METROlab
Magnetic precision has a name

3-Axis Magnetometer on a Chip

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Why magnetometers?

"You can only make as well as you can measure"

Joseph Whitworth
1803-1887
Engineer,
entrepreneur,
inventor,
philanthropist

Credit: Grace's Guide to British Industrial History

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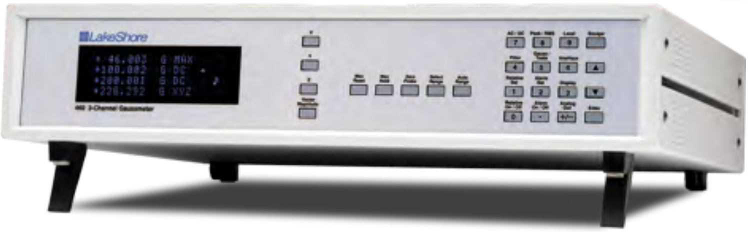
3-Axis Hall Magnetometers

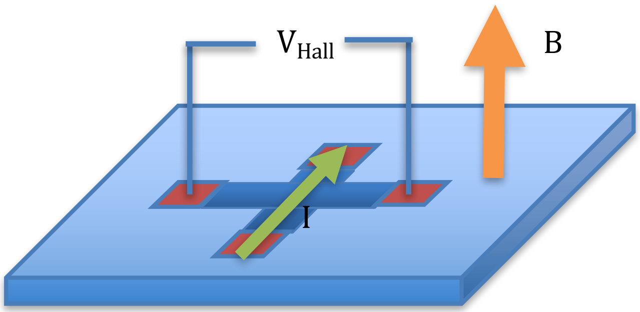
- Advantages:
  - All vector components
  - Any probe orientation
- Limitations:
  - Orthogonality
  - Sensor separation
  - Planar Hall Effect
  - Cost

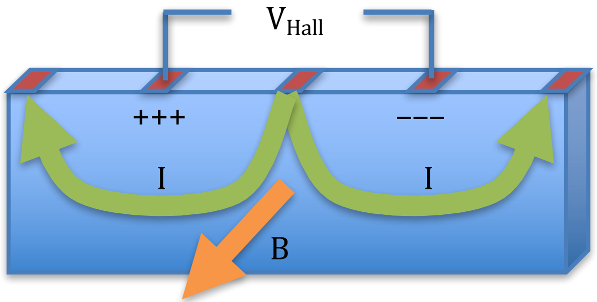


Credits:
- *LakeShore Cryotronics (Model 460)*
- *Magnetic Sciences Inc. (F.W. Bell 8030)*
- *Metrolab (THM7025)*

The first revolution

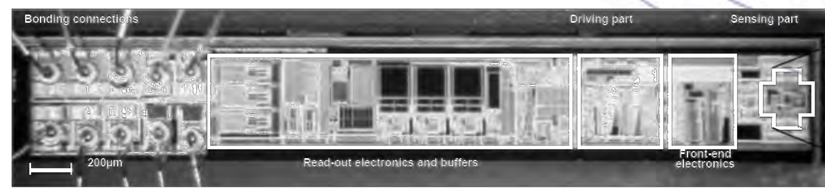
- Vertical Hall sensor
  - Integrated 3-axis sensors
- Advantages:
  - Simplified construction
  - ~100 µm active volume
- Limitations:
  - Si: lower sensitivity, higher noise



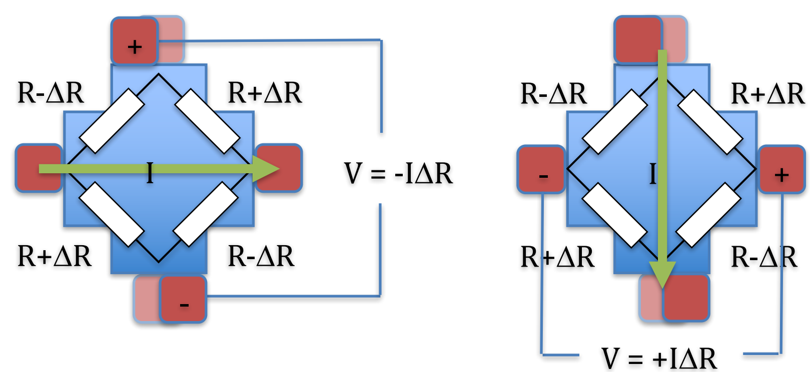


Additional advantages

- Integrated current source and amplifier
- Integrated temperature sensor
- "Spinning current" to minimize offset, Planar Hall Effect, and noise



Credit: presentation by D. Popovic (Senis) at IMMW-14



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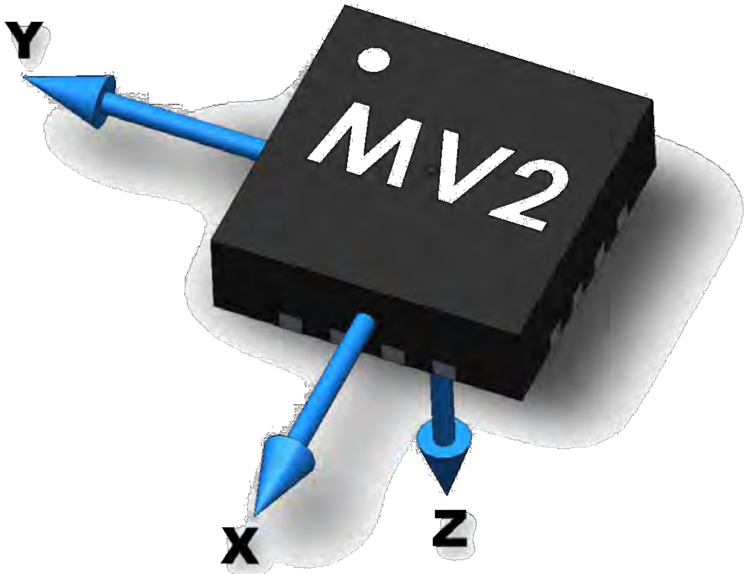
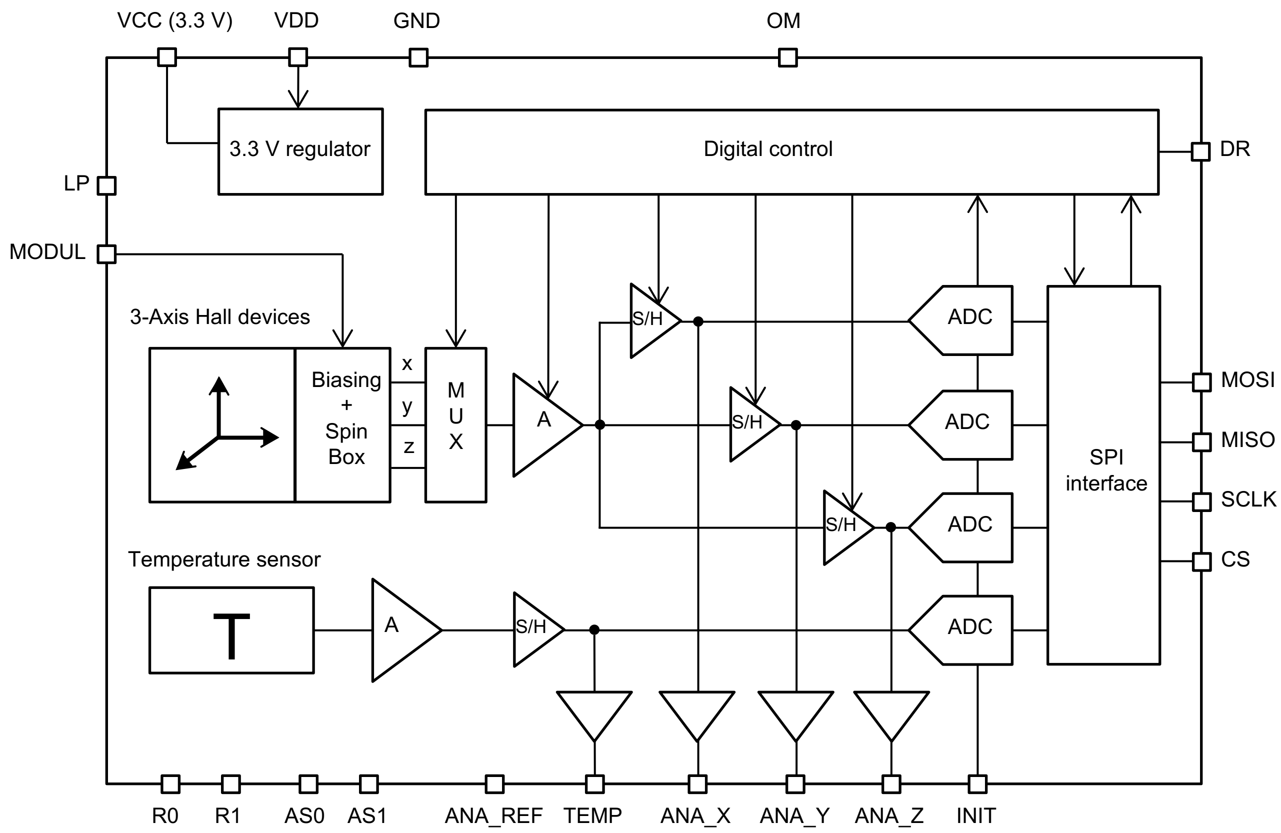
The second revolution

- Integrated ADC
  - Digital interface
- Advantages:
  - Minimize system complexity & cost
  - Minimize errors from inductive voltages
  - Additional controls
  - Sensor arrays feasible
- Disadvantages:
  - ADC performance

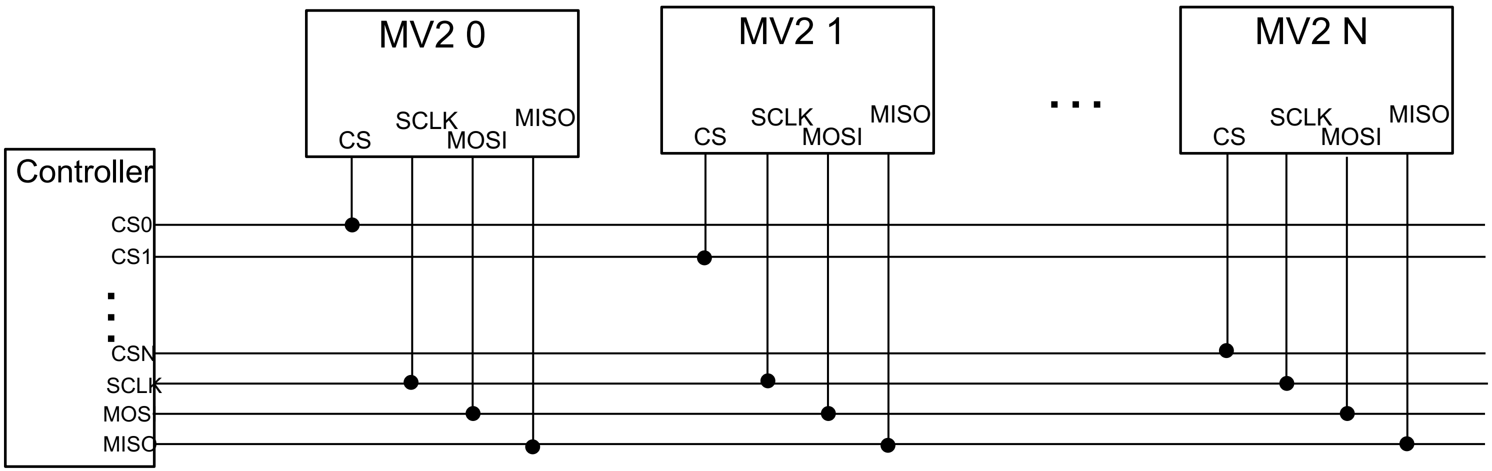


Architecture



Sensor arrays

- Communication:
  - SPI bus with individual Chip Select lines



- Synchronization:
  - INIT 1 → 0: reinitialize and start ADC conversion

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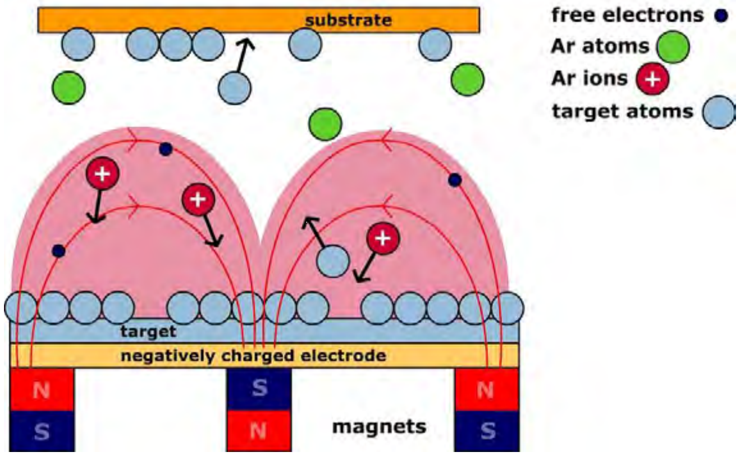
Example: magnetron sputtering

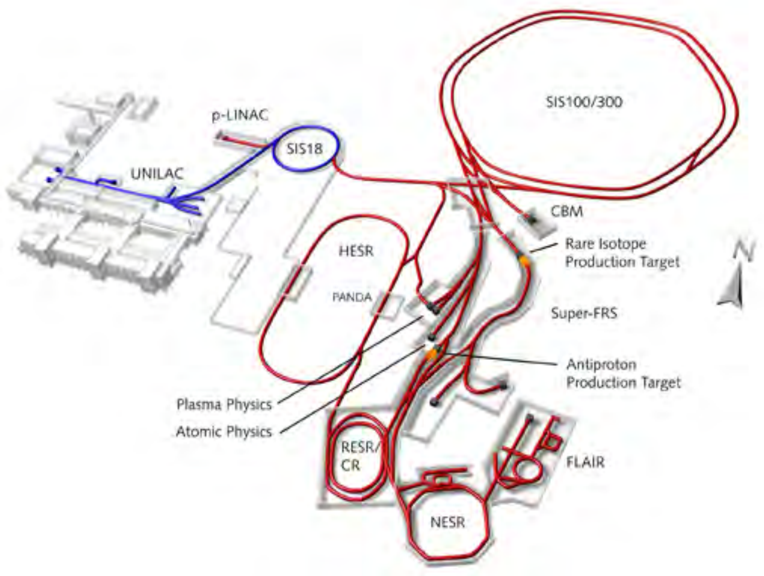
- Magnets degraded by heat, radiation
- Causes uneven deposition
- Periodic mapping of magnets
- Sensor array:
  - Minimize downtime!
  - Simplify scanning robot



Credits:
- Wikipedia: "Sputter deposition"
- Dep. of Physics of Politecnico di Milano

Example: Accelerator magnet mapping

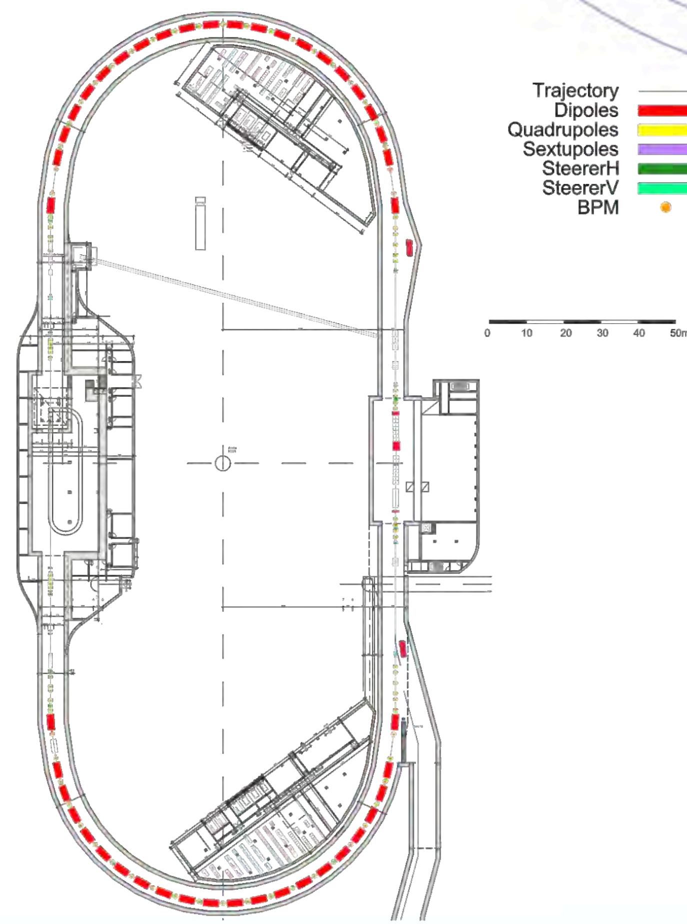
- Facility for Antiproton and Ion Research (FAIR), Darmstadt, DE
- Dipoles of High-Energy Storage Ring (HESR)
- 44 bent dipoles, 4.2 m long, 0.17-1.7 T



Credit: www.fair-center.de

Accelerator magnet mapper

- Angular map along entire magnet length
- 0.17, 0.5, 1.7 T
- 10^{-4} resolution
- 8 sensors
- Rotary motor for additional angles
- Sled for lengthwise motion
- 82 mm free gap



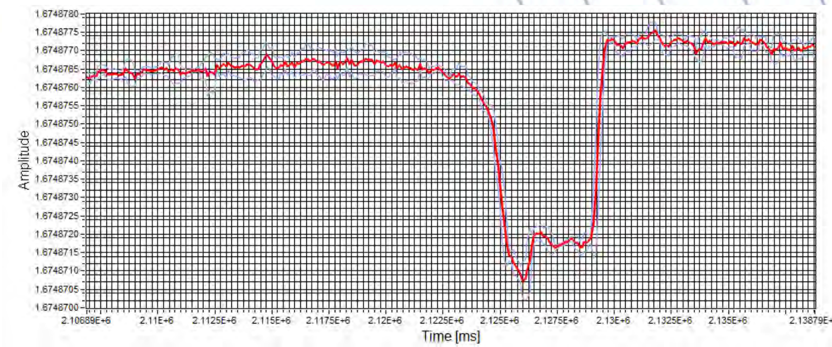
Credit: Forschungszentrum Jülich

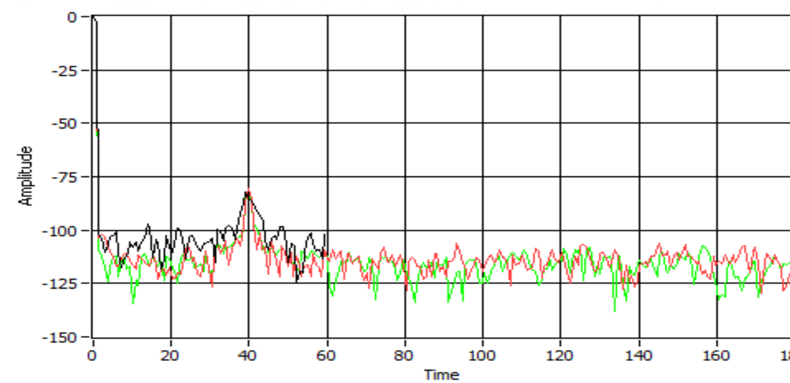
Accelerator magnet mapper

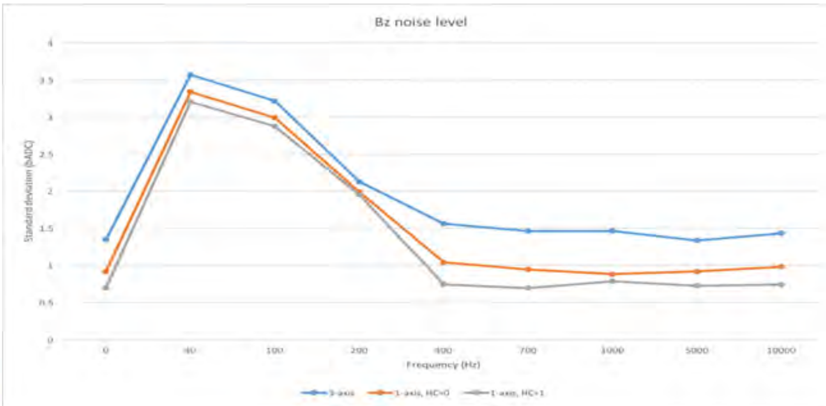
- 8 sensors @ 76 mm diameter
- Radial layout, ± 0.1 mm
- Precision mounting holes
- Temperature stabilization ~0.01C:
  - Thermal vias
  - Cu-core PCB
  - Heater
  - Current regulator
  - Insulation
- On-board electronics:
  - µP
  - Temperature sensor
  - Voltage regulator
- USB power & communication
- LabVIEW API

Heater

- Refractory metals:
  - NiCr , ~~FeCrAl~~, CuNi
  - Mo, W, Ta, Nb, Cr
- 0.5 mm NiCr plate, 1.7 T
  - // : -0.6 µT (0.4 ppm)
  - ⊥: -5 µT (3 ppm)
- Field from heater current:
  - ~4 ADC bits
  - Use AC → no DC offset
  - Coil inductance → roll-off
  - ADC integration → negligible > ~400 Hz

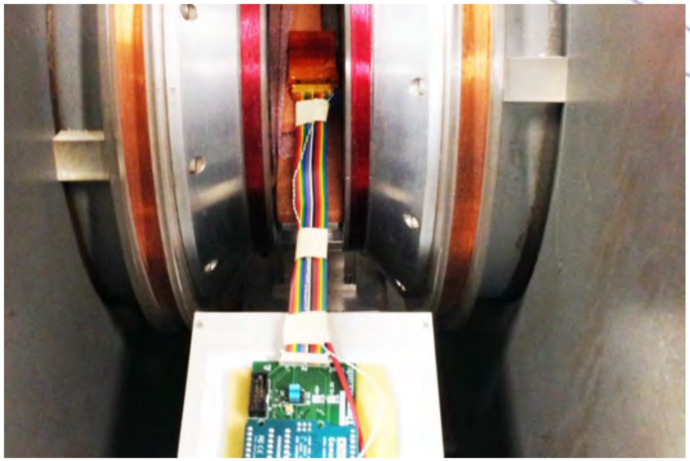






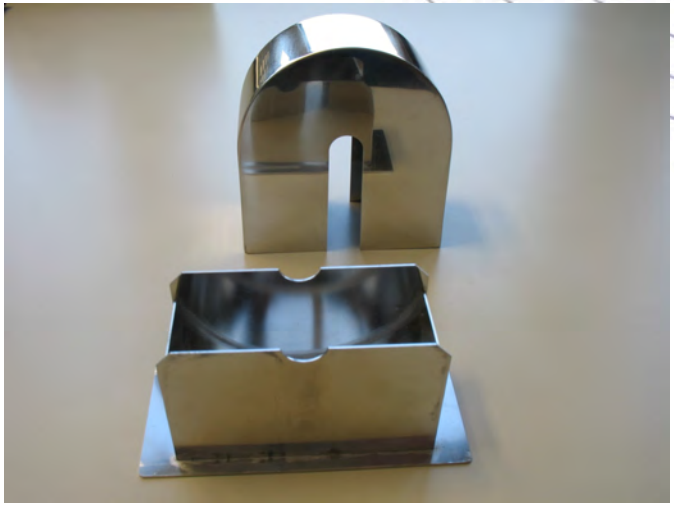
Resolution & stability

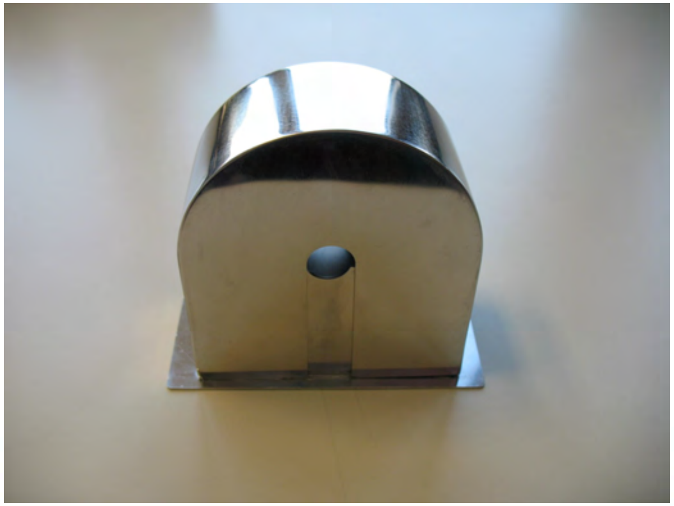
- Noise:
  - ±4.7 μT (100 mT range)
- Drift:
  - Bx, By: 0.07 bits/hour
  - Bz: 0.4 bits/hour
- Conditions:
  - 4 hour preheat
  - 16 hours measurement
  - 80 mT ± 0.5 μT
  - 35° ± 0.01°
  - 3-axis mode



Zero Gauss Chamber

- Measure initial & final zero-offset; interpolate in time
- Enclose mapper, including drive shaft
- Attenuation goal: ~50 μT → < 1 μT
- Measured:
  - 41.754 μT → 0.232 μT
  - Maximum (orientation)
  - ~6 mm below sensor





Conclusions

- Logical evolution of 3-axis Hall magnetometers
- Size, performance, cost → embedded / custom applications, e.g. mappers
- Calibration, UIF → not a "cheap gaussmeter"
- Unsuitable for special conditions (e.g. high precision, low fields, cryogenic temperatures)