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**Modulbezeichnung: Fundamentals of Metrology (FoM)** **5 ECTS**  
 (Fundamentals of Metrology)

Modulverantwortliche/r: Tino Hausotte  
 Lehrende: Tino Hausotte

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Startsemester: SS 2015	Dauer: 1 Semester	Turnus: jährlich (SS)
Präsenzzeit: 60 Std.	Eigenstudium: 90 Std.	Sprache: Deutsch und Englisch

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**Lehrveranstaltungen:**

Fundamentals of Metrology - Grundlagen der Messtechnik (SS 2015, Vorlesung, 2 SWS, Tino Hausotte)  
 Fundamentals of Metrology - Grundlagen der Messtechnik - Übung (SS 2015, Übung, 2 SWS, Tino Hausotte)

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**Inhalt:**

**Basic principles**

- **Essence of measuring:** SI unit system - Definitions of SI units (cd, K, kg, m, s, A, mol) - What is measuring? - Extensive and intensive quantities - Measuring, testing and gauging - Objective and subjective testing - Basic requirements for measuring - Transmission and use of the units - Correct use and notation of units - Measured value, true value, output value - Measurement deviations
- **Principles and methods of measurement:** Principles, methods and procedures of measurement - Deflection, differential, substitution and compensation measurement methods - Direct and indirect measurement methods - Analog and digital measurement methods - Absolute and incremental measurement methods - Resolution and sensitivity - Curve and kinds of curves
- **Statistics - Evaluation of measurements series:** Calculation of a measurement result based on measurement series - Basic terms of descriptive statistics - Presentation and interpretation of measured value distributions (histograms) - Frequency (absolute, relative, cumulative, relative cumulative) - Calculation and interpretation of basic parameters: location (mean, median, mode), dispersion (range, variance, standard deviation), shape (skewness and excess kurtosis) - Stochastics and distributions (rectangle, U and normal distribution) - statistical tests and statistical estimation methods - Correlation and regression
- **Measurement errors and measurement uncertainty:** Measured value, true value, conventional quantity value, detected value, output value - Influences on the measurement (Ishikawa diagram) - Measurement error (systematic, random) - Correction of known systematic measurement errors - Calibration, verification, legal verification - Measurement precision and accuracy - Repeatability conditions and precision, Comparison conditions and precision, extended comparison conditions and precision - Measurement uncertainty - Correct specification of a measurement result - Overview of standard method of the GUM (measurement uncertainty)

**Mesurands of the SI system of units**

- **Measurement of electrical quantities:** Measurement of current and voltage (current and voltage correct measurement), range adjustment - Wheatstone bridge circuit (quarter, half and full bridge, differential method and null balancing procedures) - Characteristic values of sinusoidal alternating quantities (alternating voltage bridge) - Operational Amplifier (Inverting amplifier, non-inverting amplifier, impedance converter) - Digitising chain (filters, sample-and-hold device, analog-digital conversion) - Variations in the analog-to-digital conversion
- **Measurement of optical quantities:** Light and properties of light - Photo detectors (photo resistors, photo diodes) - Sensitivity range of the eye - Radiometry and photometry - Luminous intensity (cd, candela) - Radiation laws
- **Measurement of temperatures:** Temperature, SI unit, definition - Heat transfer (conduction, convection, radiation) - Fixpoints (triple points, freezing points), fixpoint cells, International Temperature Scale (ITS-90) - Contact thermometers - Metal resistance thermometer, measurement circuits for resistance thermometers - Thermocouples, measurement circuits for thermocouples - Measurement errors of contact thermometers - Radiation laws, pyrometers (see optical quantities) - Measurement errors of pyrometers

- **Time and Frequency:** Time measurement - Atomic clock - Global Positioning System - Representation of time - Propagation of UTC - Frequency and phase angle measurement
- **Length:** Meter definition - Abbe comparator principle, errors 1st and 2nd order - Length measurement with linear encoders, motion direction, output signals, differential signals - Absolute coding (V-Scan and Gray code) - Interferometer, Michelson interferometer, basics of interference, homodyne principle, heterodyne principle, interference on homodyne interferometer, destructive and constructive interference, influence of air refractive index
- **Angle and slope:** plane angle, angle unit - material measures - angle measuring devices - slope measurement - optical angle measuring devices - measurement deviations - spatial angle, solid angle
- **Mass and force:** Definition of SI unit kilogram, mass standards, principle of mass dissemination - Definition of mass, force and torque - Measurement principles of weighing - Beam balance, spring balance, hanging and top pan balances, corner load sensitivity, DMS balance, EMC balance, mass comparators - Influences for mass determination - Force measurement, force measurement with DMS, Magneto-elastic and piezoelectric force measurement

### Branches of industrial metrology

- **Process Measurement Technology:** Definition of pressure - Pressure types (absolute pressure, overpressure, differential pressure) - Pressure balance (piston manometer), U-tube manometer, bourdon pressure gauge, diaphragm pressure gauge - Pressure sensors (with DMS, piezoresistive, capacitive, piezoelectric) - Flow measurement (volume flow and mass flow, flow of fluids) - volumetric method, differential pressure method, sinker flow meter, magnetoinductive flowmeter, ultrasonic flow measurement - Mass flow rate measurement (Coriolis, thermal)
- **Manufacturing Metrology:** Subtasks of manufacturing metrology, objectives of manufacturing metrology - Form parameters of workpieces (micro-and macro-shape), structural error types, measuring, checking, monitoring - Comparison of classical measuring and coordinate measuring, standard geometrical features - Designs and basic structure of coordinate measuring machines - Procedure for measuring with a coordinate measuring machine
- **Micro and Nanometrology:** Demands of the microsystem technology on metrology - Sensors and probing systems of microsystem technology (tactile sensors, opto-tactile fiber probe, focus sensor, chromatic white light sensor) - Atomic force microscope (structure, working methods), scanning tunneling microscope - Nano coordinate measuring: 3-D realization of the Abbe comparator principle - Measures to reduce influences

### Lernziele und Kompetenzen:

#### Learning targets and competences:

##### Remembering

- The students have basic knowledge of fundamentals of metrology and metrology activities. - The students have fundamental knowledge for methodological and operational approach to measuring tasks of static measurement types, to solve basic measurement tasks and to establishing measurement results from measurement values.

##### Understanding

- The students are able to describe the characteristics of measuring instruments and measurement processes. - The students are able to describe the international system of units (SI) and the traceability of measurement results

##### Applying

- The students are able to run basic measurements of static measurands.

##### Evaluating

- The students are able to evaluate measuring systems, measurement processes and measurement results.

### Literatur:

- DIN e.V. (Hrsg.): Internationales Wörterbuch der Metrologie - Grundlegende und allgemeine Begriffe und zugeordnete Benennungen (VIM) ISO/IEC-Leitfaden 99:2007. Beuth Verlag GmbH, 3. Auflage 2010
- Hoffmann, Jörg: Handbuch der Messtechnik. 4. Auflage, Carl Hanser Verlag München, 2012 - ISBN 978-3-446-42736-5

- Lerch, Reinhard: Elektrische Messtechnik. 6. Auflage, Springer-Verlag Berlin Heidelberg, 2012 - ISBN 978-3-642-22608-3
- Richter, Werner: Elektrische Meßtechnik. 3. Auflage, Verlag Technik Berlin, 1994 - ISBN 3-341-01106-4
- Kohlrausch, Friedrich: Praktische Physik : zum Gebrauch für Unterricht, Forschung und Technik. Band 1-3, 24. Auflage, Teubner Verlag, 1996 - ISBN 3-519-23001-1, 3-519-23002-X, 3-519-23000-3
- Ernst, Alfons: Digitale Längen- und Winkelmesstechnik. 4. Auflage, Verlag Moderne Industrie, 2001 - ISBN 3-478-93264-5
- Pfeifer, Tilo: Fertigungsmeßtechnik. R. Oldenbourg Verlag München Wien, 1998 - ISBN 3-486-24219-9
- Keferstein, Claus P.: Fertigungsmesstechnik. 7. Auflage, Vieweg+Teubner Verlag, 2011 - ISBN 978-3-8348-0692-5
- Warnecke, H.-J.; Dutschke, W.: Fertigungsmeßtechnik. Springer-Verlag Berlin Heidelberg New York Tokyo, 1984 - ISBN 3-540-11784-9

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### Studien-/Prüfungsleistungen:

Fundamentals of Metrology (Prüfungsnummer: 47701)

(englische Bezeichnung: Fundamentals of Metrology)

Prüfungsleistung, Klausur, Dauer (in Minuten): 60

Anteil an der Berechnung der Modulnote: 100%

weitere Erläuterungen:

- **Prüfungstermine**, eine **allgemeine Regel der Prüfungstagvergabe** und **Termine der Klausureinsicht** finden Sie auf StudOn: Prüfungstermine und Termine der Klausureinsicht
- Die Lehrveranstaltungen *Grundlagen der Messtechnik [GMT]* im Wintersemester und *Fundamentals of Metrology [FoM]* im Sommersemester sind **inhaltlich identisch**. Beide Lehrveranstaltungen werden **bilingual** (Vorlesungsunterlagen: englisch-deutsch, Vortragssprache: deutsch) gehalten.
- Die **Prüfungen** über *Grundlagen der Messtechnik [GMT]* (Prüfungnr. 45101) und *Fundamentals of Metrology [FoM]* (Prüfungnr. 47701) sind **inhaltlich identisch**. Die Aufgabenstellung der Prüfung über *GMT* ist nur **in Deutsch**, während die Aufgabenstellung der Prüfung über *FoM* **bilingual** (englisch-deutsch) ist.

Erstablingung: SS 2015, 1. Wdh.: WS 2015/2016

1. Prüfer: Tino Hausotte

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### Organisatorisches:

- Unterlagen zur Lehrveranstaltung werden auf der Lernplattform StudOn ([www.studon.uni-erlangen.de](http://www.studon.uni-erlangen.de)) bereitgestellt. Das Passwort wird in der ersten Vorlesung bekannt gegeben.