

Infrastructure

Thüringer Innovationszentrum Mobilität / ThIMo



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Thüringer Innovationszentrum
MOBILITÄT

th
TECHNISCHE UNIVERSITÄT
ILMENAU

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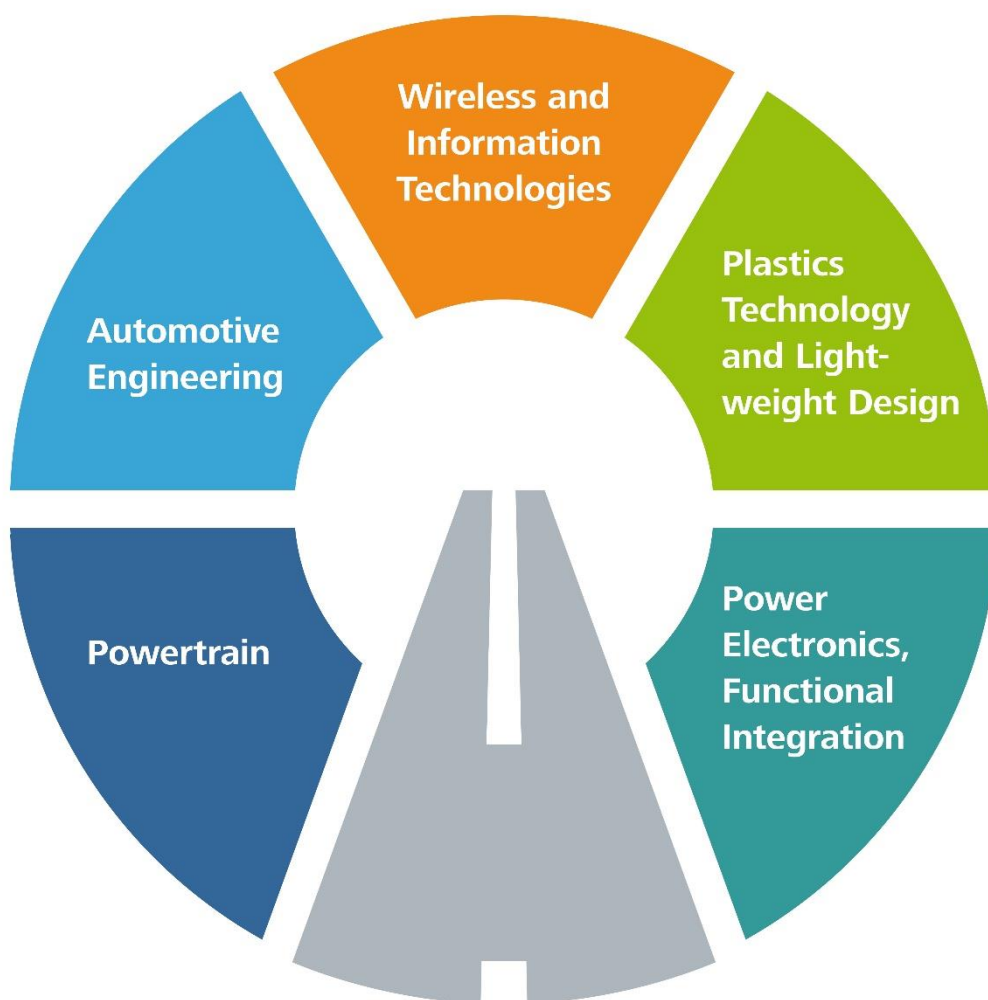


Key Competence Power Electronics, Functional Integration

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Key Competences

The Thuringian Center of Innovation in Mobility (ThIMo) supports the industrial change towards a sustainable mobility. We offer scientific expertise and infrastructure for joint research projects with industry partners, development or contractual research and services.



Within their key competences, ThIMo scientists together with partners from the TU Ilmenau and other facilities devise solutions being highly relevant for practical applications.



- Hybrid and adaptive Powertrain Technologies
- Alternative- and gaseous (mixed) fuels
- Exhaust after treatment
- Optimization of turbochargers and their parts

Contact:

Office of ThIMo

Phone: +49 3677 69-2530

Mail: thimo@tu-ilmenau.de



Powertrain

1. Testing Facilities



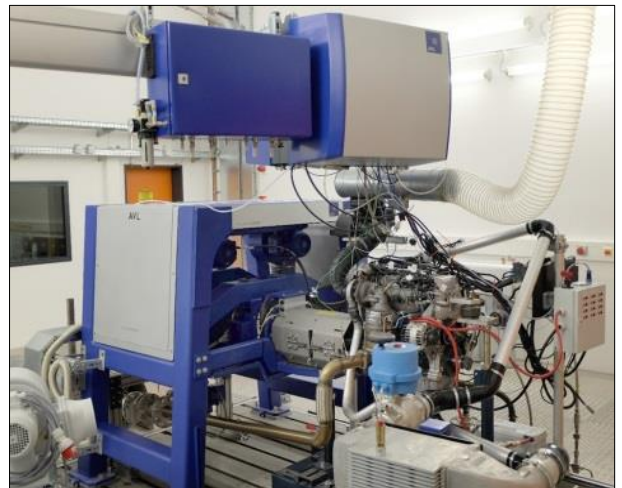
Engine Test Bench

AVL Dynospirit 370/4,5-8

Modern high dynamic engine test bench for a wide range of modern engines.

Specification:

- Torque: MD=785 Nm
- Power: P=370 kW
- Rotational Speed: n=8000 1/min
- Inertia: $\Theta=0,273 \text{ kg m}^2$
- Measured Values: p,T,P,M
- Indexing: AVL Indimodul
- Exhaust Measuring: Gaseous Emissions
AVL SESAM i60 FT
- Fuels: Gasoline, Diesel



Hot gas Test Benches

Hot gas test benches for turbocharger mapping, thermomechanical investigations and other several, possible investigations including components underlying a gaseous fluid flow.

Specification Test Bench 1:

- Power: P=400 kW
- Massflow: m= 1500 kg/h
- Temp-Range: T=150-1100 °C
- Special: Capable of tThermoshocks

Specification Test Bench 2:

- Power: P=200 kW
- Massflow: m=1000 kg/h
- Temp-Range: T=150-1100 °C
- Special: Capable of ClosedLoop



Powertrain

2. Measurement Systems



Measurement and Analysis Systems

Stationary Exhaust Measurement Device (AVL) SESAM i60 FT

Multi component exhaust gas measurement system for detailed determination of every single exhaust gas component.

Specification:

- Principle: Infrared spectroscopy
After treatment over Fourier Analysis
- Sampling rate: 1Hz
- Reactional speed: 1Sek (t_{10} to t_{90})
- Measurable gases:
nitric oxide, alcohols, aldehyde,
ammoniac, CO, CO₂, CH₄, SO₂,
formaldehyde, aromatic hydrocarbon,
pentane, octane



High-dynamic DC-Voltage source VES2 (Vehicle Energy System, Kratzer Automation)

DC Source for static and dynamic loading of electric engines and DC Drain for investigating battery like component behaving.

Specification:

- Power: $P = 250 \text{ kW (340PS)}$
- Voltage Output: $U = 40 - 800 \text{ V}$
- Current Output: $I = +/- 0 - 700 \text{ A}$
- Voltage reactional speed: $< 400\mu\text{s}$
- Current reaction speed: $< 400\mu\text{s}$



Powertrain

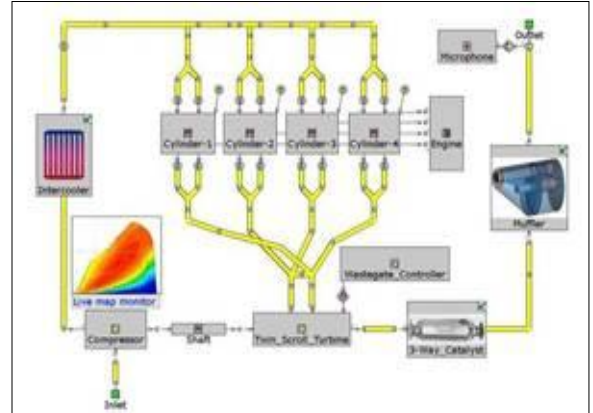
2. Measurement Systems



Numerical Simulation

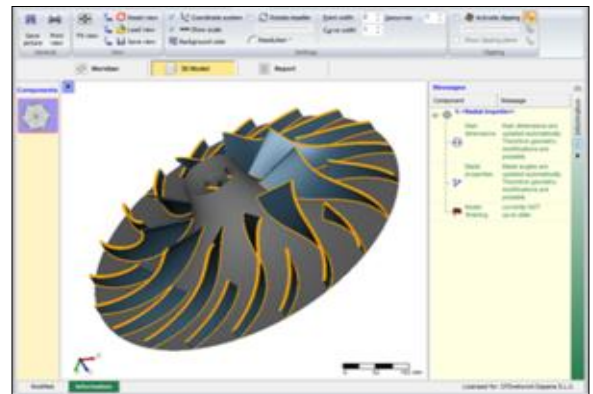
Engine Simulation

Over an 1-D engine simulation tool (GT Power) for science and teaching.



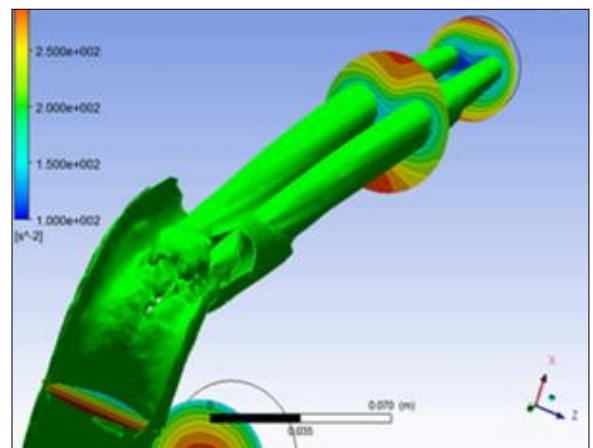
Turbocharger Dimensioning

CFTurbo is used to construct and shape turbochargers as needed for scientific investigations and also for teaching students.



Computational Fluid Dynamics

With ANSYS CFX and FLUENT, our staff has the possibilities to investigate fluid streams in three dimensions.



Powertrain

2. Measurement Systems



Variable gas composition unit

- engine test bench supply with gaseous fuels
- gas mixtures generation with any composition

Specifications:

- gas components & maximum mass flow rate
 - methane (60 kg/h)
 - carbon dioxide (15 kg/h)
 - nitrogen (11 kg/h)
 - hydrogen (7 kg/h)
 - compressed natural gas (80 kg/h)
- gas pressure variable up to 16 bar
- 500 litres buffer tank for dynamic engine operation





- X-in-the-loop test and simulation techniques
- Assistance systems for optimized driving safety and energy efficiency
- longitudinal and transverse dynamics control for autonomous vehicles
- Integrated active suspension systems for multi-actuated and electric drive vehicles
- Research and test center for non-exhaust-emissions



Contact:

Univ.-Prof. Dr.-Ing. Thomas Bachmann

Director of the Automotive Engineering Department

Phone: +49 3677 69-3842

Mail: thomas.bachmann@tu-ilmenau.de



Automotive Engineering

1. Testing Facilities (System)



MASTER: Four-Roller Power Dynamometer

Modern vehicles are equipped with an increasing number of technical functions in order to enhance safety, comfort and performance. Despite the increasing complexity, manufacturers expect short development cycles with a constant price-performance ratio. Therefore the four-wheel power dynamometer was integrated as a MASTER node in a real-time test and development environment, which allows to test products from different development stages. This leads to a faster and more effective development of automobiles.



Automotive Engineering

1. Testing Facilities (System)



MASTER: Four-Roller Power Dynamometer

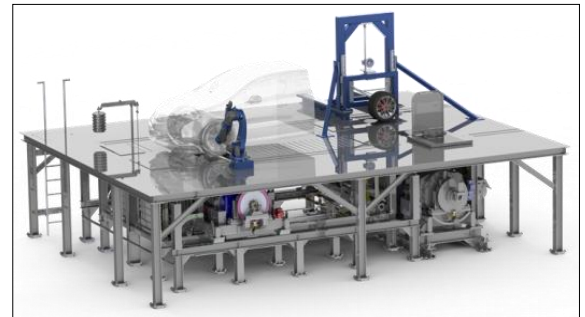
Technical Properties

- Test chamber (LxBxH) 12x7, 5x4,5 m
- Air conditioning -20 bis 45 °C
- Max. power 4x230 kW
- Roller diameter front 48", rear 75"
- Wheel and axle load operation possible



Corner Module

- Examination of longitudinal-, transverse- and vertical-dynamic tire characteristics
- Analysis of electric drives up to 250 kW
- Experimental analysis of spring, damper and suspension characteristics



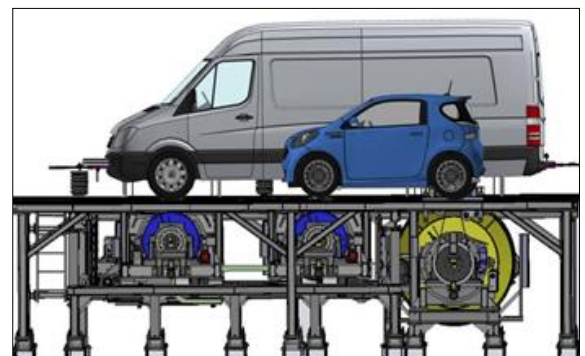
Environmental Analysis of Emissions

- Environmental analysis of exhaust and non exhaust particle emissions
- Automated measuring head positioning using an industrial robot
- Efficiency optimization / friction reduction on the subsystem level for reduced CO₂ emissions



Vehicle Properties

- Speed up to 250 km / h
- Spreading width 0.8 to 2.3 m
- Wheelbase 2.1 to 4.4 m
- Max. Wheel load 1.25 t



Automotive Engineering

1. Testing Facilities (System)



Testing Center for Suspension and Brake Systems

Testing center used for interdisciplinary research tasks with regard to driving safety, driving comfort and environmental protection.

- Simulation of heavy vehicles (transporters)
- High performance testing and comfort analysis (NVH)
- Investigations on braking systems, chassis components and complete axles

Specifications:

- Revs: $n_{\max} = 2500 \text{ min}^{-1}$
- Speed: $v_{\max} = 310 \text{ km/h}$
- Momentum: $M_{\max} = 2300 \text{ Nm}$ (up to 1100 min^{-1})
- Inertia: $I_{\max} = 191 \text{ kgm}^2$
- Air conditioning: $Q_{\max} = 4200 \text{ m}^3/\text{h}$
-20 to +50 °C; 15-85% air moisture



Experimental Platform for Real-Time Coupling

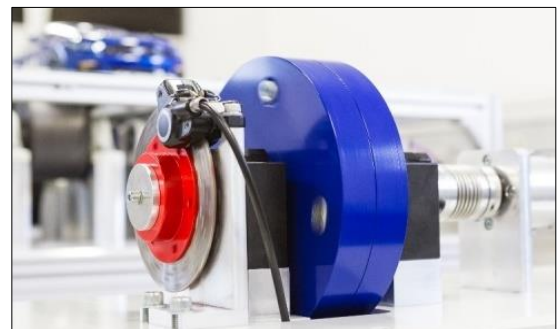
Model Roller Dynamometer

- Demonstrator for real-time coupling of roller test stands and simulation platforms
- Scaled illustration of test scenarios for drive and suspension technology
- Real-time coupling enables a reproducible, true-to-life test
- Investigation of complex physical phenomena



Model Brake Dynamometer

- Demonstrator for real-time coupling of brake test stands and simulation platforms
- Scaled illustration of test scenarios for brake technology
- Real-time coupling enables a reproducible, true-to-life test
- Consideration of complex tribological properties



Automotive Engineering

1. Testing Facilities (Components)



Friction Test System for Shock Absorbers

Galdabini Quasar 5

Machine for tensile and compression tests for the material characterization of elastomers, which has been specially developed for friction measurements in automotive shock absorbers.

Specifications:

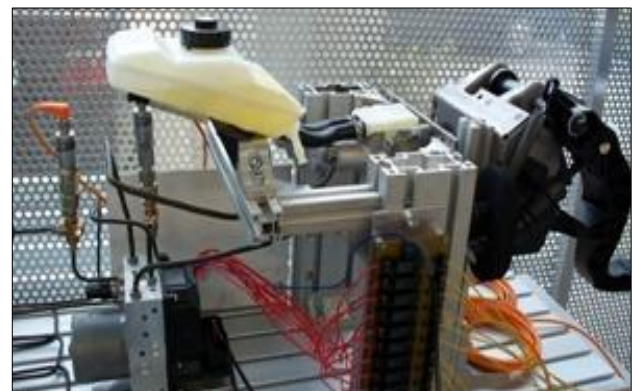
- Standard measuring equipment: force sensor + extensometer
- Additional force, pressure and differential pressure sensors Additional attachments for introducing lateral forces into the damper



Hardware-in-the-Loop Test Stand

Test stand for the investigation of algorithms developed for anti blocking systems (ABS), electronic stability programs (ESP) and other driving safety systems.

- Hardware: Main brake cylinder, four Wheel brakes, hydraulic control
- Hydraulic control unit (HCU) follows control strategies implemented in MATLAB / Simulink using a dSpace interface



Automotive Engineering

1. Testing Facilities (Components)



Dynamic driving simulator

Simulator mock-up

Mock-up for the investigation of user acceptance of different assistance systems and human-technology interactions (MTI or HMI).

Set-up:

- Environmental visualization via 98" 4K screen
- active steering wheel (*Sensodrive*)
- Pedals (throttle, brake) / active pedals are planned

Function:

- Realization of a detailed vehicle simulation with different software tools (IPG CarMaker / PreScan / AMESim)
- CAN communication enables direct influence on steering wheel characteristics in the form of stiffness, damping and friction
- Hardware communication (dSpace / National Instruments): real-time transmission of steering angle and torque to the simulation environment
- feedback active adjustment of the steering wheel



Hexapod motion system

Extension of the simulator mock-up by an electrical hexapod motion system for realistic vehicle dynamics simulation dynamic feedback.

Field of research:

- Development of novel vehicle dynamics control and driver assistance systems
- Acceptance studies of new driving systems
- Complex and realistic mixed traffic simulations
- Cooperative driving with "human-in-the-loop"



Specification, motion system:

direction	amplitude		speed	acceleration
longitudinal	-0,499 m	+0,628 m	+/- 0,79 m/s	+/- 7,00 m/s ²
lateral	-0,506 m	+0,506 m	+/- 0,81 m/s	+/- 7,00 m/s ²
vertical	-0,383 m	+0,372 m	+/- 0,55 m/s	+/- 10,00 m/s ²
roll	-24,01 deg	+24,01 deg	+/- 34,3 deg/s	+/- 250 deg/s ²
pitch	-25,05 deg	+28,02 deg	+/- 37,4 deg/s	+/- 250 deg/s ²
yaw	-27,25 deg	+27,25 deg	+/- 41,3 deg/s	+/- 500 deg/s ²



Automotive Engineering

1. Testing Facilities (Components)



Vibration Testing System

TIRA TV 50350-120

Examination of component vibrations and durability

Specifications:

- Rated Power: Sine: 2700 N; Shock: 4000 N
- Swing path max. 25.4 mm
- Sample weight up to 25 kg



Climate Test Chamber

FEUTRON 3636/17

Climatic examination of components

Specifications:

- Chamber volume 600l
- (770x1020x745) mm
- Sample weight 3x30 kg
- Temperature range (-75 ... 180) °C
- Humidity range (10 ... 95)%
- Change speed $\pm$ 5K



Automotive Engineering

1. Testing Facilities (Components)



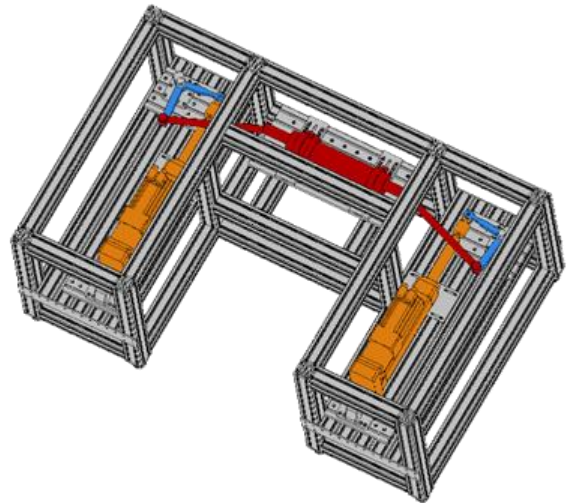
Steering System Test Bed

Research

- Static and dynamic load scenarios for power steering actuation systems
- Power and efficiency measurements

Technical Features

- Electro-mechanical actuators with max. 17,8 kN
- 300 mm of way at up to 267 mm/s
- Constructive realization of steering kinematic
- Max. incidence angle: ca. 30 deg
- Track widths and track lever lengths covering all classes of vehicles (small cars up to SUV)



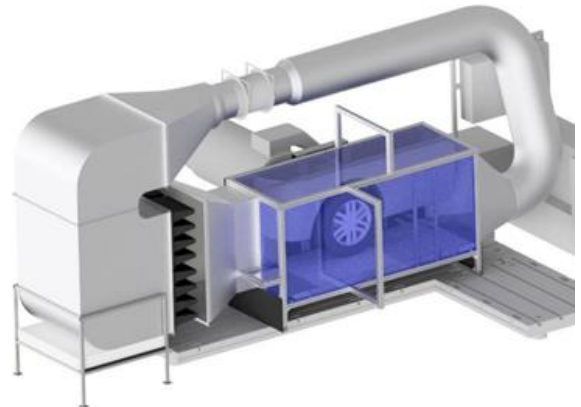
Windtunnel Test Bed

Research

- Validation of turbulence-, and particle models (CFD)
- Visualisation and measurement of particle dispersion (non exhaust emissions)
- Analysis of particle deposition mechanisms

Specification

- Max. volume flow: 7400 m³/h equals 5 m/s inside the plenum
- Eclectic Engine: P_{max} 135 kW / M_{max} 1740 Nm / n_{max} 2600 1/min
- Solid and fluid seeding

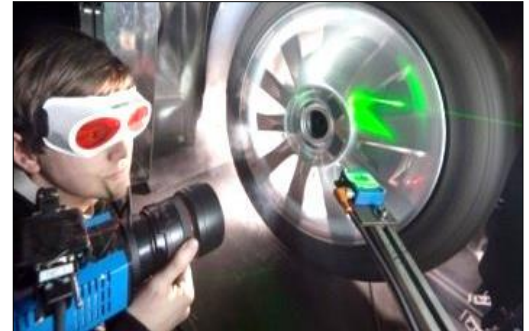




Particle Image Velocimetry (PIV)

2D/3D – Flow visualization for various vehicle technical applications

Laser: Double pulsed laser Nd:YAG200 mJ/Puls at 532 nm, 15 Hz
Camera: 2x 2048x2048 Pixel, 4 GB, 14 Bit, 15.56 fps, 400 ns Interframing-time
Optic: Movable mirror arm, divergent laser 35/50/85mm AF objectives
Equipment: Particle Generator, 1 μm 2x Tilt Adapter X-Z traverse
Computer: Synchronisation unit, Workstation
Software: VidPIV + Tecplot 360



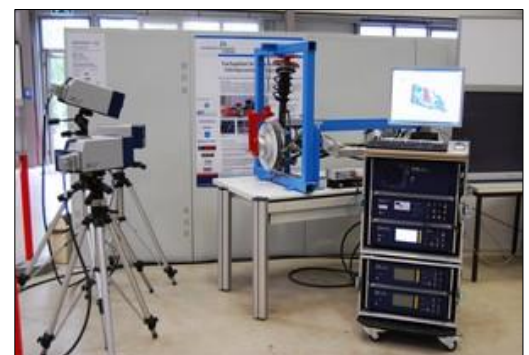
3D Laser Scanning Vibrometer

PSV 400 3D

Non-contact 3D vibration measurement technology,
Applicable also at the customer site

Specifications:

Frequency range: 0 – 1 MHz
Data collection: 4 canals
Distance: > 0,4 m
Object width: $\geq 1 \text{ mm}^2$
Velocity: 10 m/s (max.), 2,5 MHz (max.)
0,5 m/s (max.), 350 kHz (max.)
Signal generator 512 kHz (bandwidth)
0 – 10V, $\pm 5 \text{ mA}$
Measurement: 2x2 up to 512x512 measurement points
Resolution: 6400 FFT lines



Automotive Engineering

2. Measurement Systems



Real-Time Systems for Measurement and Control Tasks

PXI/Compact-PCI (Fa. National Instruments)

Autobox (Fa. dSpace):

- Prozessor-Board, DAQ-Board, HIL-Board
- 7 slots (AutoBox)
- Operation with 12V, 24V and 48V vehicle wiring

MicroLabBox (Pr. dSPACE):

- DS1202 Processor-Board
- A/D and D/A I/O Boards
- CAN Communication

Hardware-in-the-Loop Test Stand (Pr. dSPACE):

- DS1006 Processor-Board
- A/D und D/A I/O Boards
- CAN und FlexRay Communication
- Integrated control of Suspension systems



Source: dSpace

Racelogic VB3i / Video VBOX Pro

- Detection of driving condition sizes, e.g. Speed, lateral and longitudinal acceleration as well as position in combination with a 4-channel camera system for driving documentation
- Additional equipment for highly dynamic vehicle data and vehicle dynamics measurement
- Measurement wheel - Correvit Datron



Specifications:

- 100 Hz DGPS
- 500 K Can-Bus-Anschluss
- Data logger
- 4xAI, 2xAO, 2xDI, 2xDO
- 4 cameras
- 2 Microphone
- Video-Overlay



Quelle: Racelogic

Fahrzeuganalyse

Automotive Engineering

2. Measurement Systems



Bidirectional Telemetry System

System for bidirectional data transmission between the main station and a test vehicle, which is used for vehicle dynamics development and modeling (analysis of driving behavior).

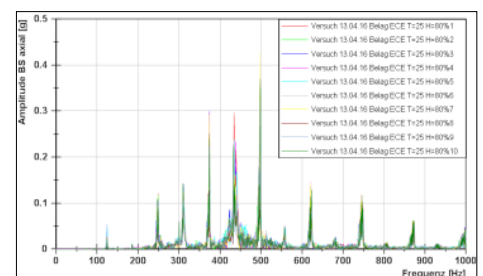
- 3km range (omnidirectional)
- Sampling rate:
48kSps (stand-alone mode)
24kSps (modules coupled)
- Bandwidth per channel:
20kHz (stand-alone mode)
10kHz (modules coupled)
- 8x Analog, 4x Digital, 8x ICP, 4x Thermocouple, 1x CAN



Vibration and Acoustics Measuring System

LMS SCADAS Mobile

- Mobile test hardware for noise, vibration and lifetime tests
- Compact size and light weight
- Robust design for extreme conditions and temperatures
- Very quiet, operation without fan
- Up to 204.8 kHz sampling rate per channel
- 24-bit ADC technology
- 150 dB dynamic range



Automotive Engineering

2. Measurement Systems



Fuel Consumption Measurement System

Gregory Flowtronic Sensor Series S8005

Accurate measurement of the fuel consumption of internal combustion engines with high accuracy

- Can be used on engines with petrol, diesel, alcohol and biofuels
- Accurate and highly dynamic measurement of minimum flow rates (idle) and high volume flows (full load)
- Can be used in mobile driving tests as well as on the test bench

Specifications:

- Measuring range: 0.1 to 250 l / h
- Measurement accuracy: +/- 0.5%
- Volume resolution: 0.004 ml



Source: Gregory

Automotive Engineering

2. Measurement Systems



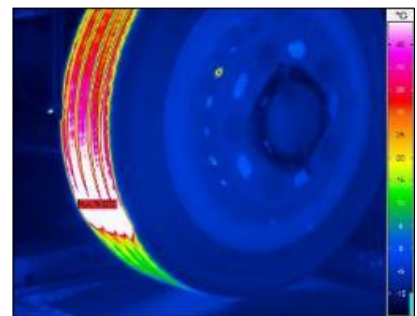
High- speed- Thermography

Thermography Camera InfraTec ImageIR 8300

Detector format: (640 x 512) Infrared-Pixel
Temperature resolution: 20 mK
Spectral range: MWIR, (2,0 ... 5,7) μm
Frame rate: Full image: 355 Hz
Half image: 670 Hz
Quarter imager: 1.200 Hz
Split image-line-mode: 5.000 Hz
Measurement accuracy: +/- 1 K or +/- 1 %
Calibration: 10 up to 850 ° C

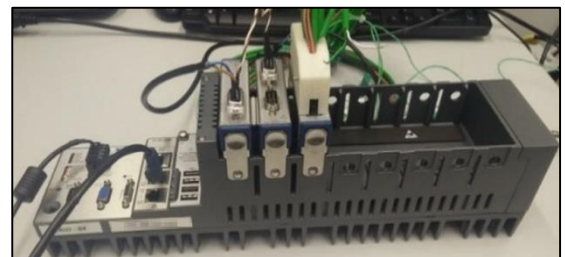


Source: InfraTec



Free-Sense HAT cRIO-9082

- Intel Core i7, 2GB RAM, 32 GB
- LabView Real-Time
- Maximum number of measuring cards: 8



Temperature Measuring Cards

NI 9213 high speed module:

- 16 channels
- Maximum sample rate 75 S/s
- Supports standard thermo-sensor types (J, K, S...)

NI 9214 precision module:

- 16 channels
- Measurement accuracy up to 0,45 °C
- Supports standard thermo-sensor types (J, K, S...)



Source: National Instruments

Automotive Engineering

2. Measurement Systems



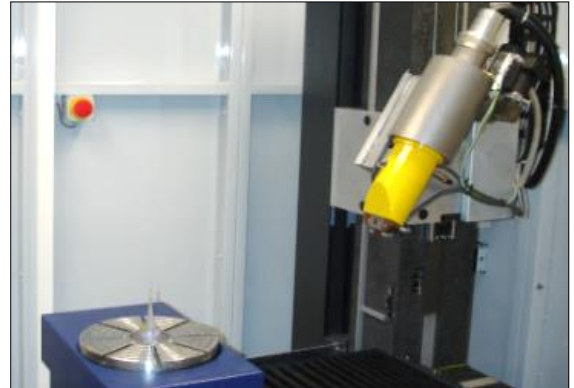
Computer-Tomograph for Component Analysis (μm -Range)

Ray Scan 200

- 2D and 3D material and structure analyzes
- Microstructure analysis
- Defect analysis
- Measuring tasks

Specifications:

- X-ray source: Micro focus 10-250 kV
- Burning spot: 3-250 μm
- Object dimensions $\varnothing$ / H: 1-600 mm / 1-1500 mm
- Max. Object weight: 80 kg
- Active area detector: 410 x 410 mm²
- Detector Pixels: 1024 x 1024 (2048 x 2048 optional)
- Digitization: 16 bit
- Measurement time incl. Reconstruction: 2 - 30 min.
- Detectability: 1 μm
- Contrast: <1%
- Operating modes: 3D-CT and radioscopy



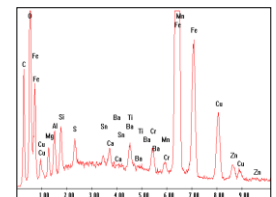
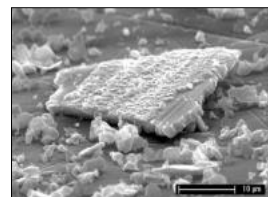
Scanning Electron Microscope with Element Analysis

JEOL JSM-6610 + EDX

Analysis of physically and chemically properties of components in nm-range

Specifications:

- Resolution of 3 nm at 30 kV
- Large sample chamber (350x340x230) mm with fully motorized sample table and a max. sample weight of 5kg
- Samples with a diameter of up to 208mm can be approached at any surface point
- Low-pressure operation with BSD allows high resolution
- Integrated element analysis (from boron to americium)
- 30 mm² active detector area
- Gold / Carbon sputter system





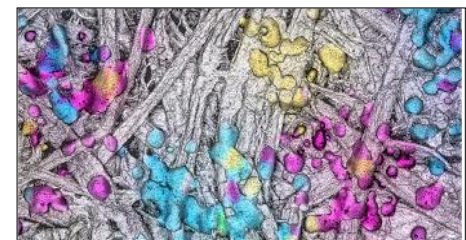
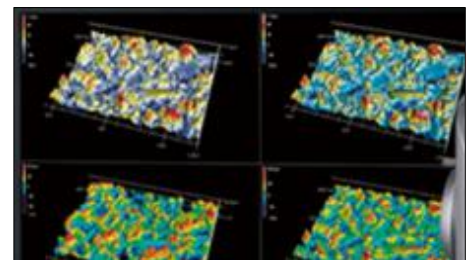
Laser Scanning Microscope

Keyence VK-X 3D-Laser Scanning Colour Microscope

Surface analysis of tribologically stressed surfaces, roughness and ripple determination, 3D analysis of seals or friction linings and particle size determination

Specifications:

- Red semiconductor laser with a wavelength of 658 nm
- More than 3 million measurement points in each level
- 16 bit PMT, color CCD image sensor (3072 x 2304)
- 5 nm high resolution
- 8x optical zoom (laser mode)
- Scanning speed up to 120Hz
- XY image composition module with software and travel table (motorized 100x100mm)
- Comprehensive evaluation and analysis software
- Large number of different lenses



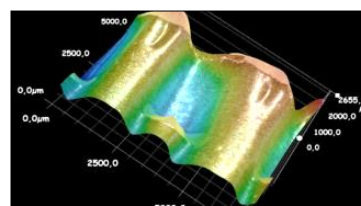
High Speed Digital Microscope

Keyence VW 9000

- Analysis of highly dynamic processes in the micrometer range
- 3D measurement of surfaces

Specifications:

- 4000 fps at 640x480 pixels
- Max. 230000 fps
- Microscope up to 1920x1440 pixels
- Magnification up to 200 times
- Macro zoom lens for long distance



Automotive Engineering

2. Measurement Systems



Measuring Arm with Probe and Laser Scanner

FARO Fusion + Laser Line Probe

- 3D measurement of components, interior and body
- 3D modeling and reverse engineering
- Positioning and calibrating in the room
- anthropometry

Construction: 2,4m / 7 axes

Accuracy tactile: 51 μ m

Accuracy optical: 35 μ m



3D Midrange Laser Scanner

FARO Focus 3D X 330

- Surveying and verification of industrial plants and installations
- Testing of large moldings and components
- Architecture and terrain surveying

Range: 0.6m - 330m

Systematic error: +/- 2mm

Special features: - Integrated GPS-receiver
- Scanning in direct sun light



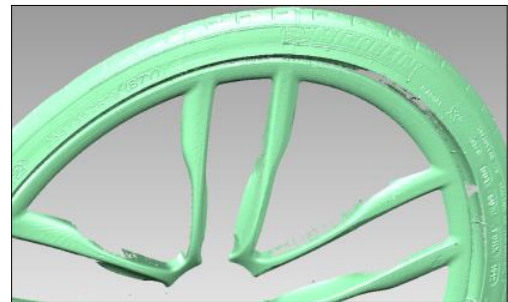
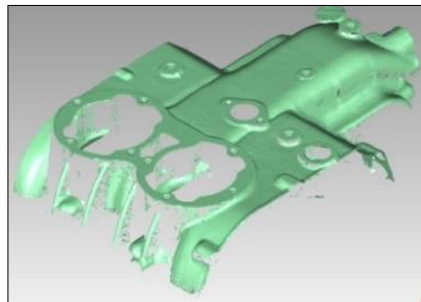
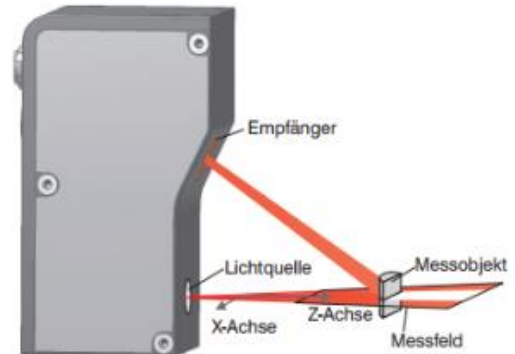
Source: FARO



Laser Line Scanner for Geometry Detection

Micro Epsilon ScanControl 2750 – 100

- Max. Profile sampling rate (test surface depended): 4000 Hz
- Typical profile sampling rate: 500Hz
- Component vibrations can be detected
- Measuring distance: approx. 500 mm
- Profile width: approx. 100mm



Automotive Engineering

2. Measurement Systems



Wheel Alignment System

Beissbarth ML 8 R easy + Hydraulic Ramp Nussbaum UNI-Lift 3500 NT Plus

- Extensive database with setpoints of vehicles
- Measurement of individual wheel position variables
- Runout compensation
- Wheel sizes up to 24 "
- 4 measuring heads with 2 infrared cameras each
- Load capacity: max. = 4000 kg (wheel free lift 3500 kg)
- Wheelbase: max. = 4050 mm
- Width: max = 2120 mm



Robotic Handling Systems

Precision Positioning Robot

- Precision positioning robot
- Max. Payload: 34 kg
- Robotic weight: 248 Kg
- Brakes: in all axles
- Max. Speed in the center of gravity: 10.3 m/s
- Operating distance: 710 mm
- Degrees of freedom: 6
- Repeatability (typical): $\pm 0.01\text{mm}$
- Repeatability (ISO 9283): $\pm 0.05\text{mm}$
- Programming language robot control: VAL3
- Self-developed Labview interface



Source: Stäubli

Automotive Engineering

2. Measurement Systems



Actuation Robots

Pedal Actuator

- Reproducible pedal operations with high dynamics and precision
- Static and dynamic measurement of the pedaling properties and associated vehicle reactions

Principle:	Servo-hydraulic
Limits:	$F = 0 \dots 1500 \text{ N}$ $v = 0 \dots 1000 \text{ mm/s}$
Modes:	Force controlled, Length controlled, Ramped actuation, Oscillated actuation, Measurement while driving possible
Data collection:	Pedal force, actuation path, Hydraulic pressure, BKV-pressure, Vehicle velocity, Vehicle deceleration



Steering Robot

Vehico CS-60B

- Performance of lateral test manoeuvres under reproducible conditions
- Highly automated driving

Technical Features

- Max. 60 Nm steering torque at 1200°/s angular speed
- Applicable steering wheel diameters from 250 mm to 440 mm
- Operation modes: open-loop (pure actuator), closed-loop (GPS)
- Conservation of manual steering and airbag function



Source: VEHICO GmbH



Pressure Measuring Mat

Tekscan TVR8404

- Analysis of pressure distribution of car tires in wheel-to-ground contact
- 36.608 piezo-resistive sensors on a surface of 268 mm x 317 mm allow the recording of the surface pressure distribution in the tire
- Recording frequencies of up to 106 Hz allow the measurement of dynamic processes during rolling
- Extensive analysis software



Highly Dynamic Force and Vibration Measurement System

Kistler Vibration Measurement System

- Determination of the dynamic force at the vehicle chassis connecting points
- Recording of oscillating forces and moments with up to 16 sensors

Specifications:

- Range: $\pm 100 \dots 1\,000\,000$ pC
- Frequency range: 0 – 45 kHz
- Drift: max. 0,2 pC/s
- Measurement uncertainty: <1%
- Measurement signal: 0-10V
- Storage of the measuring signals by direct reading of the measuring amplifiers (via Ethernet)





Wheel Load Sensor

Kistler RoaDyn S635

- Highly dynamic detection of wheel forces and moments
- 6-component wheel force sensor allows the measurement of multi-axis loads
- Complete assembly of the measuring wheel on the vehicle (as replacement for the standard wheel)
- Mounting on the tire trailer for the analysis of the behavior of the tire / road contact
- Mounting at the corner-module test stand for the analysis of the behavior under laboratory conditions

Measurement Range:

F_x	-35 ... 35 kN
F_y	-20 ... 20 kN
F_z	-35 ... 35 kN
$M_{x/y/z}$	-5 ... 5 kNm



Emission Analysis Systems

HORIBA MEXA – 2100 SPCS and SMPS

- Solid Particle Counting System (CPC) + Scanning Mobility Particle Sizer (SMPS)
- Enlargement of the surface of the particles by heterogeneous condensation makes optical detection possible (the particles are passed through saturated alcohol / n-butanol)
- Counting by means of optical scattered light detection

Specifications:

- Particle count range: 10 - 2500nm (CPC - modified)
- Dilution Factors: 150: 1 - 3,000: 1 (two dilution steps)
- Size distribution by SMPS: 2.5 - 150nm and 10 - 1000nm over 167 channels



Source: HORIBA



Mobile Exhaust Measurement Systems

AVL M.O.V.E

- **GAS PEMS iS:** The AVL GAS PEMS iS is a compact, portable exhaust-gas analyzer developed for the determination of NO / NO₂, CO / CO₂ and O₂ concentrations in the exhaust gas of diesel and gasoline engines
- **PN PEMS iS:** The PN PEMS iS has been developed for continuous measurement of particulate matter emissions [# / cm³] of solids particles under real driving conditions (RDE)

Specifications:

- Sensor principle: Advanced Diffusion Charger
- Sample preparation: Catalytic Stripper
- Max. Sampling rate: 10Hz
- Dilution rate 10: 1



Source: AVL

Differential mobility analyser (DMA)

CAMBUSTION DMS500

Function:

- Particles are charged by an unipolar corona charger with relation to the particle surface
- In a classifying unit the electrically charged particles are exposed to a static electric field, which leads to deflection in direction of 22 ring electrodes
- The trajectory (impact location on a ring electrode) depends on the electrical mobility of the particles, based on which the aerodynamic diameter is estimated

Specifications:

- Range: 5 – 1.000nm (optional: 5 – 2.500nm)
- Max. sampling rate: 10Hz
- 38 size fractions



Source: CAMBUSTION



Electrical Low Pressure cascade Impactor (ELPI)

DEKATI ELPI+

The ELPI + provides real-time measurement of particle size distribution and particle number concentration within a size range of 6 - 10,000 nm. In addition the measuring system is suitable for measuring the particle charge distribution and for gravimetric impact measurements.

Function:

- Particles are charged by unipolar corona charger
- Size-selective fractionation of the particles in a cascade impactor with 14 electrically isolated isolation stages (5 separation stages in the range of PM_{0.1})
- Collection of the particles with the possibility of a subsequent gravimetric, chemical-analytical or electron microscopic (e.g., SEM) analysis
- Electrical determination with electrometers

Specifications ELPI +:

- Measuring range: 6 - 10,000nm
- Max. Sampling rate: 10Hz
- 14 size fractions / impactor stages



Source: DEKATI

DEKATI Thermodenuder

Application for the removal of volatile and semi-volatile substances in aerosol streams, which can eliminate unwanted transformation effects in the sample.

Specifications ELPI+:

- 10 – 20 l/min sample rate
- Heating up to 300 °C



Source: DEKATI

Automotive Engineering

2. Measurement Systems



Particle- Measurement station

EN 16450-certified fine dust aerosol spectrometer

- Suitability tested and certified according to the latest EU requirements
- Applicable for environmental monitoring, immission measurement campaigns and long-term studies
- Continuous and simultaneous real-time measurement of multiple PM values (PM1, PM2.5, PM4, PM10)
- Measurement of particle number concentration and size distribution

Specifications:

- Measuring range (size): 0.18 - 100 μm
- Measuring principle: Optical light scattering
- Measuring range: 0 - 20.000 $\#/\text{cm}^3$ (number) and 0 - 10.000 $\mu\text{g}/\text{m}^3$ (mass)
- Time resolution: 1 s to 24 h



Source: Palas

Automotive Engineering

2. Measurement Systems



Condensation Particle Counter

Ultrafine Ultrafine Condensation Particle Counter (CPC) for the detection of a particle number concentration of highly dynamic processes

- Reference instrument without pre-separation, pre-dilution or thermal preconditioning
- Detection of single particles in a wide concentration range

Specifications:

- Measuring range (size): 2.5 nm (D50) - > 3 μm
- Measuring principle: Optical light scattering
- Measuring range (number): 0 - 300.000 $\text{\#}/\text{cm}^3$
- Response time: T10-90 up to < 2 s
- Sampling rate: up to 50 Hz



Source: TSI

Palas PMP-CPC 100

This condensation particle counter (CPC) is suitable for PMP applications of the EU standard ILCE

- PMP-compliant measuring system for particle count measurement
- Detection of single particles in a wide concentration range

Specifications:

- Measuring range (size): 23 nm (D50) - 10 μm
- Measuring principle: Optical light scattering
- Particle number concentration range: 0 - 1E+05 $\text{\#}/\text{cm}^3$ in single count mode and up to 1E07 $\text{\#}/\text{cm}^3$ in nephelometer mode
- Response time: T10-90 up to 2 s
- Sampling rate: 1 Hz



Source: Palas

Automotive Engineering

2. Measurement Systems



Dekati eFilter

The Dekati® eFilter™ combines a gravimetric filter holder with real-time particle measurement technology and provides an online signal on particle mass concentration

- Applicable for environmental monitoring and exhaust gas measurements in the automotive industry
- Combination of gravimetric particle measurement (U.S. EPA) and automated real-time measurement

Specifications:

- Max. particle diameter (real time): 3 μm
- Sensitivity: approx. 1 $\mu\text{g}/\text{m}^3$ or 1000 $\#/\text{cm}^3$ for 70 nm particles
- Measuring principle: diffusion charger
- Sampling rate: up to 1 Hz



Source: Dekati

3-stage cascade impactor with ITES

3-stage cascade impactor according to ISO 23210 for the detection of the concentration in flowing gases in the fractions > PM10, PM10 and PM2.5. In addition, the ITES serves as a control and regulation unit for the isokinetic partial flow extraction

- Emission measurement/sampling according to EN, ISO and VDI standards (ISO 23210 and VDI 2066)
- Automated measuring system - applicable for environmental monitoring and exhaust gas measurements

Specifications:

- Max. mass concentrations: 200 mg/m^3
- Max. temperature range: 400 $^{\circ}\text{C}$
- orifice measuring section: 0.5 - 4 m^3/h



Source: Paul Gothe



Particle Generator

Generation of test aerosols from powders, pollen and spores

- Highest short-term and long-term dosing constancy and possibility for impulse operation
- Dispersion of almost all non-cohesive dusts

Specifications:

- volume flow: 0,5 - 5,0 m³/h
- maximum particle number concentration: approx. 1E+07 #/cm³
- Mass flow rate (particles): 0.04 - 430 g/h (at assumed plug density of 1 g/cm³)
- Particle size range: 0.1 - 100 µm
- dispersing gas: any possible (usually air)



Source: Palas



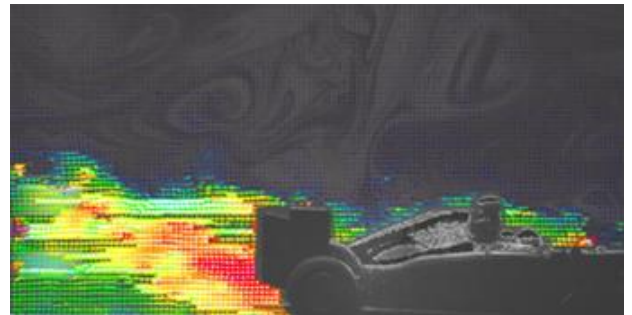
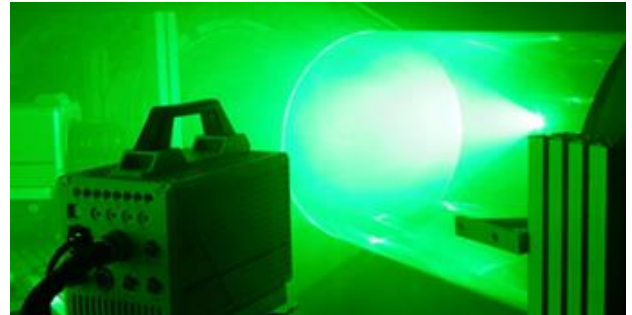
Flow measurement and Visualization

High Speed PIV

- Highly dynamic visualizations of velocity and acceleration fields at a sampling frequency of up to 10.000 Hz
- Automated traversing of illumination and image capture device

Specifications:

- camera sensor: 2048x2048 pixels
- Pixel size: max. 10x10 μm
- Frame rate: up to 20,000 Hz
- Recording time at 100 fps: 13.3 s (full frame)
- Recording time at 100,000 fps: 6.86 s (red. resolution)



Source: ILA5150

Omiprobe

- Measurement of flow vectors up to 160 °
- For measurement tasks with unknown flow directions or when backflow is expected

Specifications:

- Number of holes: 14
- Temperature: 600° C
- Flow angle: $\pm 160^\circ$
- Velocities: 3 m/s bis Mach 0,95
- Velocity accuracy: $< \pm 1 \text{ m/s}$
- 1 m/s



Source: Vectroflow



Precision Balance

Mettler-Toledo Balance XSR225DU (analytical balance for small loads)

- Maximum weighing Capacity: 220 g/121 g
- readability: 0,1 mg; 0,01 mg
- Repeatability (typical): 0,02 mg (10 g)
- Minimum sample weight: 20 mg
- DAkkS Certificate
- usage: weighing of unloaded and loaded filters



Source: Mettler Toledo

Sartorius Cubis manual mass comparator MCM40K3

- Maximum weighing Capacity: 41 kg
- readability: 0,1 mg
- Repeatability (test weight): 2 mg
- DAkkS Certificate
- usage: precise mass loss determination of brake discs and tires



Source: Sartorius

Automotive Engineering

3. Research Vehicles



Opel Ampera

Vehicle with Range Extender for the Examination of drive concepts

- Maximum power: 111 kW / 150 hp
- Max. Torque: 370 Nm
- Vmax: 161 km / h
- 0-100 km / h: <10 sec
- Empty weight: 1732 kg
- Electric drive: 54 kW generator
- 16 kWh battery
- 40-80 km range



Range Extender: 4 cylinder Otto engine, 1398 cm³
63 kW/86 hp at 4800 rpm
>400 km range

Mitsubishi i-MiEV

- Vehicle with electric drive
- Investigation of drive concepts
- Investigation of HMI

Power:	49 kW/67 PS	Capacity:	16 kWh
0-100 km/h:	15,9 s	Range:	150 km
Vmax.:	130 km/h	Empty weight:	1110 kg



Land Rover Range Rover Evoque

- Vehicle with dynamic tire pressure control, semi-active suspension and decoupled braking system with continuous wheel-slip control
- Examination of driving dynamics

Power:	110 kW/150 PS
Inertia:	380nm
Vmax.:	182 km/h
Empty weight:	2275 kg
Tire size:	235/55 R19





Audi A5 Sportback

- Man-machine interaction (e.g., pedal feel characteristics)
- Brake-by-Wire

Model series B8

- Otto engine, displacement: 1984 cm³
- Power: 155 kW / 210 PS
- Max. Inertia: 350 Nm
- Acceleration: 0-100 km/h: 6,4-7,9 s
- Empty weight: 1590 kg
- Vmax: 241 km/h



Audi e-tron 55 quattro S-Line

Research

- Demonstrator for innovative propulsion technologies
- Development and validation of integrated chassis control systems for fully electric Sport Utility Vehicles (SUVs)
- Automated Driving



Tire Measurement Trailer

- Developed by division of automotive engineering
- Analysis of the adhesion behavior of tires on dry and wet roads
- Electro-servo-hydraulic brake system for the realization of brake slip
- Measurement and control of the braking system using LabVIEW Realtime (Real-Time System CompactRIO)
- Highly dynamic force and torque recording
- Defined adjustment of wheel position variables
- Great variation of wheel loads
- Highly dynamic tire inflation pressure system



Automotive Engineering

4. Software Applications

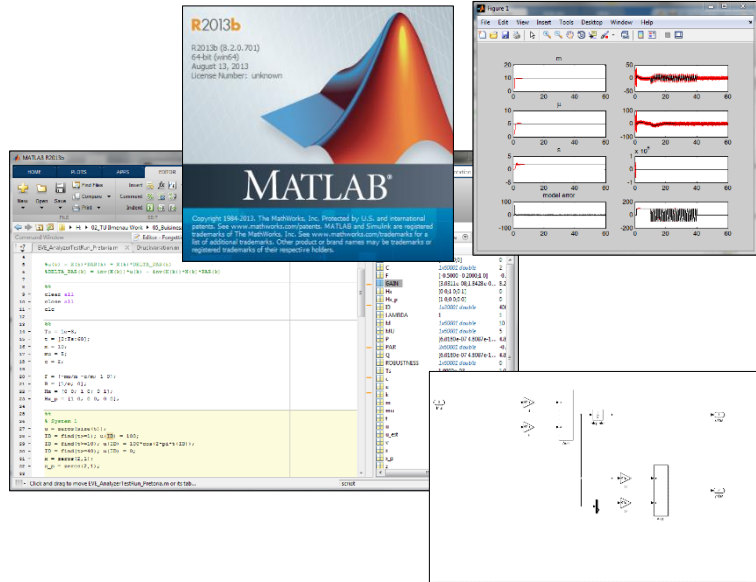


MATLAB/Simulink

Computer-algebraic solver for differential equations

Application:

- Data collection and data analysis
- Rapid Control prototyping and optimization
- Prototypical software development
- Statistics, signal and image processing
- (Co) Simulation



InMotion

Mobile real-time simulation platform with multivalent interfaces:

- Interfaces to MATLAB / Simulink, C-Code
- Communication interfaces: UDP / IP, TCP / IP, CAN, FlexRay, USB
- Application: Complete vehicle simulation (IPG CarMaker) for the representation of complex test scenarios through real-time networking



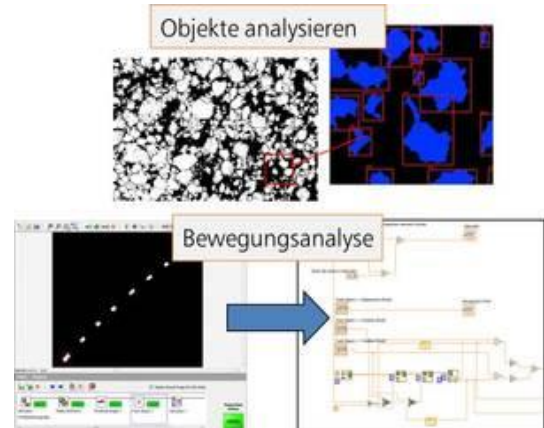
Automotive Engineering

4. Software Applications



IMAQ

- PC-based image processing
- Online and offline image analysis
- Automated image analysis using sequences
- Automatic testing of dimensional and positional deviations
- Interface to LabVIEW



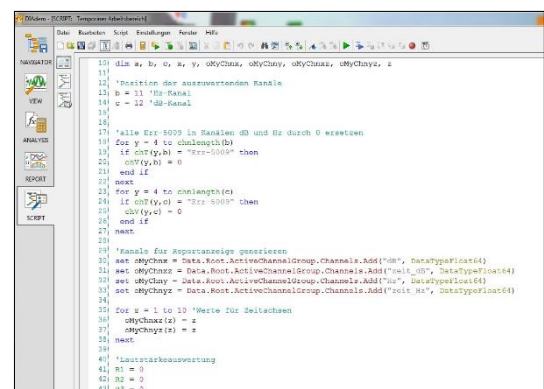
IPG CarMaker

- Virtual vehicle testing in the pre-development stage
- Possibility to implement driver and vehicle models (or even individual subsystems) and related regulations
- Application: Simulations for preliminary investigation of new concepts and newly developed control systems



Diadem

- Creation of applications for measurement data recording
- Automated data analysis with DIAdem script
- Application: data acquisition, data evaluation



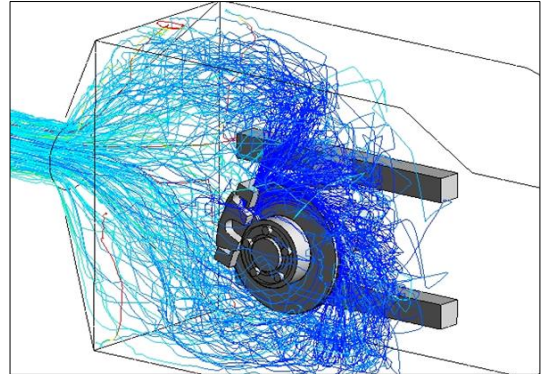
Automotive Engineering

4. Software Applications



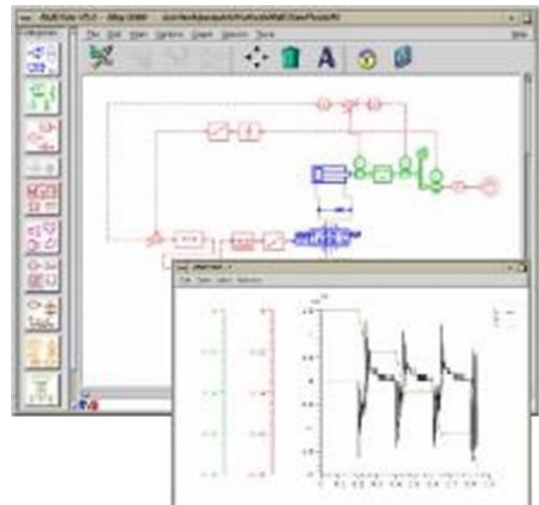
ANSYS

- FEM software for linear and non-linear problems in the fields of structural mechanics, structural dynamics, fluid mechanics, thermodynamics, piezoelectricity, electromagnetism and combined approaches
- Application: NVH analysis / analysis of aerosol flows (fine dust emissions) / friction simulation in automotive vibration dampers



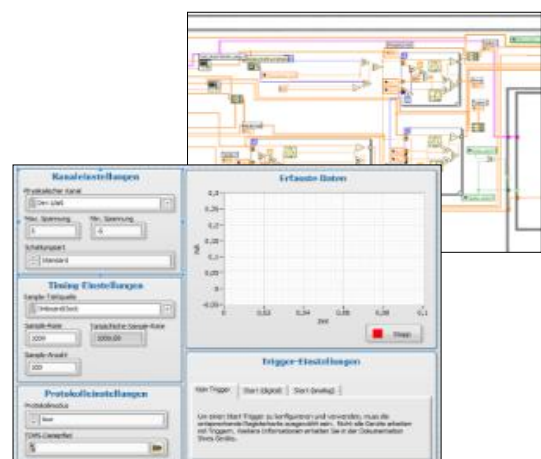
AME Sim

- Simulation of hydraulic and pneumatic systems, signal processing, fluid and heat transfer coupling
- Application: Unsteady system simulation of electrohydraulic braking systems



LabView

- Software for system development used in measurement, test, control and regulation applications
- Fast hardware access with fast insight into data
- Creation of real-time applications for measurement data and controlling processes
- Creation of executable programs in customer order (stand alone applications)
- Application: Data acquisition and control of automated systems



Wireless and Information Technologies Topics



- Automotive antenna and wireless transmission systems for terrestrial and satellite communications, sensor technologies, satellite navigation and localisation
- Automated and connected driving, car-to-X, ITS-G5, mobile communications 5G, 6G
- Measurement and testing, modelling and realistic emulation of wireless propagation channels for different wireless functionalities
- Over-the-air end-to-end tests, verification and validation of automotive wireless systems in virtual environments
- EMC and human exposure in electromagnetic fields: Exposure measurement and assessment of vehicle-internal and external radio services



Contact:

Univ.- Prof. Dr. rer. nat. habil. Matthias Hein

Spokesman ThIMo Project

Acting Director, Inter-Departmental Institute for
Mobility Research - IMF-ThIMo

Head of the RF & Microwave Research Group

Phone: +49 3677 69-2832

Email: matthias.hein@tu-ilmenau.de





VISTA: Virtual road – simulation and test area

The Virtual Road – Simulation and Test Area (VISTA) serves research, development and system evaluation of automotive wireless services as well as real-time capable X-in-the-loop test environments. The test area consists of a pyramidal absorber-lined and air-conditioned em shielded chamber of size 16 m × 12 m × 9 m.

The main frequency range from 400 up to 6000 MHz is covered with 111 dual polarised antennas in the elevation range from -20° to $+90^\circ$. Radio services like DVB-T, GNSS, SDARS, LTE, and ITS-G5 operate in this range. The side frequency range from 70 up to 400 MHz is covered with 22 dual polarised antennas and enables to additionally address analogue and digital audio broadcast. The turntable has a diameter of 6.5 m and can be adjusted over 360° with 0.1° resolution. The maximal distance for EMC measurements is 5 m. A dynamometer with maximal mechanical load of 2500 kg and a wheel base up to 3.5 m provides driving speeds up to 100 km/h.

An additional mechanical positioning system (gantry, accuracy 0.02°) allows to illuminate the area of the turntable with any antenna system (< 20 kg) on circular paths of 3 m diameter (elevation $\pm 110^\circ$) up to the millimeter wave frequency range.



Wireless and Information Technologies

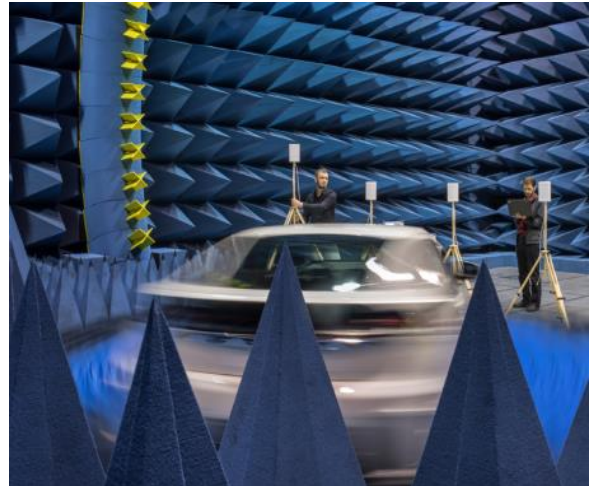
1. Testing Facilities



VISTA – Virtual road – simulation- and test area

- Combination of wireless and automotive engineering measurement methods with focus on antennas, radar sensing, and system performance
- Emulation of environmental and operating conditions and their interactions
- Verification & validation in virtual environment, over-the-air testing of installed system performance
- Concepts for automated and connected driving on road and rail: Automotive antennas, sensor technologies, EMC, human exposure, combined terrestrial and satellite-based mobile communications, radar, navigation

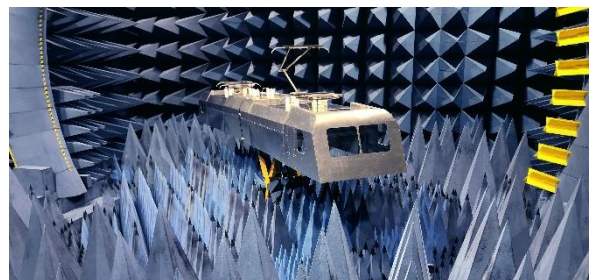
Shielded chamber	16 m × 12 m × 9 m
Frequency range	70...6000 MHz
Turntable	Ø 6.5 m, (360±0.1)°
EMC distance	≤ 5 m
Speed	≤ 100 km/h
Car wheel base	≤ 3.5 m, Mass load ≤ 2.5



Antenna measurements in VISTA

- Measurement of automotive antennas in installed state
- Antenna characteristics, radiation pattern, gain, polarisation, derived measurement parameters (TRP, XPD, AR, etc.), influence of installation site and environment
- Comprehensive software for digital post-processing of measured data
- Antenna measurement arch with multi-probe technology

Manufacturer	Satimo Industries SAS
Technology	Spherical nearfield measurement
Frequency range	70...6000 MHz
Probes (resolution)	111 at 400...6000 MHz (1°) 22 at 70...400 MHz (5°)
Max. object size	4 m (< 220 MHz) 5.2 m (< 3300 MHz) 3 m (5800 MHz)
Typ. measurement time	30 min for 3D pattern at up to 10 frequency points



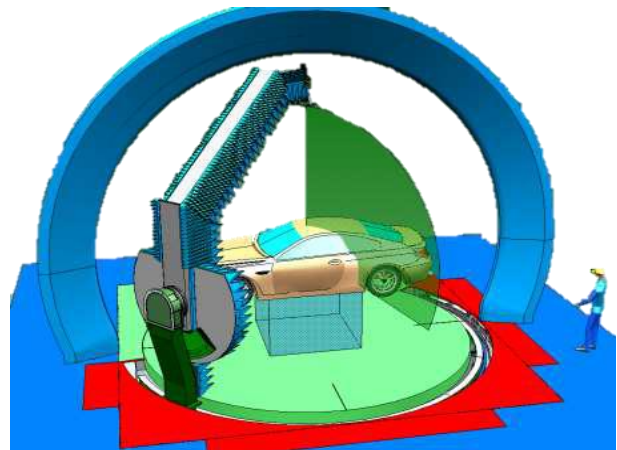
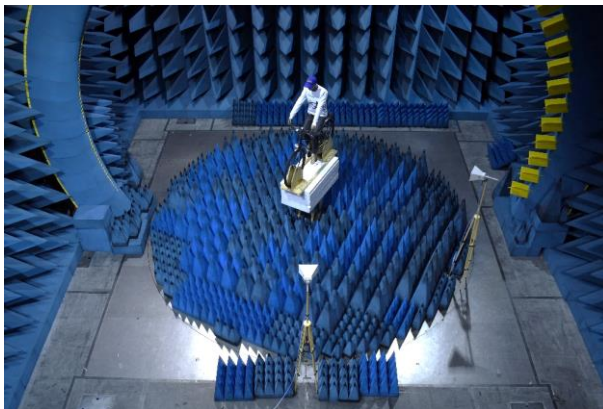
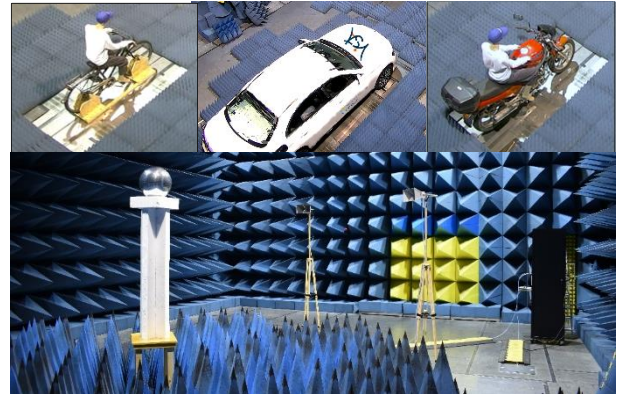
Wireless and Information Technologies

2. Measurement Systems



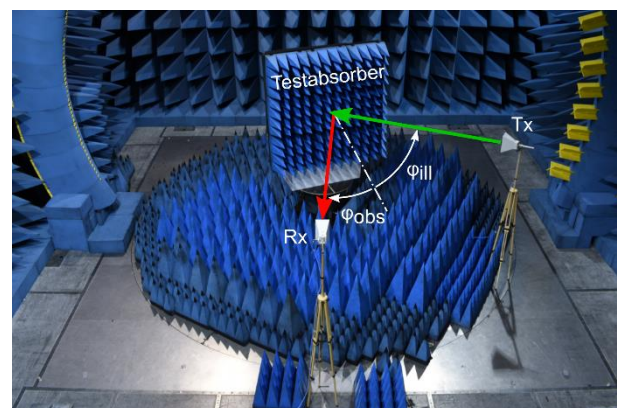
Antenna and RCS measurements (RF, microwave & millimetre wave)

- Monostatic and bi-static RCS measurements covering the frequency ranges 0.8...26.5 GHz and 67...115 GHz
- Measurements with variable illumination and observation angles (2D, 3D)
- Broadband dual-polarimetric measurement of different traffic-relevant radar objects (real size and scaled)
- Power calibration using certified reference objects
- Extensive digital signal post-processing



Modeling of electromagnetic microwave absorbers

- Broadband reflectivity measurements in the frequency range 0.8...18 GHz
- Automated monostatic and bi-static measurements at variable illumination / observation angles
- Characterisation of weakly reflecting microwave absorbers down to -60 dB
- Vertical test plane (1.80 m x 1.80 m) for evaluation of different absorber configurations
- Comparison with numerical simulations (full-wave simulations and ray tracing)



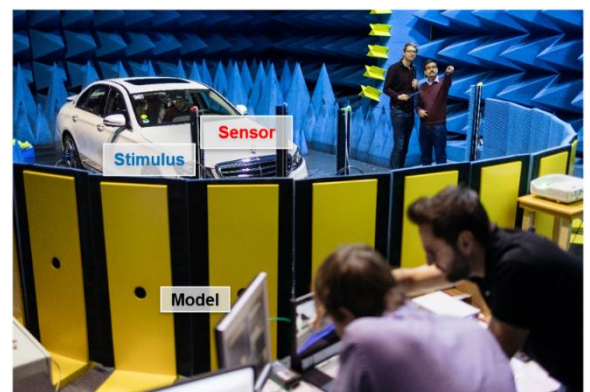
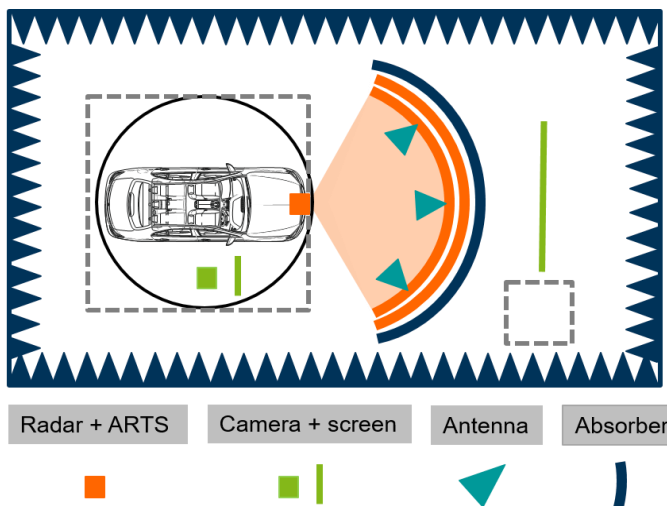
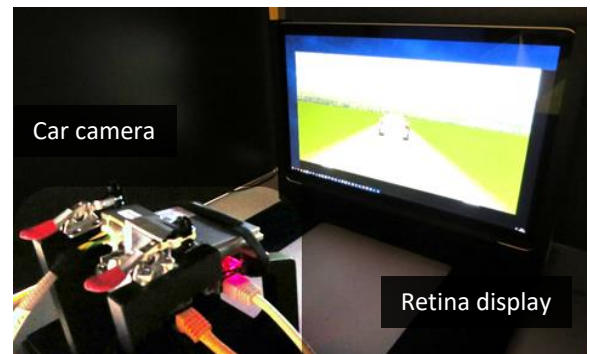
Wireless and Information Technologies

2. Measurement Systems



Testbed for system evaluation of automotive radar

- Manufacturer and platform independent over-the-air testing of automotive radar systems in VISTA
- Digital radar-target simulator
 - Automotive radar test system for real-time and broadband simulation of Doppler shifts and radar cross sections
 - Type: dSPACE DARTS-9030 M
 - Frequency range: 75...82 GHz
 - Chirp signal bandwidth: 1000 MHz
 - Minimum distance: 7.5 m
 - Maximum distance: 1000 m
 - Number TX modules: 8
- Scenario-based camera stimulation
 - Photo-realistic HiL tests of automotive camera
 - Retina display (resolution 2560 x 1600; 227 dpi)
 - Stand-alone operation or fusion with automotive radar
 - External interface via CAN data bus
- Hardware-in-the-loop (HiL) test system Scalexio E31275 with ControlDesk, ConfigurationDesk, and AutomationDesk
- Spectral analysis up to 110 GHz including analysis of modulation contents up to 4 GHz bandwidth



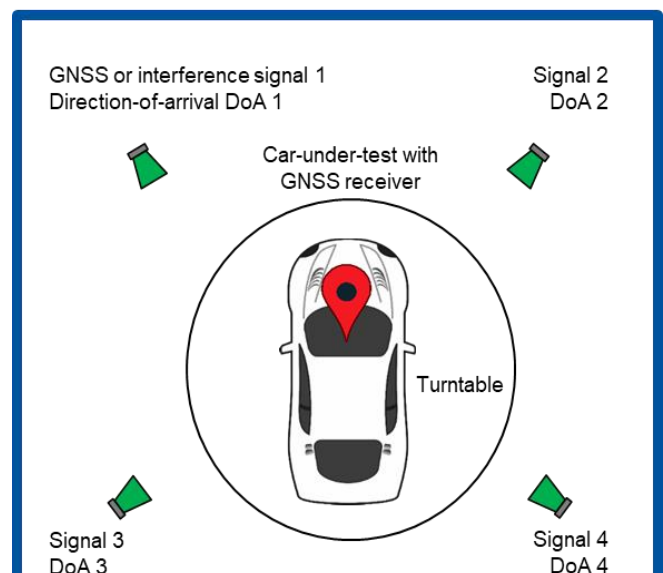


Adaptable electromagnetic boundary conditions for antenna measurements

- Studies of the effect of electromagnetic boundary conditions on the radiation behaviour of automotive antennas
- Artificial ground plane for antennas
- Glass fibre-reinforced plastic frame :
 - Diameter: 5.8 m
 - Height adjustable: 0.7...2.3 m
- Fabric: Bottom layer of silver-plated nylon parachute silk with conductive PU coating (Shieldex® Berlin RF)
 - Areal resistance: Average 300 mΩ/m² (max < 500 mΩ/m²)
 - Shielding effectiveness: Average up to > 60 dB in the frequency range 0.3...5 GHz
- Top layer of silver-plated nylon parachute silk with additional copper/nickel coating (Shieldex® Nora Dell CR)
 - Areal resistance: Average 9 mΩ/m²
 - Shielding effectiveness: Average up to 95 dB in the frequency range 0.3...10 GHz



Shielded anechoic chamber (VISTA)



Emulation of satellite navigation

- GNSS satellite simulation with 4 synchronised Rohde & Schwarz signal generators Type: SMBV100B
- Illumination of the scenario from different directions (azimuth and elevation) to reproduce the real direction-of-arrival of the satellite signals
- Generation of defined noise and interference signals to evaluate the immunity of receivers
- Test of complete receivers in installed state
- Scenarios based on GPS and Galileo as well as combinations



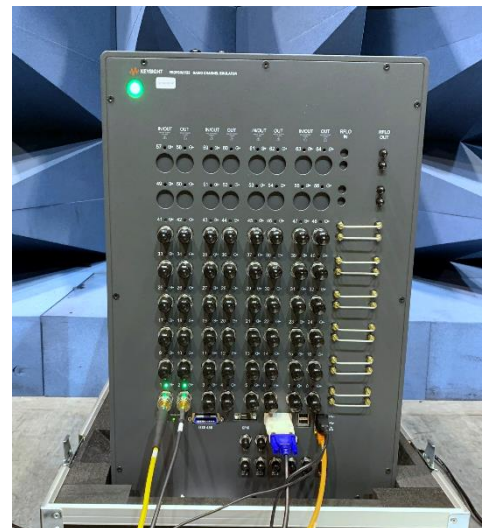
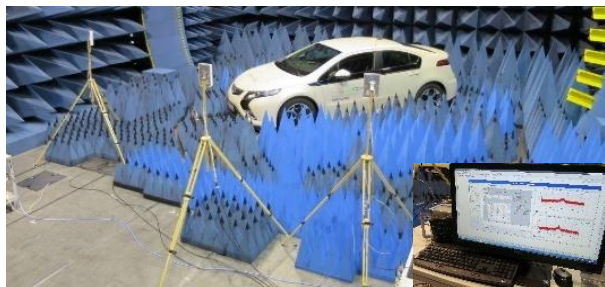
Wireless and Information Technologies

2. Measurement Systems



Wireless channel emulation in VISTA

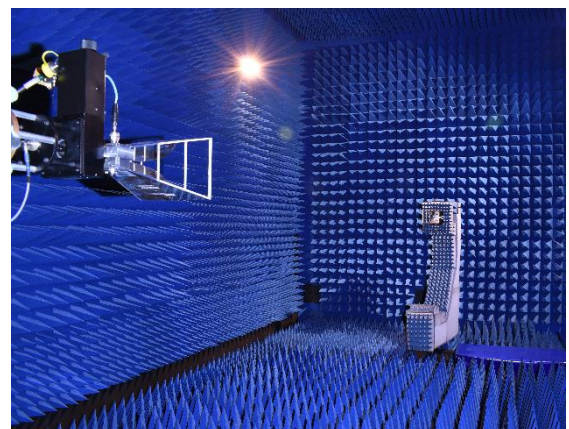
- Combined hardware- and software-based modeling of mobile services (LTE, 5G, DSRC, C-V2X) with over-the-air methods
- Emulation of ray clusters using sectorised antenna arrays
- MIMO functionality
- Adjustment of Doppler shifts, signal delays, and angular directions in terms of absolute values and spreads
- Measurement of relevant transmission parameters such as data throughput in uplink and downlink, RSRQ, RSRP, RSSI, CQI, and SINR
- Channel emulator: Keysight Prosim F32
 - 24 channels
 - Frequency range 0.35...6 GHz
 - Bandwidth 40 MHz
 - Channel modeling software for LTE-A and MANET scenarios
 - Emulation of shadowing (large-scale fading) from 0 to 100 dB in 0.01 dB steps
 - Remote configuration and control of emulations



Antenna measurement laboratory (complementary to VISTA)

Antenna characterisation through far-field measurements, optionally nearfield – far-field transformation if used as spherical nearfield scanner

Manufacturer:	Nearfield Systems, Inc.
System:	NSI-800F-10x with nearfield measurement option NSI-SW5305
Shielded room:	8.9 m x 5.1 m x 5.1 m
Frequency range:	0.8 ... 110 GHz
Maximum load of positioner:	10 kg
Measurement distance:	5 m
Angular resolution:	0.03°



Wireless and Information Technologies

2. Measurement Systems



Channel Sounder

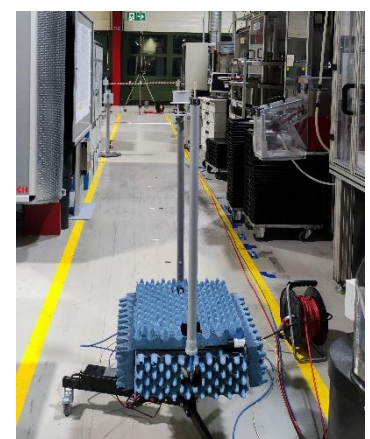
Sub 6 GHz Sounder

- Instrumentation: Hardware for polarimetric, double-directional, mobile channel measurements
- Specifications:
 - Antenna arrays for 2.53 GHz and 5.2 GHz
 - Approx. 100 MHz bandwidth [antenna arrays for 3.75 GHz currently planned]
 - Software-defined radio transceivers up to 6 GHz
- Picture on the right: - Antenna arrays for 2.53 GHz, implemented as stacked polarimetric uniform circular patch array (SPUCPA) with high-frequency switches in the chassis.



mm-wave to THz measurement and sounder technologies

- Instrumentation:
 1. non-linear HF characterization with PNAX up to 67GHz
 2. Network measurement technology up to 340 GHz
 3. Broadband technology up to 16 GHz bandwidth (AWG7000 and DPO70000)
 4. Multi band UWB channel sounder up to 300 GHz
- Specifications of UWB channel sounder:
 1. ≤ 7 GHz bandwidth
 2. Up to 2h realtime data storing with 4 channels
 3. Multi-band operations up to 3 frequency bands in parallel
 - Microwave range: 0...3.5 GHz / 3.5...10 GHz
 - mm-wave range: 24...40 GHz / 57...66 GHz / 71...78 GHz
 - THz range: 180...220 GHz/ 280...340 GHz
 4. Measurement of 5G and 6G radio channels
- Tests:
 - Channel Sounding, BS-UE, AP-UE, D2D, incl. V2X
 - Spatial-temporal characterization of radio channels
 - Test of 5G and 6G technologies



Wireless and Information Technologies

2. Measurement Systems



EMC measurements

Pre-compliance EMC measurements of radiated and conducted emissions in VISTA

- EMC chamber: Shielded semi-anechoic chamber, 16 m x 12 m x 9 m
- Antenna mast: Measurement heights 1 ... 4 m
- Instruments: EMI test receiver, Rohde & Schwarz ESR-7, Artificial mains network Rohde & Schwarz ENV432
- Frequency range: 9 kHz ... 6 GHz
- Measurement distance: 3... 5 m



Human exposure (RF und ELF)

- Instrumentation: Handheld selective radiation meter Narda SRM-3006
- Frequency range: 9 kHz to 6 GHz
- Antenna: Triaxial E-field antenna
0.027... 3.0 GHz
0.42 ... 6.0 GHz
- Special feature: code-selective UMTS and LTE measurements
- Tests: Field measurements of electric field strengths for different radio services in terms of human exposure in RF electromagnetic fields
- Instrument: Combined E- and H- field analyser Narda EHP-50F
- Frequency range: 1 Hz to 400 kHz
- Special feature: Weighted peak assessment, FFT spectral analysis
- Tests: Field measurements of ELF electric and magnetic fields, e.g., at electrical power supply sites (overhead lines, transformer stations)



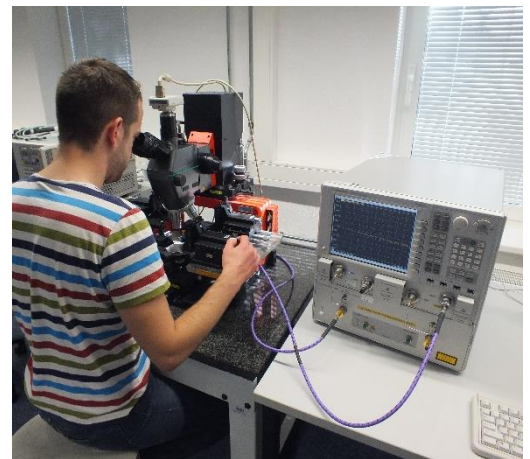
Wireless and Information Technologies

2. Measurement Systems



Microwave measurements (Frequency domain and time domain)

- Coaxial vector network analysers:
 - Agilent PNA-X N5242, 4-port test set,
 - Nonlinear X-parameters 0.01...26.5 GHz
 - Light-wave component analyser Agilent N4376D,
 - Agilent PNA E8361A: 0.01...67 GHz,
 - Keysight PNA N5222B: 0.01...26.5 GHz und 67...115 GHz
 - 4-port test set 0.01...50 GHz,
 - Pulse test set 0.2...40 GHz;
 - Anritsu MS4630B (10 Hz bis 300 MHz)
 - Keysight FieldFox N9952A - Microwave Analyser up to 50 GHz
- Maury tuner-based noise parameter measurement 1...26,5 GHz
- Noise factor analyser 0.01...26.5 GHz (Agilent N8975A)
- Spectrum analyzers
 - 50 GHz und 75...110 GHz (Agilent PSA E4448A, ext. Mixer)
 - 26 GHz (Rohde & Schwarz FSEM)
 - 32 GHz (Anritsu MS2802A)
 - 50 GHz (Keysight FieldFox N9952A)
- Wafer probing stations:
 - Suess PM4
 - Cascade Summit 9000
 - Vacuum wafer prober Suess MicroTec PMV150 with Thermochuck (-40 bis 150oC)
- Time-domain reflectometer (LeCroy SDA100G)
- Transient analysis (HP 70820A)
- 4-GHz four-channel real-time oscilloscope (Keysight DSOS404A with Smart Mixer 60...90 GHz)
- 11-GHz four-channel real-time oscilloscope (LeCroy SDA 11000)
- 20 GHz Agilent Infiniium DCA-X 86100D oscilloscope with optical inputs 750...1650 nm
- 70-GHz sampling oscilloscope (LeCroy SDA 100G)
- Signal Source Analyser 26.5 GHz (Rohde & Schwarz FSUP)
- Signal sources: e.g. Agilent PSG E8257D up to 50 GHz ; SMIQ06B up to 6 GHz; Vector Signal Generator R&S SMBV100B (GPS, Galileo)
- Optical profilometer "Alicona infinite focus" (resolution: vertical 20 nm, horizontal 600 nm)
- PCB prototyping with LPKF ProtoMat S103
- Nearfield antenna measurement system EMSCAN RFxpert RFX2-62 for fast measurement of radiation properties of planar structures 0.3...6 GHz
- Compute server Windows- and Linux-based
- Simulation tools for RF circuit design: MicroSim (PSpice), Serenade
- Simulation tools for 2D/3D microwave field calculations: Keysight ADS, Ensemble (MoM), IE3D (MoM), Ansoft HFSS (FEM), CST Microwave Studio (FDTD) including current desktop computing technology
- Data processing: MatLab with SimuLink Toolboxes (The Mathworks)



Wireless and Information Technologies

2. Measurement Systems



FORTE test facility of Fraunhofer IIS (Facility for over-the-air research and testing)

- Measurement platform for mobile satellite terminals in the Ku and Ka bands with motion and channel emulators
- Measurements of 5G phased-array antennas in frequency range FR2 (> 6 GHz)
- Over-the-air test environment for communication and navigation systems (GNSS) up to 6 GHz
- Emulation of realistic, three-dimensional and virtual electromagnetic environments using wavefield synthesis (WFS) for electrically small test objects, and wireless cable for electrically large test objects

Detailed information at:

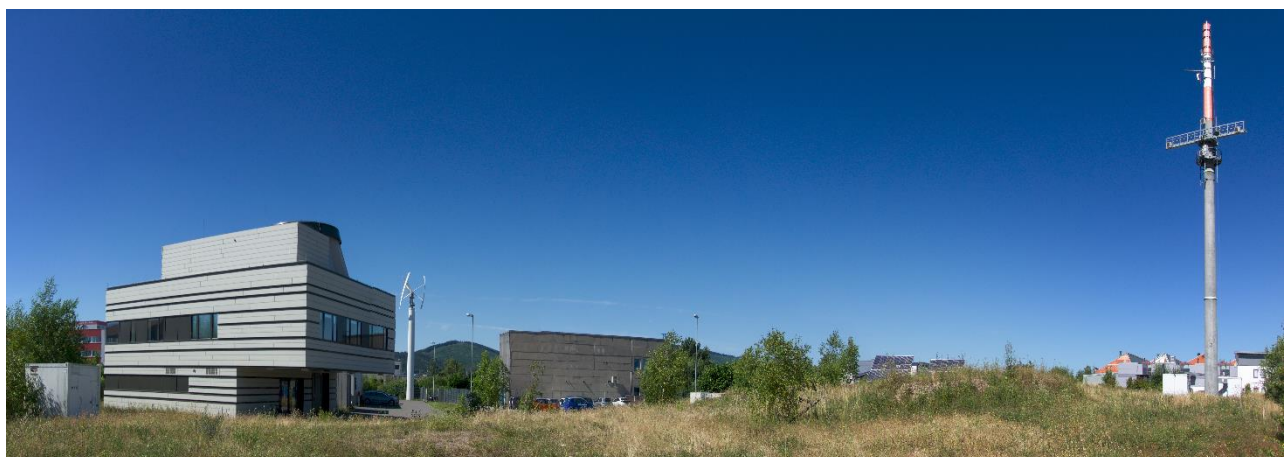
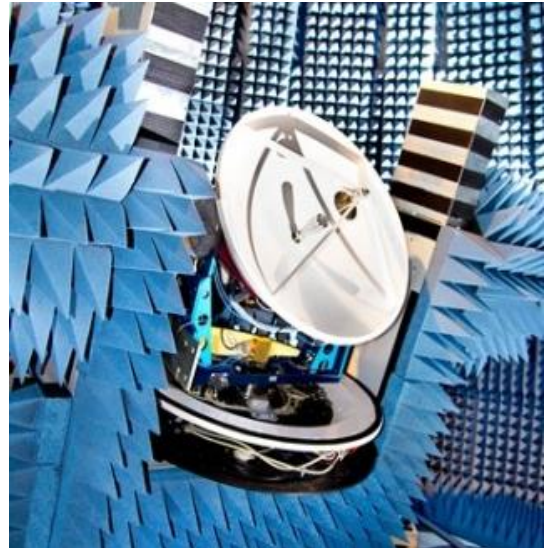
https://www.iis.fraunhofer.de/en/ff/kom/satkom/forte_satcom.html

In cooperation with Fraunhofer Institute for Integrated Circuits IIS:

Contact Person:

Dr.-Ing. Markus Landmann

markus.landmann@iis.fraunhofer.de



Wireless and Information Technologies

2. Measurement Systems



FORTE test facility of Fraunhofer IIS (Facility for over-the-air research and testing)

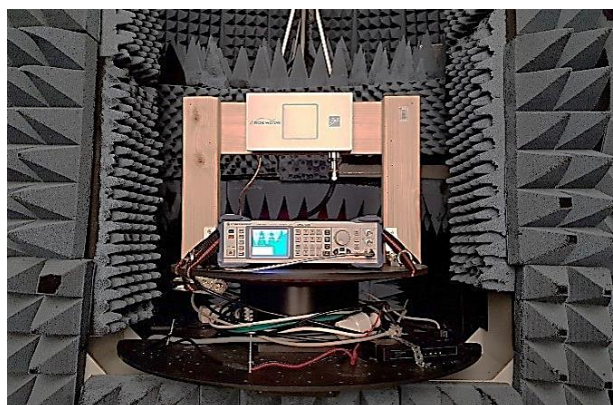
Research platform SatCom

- Testing of SatCom-on-the-move (SOTM) terminals for:
 - Global VSAT Forum SOMAP type approvals
 - Terminal manufacturers and satellite operators
- Competences:
 - Synchronised playback of realistic profiles via satellite, motion, channel and GPS emulators
 - Tests with standard motion profiles for land-mobile and maritime applications
 - Motion Emulator: Angle (roll, pitch, yaw): up to $\pm 45^\circ$ / continuously
Rate: 300°/s
Acceleration: 1000°/s²
 - Satellite Payload: 50 m antenna tower for satellite payload emulation with 80 MHz bandwidth
 - Channel Emulator: Realistic C/N and realistic shadowing profiles
 - Sensor array on the antenna tower for precise estimation of antenna de-pointing and adjacent-satellite interference (ASI)



Research platform 5G-mmWave

- Testing of 5G beamforming antennas in frequency range FR2
 - Platform development in the context of national funded projects
 - Projects with industry e.g. Anokiwave, Alcan, Kymeta
- Competences:
 - Measurement of antenna characteristics in far-field: Antenna pattern, gain, HPBW and SLL
 - Measurement of beamforming and null-steering capabilities



Wireless and Information Technologies

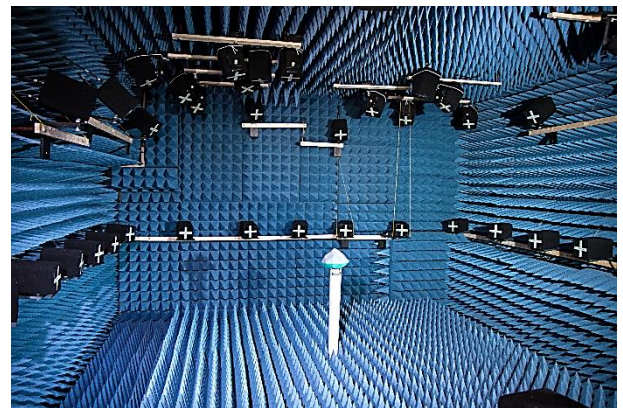
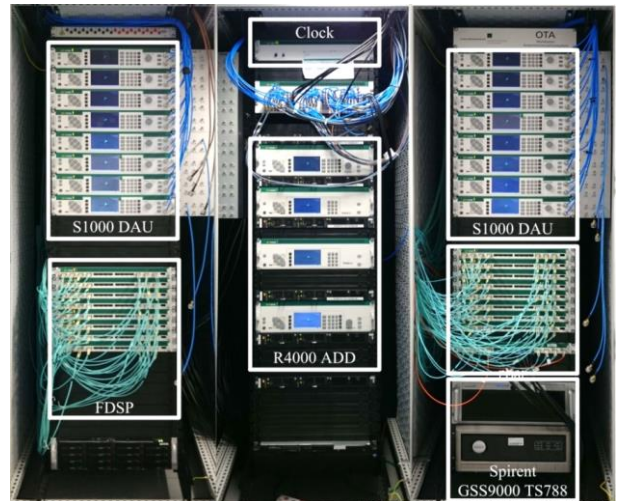
2. Measurement Systems



FORTE test facility of Fraunhofer IIS (Facility for over-the-air research and testing)

Research platform MIMO-OTA

- Testing of MIMO transceivers up to 6 GHz for:
 - Mobile broadband (incl. LTE testbed, 5G)
 - GNSS positioning accuracy, interference immunity etc.
 - Industrial communication
 - V2V and V2I
- Signal generation
 - GNSS emulator Spirent GNS9000
 - Mobile communications: Rohde & Schwarz CMW 500
- Approaches
 - Wavefield synthesis for electrically small test objects
 - Wireless cable for electrically large test objects (e.g. vehicles)
- Channel modelling
 - (Geometry-based) stochastic channel models (e.g. 3GPP TS 38.901)
 - Ray tracing
 - Measured channels
 - Technical parameters
 - Frequency range: 0.3...6 GHz
 - Bandwidth: 80 MHz
 - RF Output: + 10 dBm
 - Connectivity: 12 Inputs x 32 Outputs = 384 Channels
 - 3072 taps / Impulse response



Detailed Information at: <https://www.iis.fraunhofer.de/de/profil/standorte/forte.html>

Plastics and Lightweight Design Topics



- Weight-reducing structural and drive components
- Material design, joining and connection techniques for functional and high-performance systems
- Functionalized automotive components, material systems and surfaces
- Flexible, efficiency-enhanced processing chains suitable for serial production
- Environmental compatibility and processing of renewable raw materials
- Material and process simulations for design and optimization of molded parts and manufacturing processes



Contact:

Univ.-Prof. Dr.-Ing. Dipl.-Wirt.Ing. Florian Puch

Head of Plastics Technology Group

Phone: +49 3677 69-2841

Mail: kti@tu-ilmenau.de





Extrusion and Foil processing

Single-screw extruder ES 45

- Plastification of plastic granules & powders
- Processing of plastic into foils or semi-finished products

Specifications:

- Screw diameter: 45 mm
- Screw length: 25 D to 50 D
- Screw speed max. 160 rpm
- Drive power: 17.2 kW
- Extrusion height: 1,000 mm
- Throughput PE: 150 kg/h
- Throughput PP: 150 kg/h
- Amount of sensors: 8
- Smooth und grooved feed section



Source: WEBER

Cast film line TYP LCR 350 HD

- Production of organic sheets, films and boards

Specifications:

- Roller group with three big rolls
- Roll diameter: 145 mm
- Roll width: 400 mm
- Production of boards with 0.3 to 2 mm thickness and 350 mm widthness
- Oil-based roll heating



Plastics and Lightweight Design

1. Plastics Technology Center



Twin-screw extruder ZSK 40

- Compounding thermoplastic materials
- Incorporating organic and inorganic fillers and reinforcing materials, flame retardants, reinforcing fibres

Specifications:

- Screw diameter: 40 mm
- Screw length: 38 D
- Screw speed: max. 400 rpm



Twin-screw extruder ZSK 25

- Compounding thermoplastic materials
- Incorporating organic and inorganic fillers and reinforcing materials

Specifications:

- Screw diameter: 25 mm
- Screw length: 36 D
- Screw speed max.: 600 rpm



Blown film line „Blowmaster“

- Miniaturized blown film line with a comparable range of functions

Specifications:

- Max. height: 2,10 m
- Assemblable and transportable
- Max. foil width: 500 mm
- Incl. stabilization of the foil tube by an integrated cooling ring





Injection molding

KraussMaffei type KM 160/750/180 CX V

- Two-component injection molding
- Overmolding of aluminum and organic sheets with suitable plastics
- Multiple component injection molding for manufacturing plastic components that conduct electricity
- Sandwich injection molding
- With turntable tool



Specifications:

- Clamping force: 1,600 kN
- Fully hydraulic dual-platen clamping system
- Injection unit 1: Size: 750; horizontal; Screw diameter: 45 mm; Nozzle radius: 10 mm; Nozzle bore: 4 mm
- Injection unit 2: Size 180; vertical; Screw diameter: 30 mm; Nozzle radius: 10 mm; Nozzle bore: 4 mm



KraussMaffei type KM 80 CX 380

- Injection molding machine with interchangeable mold inserts
- Production of specific molded parts

Specifications:

- Clamping force 800 kN
- Fully hydraulic dual-platen clamping system
- Injection unit : Size: 380; horizontal; Screw diameter: 35 mm
- Working volume: 154 cm³
- Injection pressure max.: 2,429 bar



Plastics and Lightweight Design

1. Plastics Technology Center



Fibre composite technology with a hydraulic 4-column press

ATM Typ RWP700

- RTM process and fibre composites

Specifications:

- Clamping force: 100 t
- Opening stroke: 500 mm
- Clamping area: 750 x 750 mm
- Settable time and temperatures
- Heating temperature: max. 250 °C



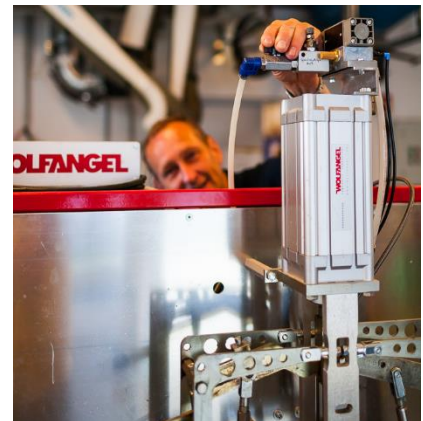
Resin preparation systems and purifiers

Wolfangel 100/120/25/17

- Piston injection system
- Epoxy resin and unsaturated polyester resin

Specifications:

- Pressure: up to 10 bar
- Vacuum-supported
- Variable mixing ratio



Eldomix 103

- Heatable gear pump
- Suitable for epoxy resin, unsaturated polyester resin, polyurethane (including foams)

Specifications:

- Mixing ratio: 100:100 to 100:20
- Volume flow: 0.1 – 1.0 l/min
- Melt temperatures up to 80 °C
- Vacuum support possible



Plastics and Lightweight Design

1. Plastics Technology Center



Production and processing of organic sheets

Thermoforming System

Rucks type KV 293-5

- Hydraulic 4-column upstroke press 430 kN
- Integrated preheating station and material transfer system
- Vacuum pump 3 mbar, 13 m³/h
- Energy consumption display and diagnostic program
- Forming of thermoplastic semi-finished products, in particular organic sheets and foils



Source: Rucks

Direct extrusion line to produce continuous fiber reinforced organic sheets

SUCHY Textilmaschinenbau GmbH 022/19

Impregnation of three endless fiber layers with thermoplastic melt

- Gravimetric feeding of plastic via a metering device to the twin-screw extruder
- Melting of the plastic in the extruder
- The thermoplastic is fed through a distributor into three melt pumps
- Transfer of the melt to three direct extrusion tools using two heating hoses each
- Impregnation of the fiber layers pre-stressed and preheated by the roll holders with the melt
- Feeding to a calender roller, which presses the layers together and pulls them through the system
- Side and length trimming to the required dimensions in the downstream integrated process
- Overall control of the system via a central touch screen



Plastics and Lightweight Design

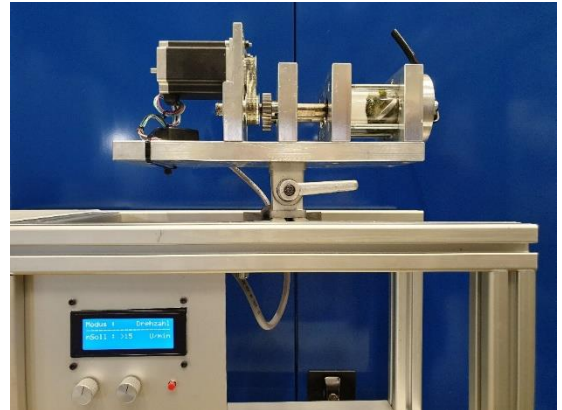
1. Plastics Technology Center



Treatment process, crash test and permeability

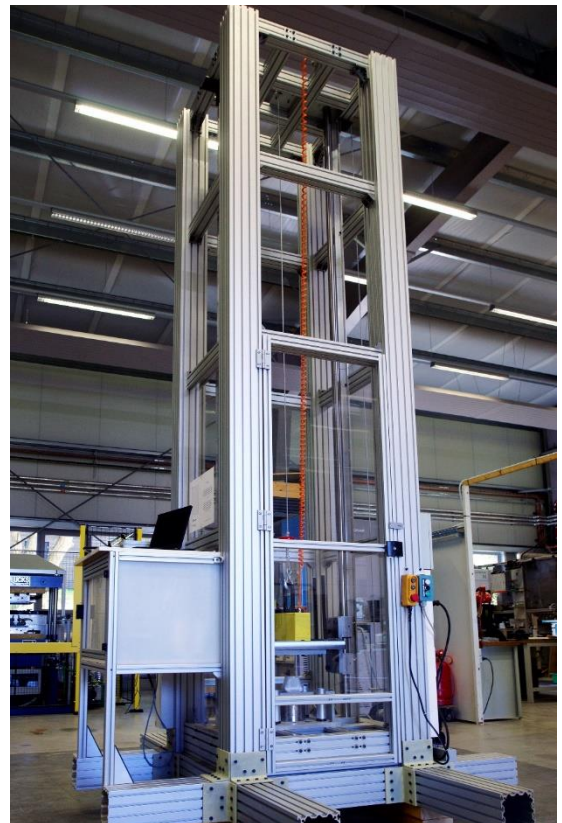
Miniature indoor mixer

- Transparent mixing chamber for simulating the mixing process of plastics with fillers in an internal mixer
- Model fluids (e.g. silicone oil) instead of plastic
- Motor torque: 3.1 Nm
- Speed: up to 600 rpm
Rotor arrangement: counterrotating
- Gap width: 1 mm
- Chamber volume: 53.3 cm³



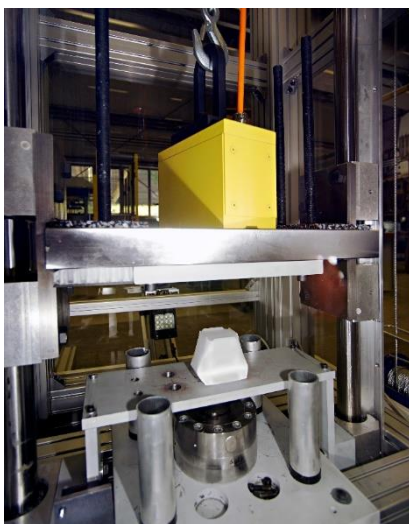
Drop tower

- Experimental investigation of crash relevant components regarding deformation behaviour
- Max. drop height 3 m
- Max. mass 291 kg
- Max. impact speed 25 km/h
- Determination of force-displacement curves
- Optical evaluation using a high-speed camera



Permeability test for semi-finished fiber materials

- Measurement of the permeability of flat fabrics
- Glass tool 300 mm x 300 mm



Plastics and Lightweight Design

2. Measurement Systems



Thermal analysis

DSC Analysis (differential scanning calorimetry)

- Temperature range -170 °C to 600 °C DIN EN ISO 11357-1
- Glass transition temperature DIN EN ISO 11357-2
- Melting temperature DIN EN ISO/DIS 11357-3
- Melting enthalpy, specific warmth capacity DIN EN ISO 11357-4
- Crystallization behaviour



TGA-FTIR (thermal gravimetric analysis)

- Temperature range 23 °C to 1,000 °C DIN EN ISO 11358
- FTIR (infrared spectroscopy) with ATR Analysis
- Decomposition temperature, analysis of gas phases and solid materials DIN 51006
- DIN EN ISO 9924-1; DIN EN ISO 9924-2; DIN EN ISO 21870



DMA (dynamic mechanical spectroscopy)

- Temperature range -170 °C to 600 °C
- Frequency range 0.01 Hz to 100 Hz
- Tensile test, three-point bend test and shearing test
- Dynamic viscosity, glass transition temperature and temperature resistance
- DIN 53440, DIN 53513, DIN EN ISO 6721-1



TMA (thermomechanical analysis)

- Temperature range -170 °C to 600 °C
- Temperature-dependent dimension variation
- Glass transition temperature DIN 53752; ISO 11359-2, DIN EN 14617-11



Plastics and Lightweight Design

2. Measurement Systems



Thermal analysis

Light-Flash-Apparatur

- Thermal conductivity measurements
- ASTM E1461, ASTM E2585, DIN EN 821-2, DIN 30905, ISO 22007-4, ISO 18755, ISO 13826; DIN EN 1159-2, etc.
- Temperature range -100 °C to 500 °C

HDT Vicat

- Softening temperature measuring system DIN EN ISO 306
- Heat deflection temperature DIN EN ISO 75-1, -2, -3

High pressure capillary viscometry

- Temperature range 23 °C to 400 °C
- Shear rate range 1 /sek to 10000 /sek
- Rheological behavior of polymer melts
- Viscosity testing
- DIN 54811



Rotation and oscillation type rheometer

- Temperature range 23 °C to 300 °C
- Shear rate range 0.0001 /sek to 1,000 /sek
- Flow curves, curing behaviour of resin systems with plate/plate and cone/plate
- DIN 53018, ISO 3210, DIN 53019, ISO 3219, DIN 54453



Melt Index Test

- MFI, MFR DIN EN ISO 1133



Plastics and Lightweight Design

2. Measurement Systems



Material analysis

Gel permeation chromatography (GPC)

- Molecular weight distribution, chain lengths analysis
- Molecule chains degradation, ageing experiments

Oxygen transmission rate measurement

- Barrier properties of plastics versus oxygen
- Oxygen permeability measurements at foils and containers
- DIN 53380, ASTM F2622

Water vapour transmission rate measurement

- Barrier properties of plastics versus water vapour at foils and containers
- Water vapour permeability measurements
- ASTM F-1249, TAPPI T557, JIS K-7129

Moisture analyzer

- Measurement of residual humidity content
- DIN EN ISO 15512

Density analyzer scale

- Density determination of products with buoyancy force
- DIN EN ISO 1183-1

Sieve analysis

- Grain size determination and grain size distribution
- DIN 66165

Infrared spectroscopy

- To analyse the composition

Sample preparation

- Microtome, grinding and polishing

Sample conditioning

- Mobile granulate dryer with dry air technology
- Dynamic clima chamber for standard-compliant material tests under dynamic conditions (5 K/min, -40 ° C to 180 ° C, 10 to 98% r. h.)
- 30 litre cool box up to a temperature of -40 °C
- Muffle/preheating/ashing furnaces and accessories



Plastics and Lightweight Design

2. Measurement Systems



Analysis of the mechanical properties and behaviour of materials

Universal test machine

- Tensile test, compression test, torsion test and bend test up to 20 kN
- Optional thermal stress test (20 °C to 200 °C)
- DIN EN ISO 527-1, -2; DIN EN ISO 178

Universal test machine

- Tensile test, compression test, torsion test and bend test up to 50 kN
- DIN EN ISO 527-1, -2
- Special tests possible

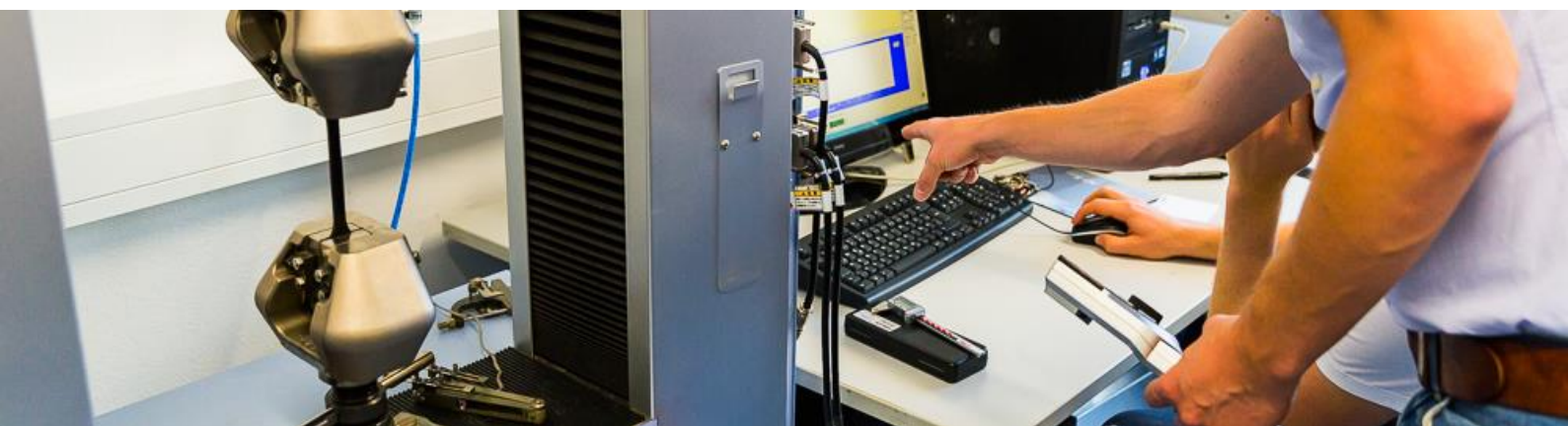


Pendulum machine

- Impact strength test
- CHARPY DIN EN ISO 179-1
- IZOD DIN EN ISO 180

Hardness tester

- Testing the Shore hardness: Shore A, D and A0
- DIN EN ISO 868 and DIN ISO 7619-1
- Ball impression hardness DIN EN ISO 2039-1
- Microhardness of surface layers DIN EN ISO 4516



Plastics and Lightweight Design

2. Measurement Systems



Analysis of surface functionalities

Stereomicroscope

- Optical assessment of damage cases
- Measurements and visual inspections
- Detail and overview shots

Polariscope

- Evaluation of stress conditions in transparent structural components

Roughness measurement

- Single test: 20 mm $\pm$ 300 μ m
- R_z , R_a , A_{Max} ; waviness; DIN EN ISO 4287

Contact angle measurement with different test liquids

- Camera supported system, Sessile-Drop-Methode
Pendant-Drop-Methode; DIN EN 828; DIN EN ISO 15989
- Wettability analysis; incl. temperature chamber



Microhardness and Mechanical Properties

- Measurement of thin film systems, surface properties
- DIN EN ISO 4516

Wallthickness analysis

Gloss and Colour Meter

- Lab values with and without gloss trap





Moldex3D

- Simulation of extrusion and injection molding processes (flow behavior and resulting properties)

B&R Automation (limited licenses)

- Machine control
- Developing digital twins with simulated parameter settings

ANSYS

- Polyflow - flow behavior during extrusion and injection molding
- Fluent - flow simulation
- Thermal - thermal simulation
- Mechanical - static and dynamic calculation of mechanical load cases
- LS-Dyna inside Workbench - highly dynamic load cases, crash behavior
- ACP - calculation of anisotropic material properties of fiber composites
- OptiSLang - Optimization of parameterized simulation models (across modules)

MATLAB

- Solving mathematical problems

Altair

- EDEM (DEM-software for bulk solids simulation)

MSC One

Structural mechanics

- Apex - CAD direct modeling, generative design
- Dyntran - structure-fluid interactions
- Marc - simulation of large deformations
- Nastran - mechanical load cases
- Patran - Creation of FE-optimized CAD models

Multi-body dynamics

- Adams - Simulation of Mechanical Systems
- Easy 5 - simulation of regulation and control technology

Acoustics and fluid simulation

- Actran - vibrations and acoustics simulation
- Cradle - fluid dynamics

Material simulation

- Digimat - Nonlinear, multiscalar material & structure modeling
- MaterialCenter - material models, data and process analysis

Simulation data and process management

- SimManager - data management along development processes

Lifetime and operational strength

- CAEfatigue - simulation of permanent load, damage modeling

Process simulation

- Simufact - simulation of forming, joining process, additive manufacturing

Thermal simulation

- Sinda - Complex Thermal Analysis





- Efficient battery charging technologies
- Energy efficient vehicle grids
- Mechatronic drives and integration technologies
- Efficient control, power electronics, packaging and converter design
- Characterisation and application of power semiconductor devices
- dc-dc-converter, dc-ac-converter



Contact:

Univ.-Prof. Dr.-Ing. Tobias Reimann
Director of the Industrial Electronics Department
Phone: +49 3677 69-2849
Mail: tobias.reimann@tu-ilmenau.de



Power Analyzer / Digital Power Meter

Yokogawa WT 3000

- highly accurate power and efficiency measurement

Specification:

- basic measurement accuracy: 0.01 % of measured value
- frequency range 0.1 Hz bis 1 MHz
- 4 input channels
- signal analysis, FFT-analysis, flicker analysis, cycle-by-cycle meas. Function
- Storage of sampled signal data
- interfaces: Ethernet, RS-232, USB, GP-IB



Source: Yokogawa

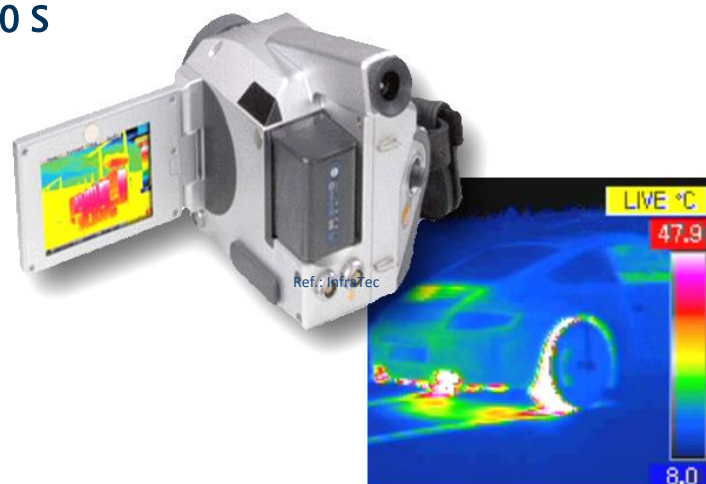
Thermography System

InfraTec VarioCAM hr Inspect 680 S

- analysis of surface temperatures in dynamic and static processes

Specification:

- resolution (detector) 640x480 pixel
- spectral range 7.5...14 μm
- meas. range -40...1200 $^{\circ}\text{C}$
- thermal resolution <0.03 K
- Recording with 0.25...60 Hz



Source: InfraTec



Electro-chemical analysis equipment

- test of battery systems



Source: Vacuum atmospheres BioLogic und Comsol

Electric machines, drives and power electronics lab

- E-machines/drives test benches
- vehicle grid simulator
- power electronics test benches
- concentricity analysis
- digital power analysers
- dynamic electronic sources and loads for experimental simulation of effects in vehicle grids battery tester
- test setups for characterisation of power semiconductor devices under lab and climate conditions

Specifications:

- high voltage source 3kV/10A
- low voltage source 15V, 3000A
- 2 rotating ac-converters 10-100Hz, ... 920V, 100kVA
- 2 rotating dc-converters ... 460V, ... 125kW
- bi-directional dc-source up to 1.200V
- 3 bi-directional dc - sources 30kW, up to 750V
- bi-directional, high-dynamic dc-source 40kW
- 1~ac-source up to 6kHz (sinus), 5kW
- passiv loads





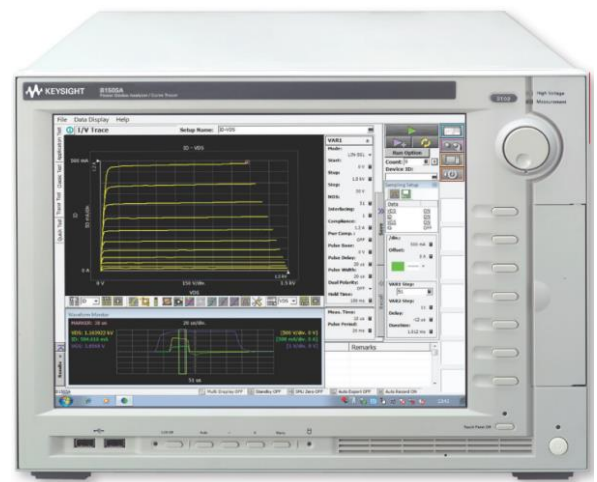
Flexible analysis system for the static characterization
of power electronic components

Keysight Technologies

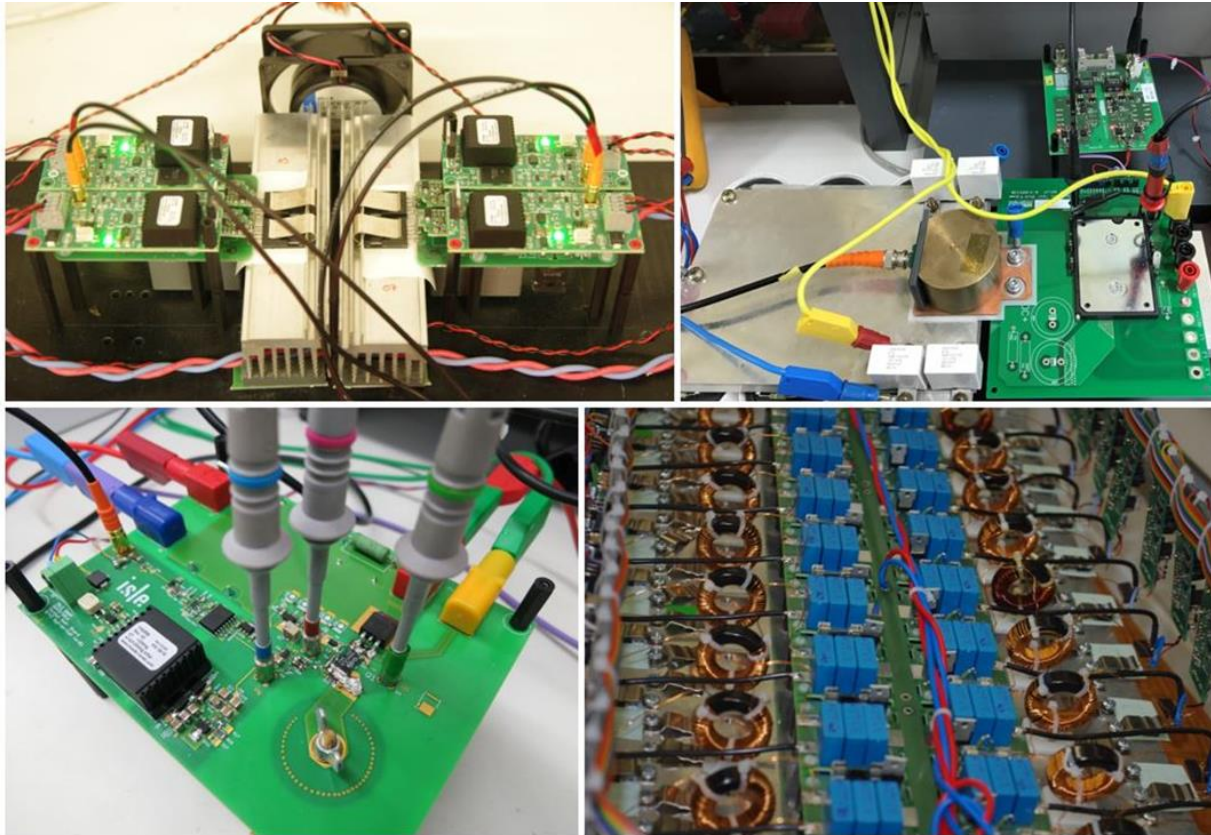
B1505A Power Device Analyzer/Curve Tracer

Specifications:

- Compliant with IEC 61326-1 / EN 1326-1 and IEC61010-1 / EN 61010-1
- CE certified
- Power range: 500A/3kV
- Measurement of on-state, forward and transfer characteristics of power semiconductor devices
- Measurement of forward and reverse blocking characteristics of power semiconductor devices
- Measurement of input, output, reverse and transfer capacitances of power semiconductor devices biased up to 3kV
- Measurement of gate-charge-characteristics of e.g. Power MOSFET, IGBT for devices rated up to 500A/3kV
- Measurement of parasitics of packages and circuit carriers (PCB, ceramics)
- Integrated main processor based on Windows 7, HD drive and GUI



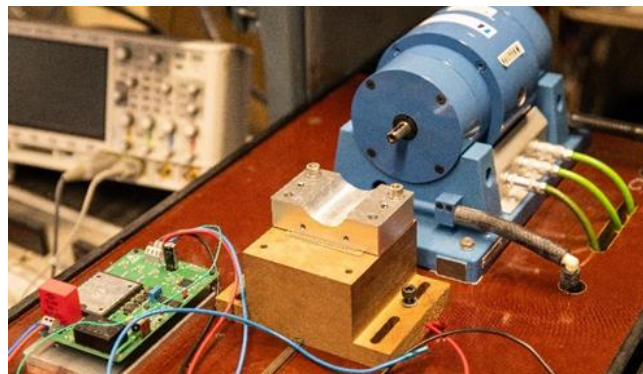
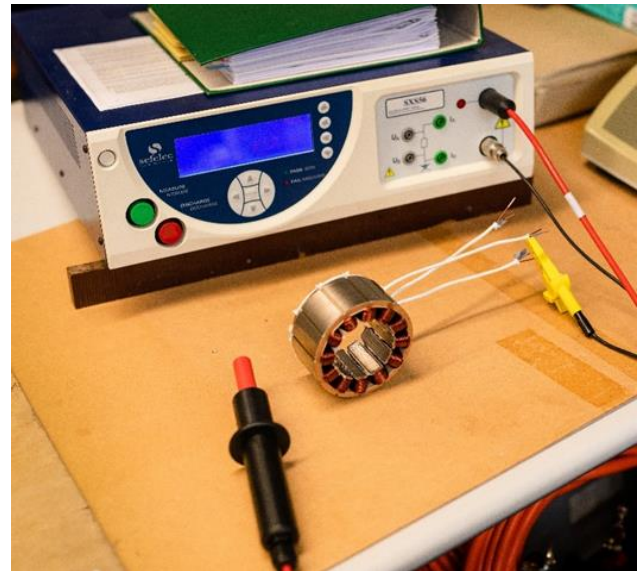
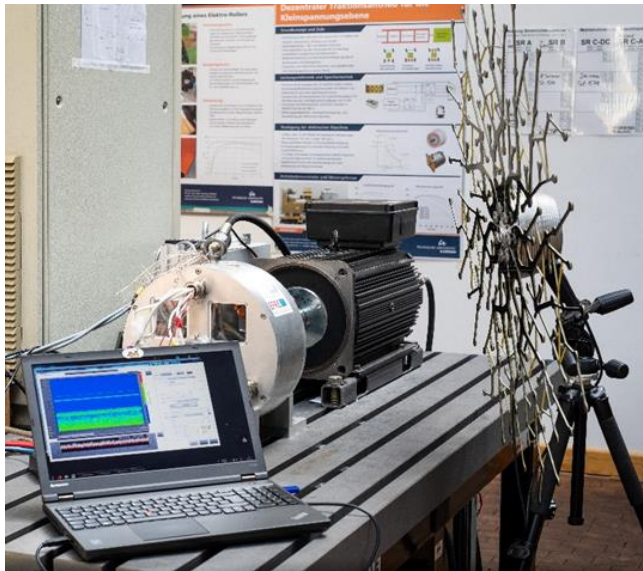
Test benches for dynamic characterization of power semiconductor devices



Types of dynamic characterization:

- Devices: IGBT, MOSFET, diode, JFET, SIT, HEMT, thyristor; (Si, SiC, GaN)
- Dynamic standard characterization (switching waveforms, switching times, switching losses, double-pulse-test)
- Short circuit behaviour (SC1, SC2)
- Dynamic latch-up-test
- Dynamic $R_{DS(on)}$
- Dynamic repetitive reverse bias test (DRB)
- H3TRB (high temperature, high humidity)
- Very high dv/dt and di/dt stress test
- SOA-tests
- Avalanche test (UIS, single-pulse, repetitive)
- Application-oriented repetitive switching test (hard and soft switching / commutation)
- Temperature cycle test
- Gate-driver optimization
- Series and parallel connection of power semiconductor devices

Test benches and laboratory equipment for electrical machines



Equipment and research possibilities:

- Test benches and loading equipment for rotating machines up to 50 kW
- Torque measuring shafts from 0.2 to 200 Nm and speeds up to 50,000 rpm
- Laboratory inverter, AC and DC sources for operating electrical machines
- Determination of machine characteristics and power measurement
- Recording of temperature curves on electrical machines
- Magnetic field measurement with probes or measuring coils
- Investigation of machine vibrations
- Acoustic camera / microphone array for analysis of airborne sound
- High-voltage tester for checking windings up to 10 kV
- Balancing station for rotors up to 5 kg and concentricity measuring device for commutators