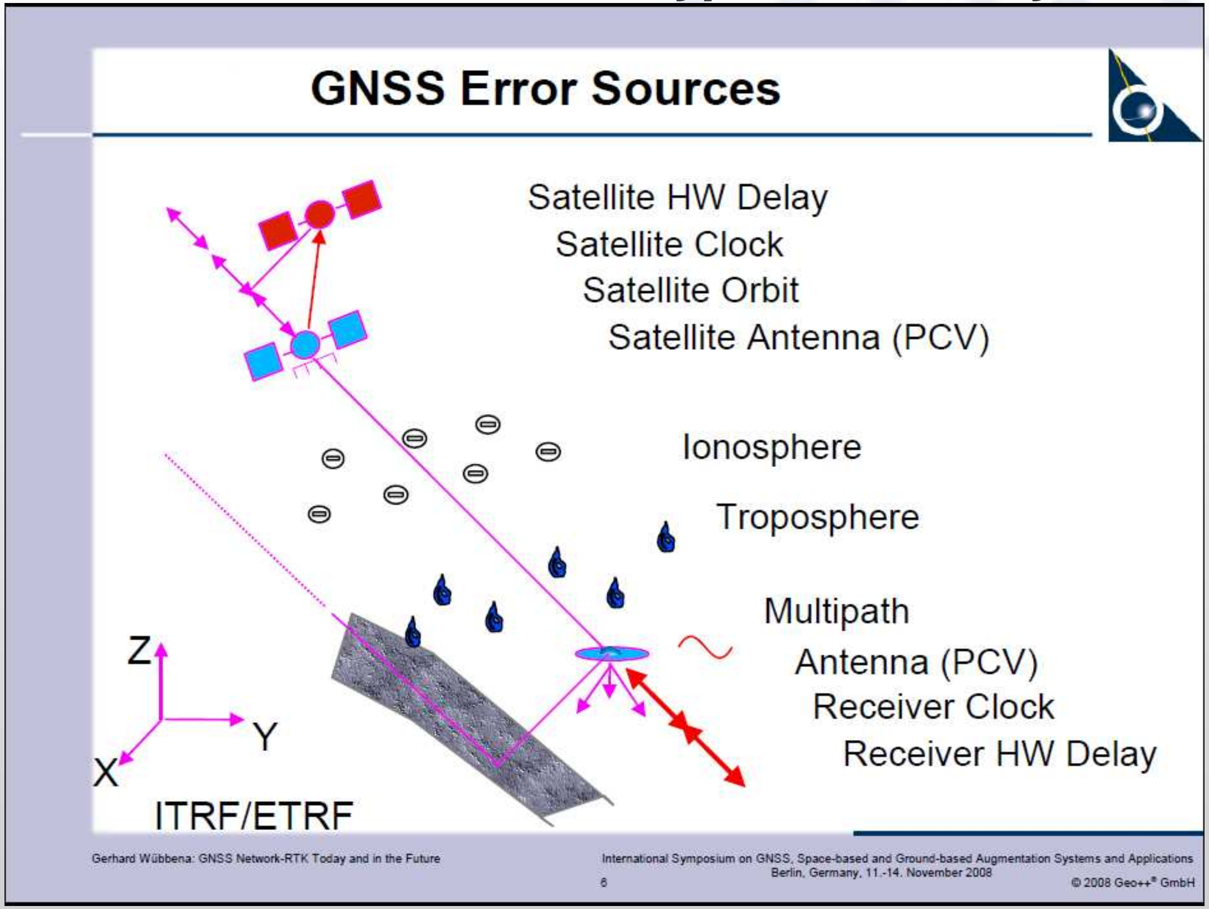


$$\text{Type A distance } u_D = \sqrt{\sum_{i=1}^{n}\sum_{j=1}^{3}\left(D_{GNSS\ j} - D_{REF\ j}\right)_i^2}$$

$$\text{Type A height } u_{dH} = \sqrt{\sum_{i=1}^{n}\sum_{j=1}^{3}\left(dH_{GNSS\ j} - dH_{REF\ j}\right)_i^2}$$

Possible prototype GNSS calibration scenario

Type B GNSS system



- Estimates of the magnitude of all of the other GNSS error sources must be made.
- Over short distances many errors will be very small to negligible.
- The main errors will be due to multipath and PCV.
- Absolute antenna PCV calibration should be made (e.g. robot or anechoic chamber) and its uncertainty included as a Type B contribution.

Graphic from Wubenna G., *GNSS Network-RTK Today and in the Future Concepts and RTCM Standards, Geo++® GmbH, 30827 Garbsen Germany,* in *International Symposium on GNSS, Space Based and Ground Based Augmentation Systems and Applications, November 11-14, 2008,* Berlin, Germany.

Possible prototype GNSS calibration scenario

Type B *D* and *dH*

The distances and height difference between the calibration points must be made with calibrated instruments possessing traceable calibration certificates and uncertainties.

ESRF calibration bench.

SLAC level calibrator.

$$u(D) \text{ and } u(dH)$$

Possible prototype GNSS calibration scenario

Uncertainty

The uncertainties in distance and height difference are determined by adding the squared contributions (Type A and Type B) and taking the square root.

$$u(D) = \sqrt{(\text{Type A})_D^{\,2} + (\text{Type B})_D^{\,2}}$$

$$= \sqrt{\left(\sum_{i=1}^{n}\sum_{j=1}^{3}\left(D_{GNSS\ j} - D_{REF\ j}\right)_i\right)^2 + u\left(D_{REF}\right)^2 + u\left(multipath\right)_D^{\,2} + u\left(PCV\right)_D^{\,2} + \cdots}$$

$$u(dH) = \sqrt{(\text{Type A})_{dH}^{\,2} + (\text{Type B})_{dH}^{\,2}}$$

$$= \sqrt{\left(\sum_{i=1}^{n}\sum_{j=1}^{3}\left(dH_{GNSS\ j} - dH_{REF\ j}\right)_i\right)^2 + u\left(dH_{REF}\right)^2 + u\left(multipath\right)_{dH}^{\,2} + u\left(PCV\right)_{dH}^{\,2} + \cdots}$$

Generally the final uncertainty is expressed as an expanded uncertainty.

$$U(D) = 2\left(u_D\right) \text{ and } U(dH) = 2\left(u_{dH}\right)$$

GNSS CORS
Calibration and Testing

Summary

- We have seen an internationally accepted ISO 17123 part 8 test procedure,
- We have seen several different approaches to GNSS antenna calibration,
- We have discussed traceability and the means to establishing uncertainty through the GUM,
- We have discussed a possible traceable GNSS calibration in the context of the GUM.
- Traceability could be integrated into CORS networks using calibrated antennas.