SWTW 2017

SW Test Workshop

Semiconductor Wafer Test Workshop

Sensors at Test – "Magnetic" Probe Cards

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Overview

- Magnetic Sensors: Hall-Effect
- Hall Sensors - Measurement Challenges
- ... after all that – We Still Want to Test on Wafer!
- Magnetic Field Generation and Probe Card – Vertical Field
- Planar Rotary Magnetic Field – Yoke versus Permanet Magnet
- ... some Probe Card Examples
- Summary

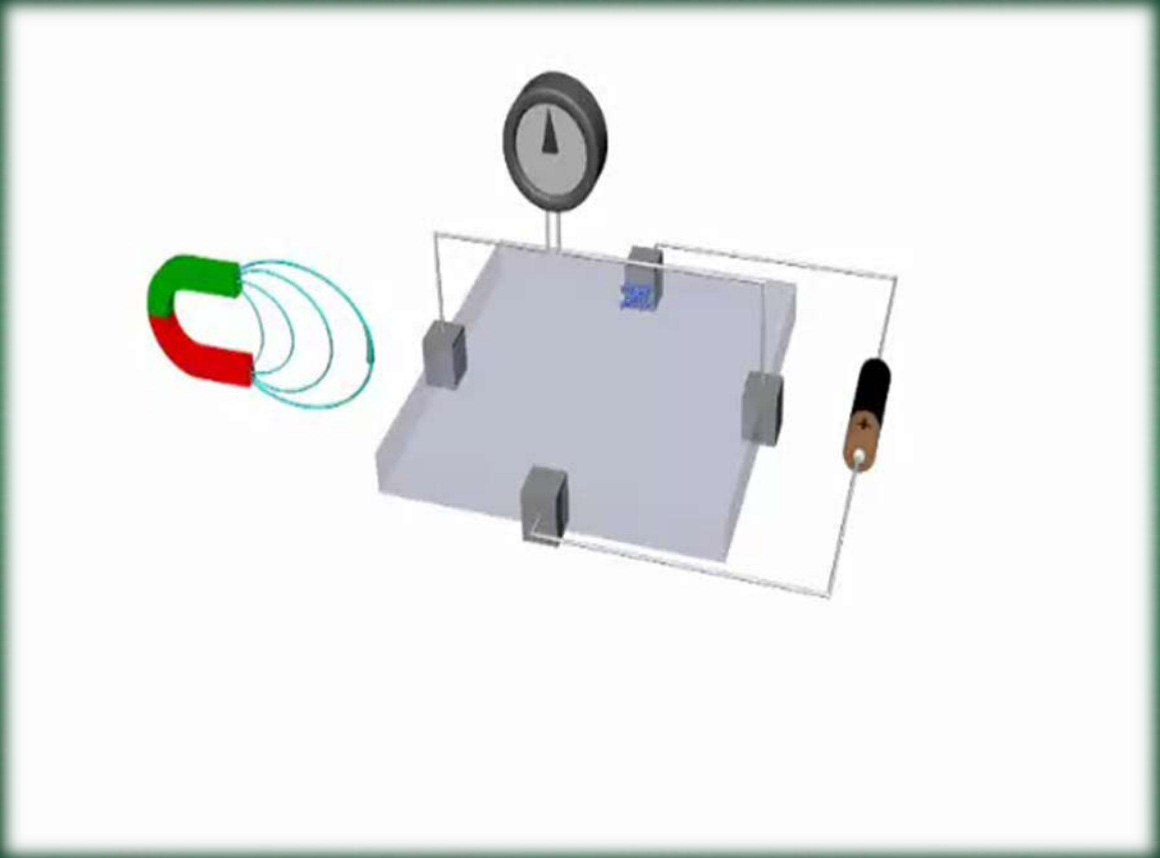
Hall-Effect – the Physics behind…

"Lorentz"-Force

- moving charge carriers deflected perpendicular to magnetic field and direction of motion

➡ **"Hall-Voltage"**

- proportional to magnetic field strength and electric current

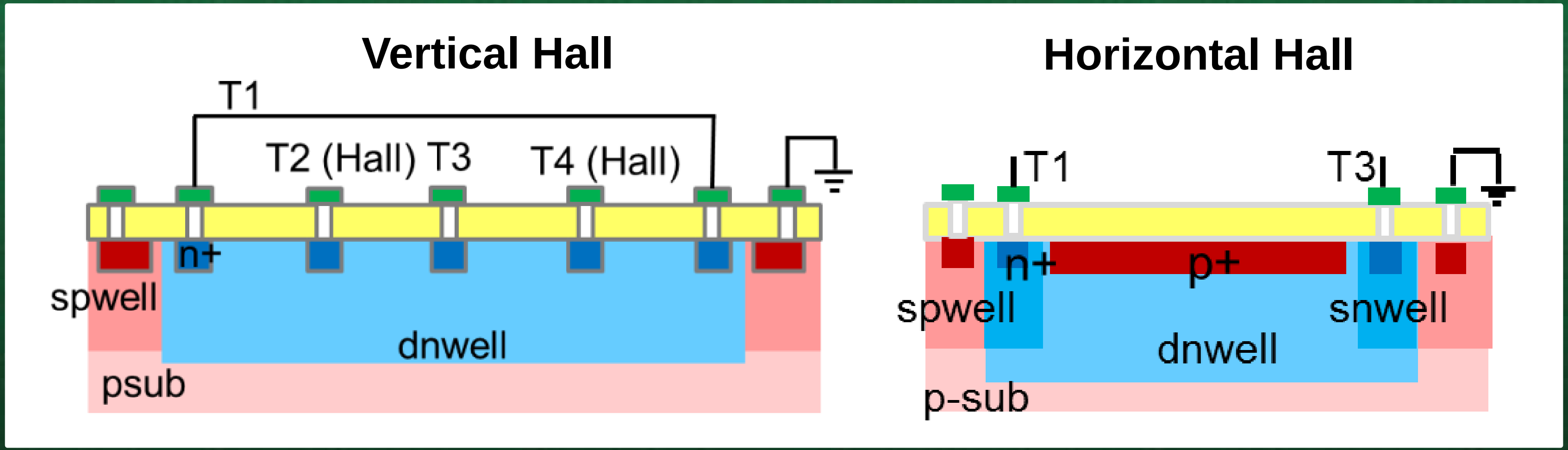


Edwin Herbert Hall
(1855-1938)

1879: Hall effect, Ph.D. thesis in Physics, Johns Hopkins University

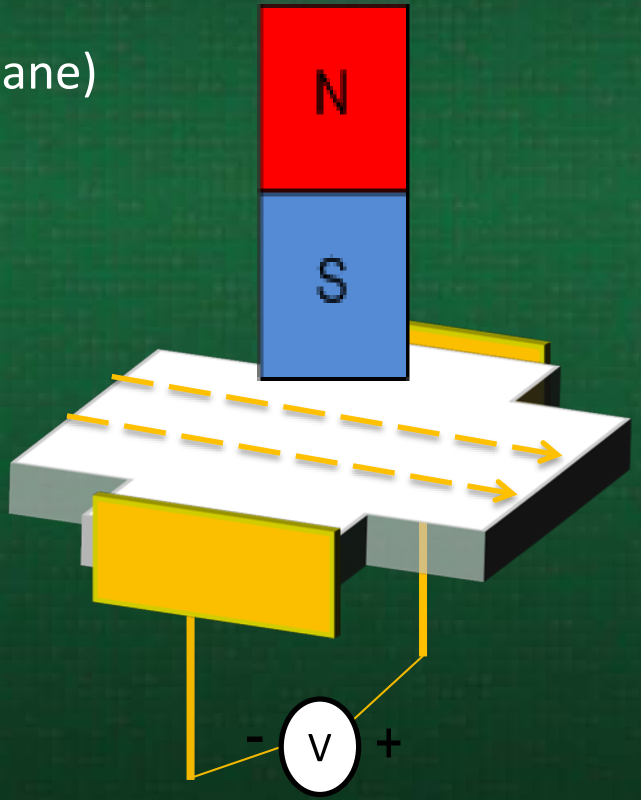
Hall Effect Sensors - Overview

- **Hall-effect sensor produces varying output voltage in relation to external magnetic field strength.**
- **Two main variations: out-of-plane and in-plane Hall**
  - Horizontal Hall: senses magnetic fields orthogonal to wafer surface (out-of-plane)
  - Vertical Hall: senses magnetic fields parallel to surface of wafer (in-plane)



Vertical Hall

Horizontal Hall



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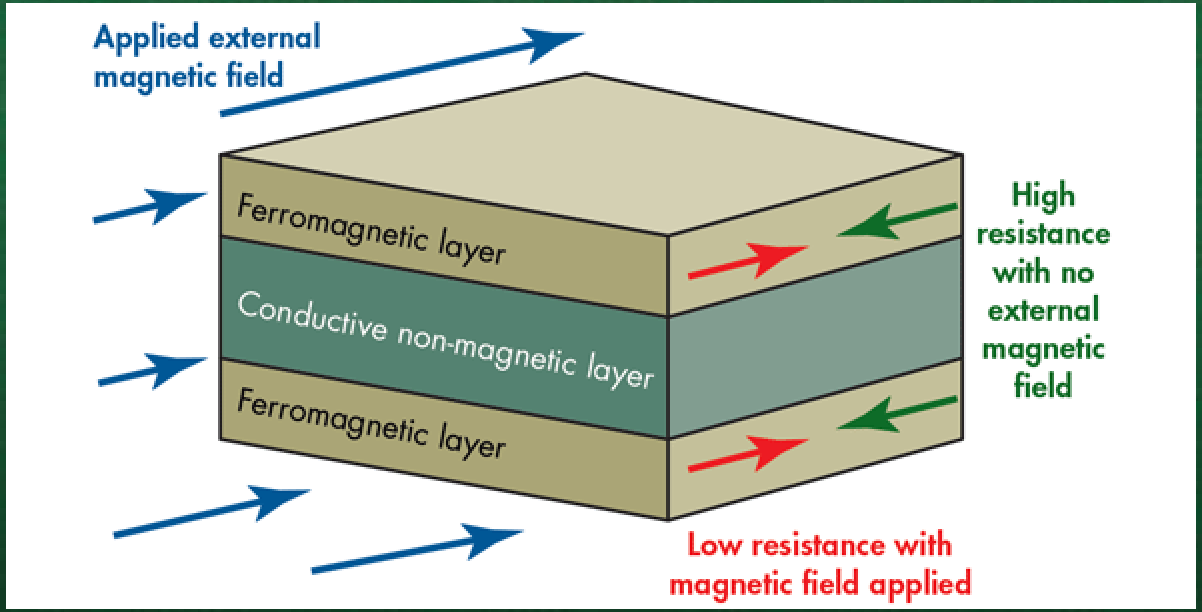
Other "fancy" Magnetic Sensing Effects...

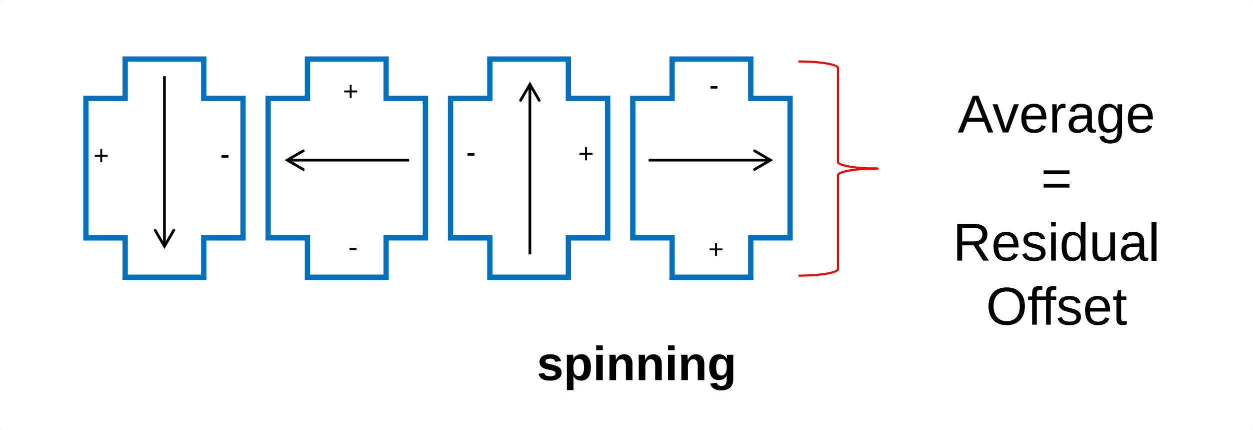
- **GMR: Giant Magneto Resistance**
- **TMR: Tunnel Magneto Resistance**
- **AMR: Anisotropic Magneto Resistance**

Magneto-resistive: based on quantum- mechanical effects: spin-dependent scattering of electrons on thin layers - "superlattices".



Measurement Parameters for Hall Sensors

- **Resistance (Ω)**
  - Voltage drop across the force terminals – proportional to contact spacing and doping level
- **Sensitivity (V/AT)**
  - Output voltage on Hall terminals with a known external magnetic field applied
- **Offset (1σ T) or (1σ V)**
  - Output voltage on Hall terminals while no magnetic field applied
  - Sources of offset
    - Process asymmetries
    - Stray magnetic fields
    - Stress in silicon
    - Test hardware
- **Common offset reduction technique involves "spinning":**



Measurement Challenges and Error Contributions

$$V_{Hall} = SIB = \frac{IB}{tne}$$ .... ideal sensor output

$$V_{Output} = VHall + VOffset$$ .... real output

S .... sensitivity
I .... current
B .... B-Field

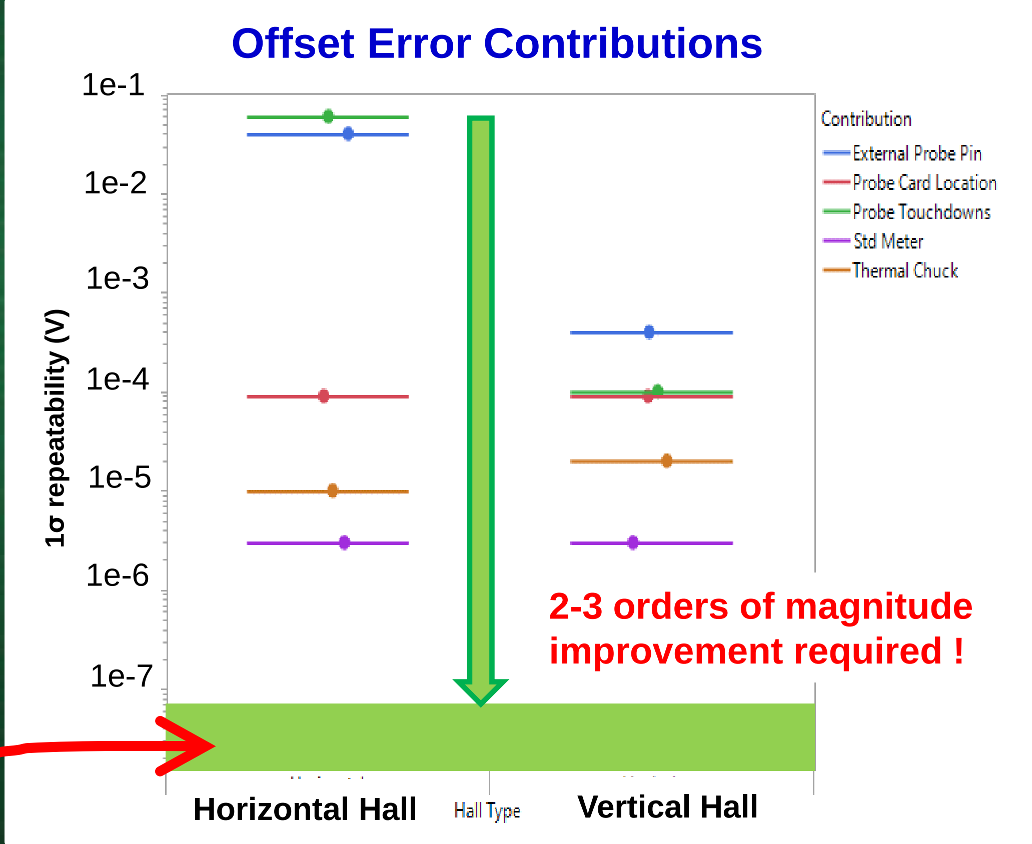
t .... thickness
n .... density of mobile charges
e .... electron charge

Output Signal Voltages (very low !)

Hall Sensor Type	Sensitivity (V/AT)	Output for Earths Magnetic Field (50µT)*
Horizontal Hall	300	**1.5 µV**
Vertical Hall	100	**0.5 µV**

*Assuming field is oriented in sensing direction for Hall sensor, 100µA force current

x 10 %

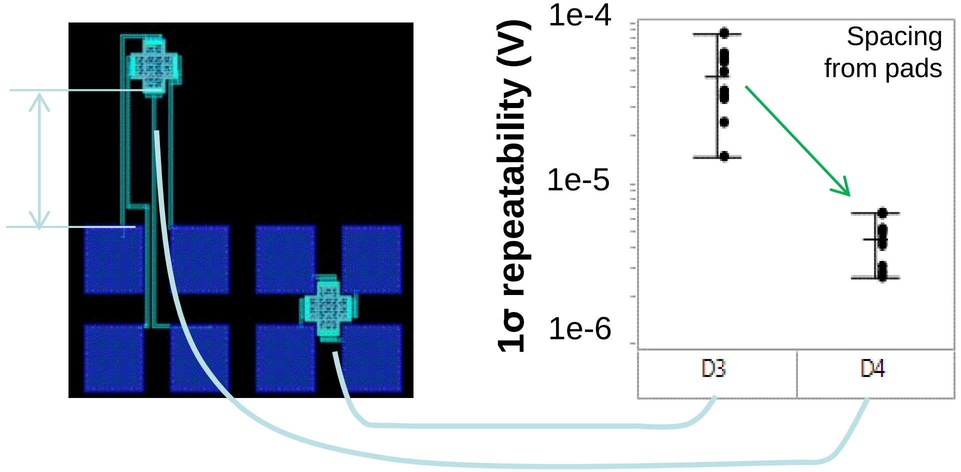

Offset Error Contributions

2-3 orders of magnitude improvement required !

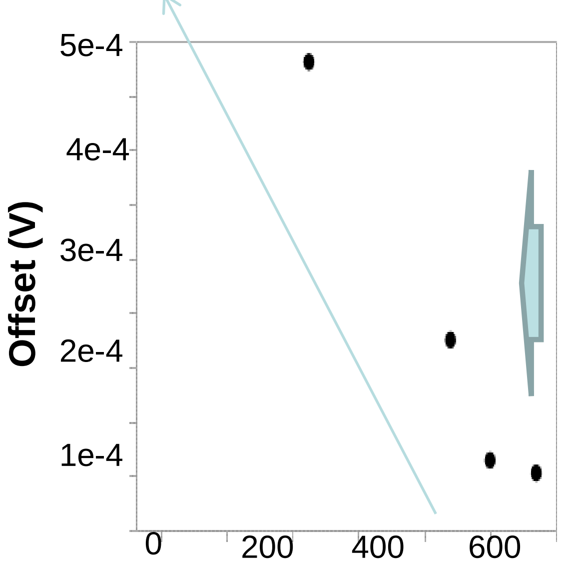
Probe Pad Stress Impact

- **Repeat probe touch down results in variability**
  - Implementing 4 phase spinning in layout can reduce this
- **Bench probing used to identify source of variation**
  - Increase Z-travel on probe tips increases offset value
  - Using probe pin on silicon surface demonstrates proximity of stress to DUT
  - Vertical devices demonstrate lower sensitivity to stress in silicon

Hall Design: Improvement by spacing DUT to pads



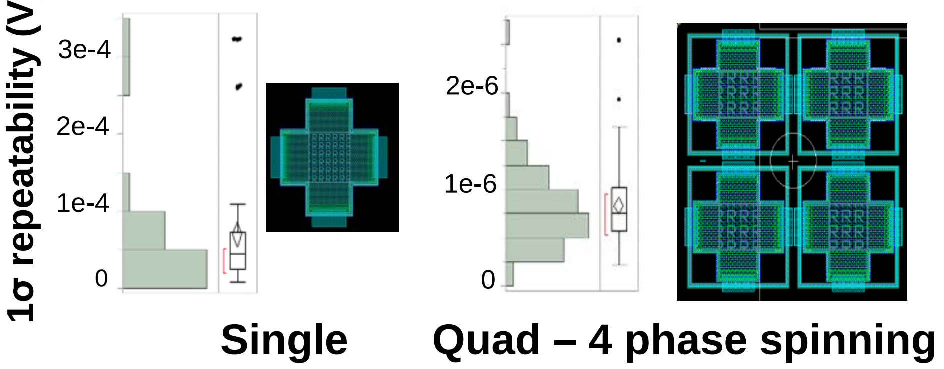
Applying Stress to Silicon



Offset voltage increases with proximity of stress to Hall device.

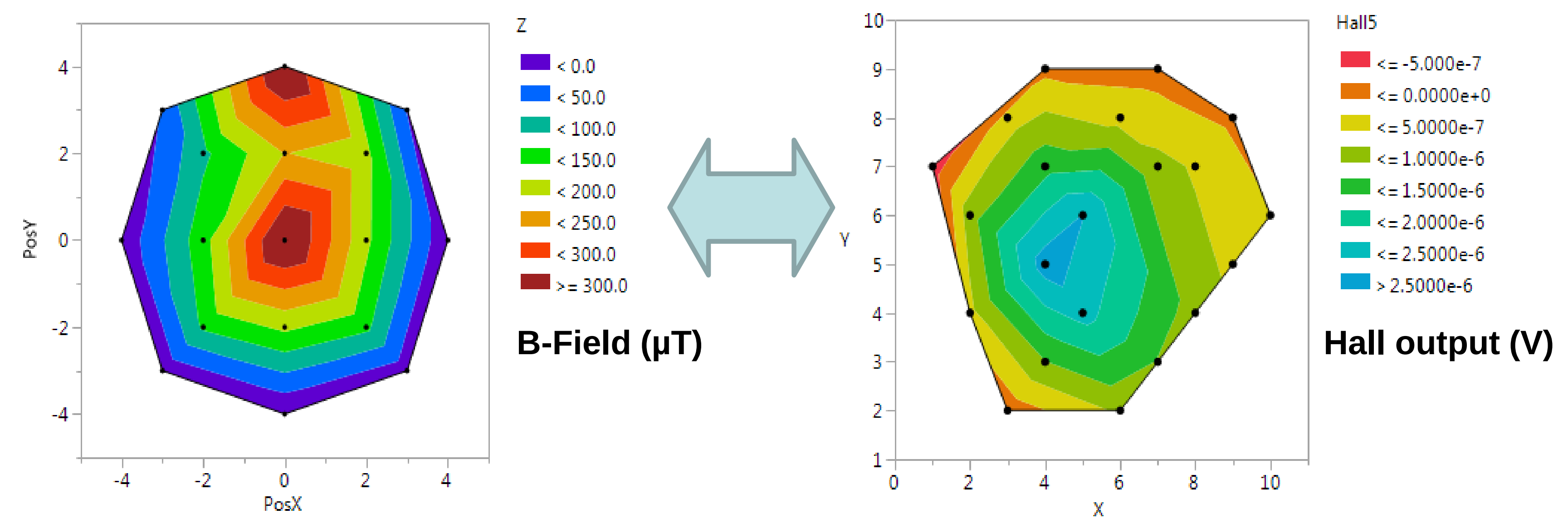
Horizontal Hall devices are more sensitive to stress compared to vertical devices.

Repeat Touch Down Variation



Thermal Chuck Influence

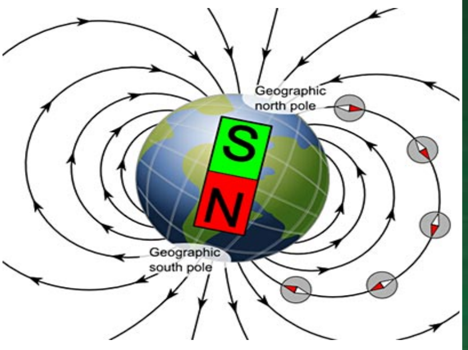
- **Initial testing over temperature displayed variation proportional to increasing chuck temperature**
  - Chuck vendor measured magnetic fields >300µT
  - Heating current is not constant – varies to achieve temperature set point
- **“Anti-Magnetic” probe chucks developed by ERS**
- **Further improvement: Turn off temperature control during probing for more accurate results**



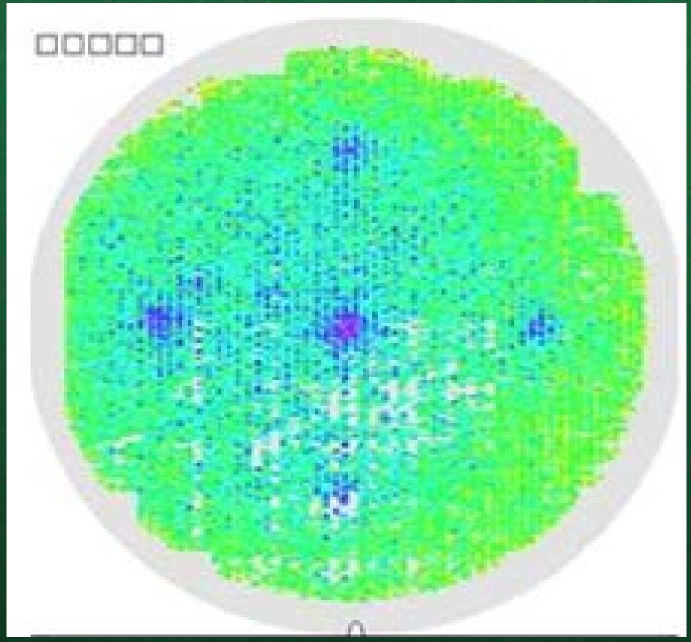
Out-of-plane magnetic field **Across wafer offset signature**

Stray Magnetic Fields

Earth's magnetic field is ~50µT ...!



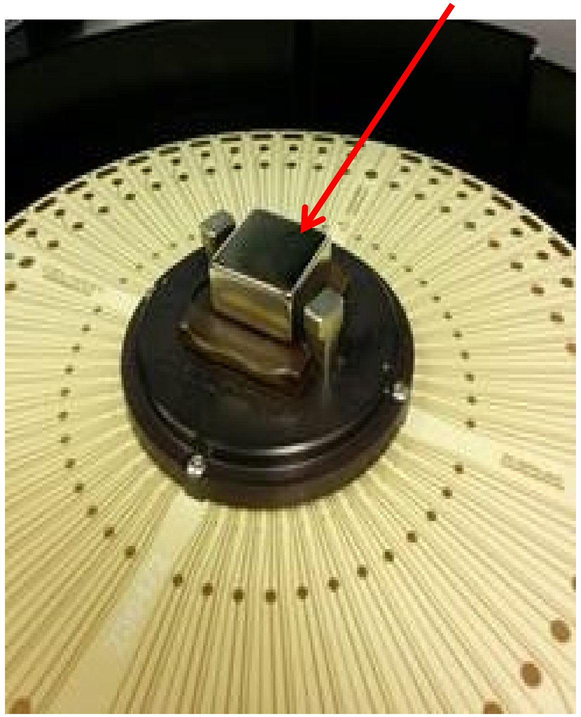
- **Expect no external magnetic fields at the DUT for offset measurements**
- **Gauss meter used to quantify stray fields in prober**
  - Sharp corners on casing produce ~400µT
  - Permanent magnets used for scrub pad and position switches up to 20mT (outside of DUT)
  - Fields vary ±30µT at DUT level (probe head powered off)

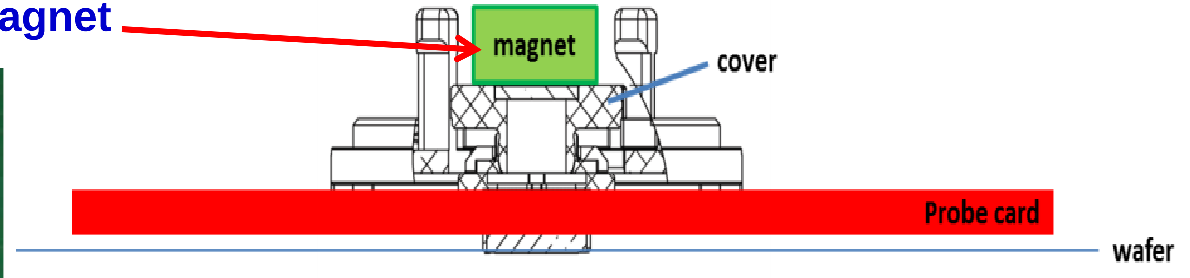


...after all that – We Still Want to Test on Wafer!

- **Proof of concept: single site probe card – wafer-level sensitivity setup**

Permanent Neodymium magnet



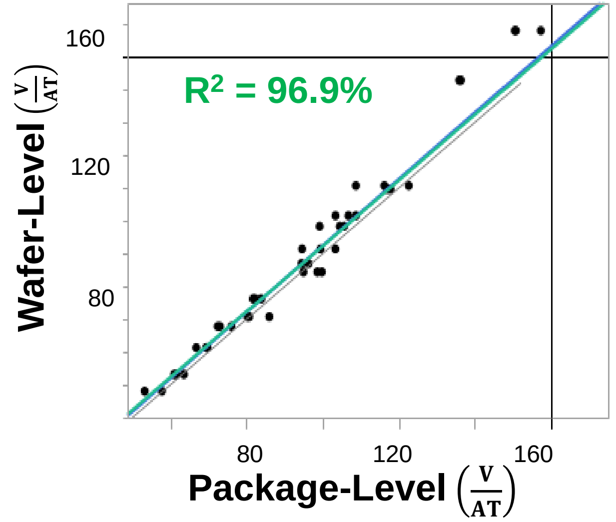


Innovative use of permanent magnets attached to probe core for wafer-level testing of hall sensitivity

- Calibrated through well characterised Hall sensors and external Gauss meter
- For both vertical and horizontal Halls

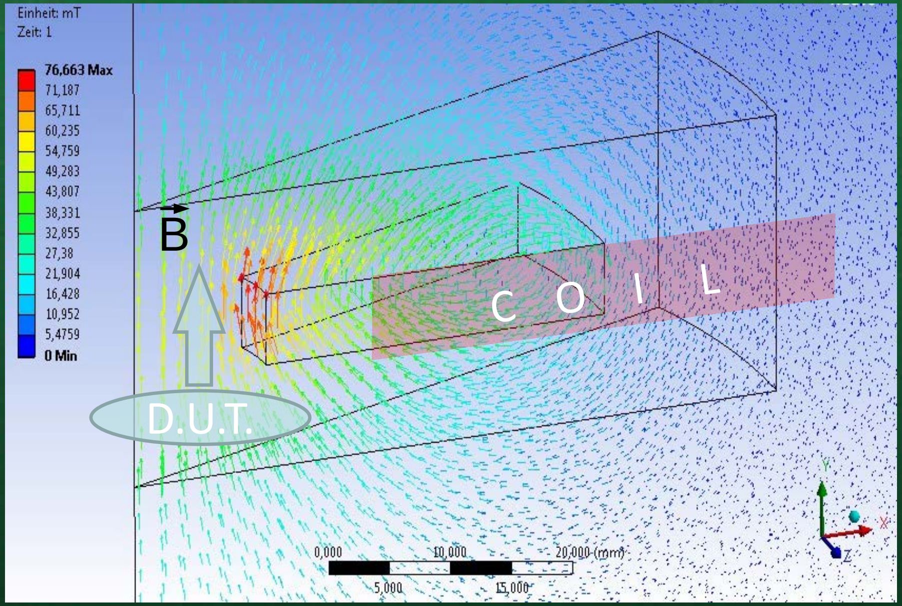
Sensitivity measured with probe card verified against packaged units – confirmed OK !

Verified Sensitivity Accuracy

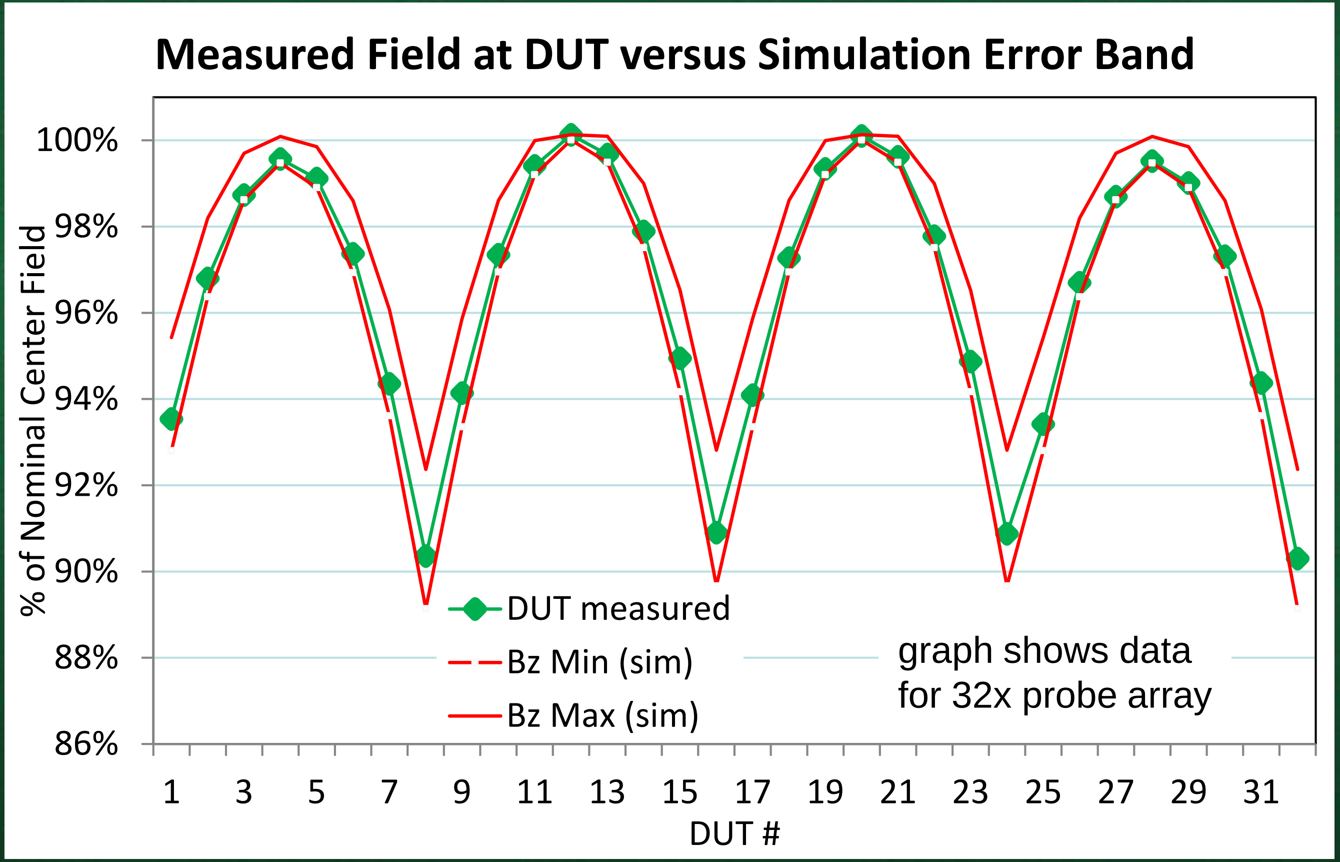


Ratiometric Hall Sensor – 16x Multi Site

- **Magnetic Design – Air Core Ribbon Coil**
  - Flux 0...50 mT
  - Test area 4 x 4 mm²
  - Uniformity ± 1%
  - Temperature -40 … 150°C
  - Forced Air Cooling (CDA) required
  - 190 W peak power @ 7.5 A , 20 % on



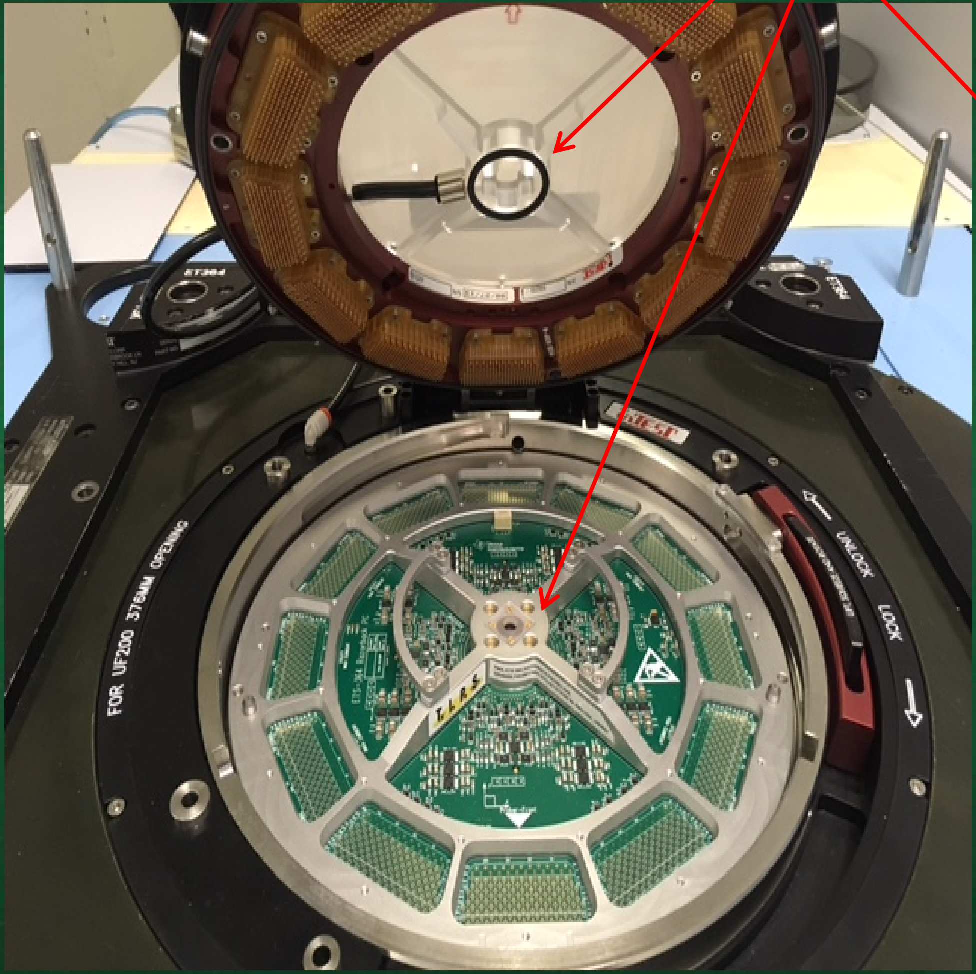
- **FEM Numerical Simulation**
  - optimize field geometry
  - determine relative multi-site calibration factors


Measured Field at DUT versus Simulation Error Band

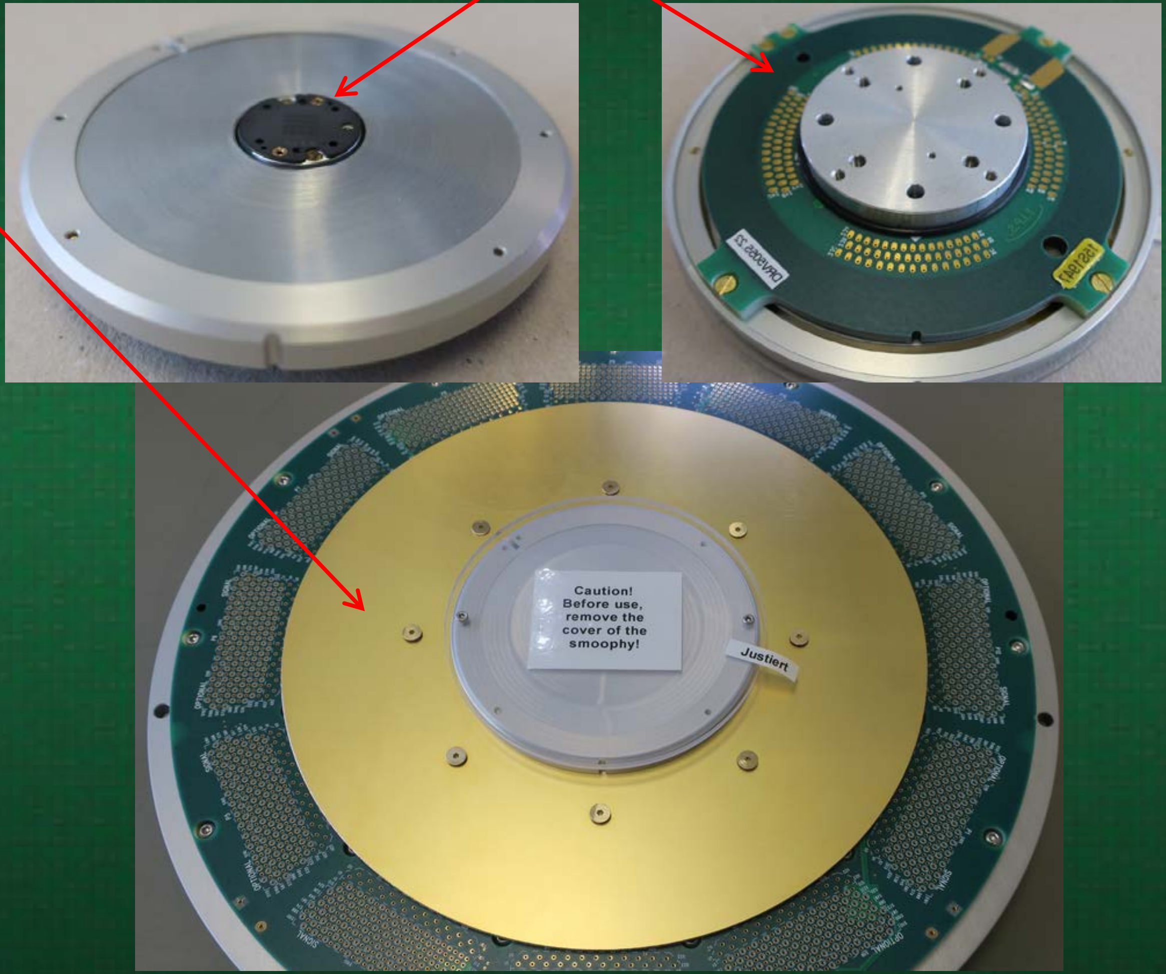
graph shows data for 32x probe array

16 x Vertical Magnetic Probe Card – Vertical Hall

Eagle "Razorback" Test Setup with TIPS Air Cooling



"SMOOPHY" – TIPS Vertical Probe Head – Integrated Ribbon Coil



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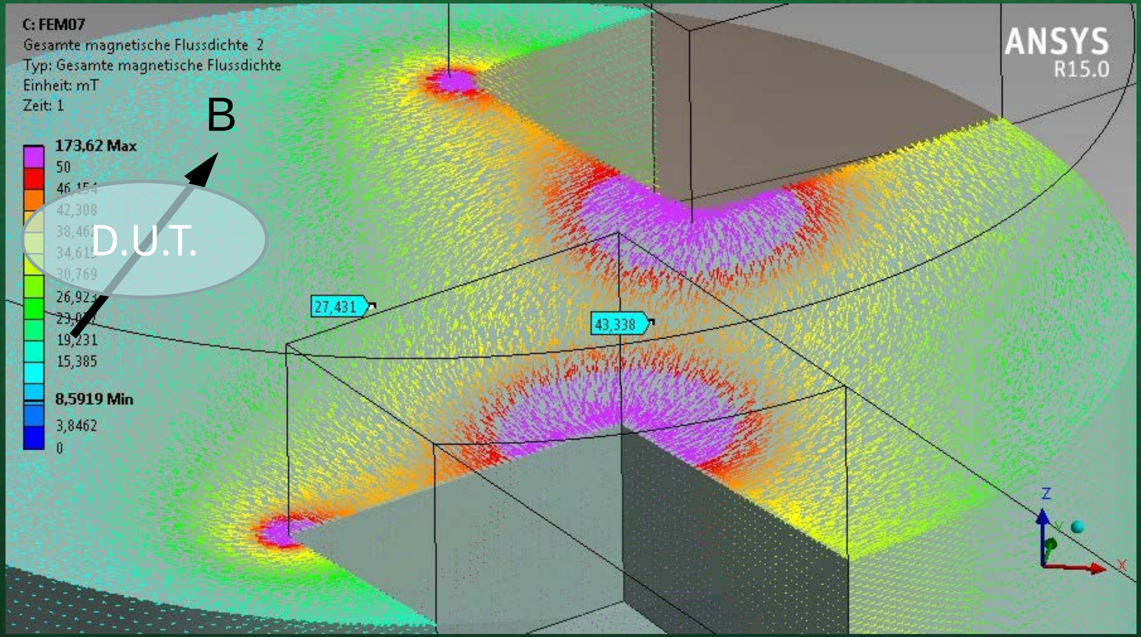
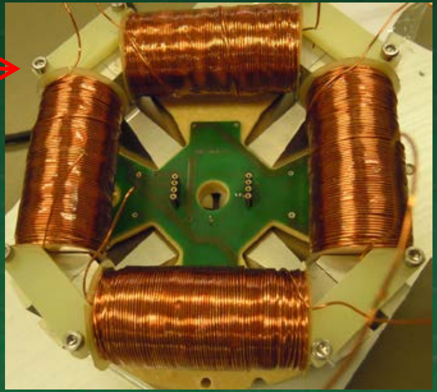
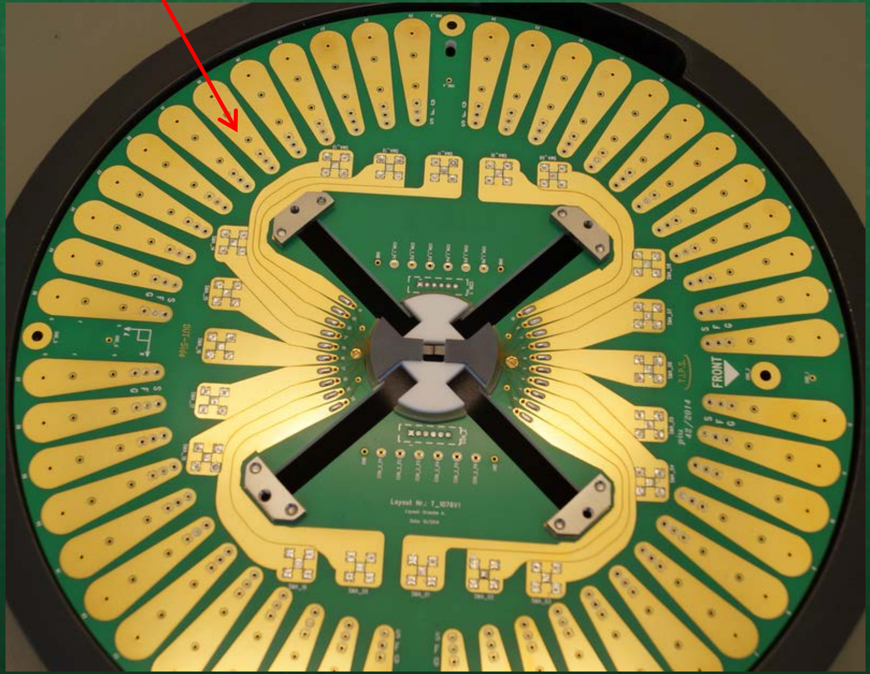
Rotating Planar Field – Coil-Yoke Magnet

- **Magnetic Design – Quadrupole**
  - Flux 0...20 mT
  - Test area 2 x 2 mm²
  - Uniformity ± 5%
  - Angular accuracy ± 1°
  - Field rotation speed max. 10 Hz (limited by eddy currents in iron yoke)



TIPS Quadrupole Field Coil integrated into Keysight 4070/4080 parametric probe card platform

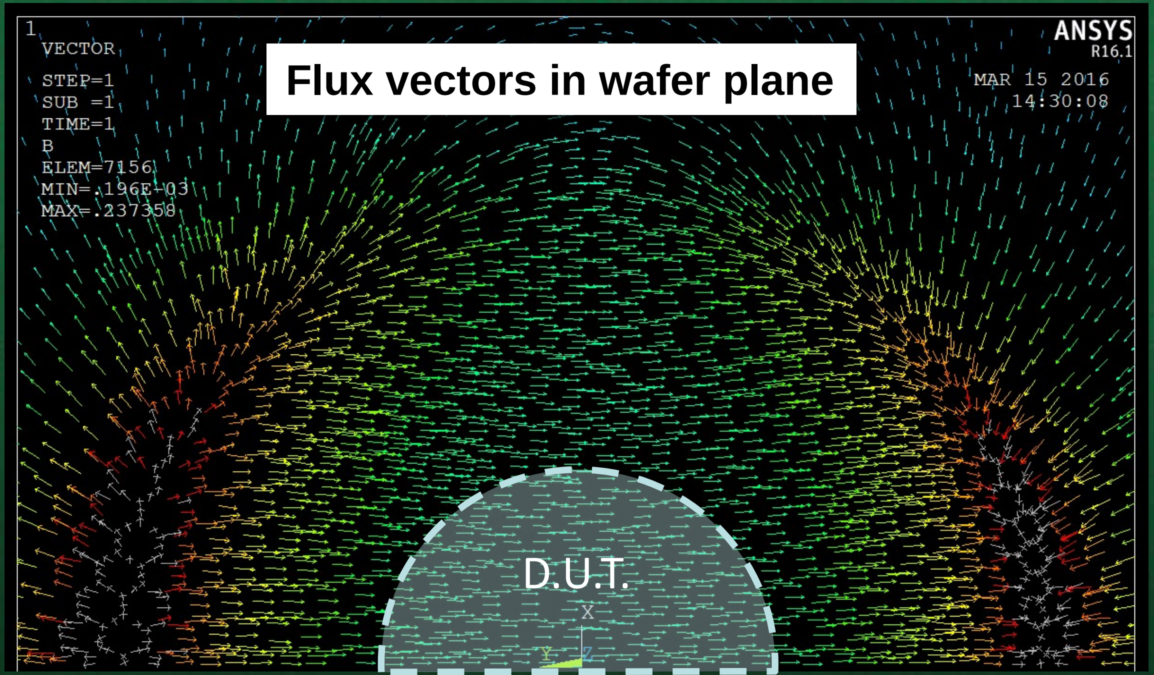


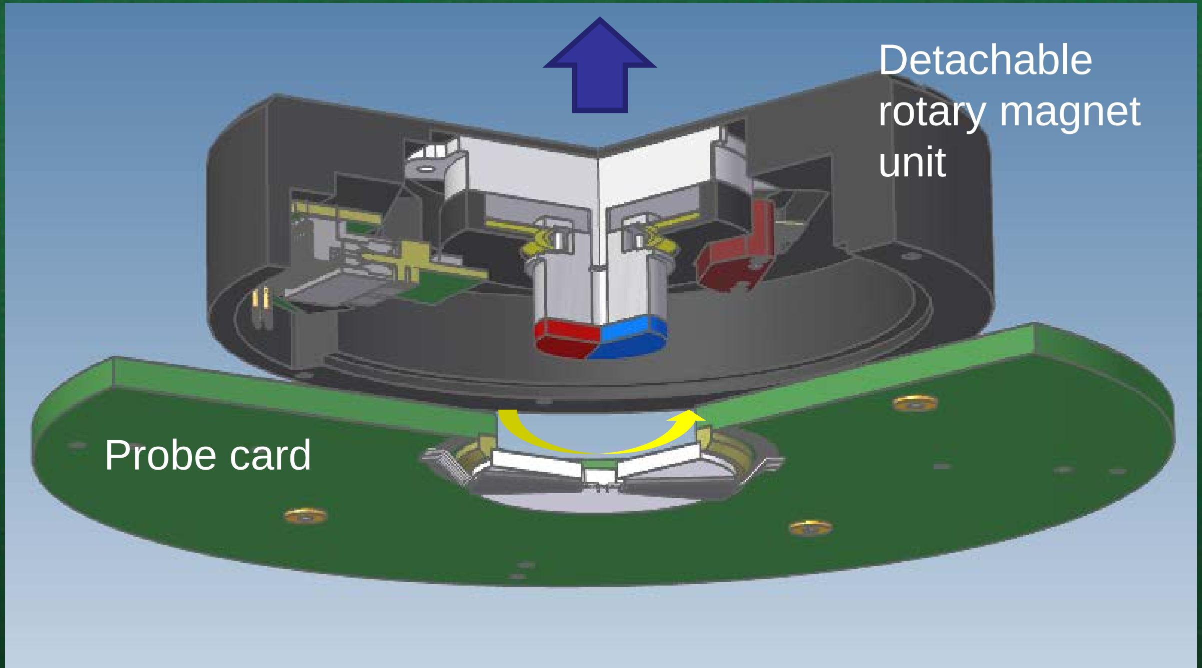


Rotating Planar Field – Permanent Magnet

- **Magnetic Design – Permanent Magnet**
  - Flux 50 mT (up to 200 mT)
  - Test area 4 x 4 mm^2
  - Magnet shape optimized for "sweet spot" - minimum field distortion at multi-site chips location
  - Flux direction uniformity ± 0.1°

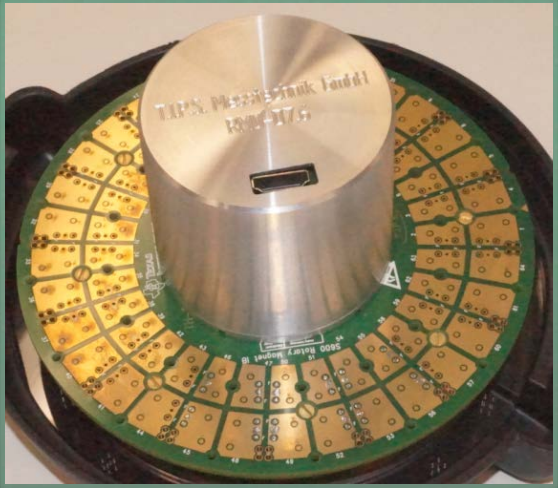
- **TIPS Rotary Magnet Unit**
  - integrated motion control
  - addressable by simple digital I/0
  - detachable from probe card – precision mount
  - High Precision : position resolution ± 0.02°
  - High Speed : rotational speed up to 2000 rpm



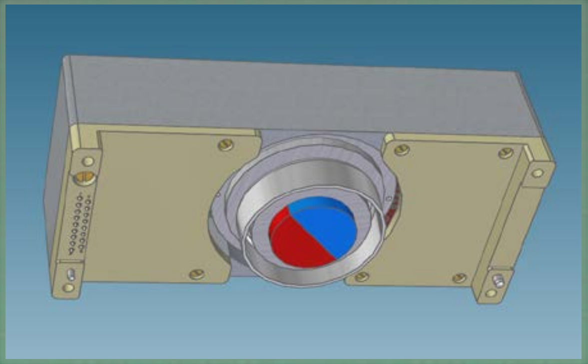


Rotary Magnet Probe Cards and more...

TIPS RMU-70
Keithley S600
parametric probe card



TIPS RMU-150
10" diameter probe card



TIPS RMU-F60
Teradyne FLEX – Final test (quad site)

Summary – Magnetics Wafer Testing

- **Hall Sensor Testing Considerations**
  - Reduce magnetic properties of measurement system in close proximity to DUT (sensor)
    - Anti-magnetic chuck (ERS)
    - Non-ferromagnetic (NF) probe cards and mother boards (Celadon, TIPS)
- **Application of Magnet Fields for Test**
  - Vertical air-core field coil (TIPS Vertical Magnetic Probe Head)
  - Fixed magnet on top hat of parametric probe card
  - Motor control of magnet rotation (TIPS Rotary Magnet Unit)
- **Magnetic Field Design**
  - FEM simulation (and its interpretation...) is a very helpful tool
- **Probe Card Design and Manufacture – "Turnkey" Approach is Required**

+++ Multi-site Test Concept +++ Magnetic Simulation and Design +++ PCB Design +++ Probe Head +++ Mechanical Integration +++ Assembly and Test +++

It's more than just mounting a few needles to a board...

Acknowledgements

- TI Dallas, project team members (too many to list them here...)
- Unnamed customers willing to explore new paths...
- Our team at T.I.P.S. Messtechnik GmbH

Thank you for your attention !