INVESTICE DO ROZVOJE VZDĚLÁVÁNÍ

Přesné magnetické snímače a jejich aplikace

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Tato prezentace je spolufinancována Evropským sociálním fondem a státním rozpočtem České republiky.

Obsah přednášky

- Rozsah měřených polí
- Typy magnetických senzorů
- Základní principy a nové trendy:
  - Polovodičové senzory
  - XMR
  - Fluxgate
  - Resonanční senzory
  - Indukční cívky

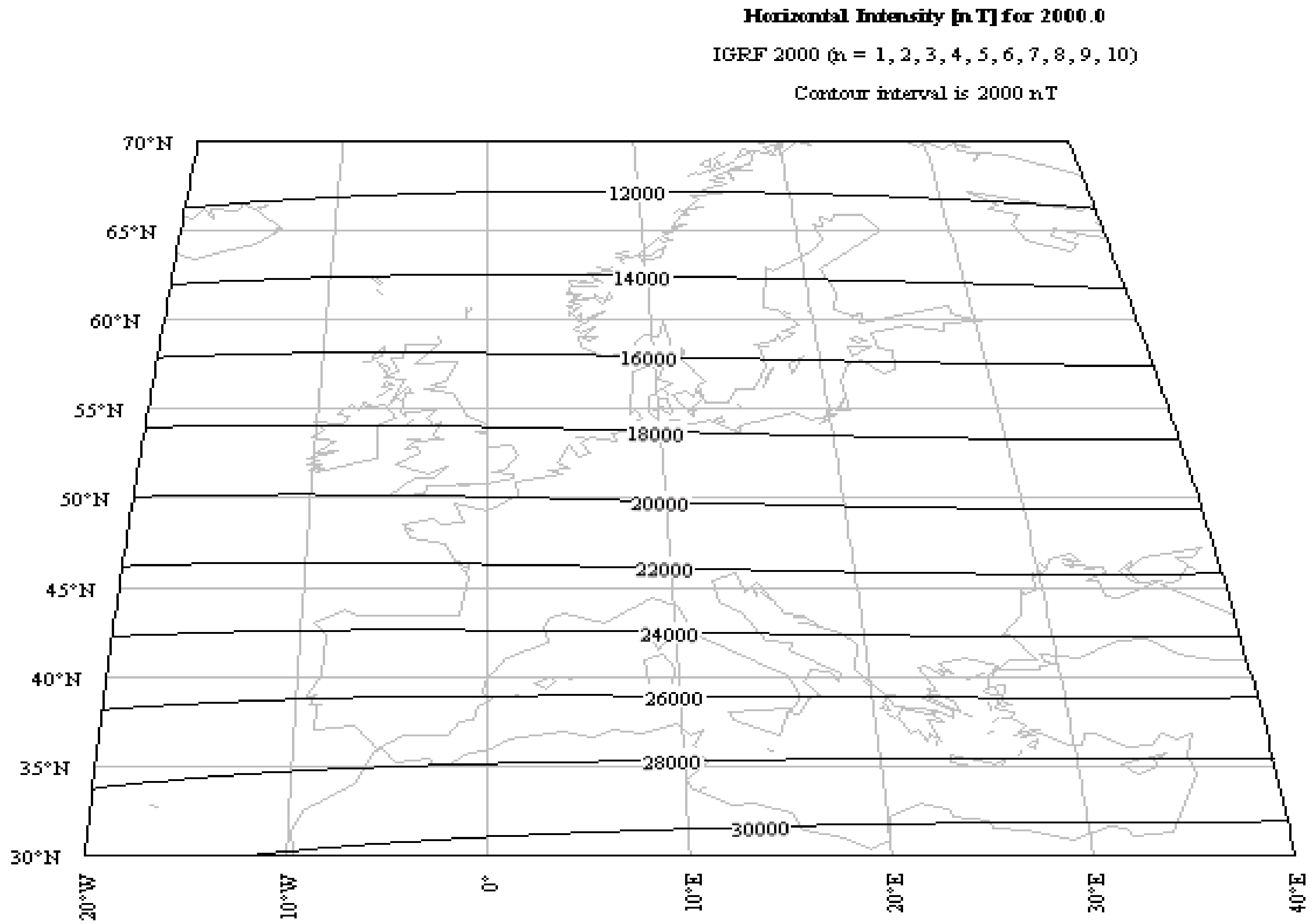
  ….

Motivation: applications

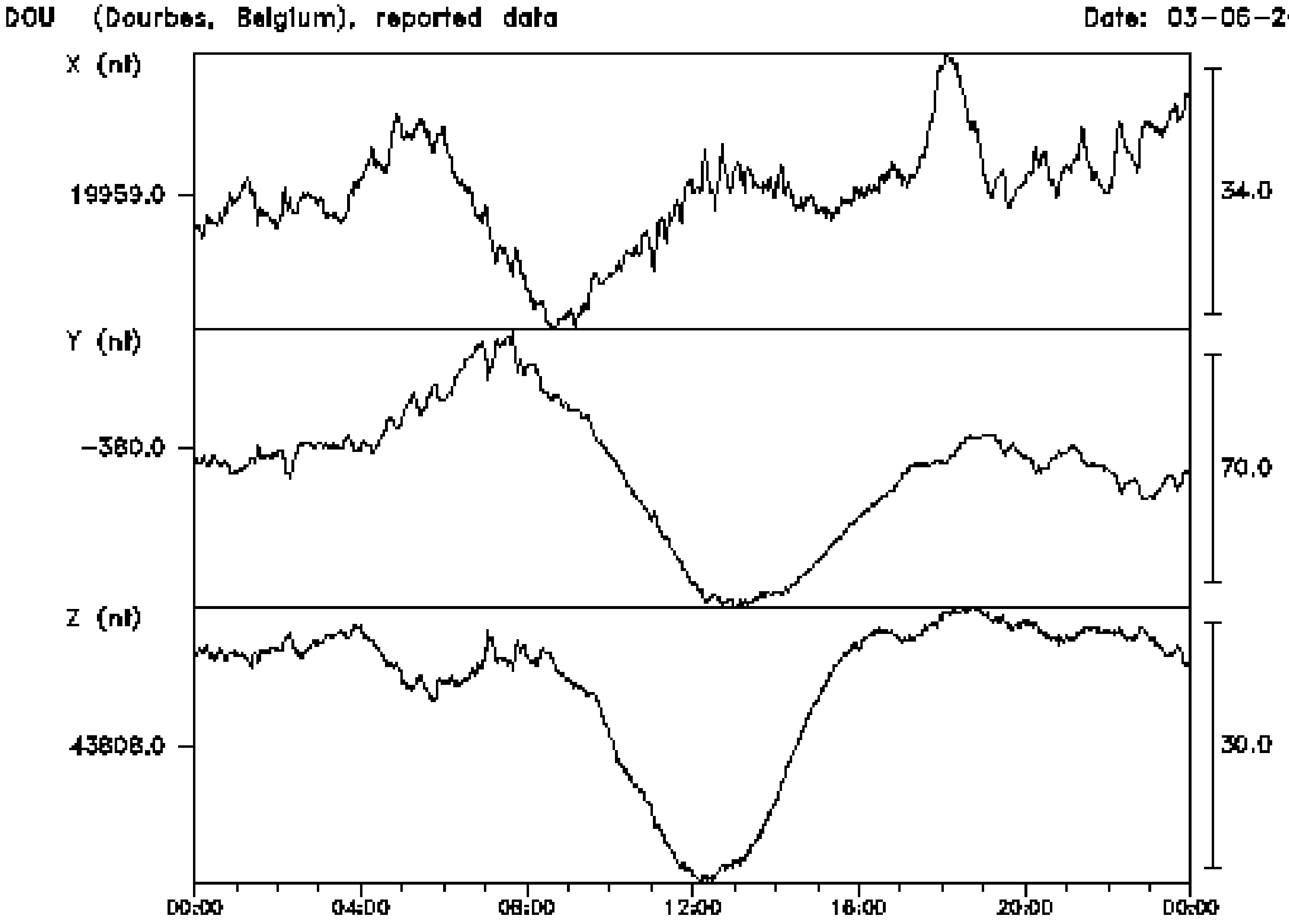
The Earth's field: total 50 μT, horizontal 20 μT

- Compass
  - 1 deg ~ 350 nT ... makes 17 m error in 1 km
  - 0.1 deg ~ 35 nT
  - gimballing error
- UXO location
  - 155 mm projectile 1.5 m deep ... 10 to 50 nT
  - bomb 6 m deep ... 1 to 5 nT

  1 nT in 50 000 nT ~ 20 ppm


Horizontal Intensity [nT] for 2000.0
IGRF 2000 (n = 1, 2, 3, 4, 5, 6, 7, 8, 9, 10)
Contour interval is 2000 nT
70°N
65°N
60°N
55°N
50°N
45°N
40°N
35°N
30°N
12000
14000
16000
18000
20000
22000
24000
26000
28000
30000
20°W
10°W
0°
10°E
20°E
30°E
40°E

Typical daily variations of the Earth’s field



Magnetic sensors: basic types

- Magnetic field sensors
  - semiconductor
  - ferromagnetic
  - other (optical, resonant, SQUID...)

Magnetic field sensors

Scalar

Measure the size of **B** ("total field B")

$$B = \sqrt{B_x^2 + B_y^2 + B_z^2}$$

only resonant sensors

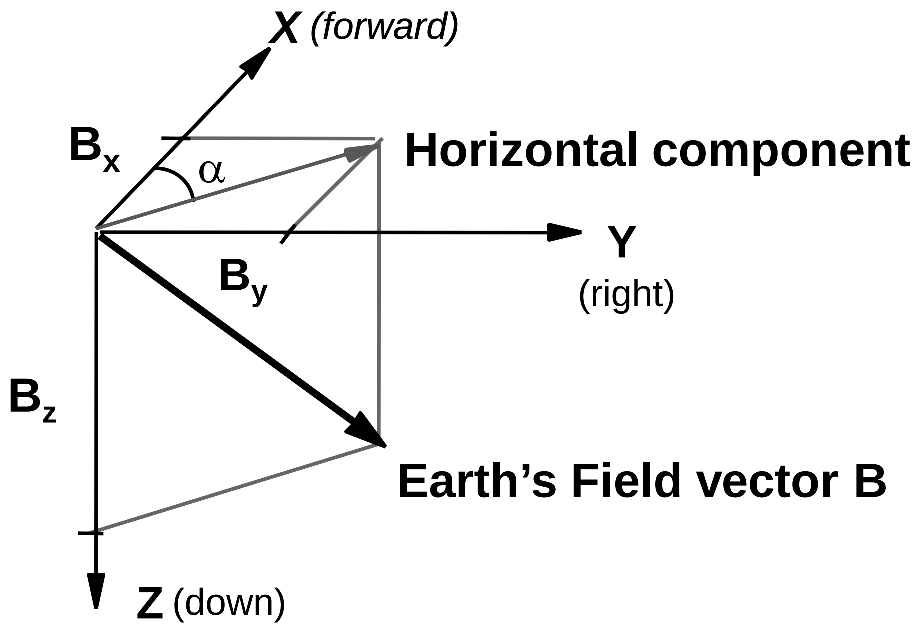
Vector

Measure the projection of **B** into the sensitive axis

- single-axis
- tri-axial

most magnetic sensors

Tri-axial sensors: compass



α = Azimuth or Heading

Magnetic field sensors: DC and AC

AC

Measure only changing field:

induction coils

$$V_i = -\frac{d\Phi}{dt} = -\frac{d}{dt}(NAB)$$

V_i .. Induced voltage

Φ .. Magnetic flux

A .. Coil area

N .. Number of turns

DC

Measure DC and AC fields

most

magnetic sensors

Basic sensor specifications

- FS range, linearity, hysteresis
- TC ("tempco") of sensitivity
- Offset, offset tempco and long-term stability
- Perming (= null change after magnetic shock)
- Crossfield sensitivity
- Noise
  - PSD , rms or p-p value
- Resistance against environment
  - temperature, humidity, vibrations

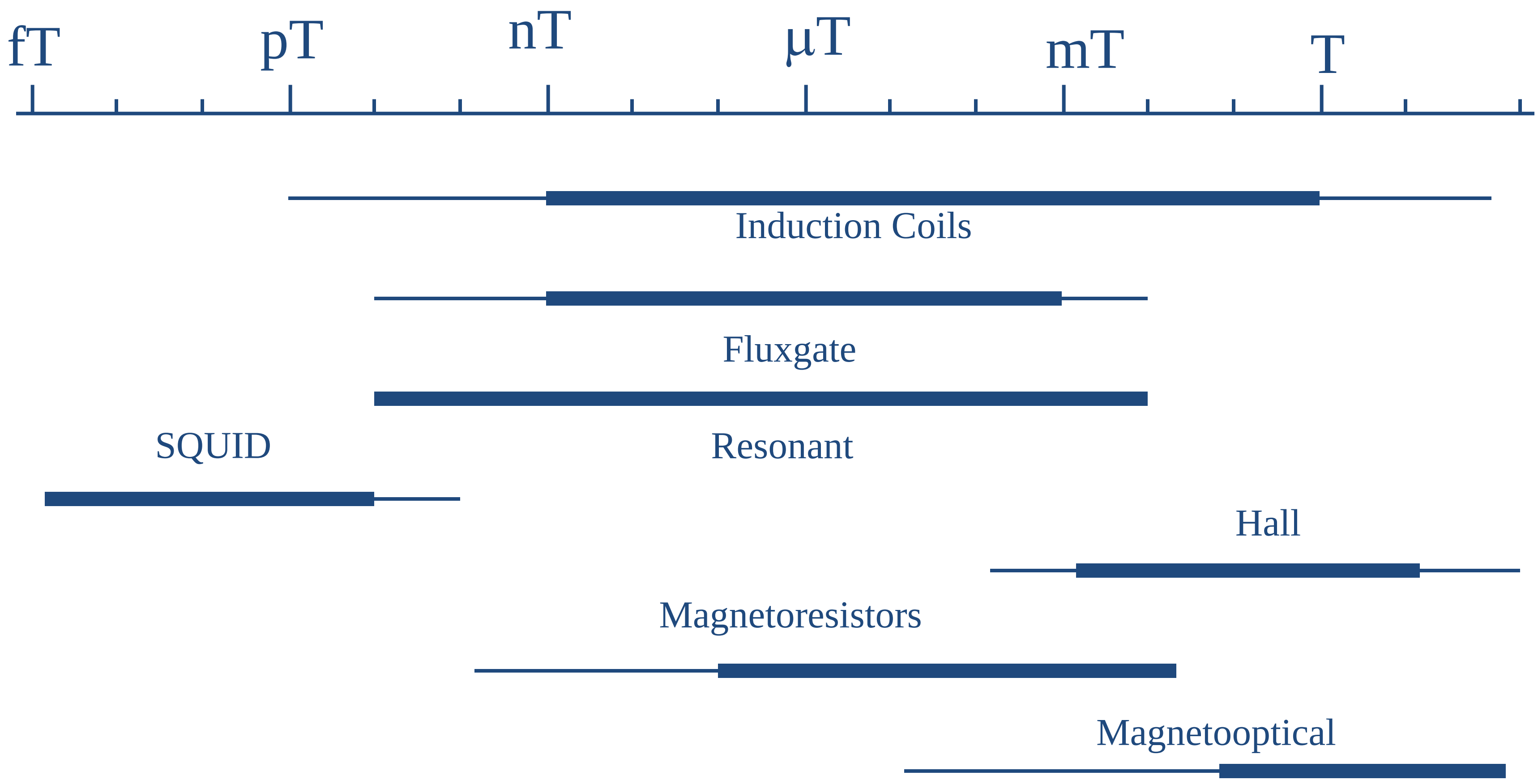
Types of magnetic field sensors

- Semiconductor sensors (Hall, …)
- Ferromagnetic magnetoresistors (AMR, GMR, …)
  - Resonant magnetometers (Proton, Cesium, ...)
  - SQUIDs (LTS + HTS)
  - Induction coils, rotating coils
  - Optical (Fibre optic, ...)
  - Fluxgate
- Other principles (GMI, magnetoelastic, …)

Magnetic field magnitudes

100 T	Pulse field
10 T	Superconducting magnet
2 T	Electromagnet
0.5 T	Surface of strong perm. magnet (NdFeB)
0.1 T	Surface of cheap magnet (ferrite)
10 mT	Power cable
50 μT	Earth's field
1 μT	Vehicle
10 fT	Human brain

Range


fT
pT
nT
μT
mT
T
Induction Coils
Fluxgate
SQUID
Resonant
Hall
Magnetoresistors
Magnetooptical

Basic rules

Dipole field (from small objects)

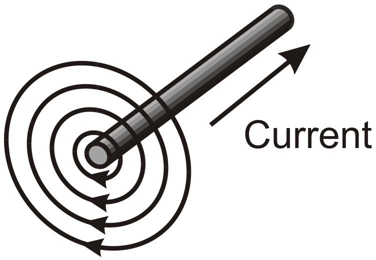
$$B \sim 1/r^3$$

Long iron pipe

$$B \sim 1/r^2$$

Long straight current conductor

$$B \sim 1/r$$

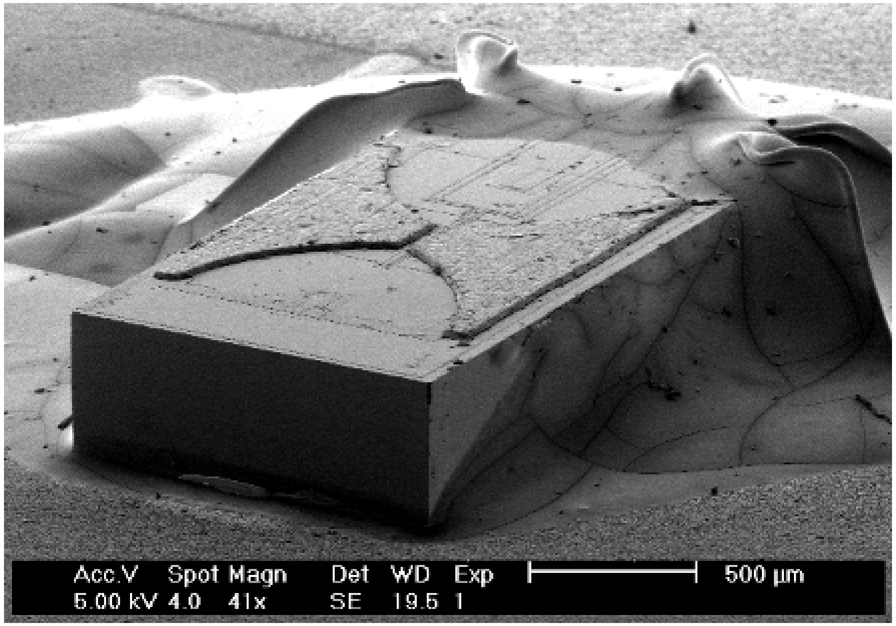


Semiconductor magnetic sensors

- Hall
  - integrated
  - GaAs, Si, (Ge)
  - non-plate: vertical, cylindrical
- Semiconductor magnetoresistors
- *Exotic*

  (magnetotransistors, magnetodiodes, rotating current domain, ...)

Permalloy Flux concentrators



Cylindrical Hall device with integrated magnetic flux concentrators (Sentron AG)

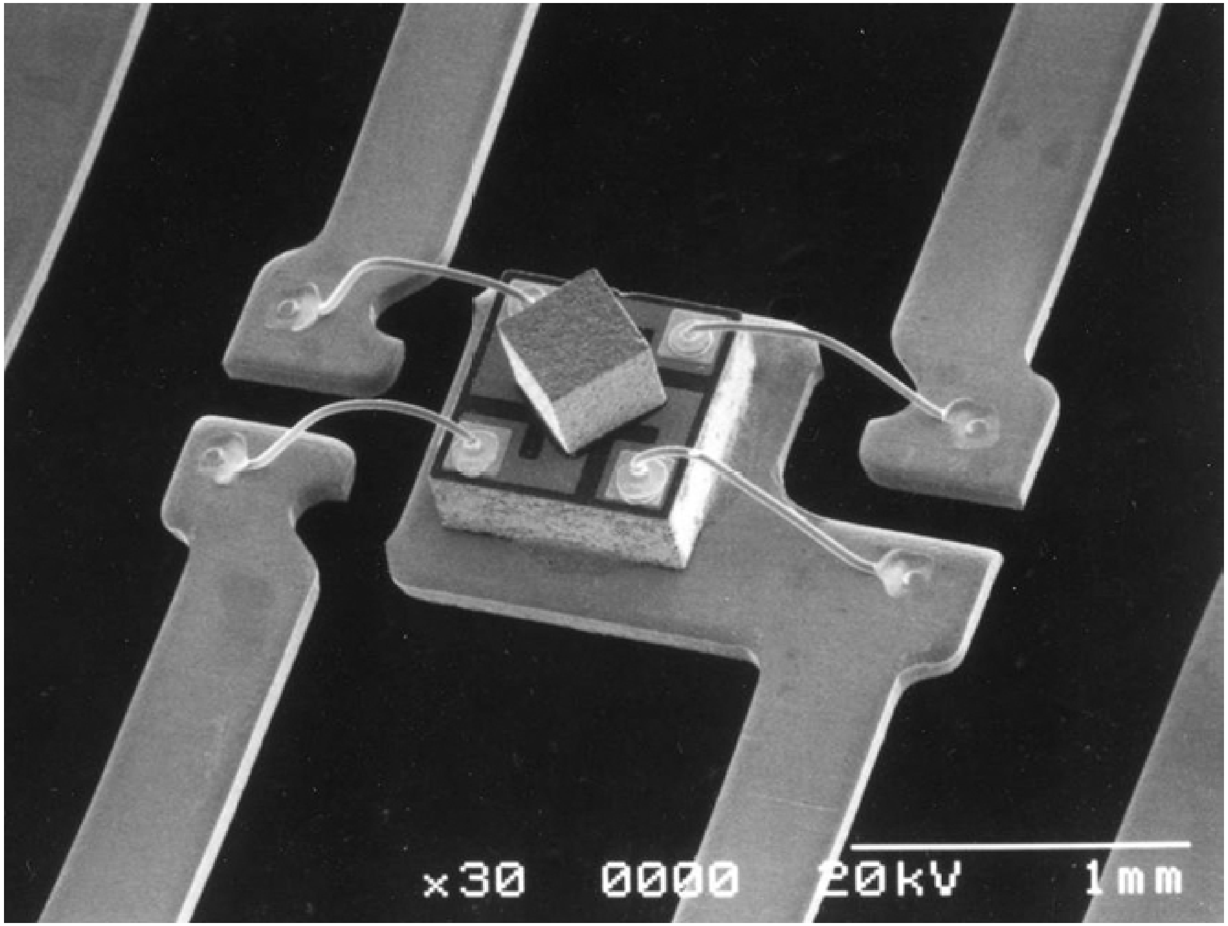
Used for Hall and MR

Increase sensitivity

Possible problems:

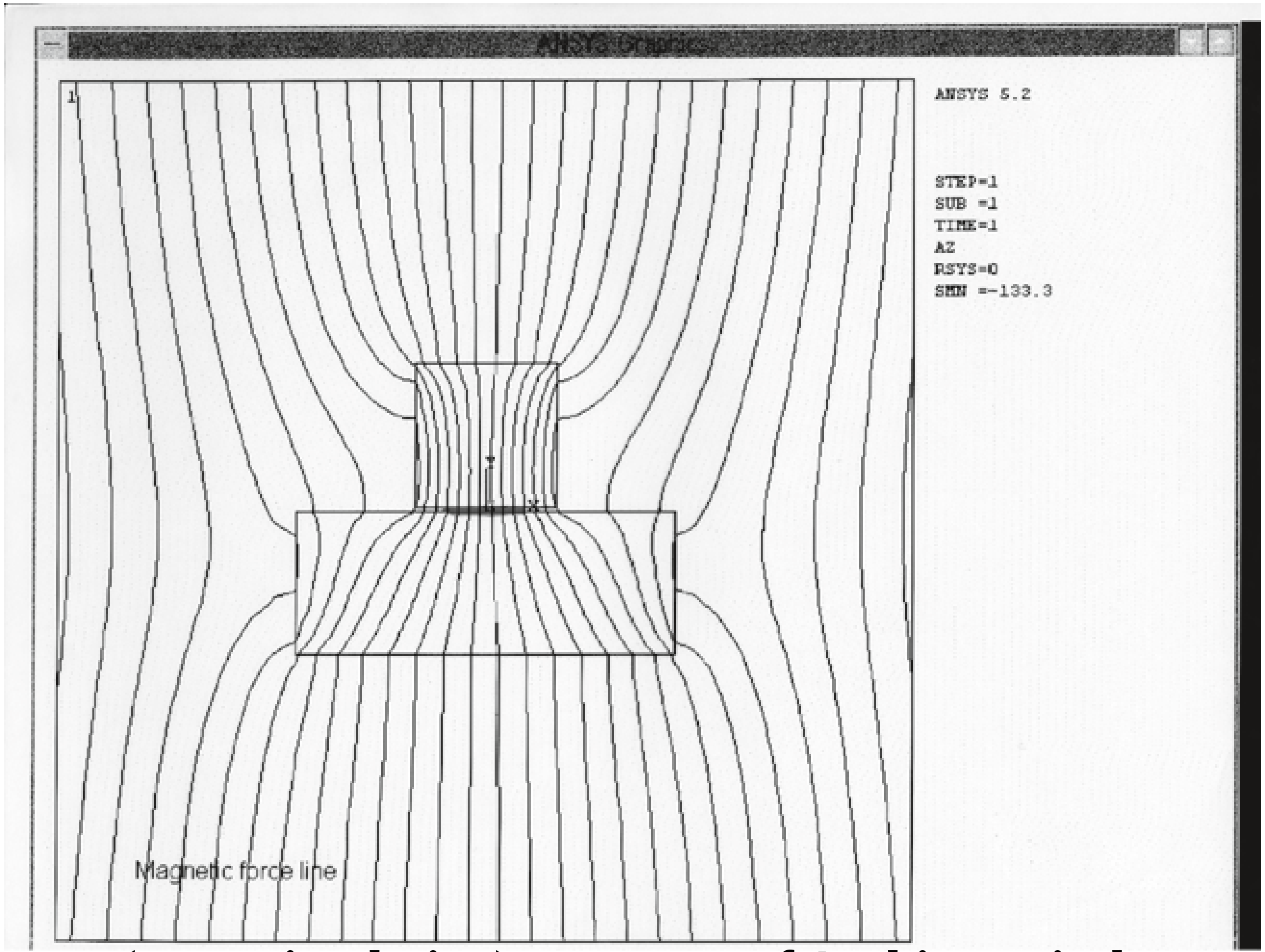
- TC of sensitivity
- perming
- linearity

InSb Hall element with ferrite field concentrator



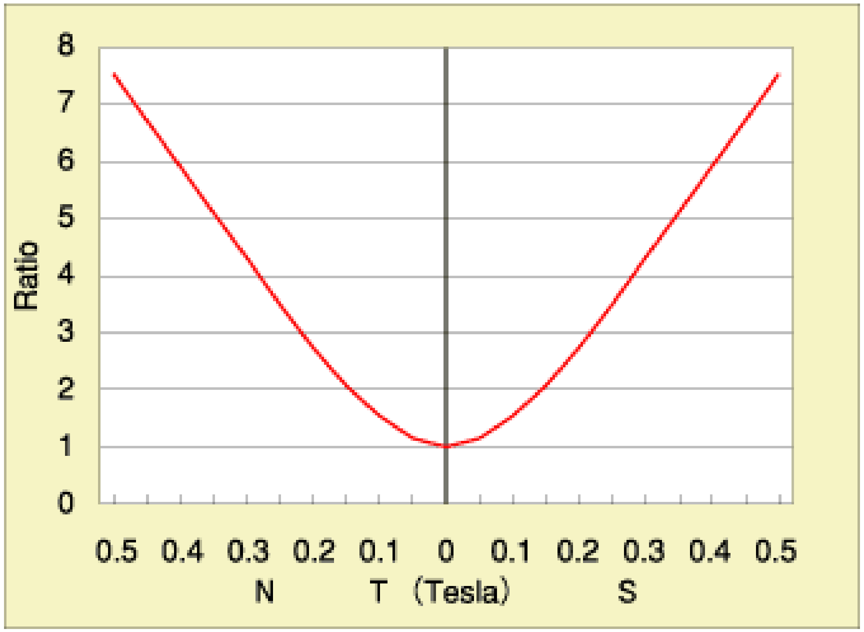
(Asahi Kasei Electronic HW series).

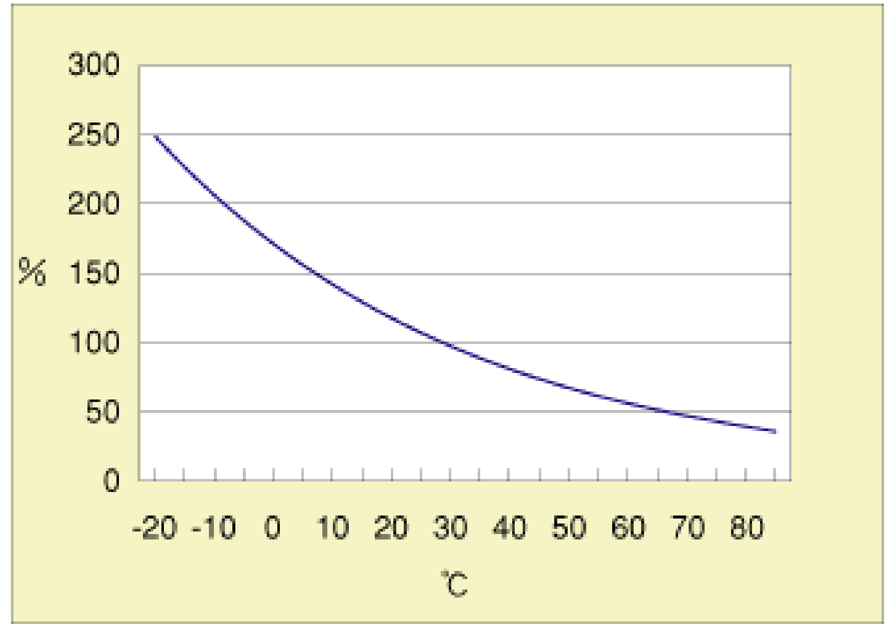
Magnetic force lines of field concentrators for a thin-film Hall sensor



(FEM simulation) - courtesy of Asahi Kasei Electronic

Semiconductor Magnetoresistors



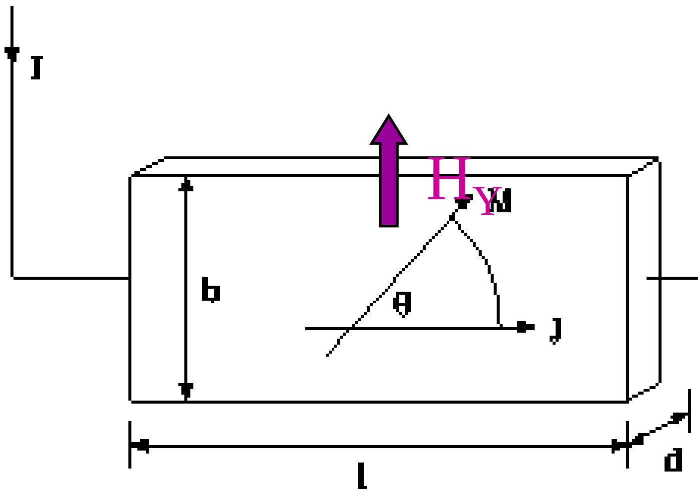


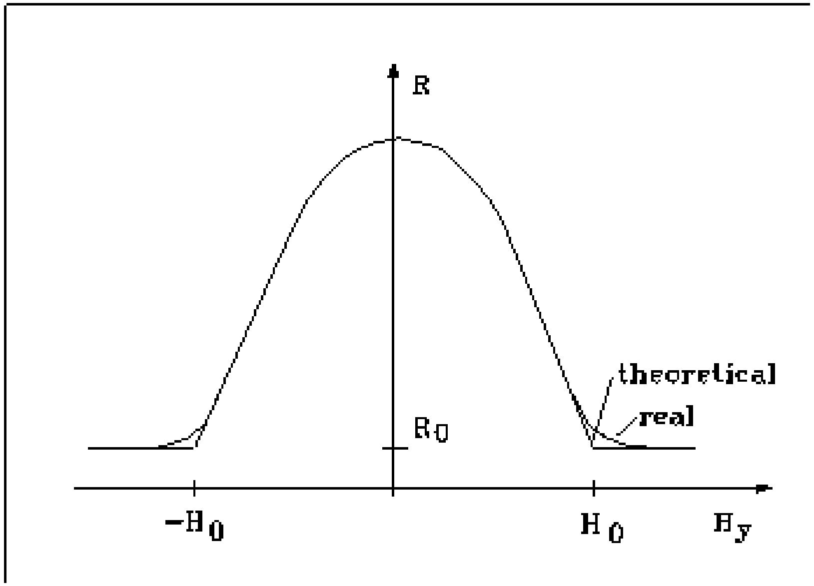
$$R_B = R_0 \frac{\rho_B}{\rho_0}\{1+m(\mu B)^2\}$$

2%/°C

www.murata.com

AMR: anisotropic magnetoresistance

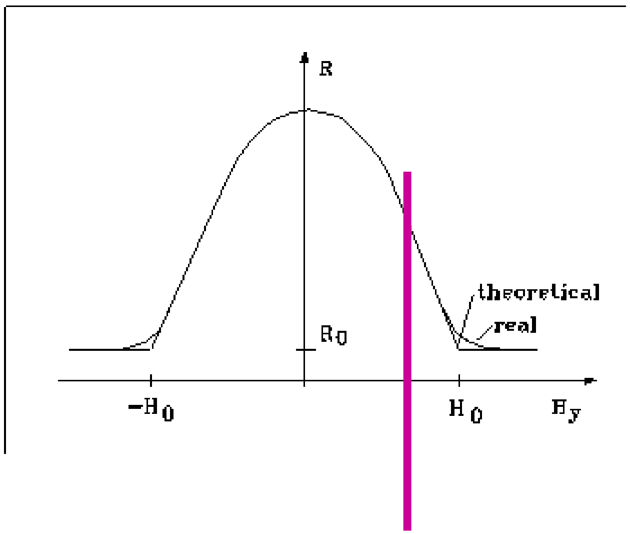




- Permalloy thin film strip deposited on a silicon wafer magnetized in x direction
- **H_Y** rotates magnetisation M → R changes by 2%-3%

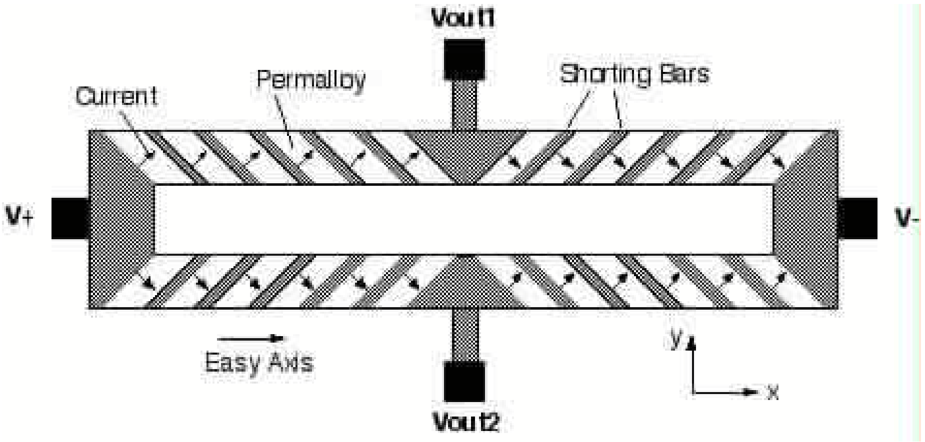
AMR: linearisation

Bad idea:



Shifting the working point by bias field

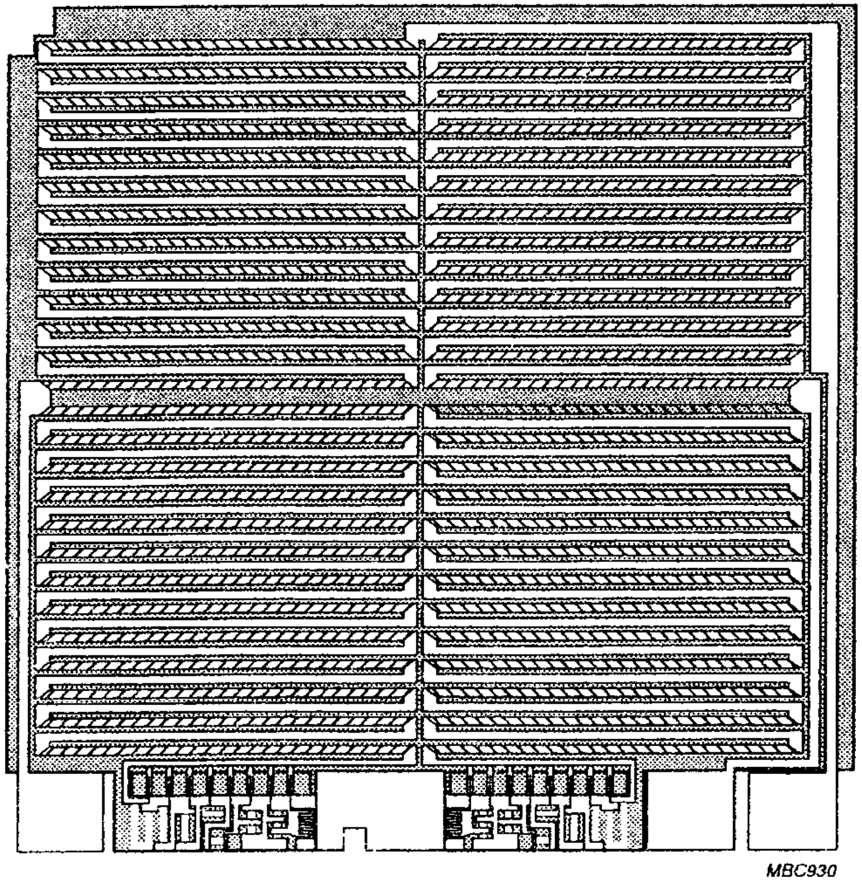
Good idea:

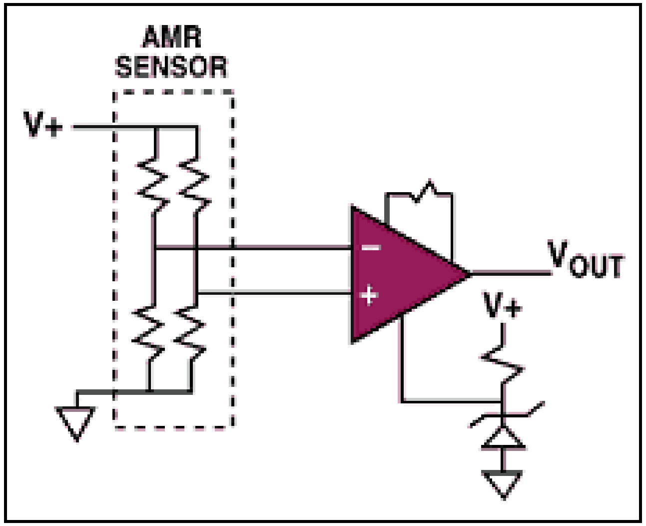


Barber-pole Al bars deflect the current by 45^0

(Honeywell)

AMR bridge sensor





Philips KMZ

Full bridge made of meandered resistors with barber-pole strips

Noise of AMR

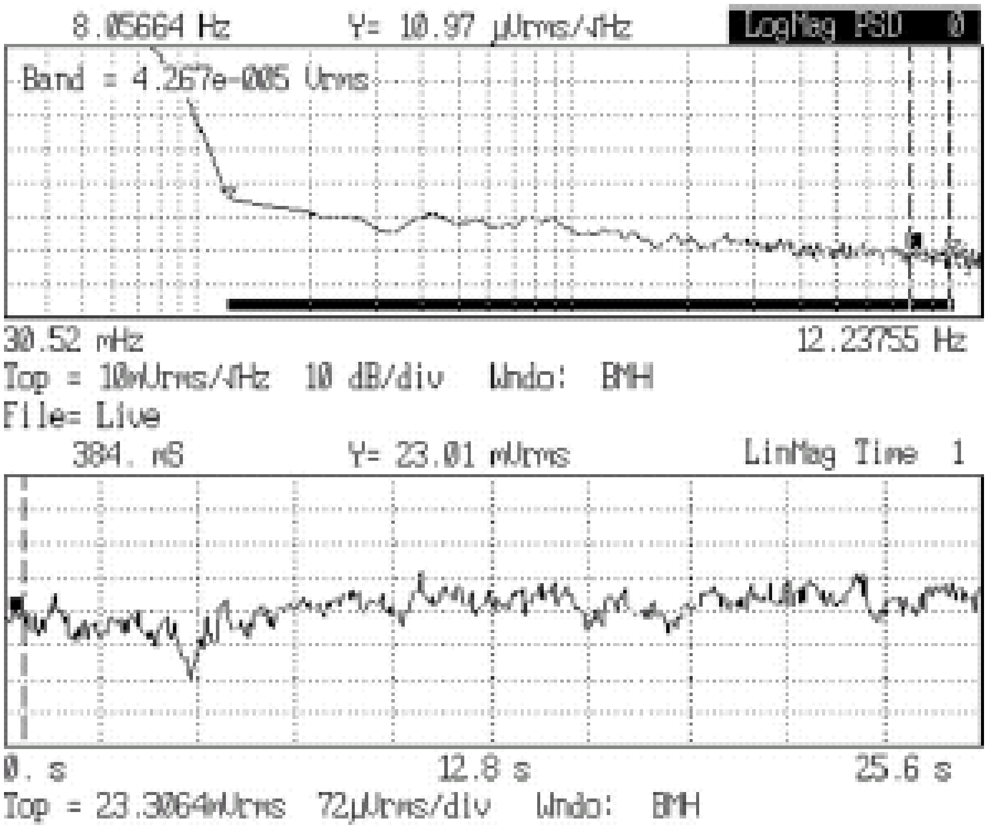
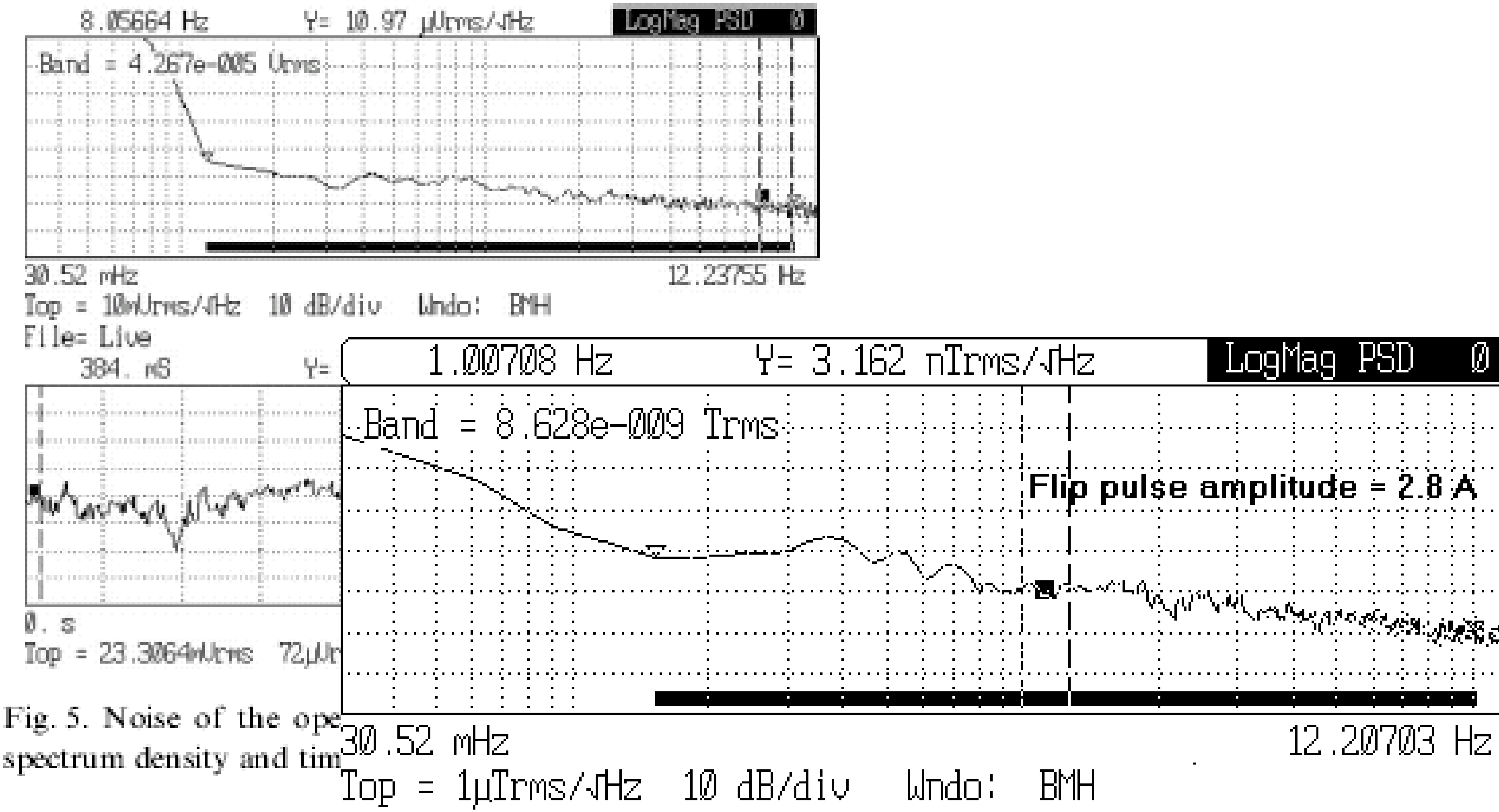
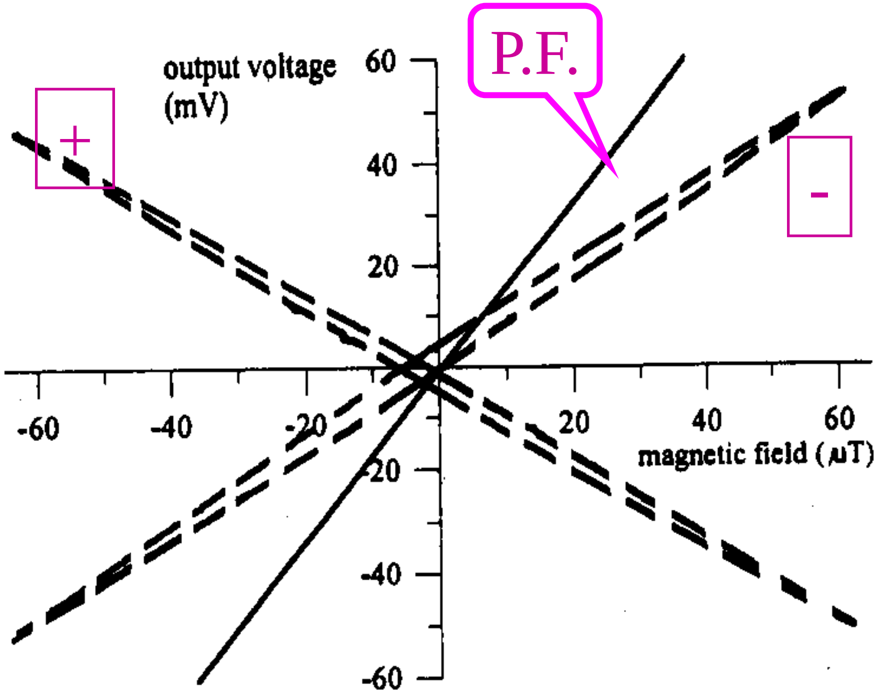


Fig. 5. Noise of the open-loop AMR magnetometer: power spectrum density and time plot (5 nT/div).

Noise of AMR


8.05664 Hz
Y= 10.97 µVrms/√Hz
LogMag PSD 0
Band = 4.267e-005 Vrms
30.52 mHz
12.23755 Hz
Top = 10mVrms/√Hz 10 dB/div Wndo: BMH
File= Live
384. mS
0. s
Top = 23.3064mVrms
1.00708 Hz
Y= 3.162 nTrms/√Hz
LogMag PSD 0
Band = 8.628e-009 Trms
Flip pulse amplitude = 2.8 A
30.52 mHz
12.20703 Hz
Top = 1µTrms/√Hz 10 dB/div Wndo: BMH
Fig. 5. Noise of the ope
spectrum density and tim

AMR: flipping



Characteristics of Philips KMZ 10

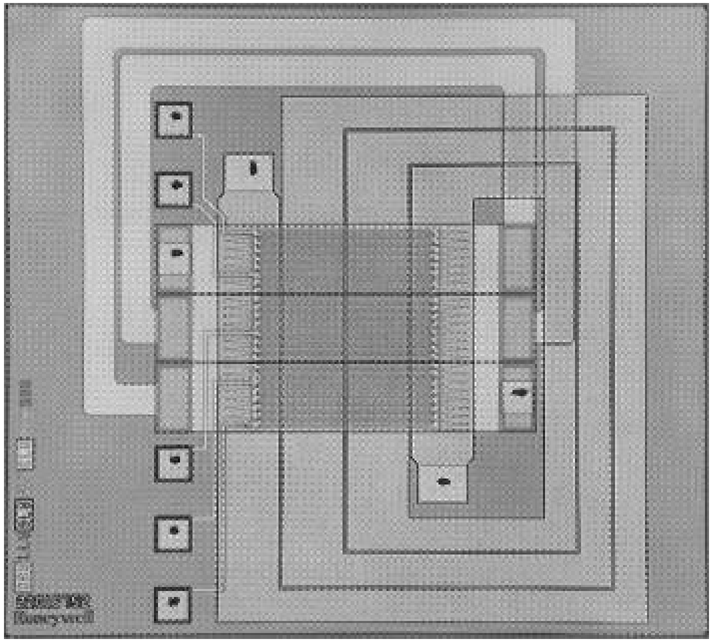
after positive [+] and negative [-] flip

P.F. is characteristics for periodicalflipping

Unwanted change of strip permanent magnetization may distort the sensor characteristic.

Periodical saturation of the permalloy strips is the cure

AMR: flipping



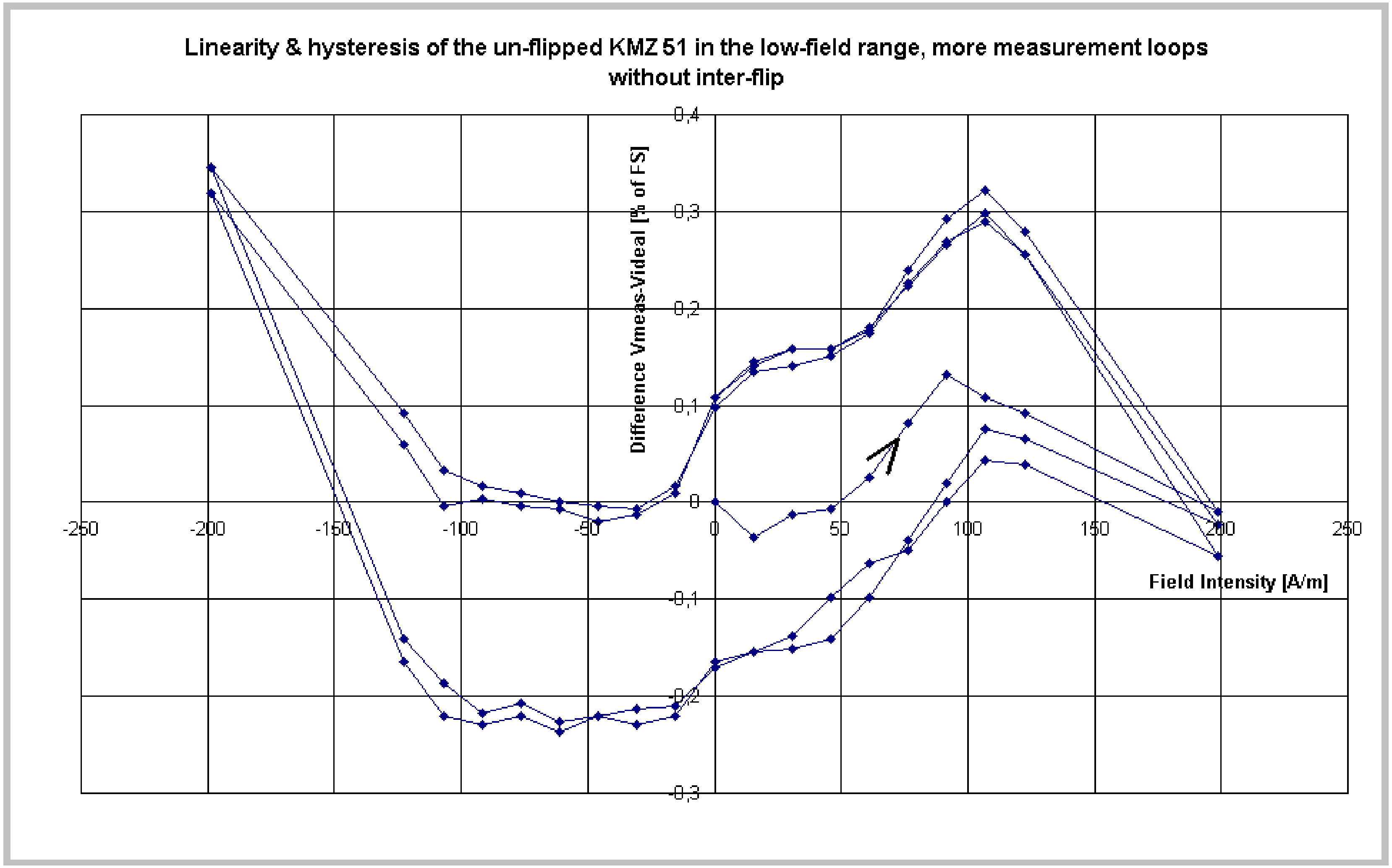
Honeywell AMR sensor

with integrated flat flipping coil

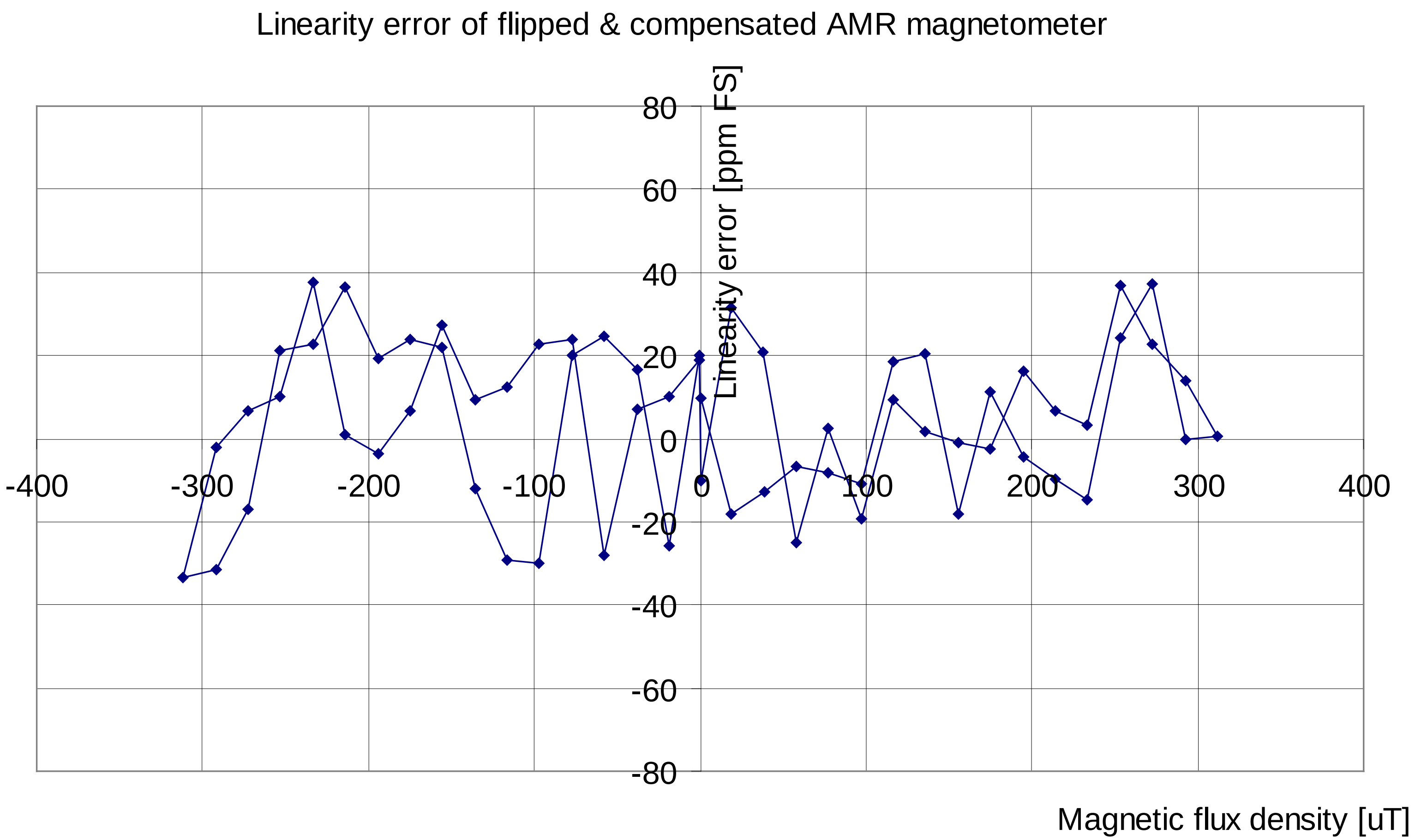
Flipping:

+ decreases offset
+ reduces perming
+ increases sensitivity
- increases power consumption

KMZ 51 – virgin accuracy



Flipped + compensated KMZ 51 - overall accuracy



KMZ 51 - overview

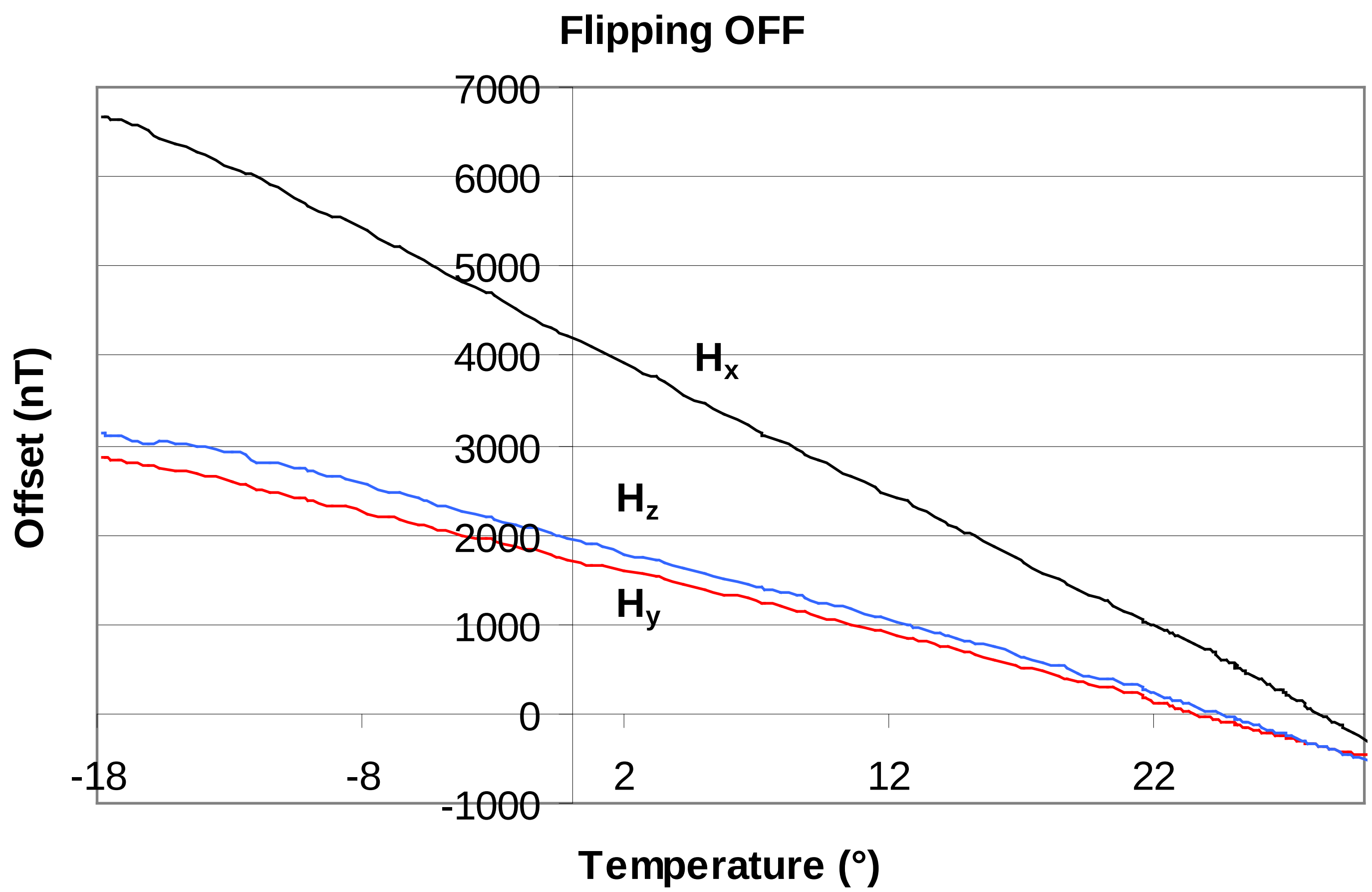
- **no flipping:**
  - Linearity and hysteresis: +/- 1 % FS (+/- 300uT)
  - Tempco. OFFSET –90 nT/K
  - Tempco. SENSITIVITY –585 ppm/K

- **flipping & feedback:**
  - Linearity and hysteresis: +/- 40ppm FS (+/-300uT)
  - Tempco. OFFSET approx. 2.1 nT/K
  - Tempco. SENSITIVITY approx. 20ppm/K

+ noise: 5 nT/sqrHz @ 1Hz

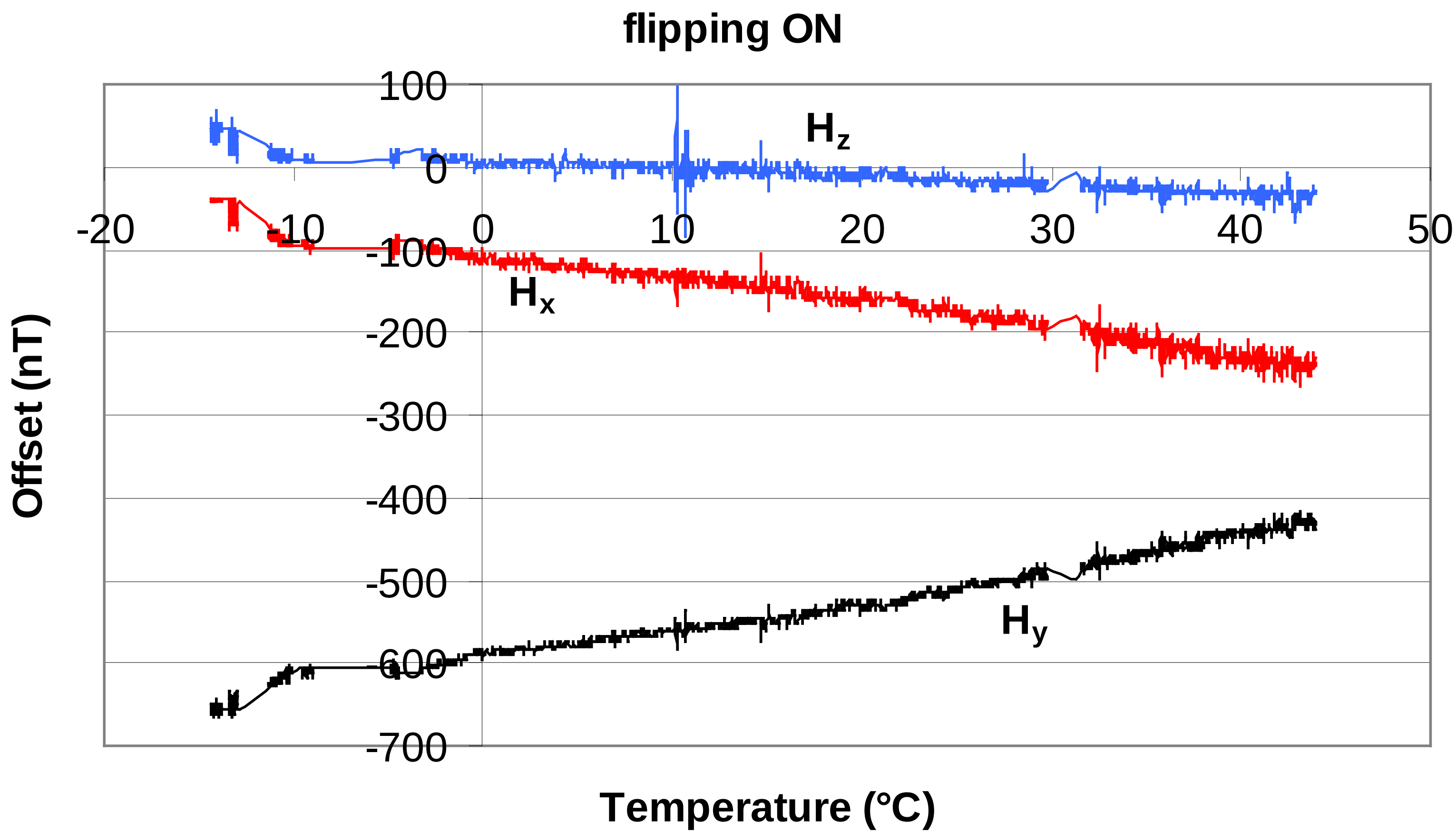
no statistics!

HMC 1001



Flipping OFF
7000
6000
5000
4000
3000
2000
1000
0
-1000
-18
-8
2
12
22
Offset (nT)
Temperature (°)
Hx
Hz
Hy

HMC 1001


flipping ON
100
0
-100
-200
-300
-400
-500
-600
-700
-20
-10
0
10
20
30
40
50
Hz
Hx
Hy
Offset (nT)
Temperature (°C)

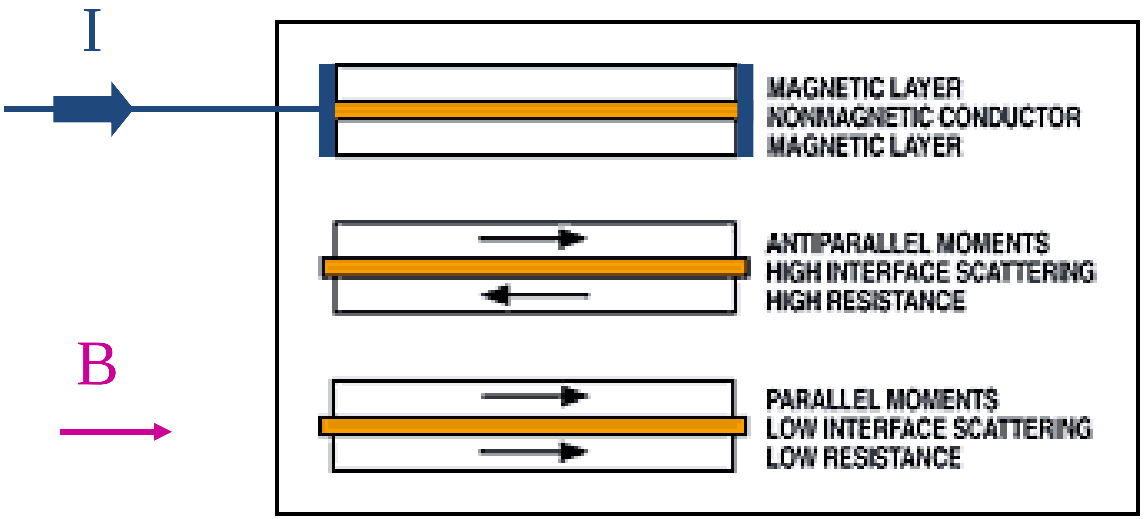
HMC 1001 – offset drift

nT/ 50 ^{O}C	x	y	z
No flipping	7 000	3 500	3 700
flipped	250	200	50

AMR vs. Hall and fluxgate

	Hall with field concentarors	AMR (KMZ 51)	AMR flipped+feedback	fluxgate
linear range	5 mT	300 μT	300 μT	0. 5 mT
size	6 mm	6 mm	6 mm	30 mm
linearity	0.1 < 0.2 %	1 %	40 ppm	1 ppm
sensitivity TC	200 ppm/K	600	20	30
offset@25^{0}C	50 μT	< 10 μT	< 1 μT	5 nT
offset TC	600 nT/K	100 nT/K	2 nT/K	0.1 nT/K
resolution	1 μT	10 nT(1 nT)	10 nT	100 pT
perming, hyst.	1 μT (?)	300 nT	10 nT	< 1 nT
BW	100 kHz	100 kHz	100 Hz	1 kHz
power cons.	55 mW	30 mW	100mW	150 mW

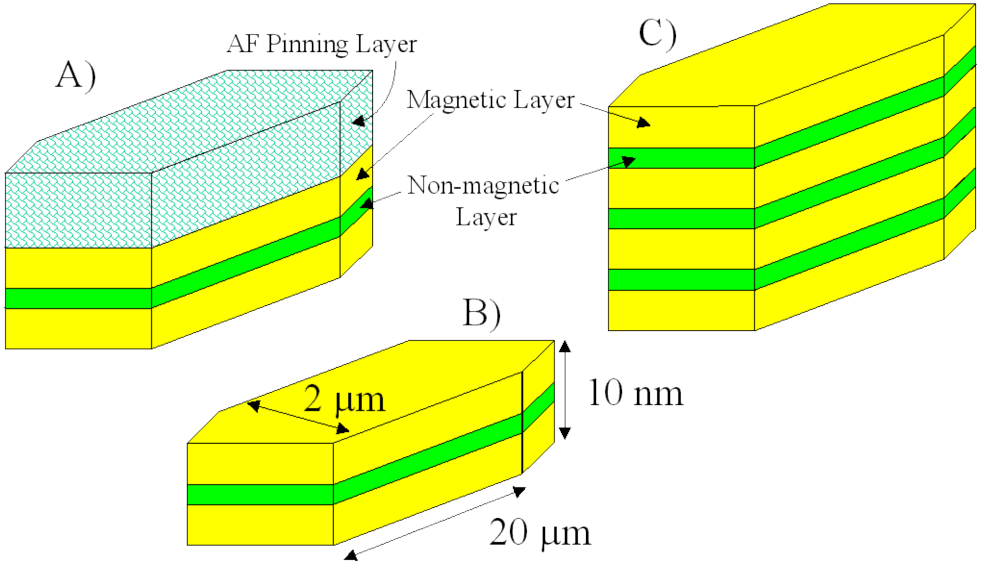
GMR: Giant Magnetoresistance



Spin - dependent scaterring:

Resistance of two thin ferromagnetic layers separated by a thin nonmagnetic conducting layer can be altered by changing the moments of the ferromagnetic layers from parallel to antiparallel.

Common GMR structures



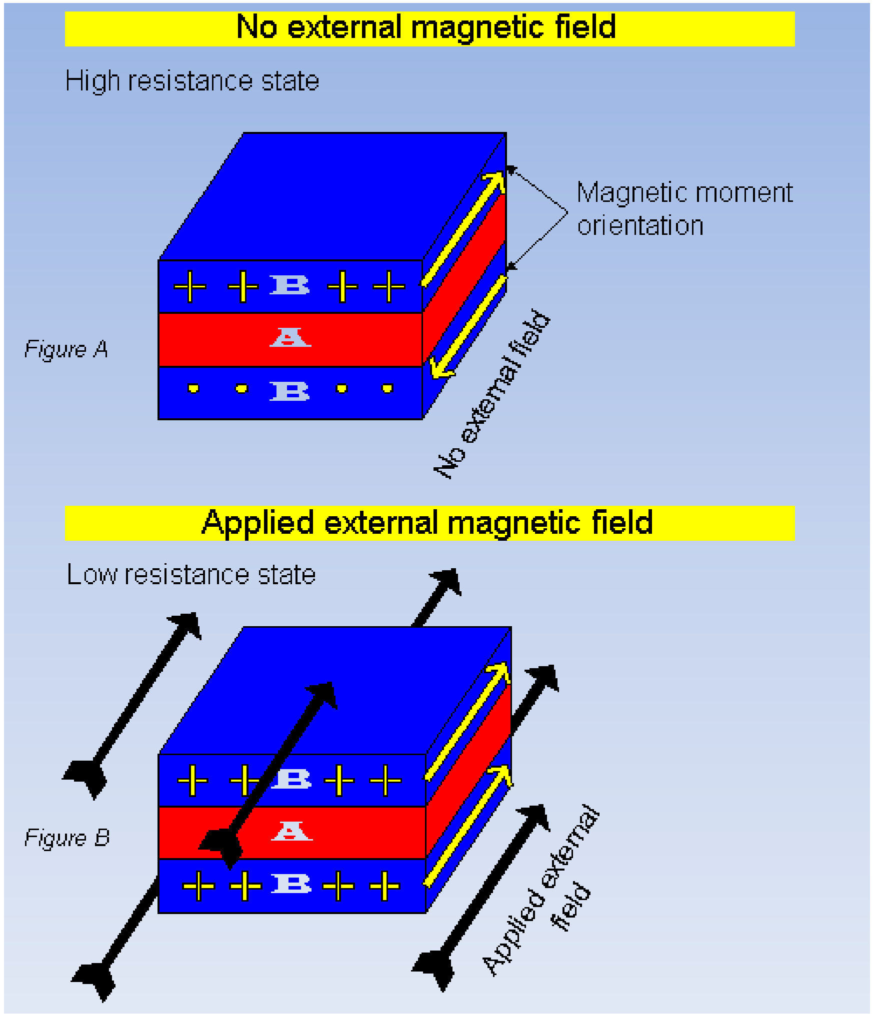
technology developed for reading heads

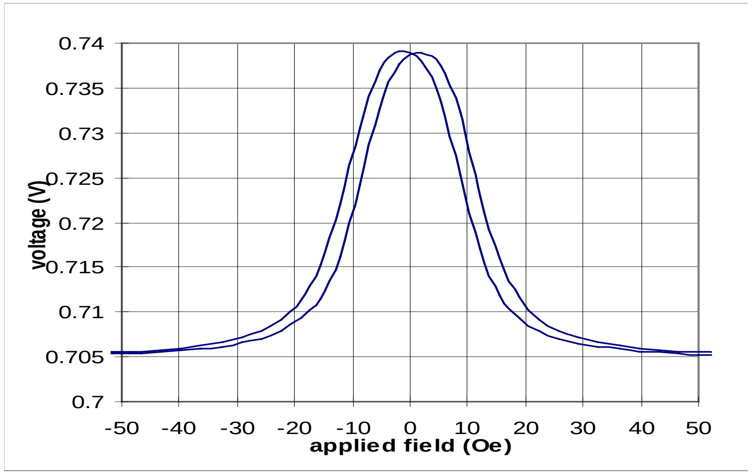
<u>A: Spin valve</u>

B: Sandwich

C: Multilayer

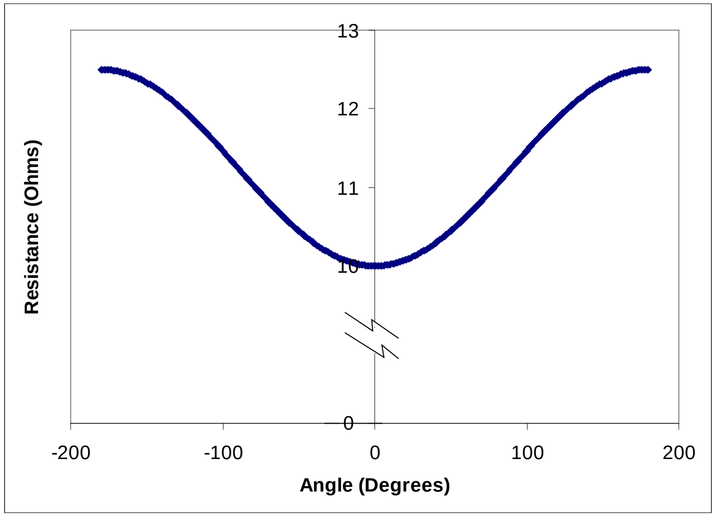
GMR sandwich

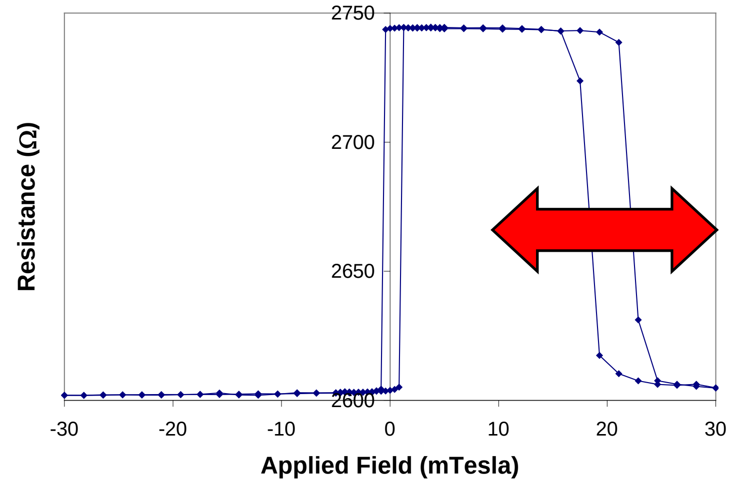




Sensitive, but not good
for linear sensors

GMR: spin valve





Angular response

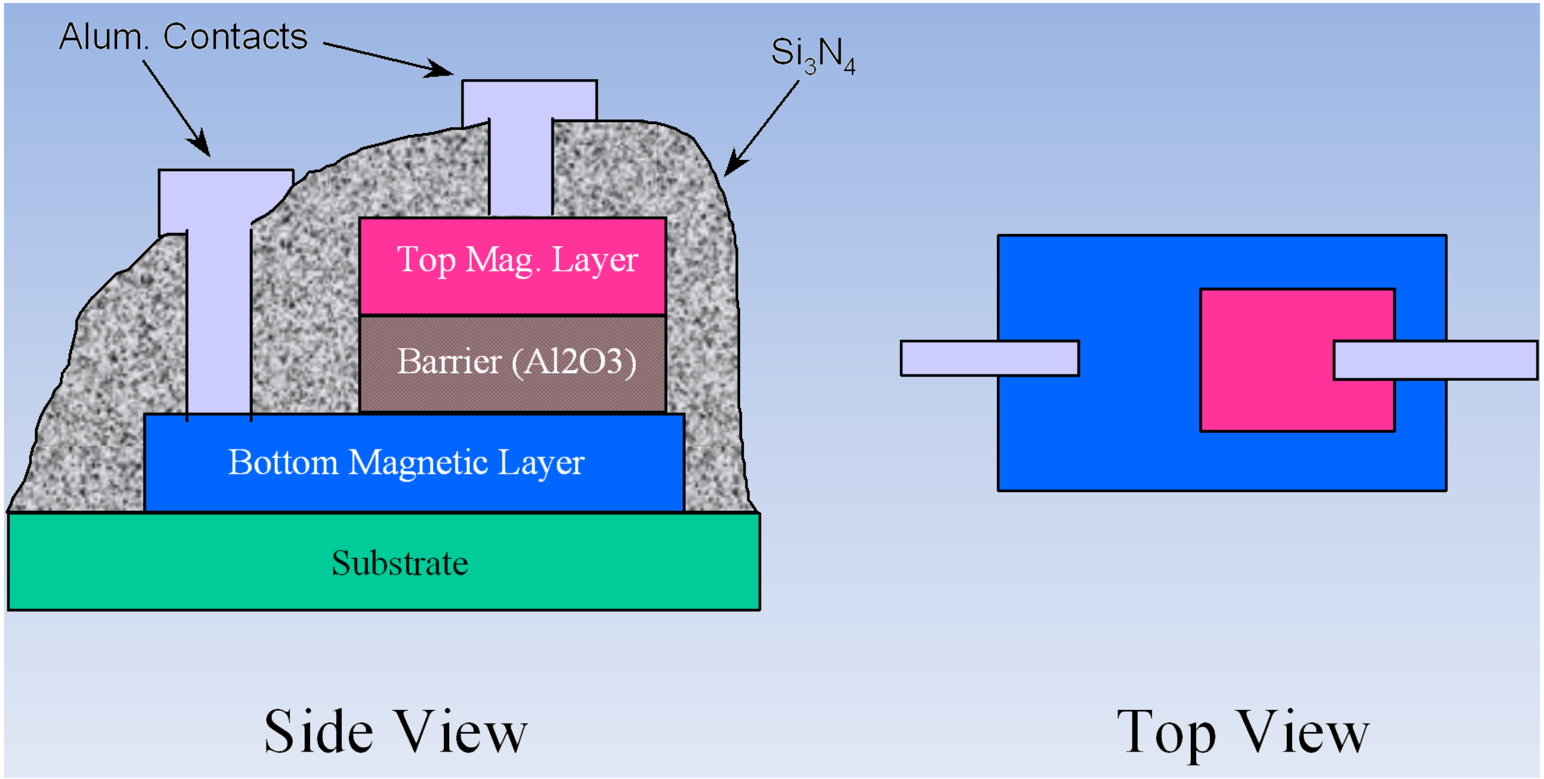
Unpinned soft layer rotates with external field

If saturated, responds only to field direction, not value

Large field response

hard layer may be demagnetized

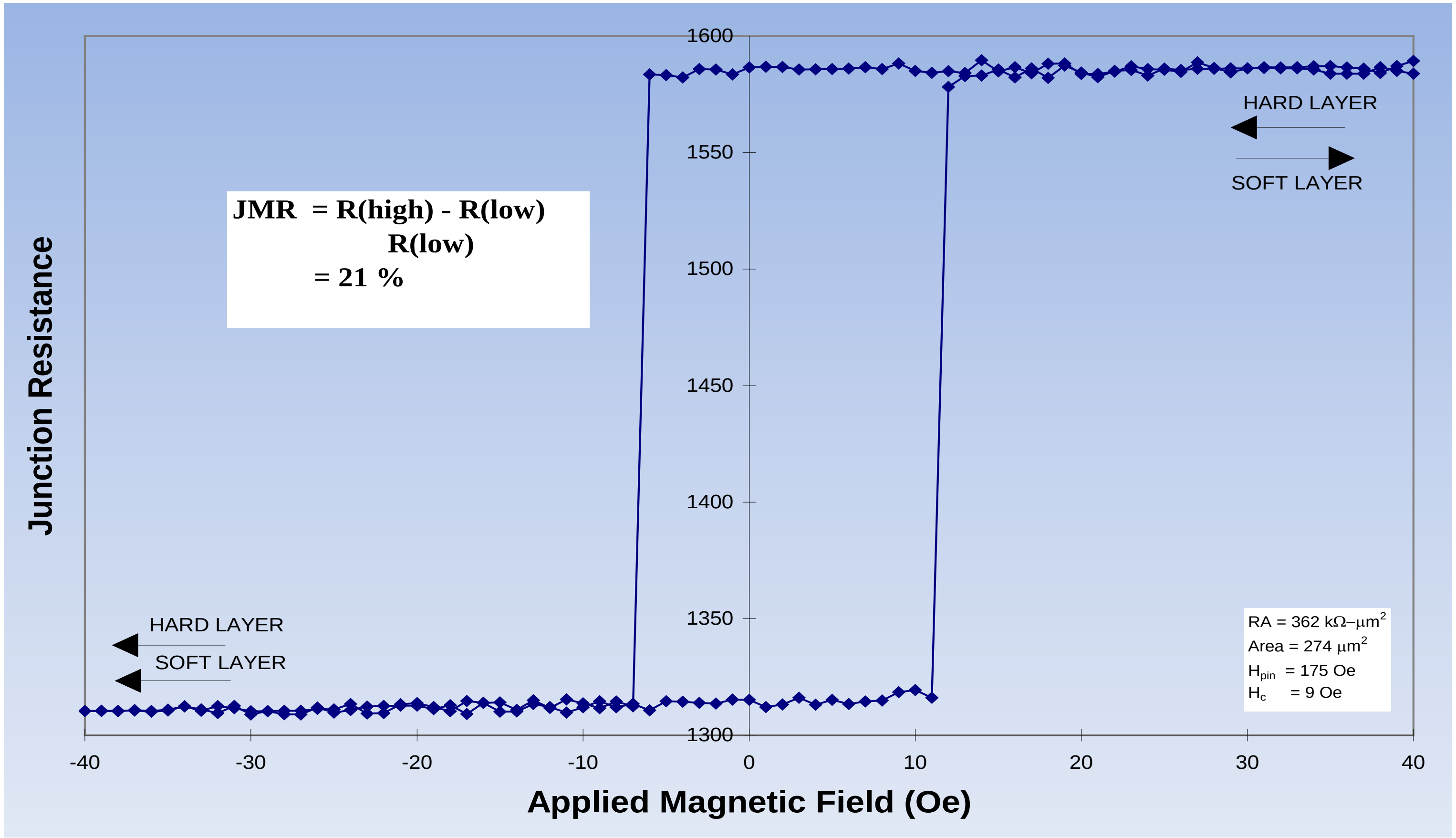
SDT (spin-dependent tunelling) magnetoresistor



source: Mark Tondra, NVE

A cross section of the SDT structure.
The vertical scale is exaggerated so the thicknesses are visible.
The lateral dimensions of the tunnel junctions range from 0.1 μm to 1000 μm.

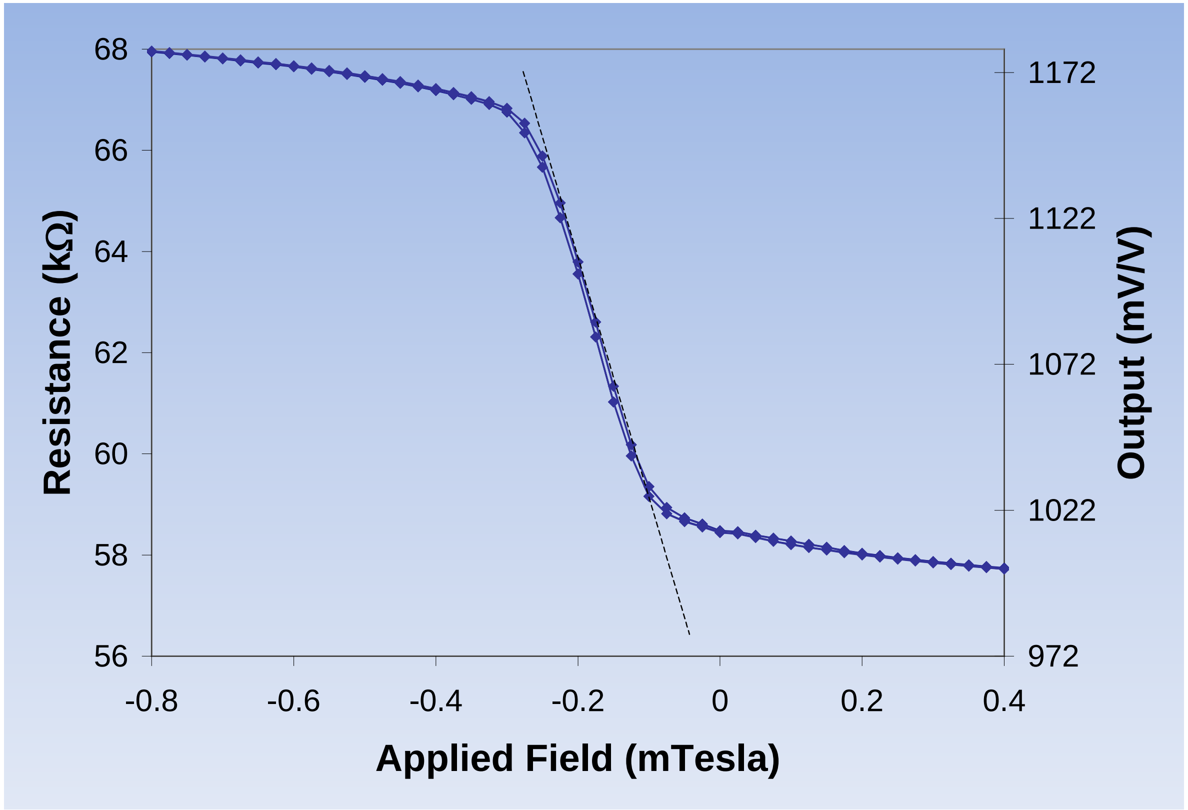
SDT (spin-dependent tunelling) magnetoresistor



The magnitude of the SDT magnetoresistance can be greater than 40% compared to ~10% for spin valves.

source: Mark Tondra, NVE

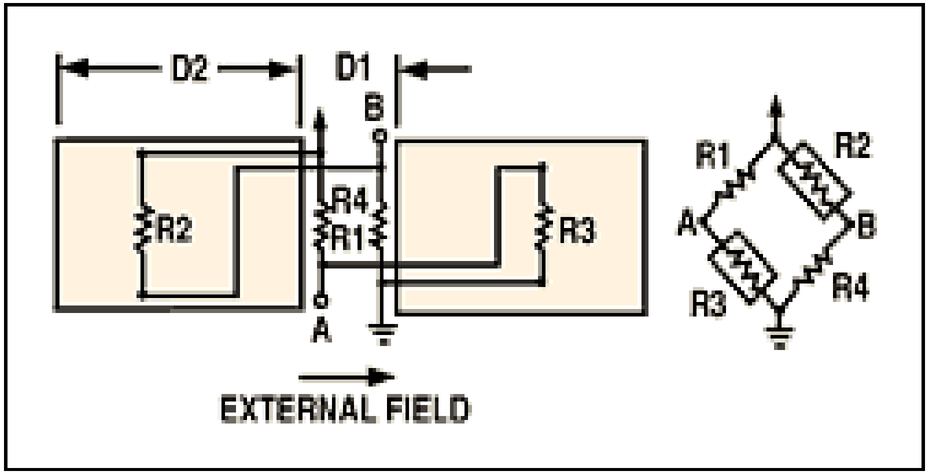
Biased SDT sensor



A common magnetic tool for getting a linear response from almost any material is to incorporate a feedback coil and measure the current in this coil that is required to keep the sensor's output at a certain value.

source: M. Tondra, NVE

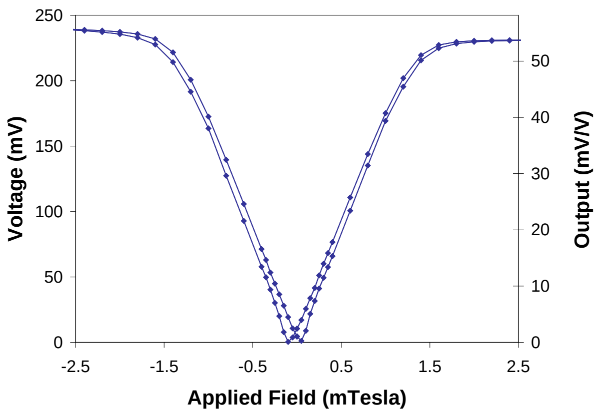
GMR bridge sensor



GMR resistors configured as a Wheatstone bridge sensor (NVE)

- R2, R3 are shielded
- R1, R4: field is concentrated by approx. D1/D2

Still has nonlinear response unlike AMR bridge (NVE)



Advantages of magnetoresistors

Compared to Hall sensors:

- high sensitivity
  - for position sensors: magnet may be cheaper or smaller or airgap higher
  - for magnetic field sensors: higher accuracy
- no piezo effect
- higher operational temperatures

GMI

Giant magnetoimpedance effect

Based on $Z \sim \delta \sim \mu \sim B$,

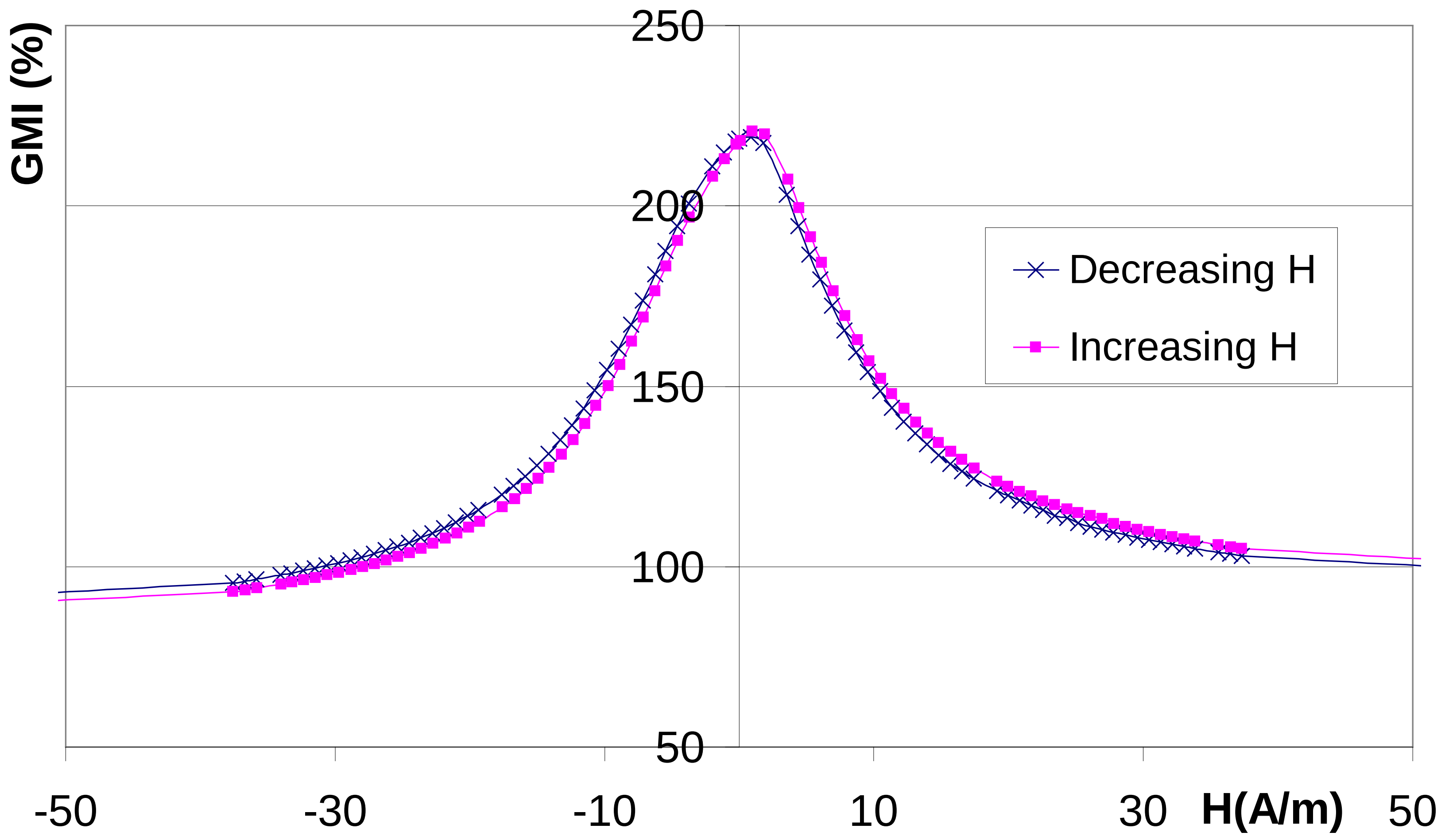
Works on MHz frequencies

Problems: perming

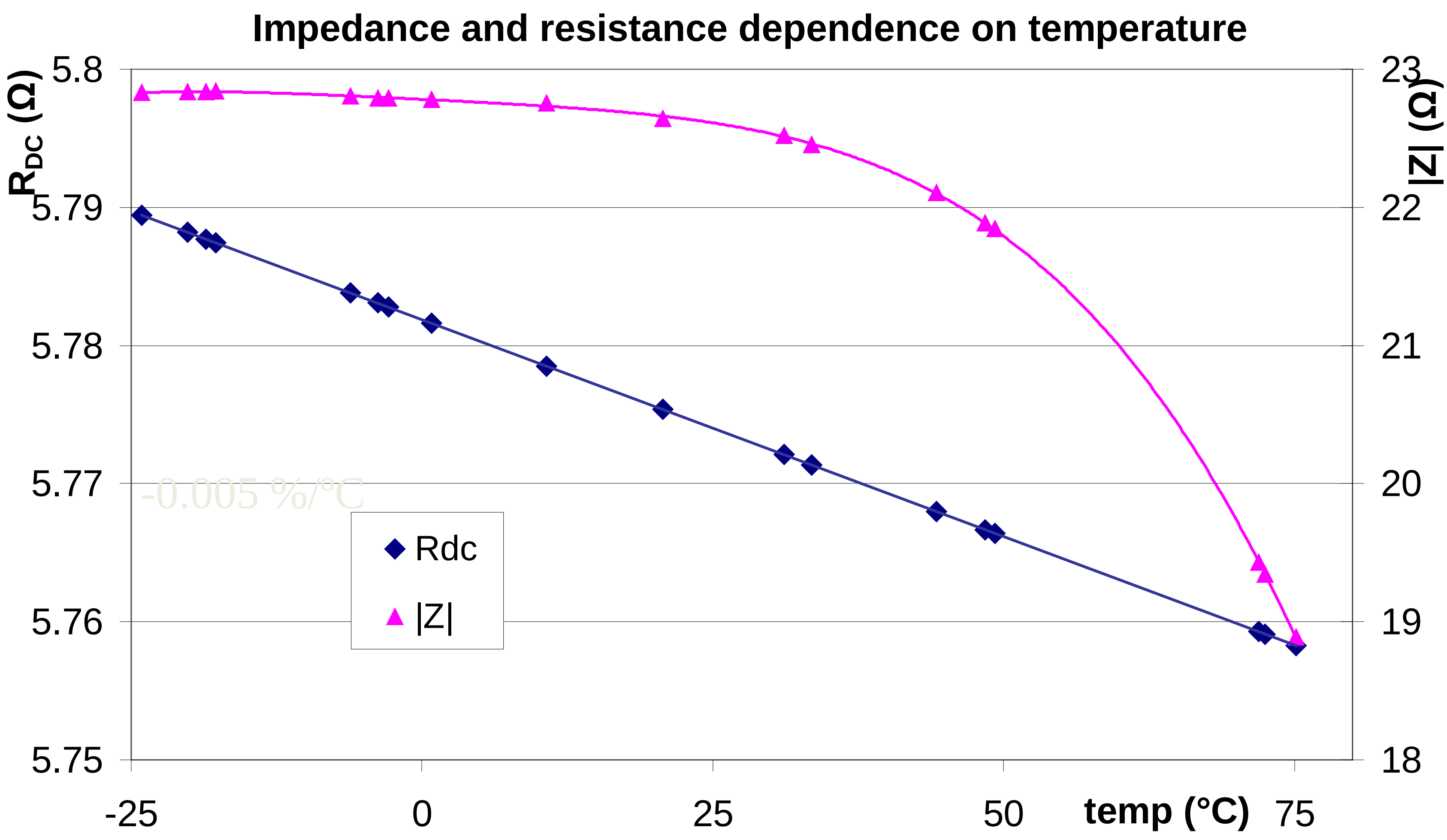
temperature dependence (30nT/K)

even response (need bias)

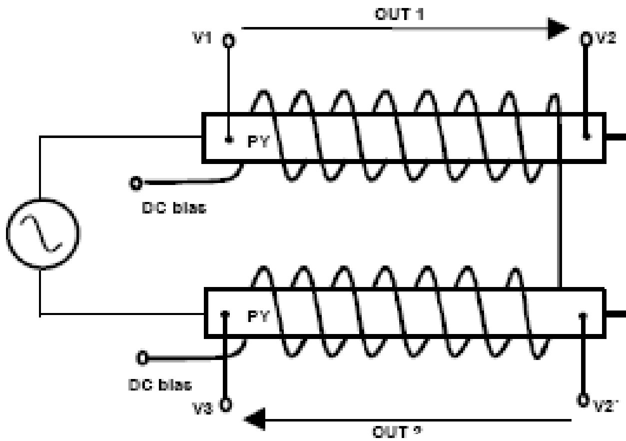
GMI curve

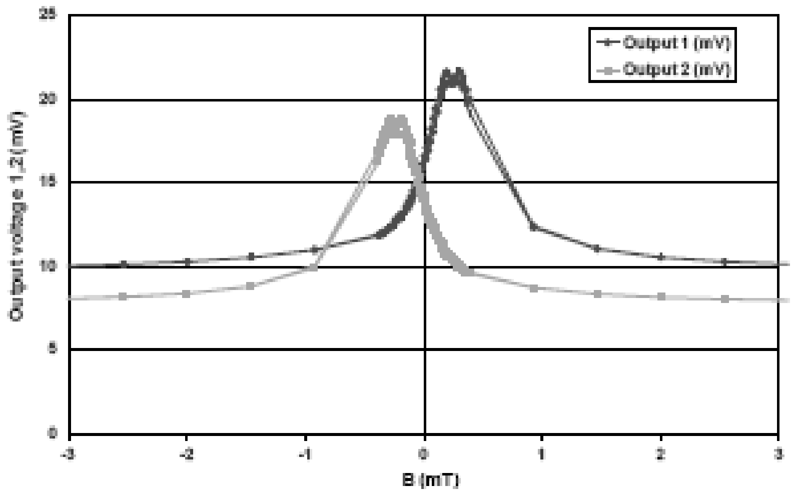

GMI (%)
250
200
150
100
50
-50
-30
-10
10
30
H(A/m)
50
Decreasing H
Increasing H

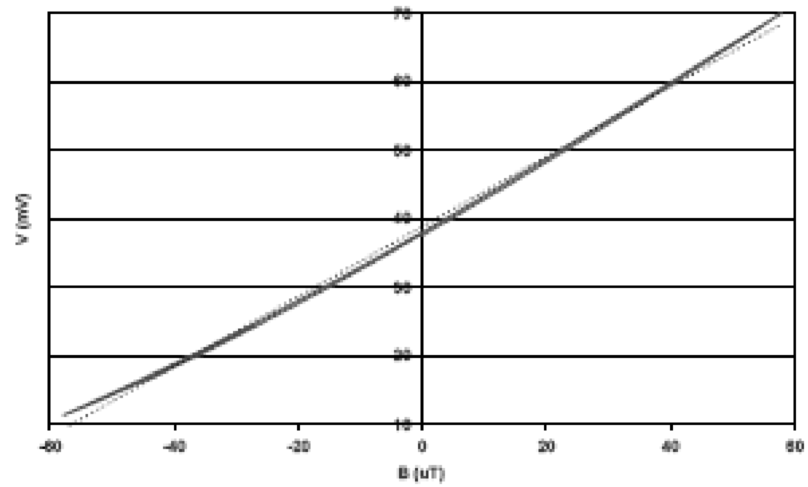
Temperature drift



Double-core GMI

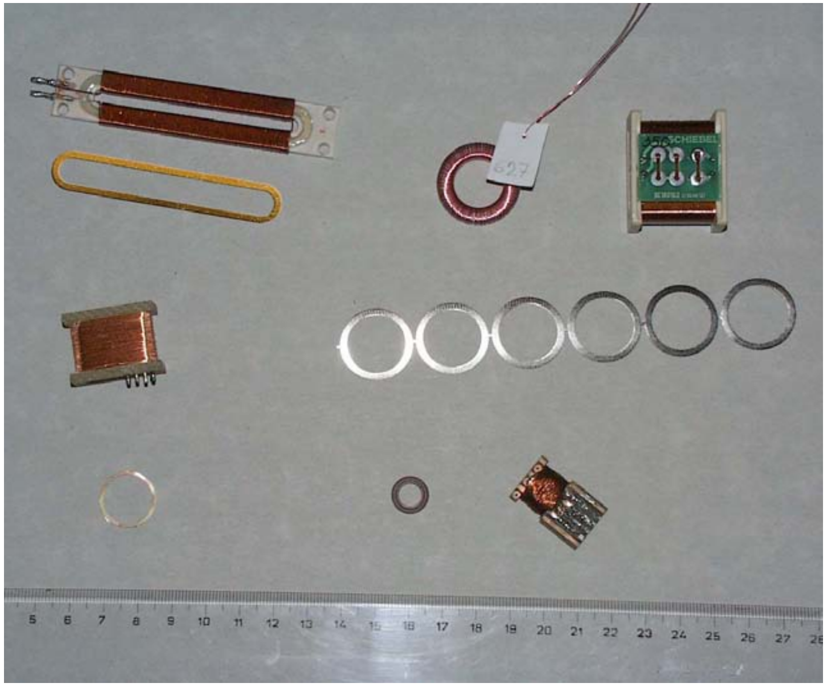






resulting characteristics

Fluxgate sensors



Classical fluxgates:

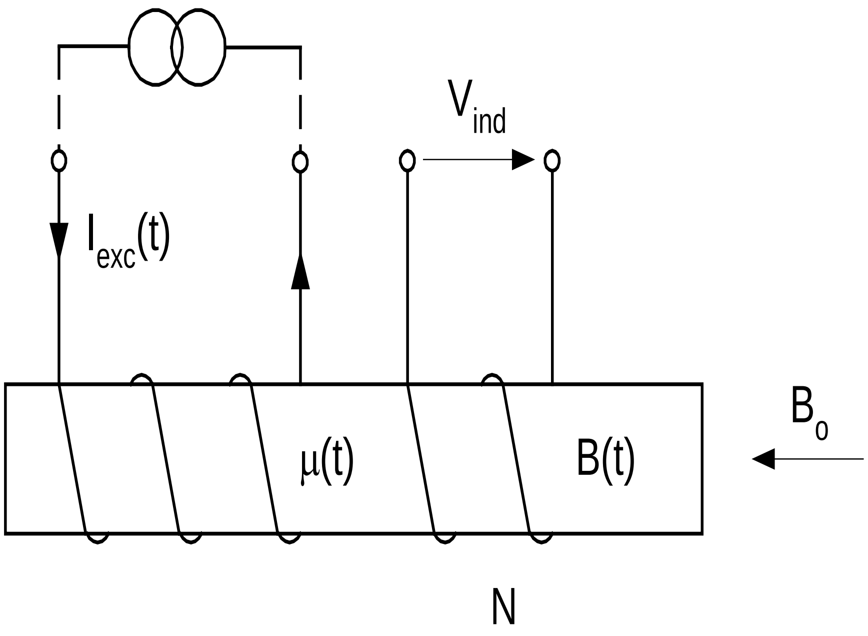
precise, but expensive (CTU Prague)

Most sensitive room-temperature magnetic sensors

Based on non-linear magnetization characteristics of ferromagnetic core.
Measure up to 1 mT
with 100 pT resolution

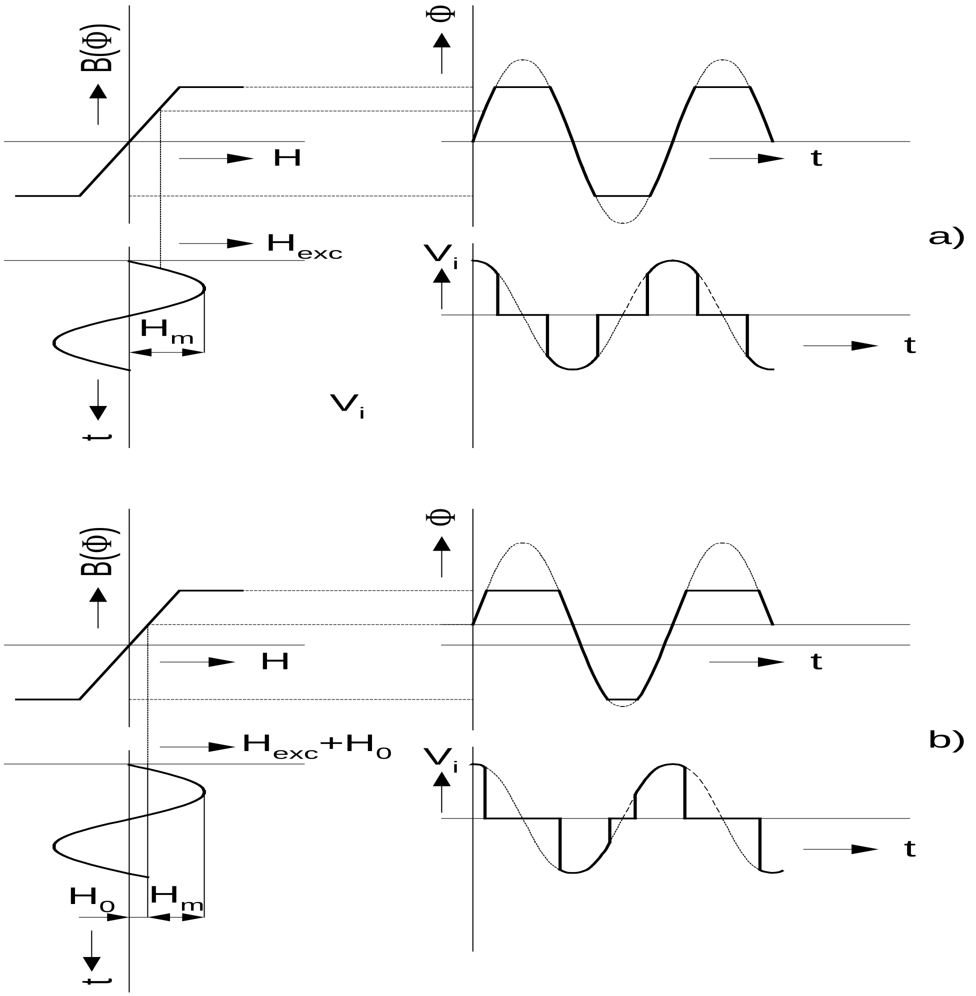
Fluxgate principle

- Ferromagnetic core
  - non-linear B-H
- Excitation and sensing coil
- Core is periodically saturated by I_{exc}, μ drops to 1 twice each period
- Measured B_0 causes 2nd harmonics in V_{ind}

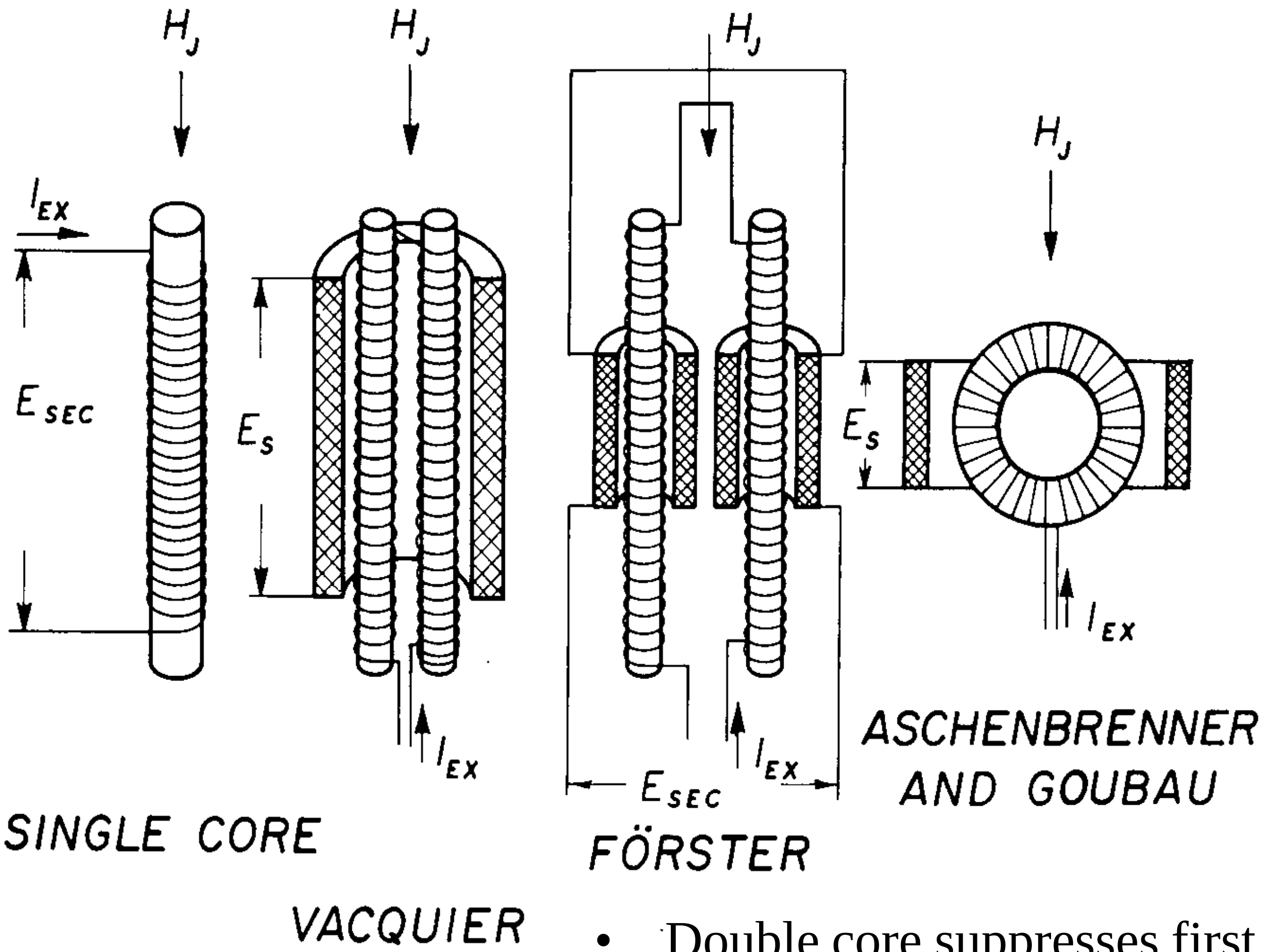


Fluxgate principle

- In absence of external field, magnetisation is symmetrical
- External measured field causes assymetry – detected in induced voltage

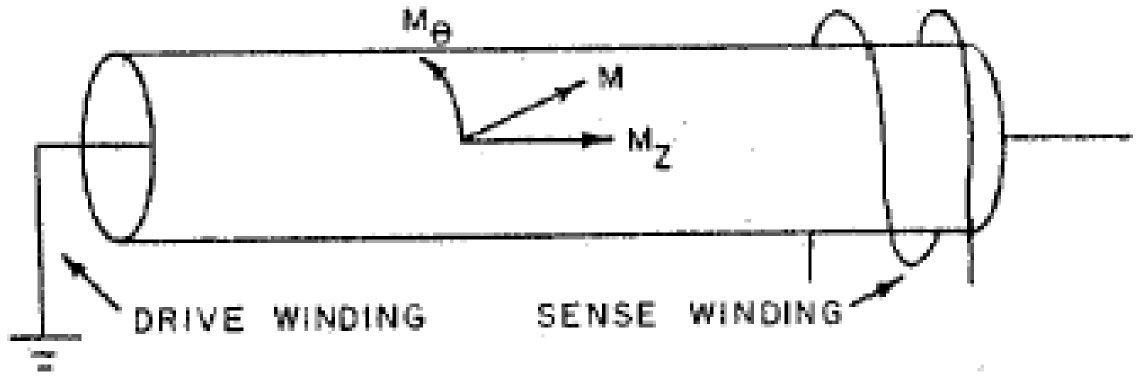


Basic types of fluxgate

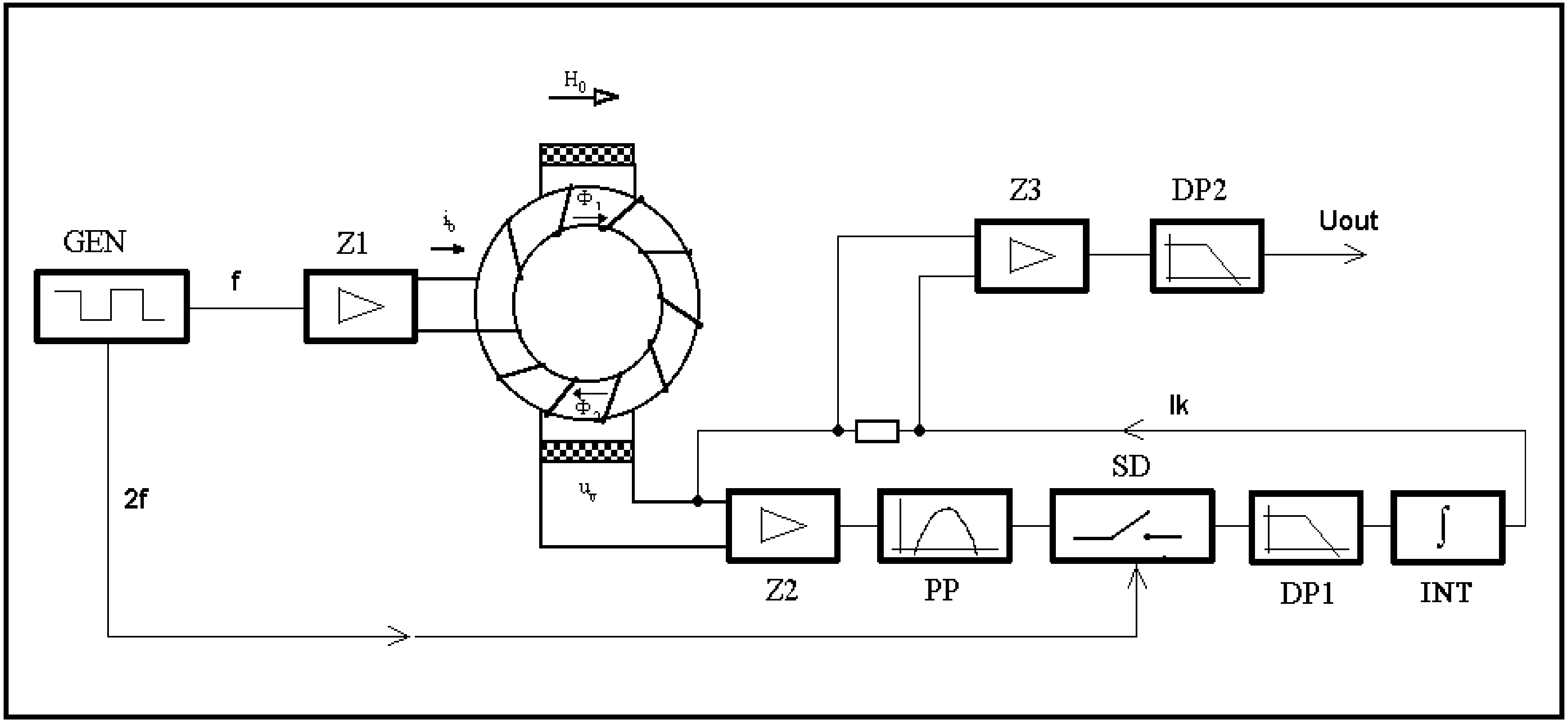


- Double core suppresses first harmonics

Orthogonal Fluxgate



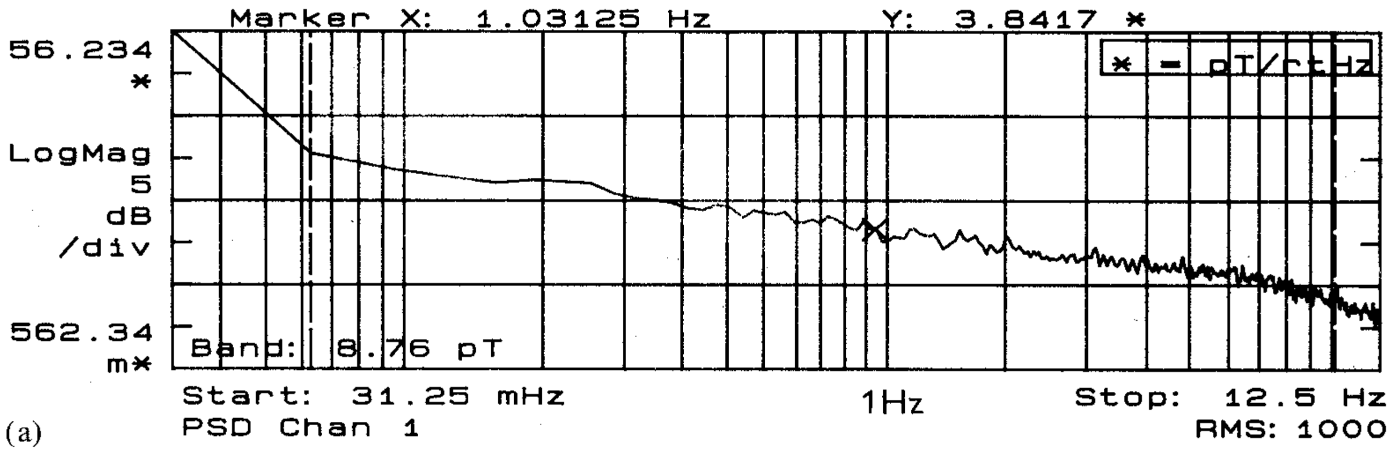
Fluxgate magnetometer



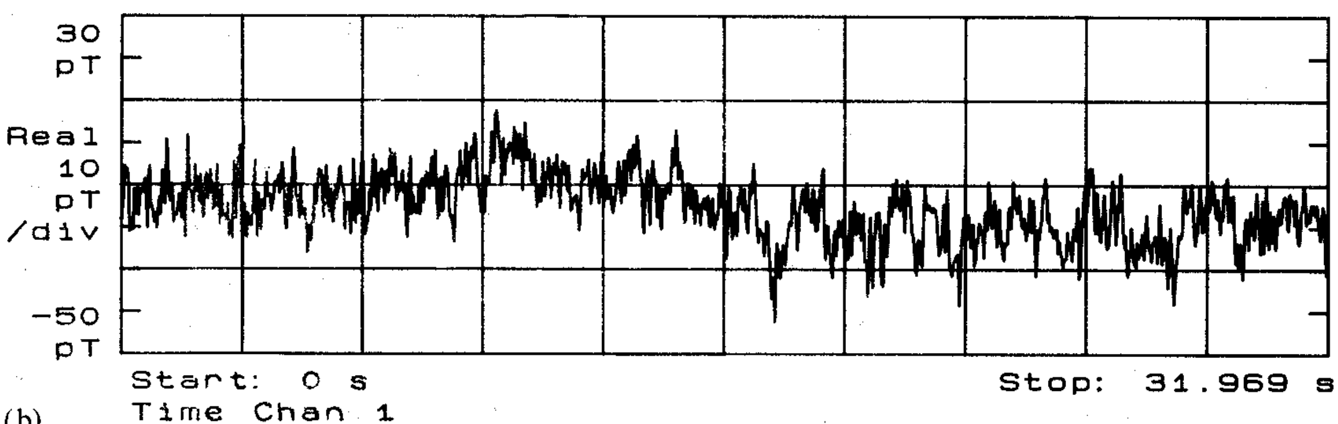
Parameters of fluxgate sensors

Parameter	Top	Standard
Sensitivity		30 μT / nT
Range	10 mT	200 μT
Linearity error	10 ppm	100 ppm
Tempco of sensitivity	10 ppm / ^{0}C	50 ppm / ^{0}C
Crossfield error for 50 μT field	< 1 nT	5 nT
Temp. offset drift	50 pT / ^{0}C	0.2 nT / ^{0}C
Perming after 10 mT shock	< 1 nT	< 5 nT
Noise (rms 50 mHz..10 Hz)	5 pT	100 pT
Long-term offset stability	2 nT/year	5 nT/8 hours
Bandwidth	10 kHz	20 Hz
Temp. range	-60 ..+200^{0}C	-20 ..+70 ^{0}C
Power consumprion	1 mW	100 mW
Size	2 mm	30 mm

Low-noise fluxgate sensor

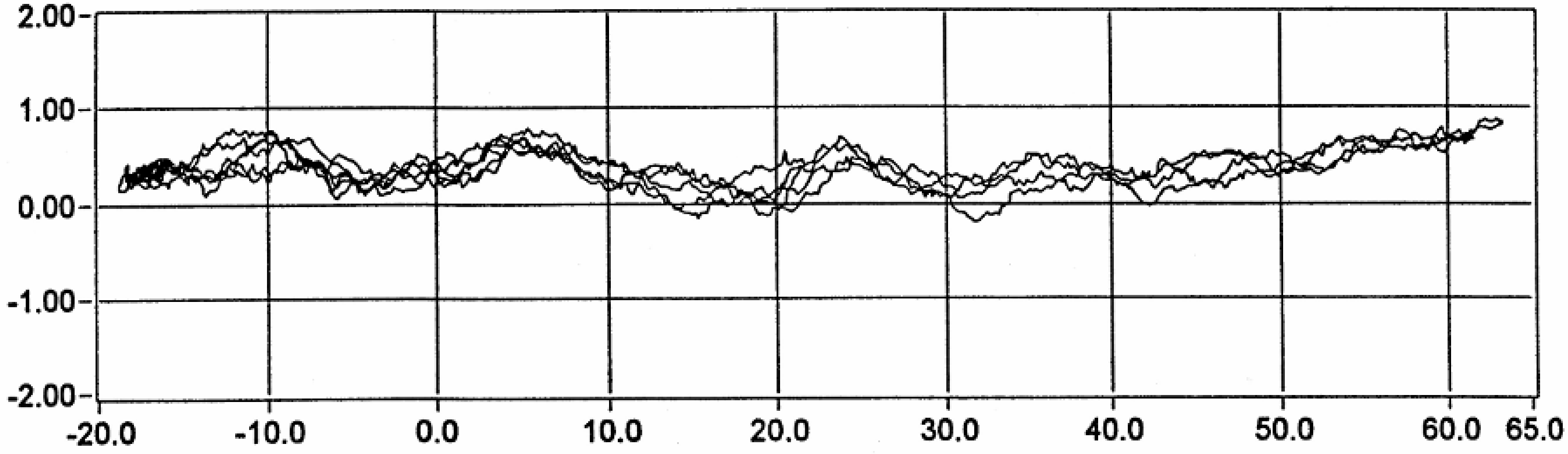


(a)

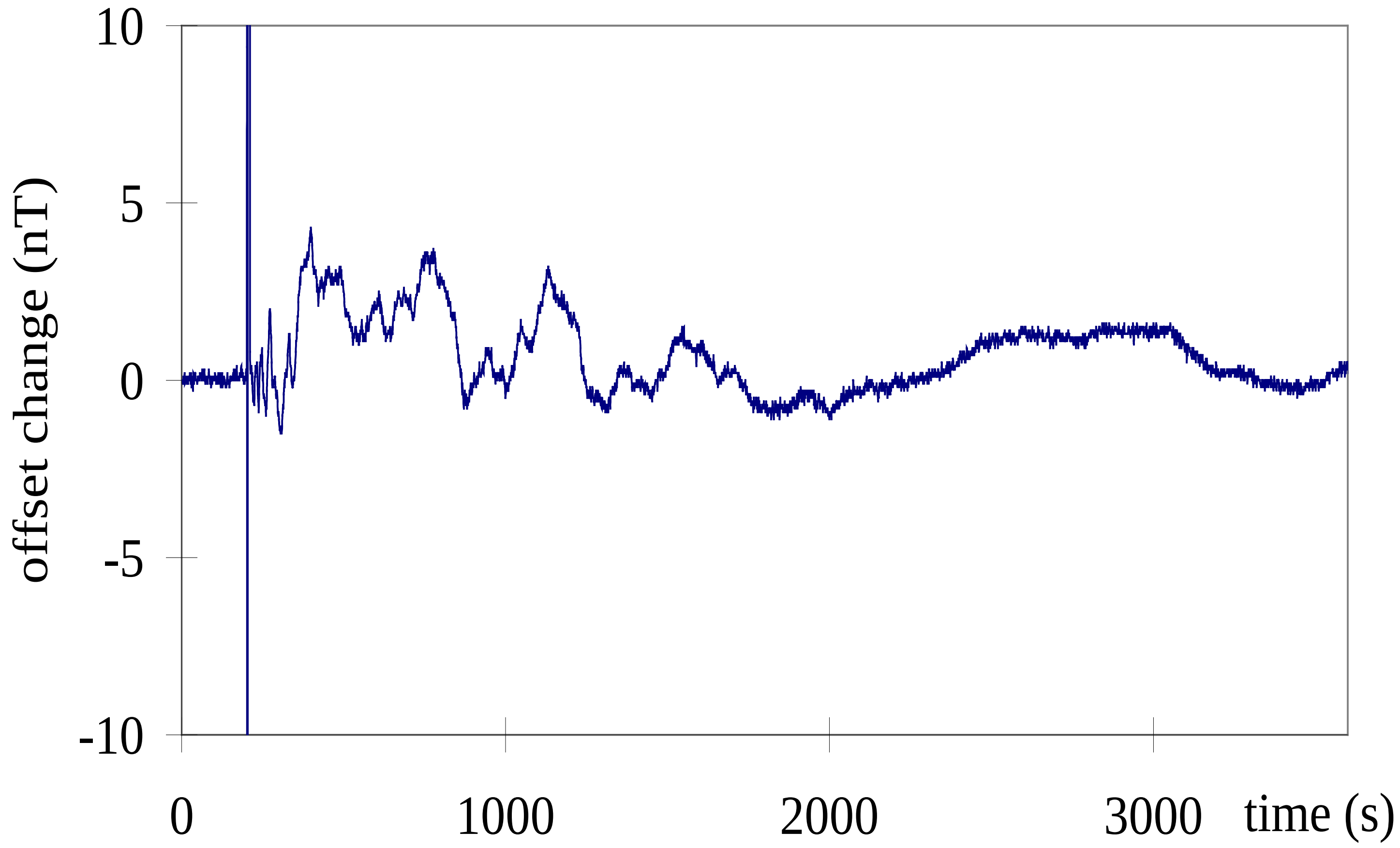


(b)

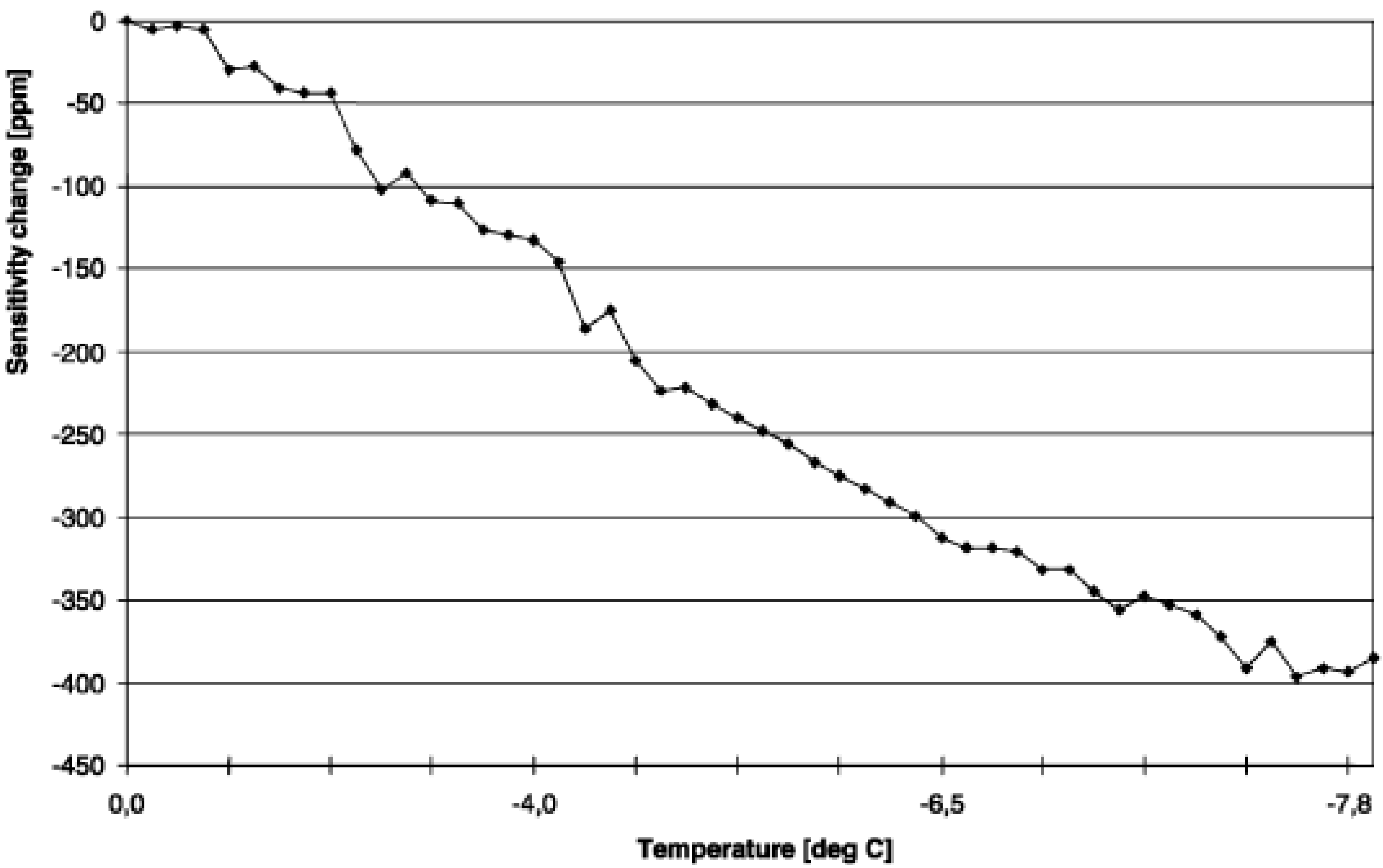
Temperature offset drift of Oersted sensor



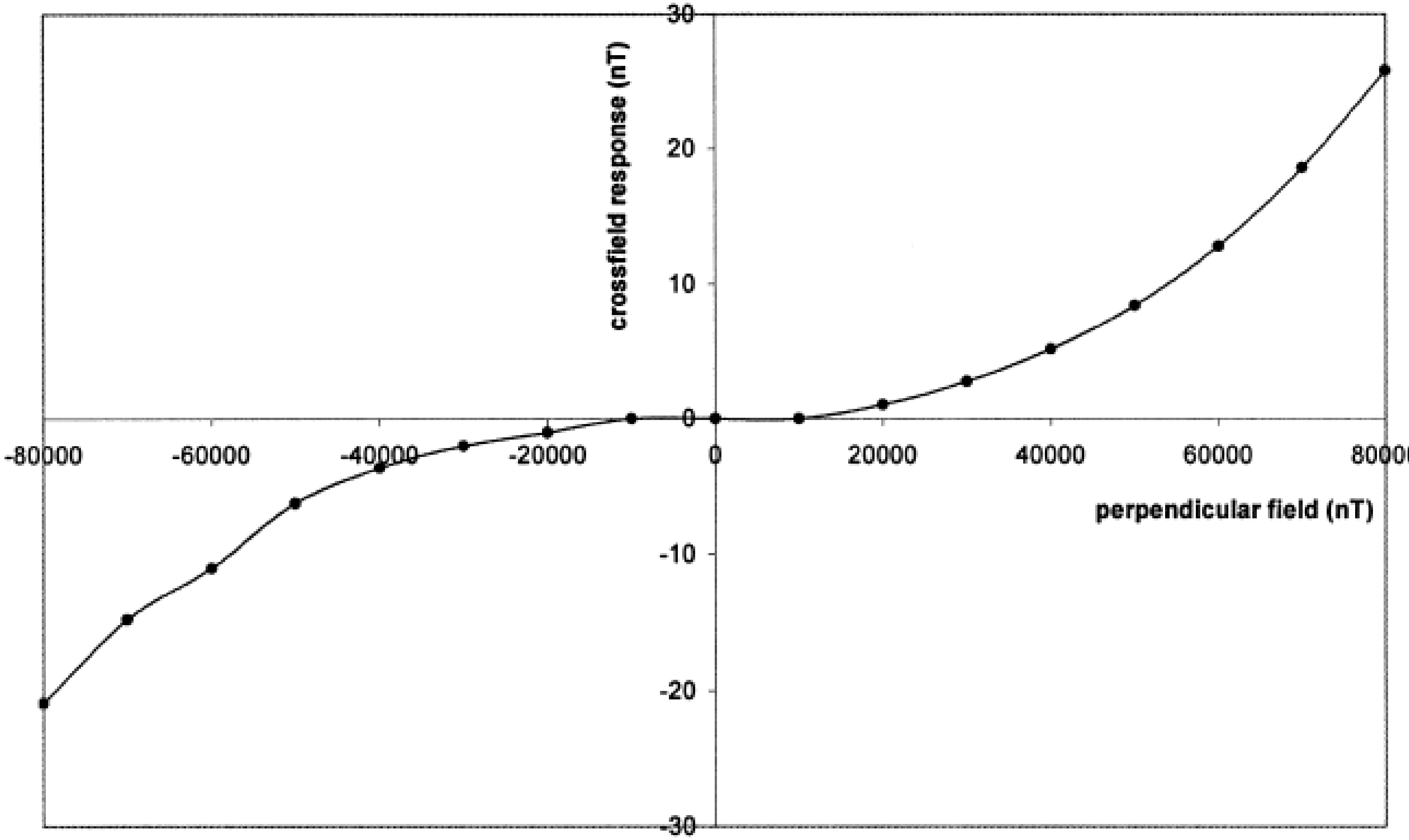
Offset recovery after temperature shock



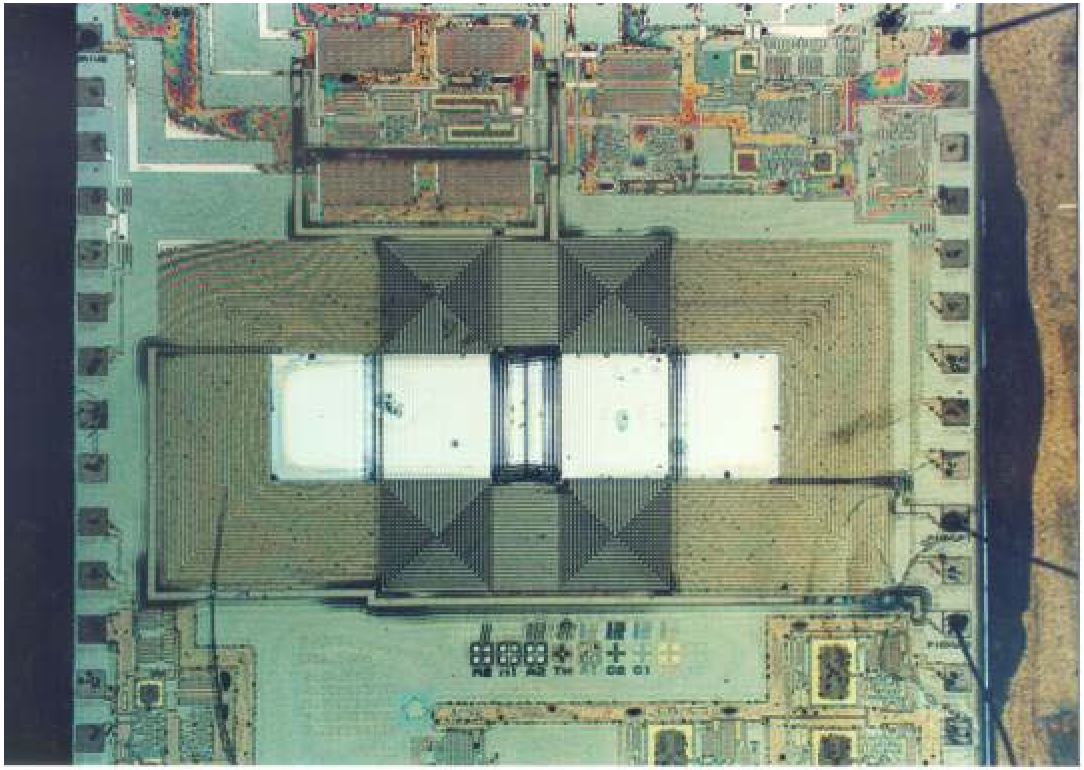
Sensitivity tempco



Crossfield effect



Micro-fluxgate sensors



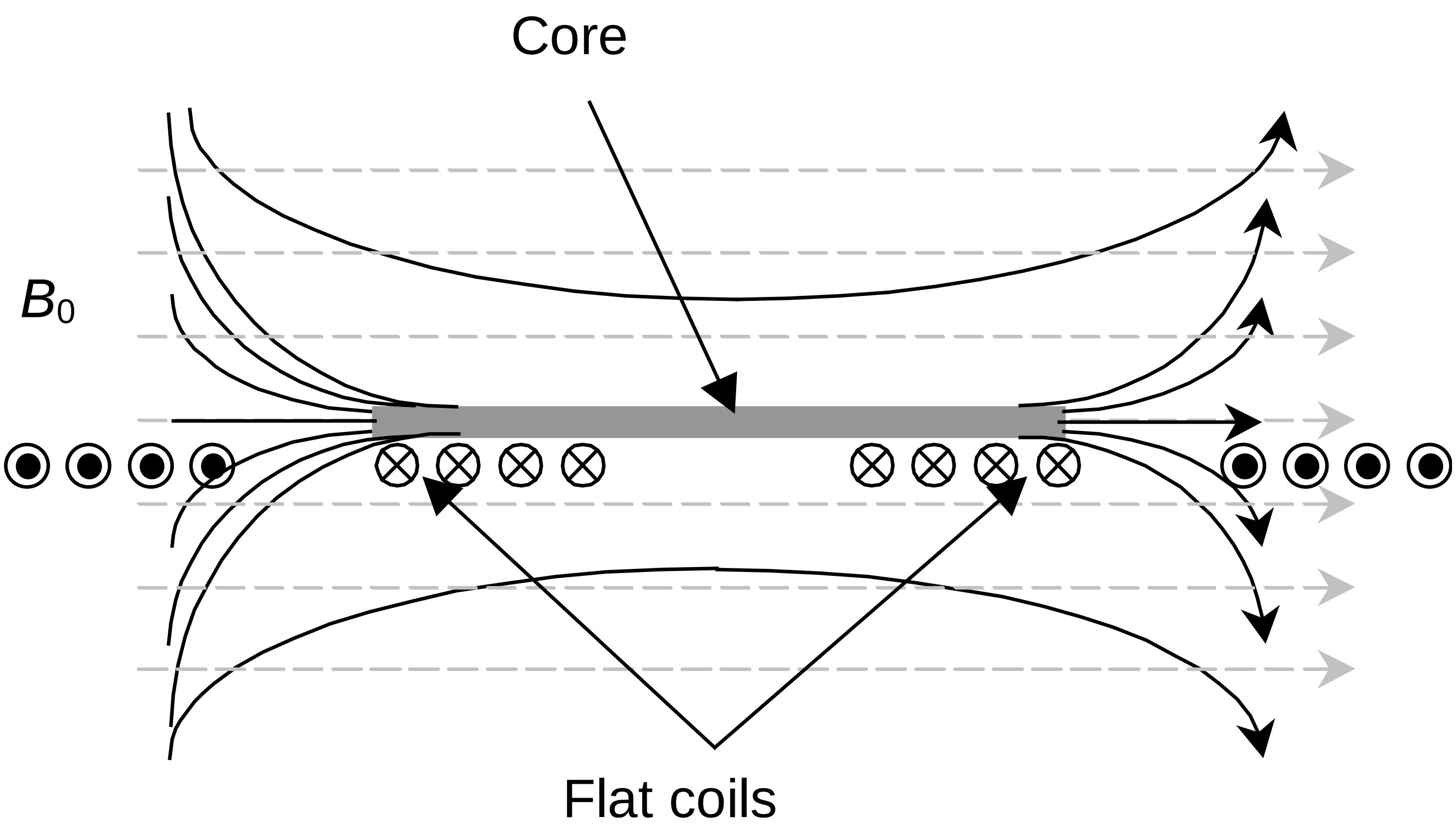
(in development)

- flat coils
- electrodeposited core or amorphous strips
- electronics on chip

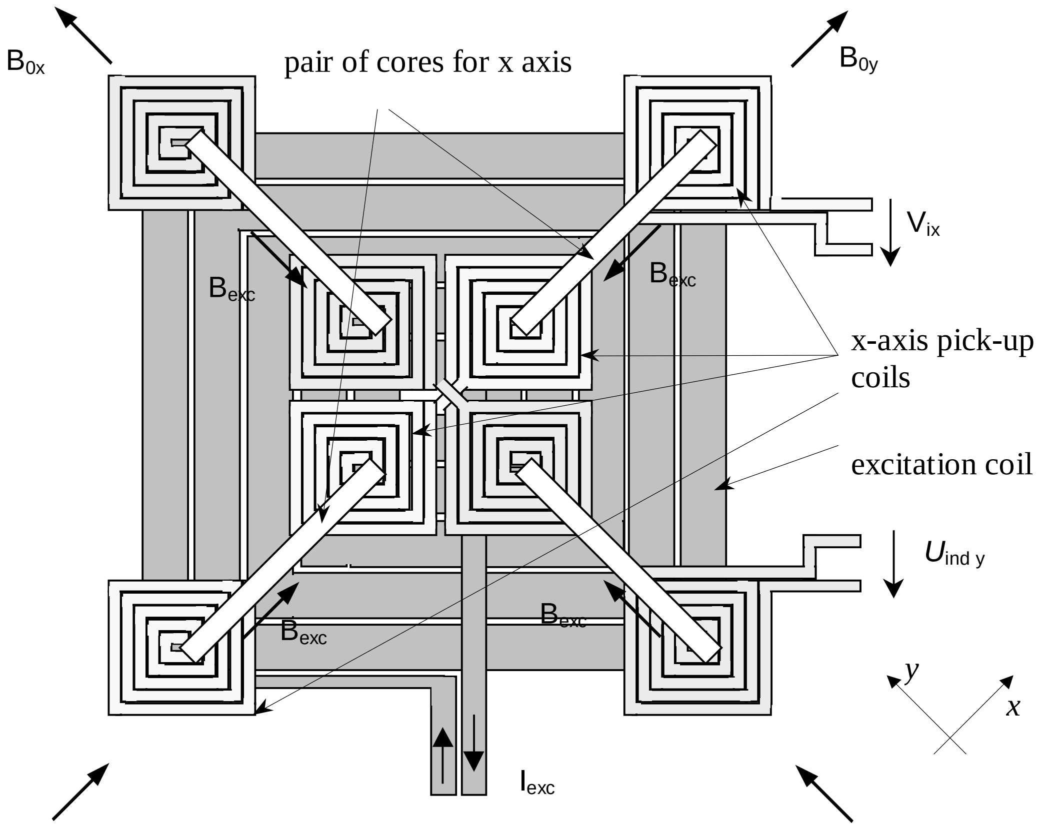
- cheap
- resolution still higher than MR

Shizuoka University

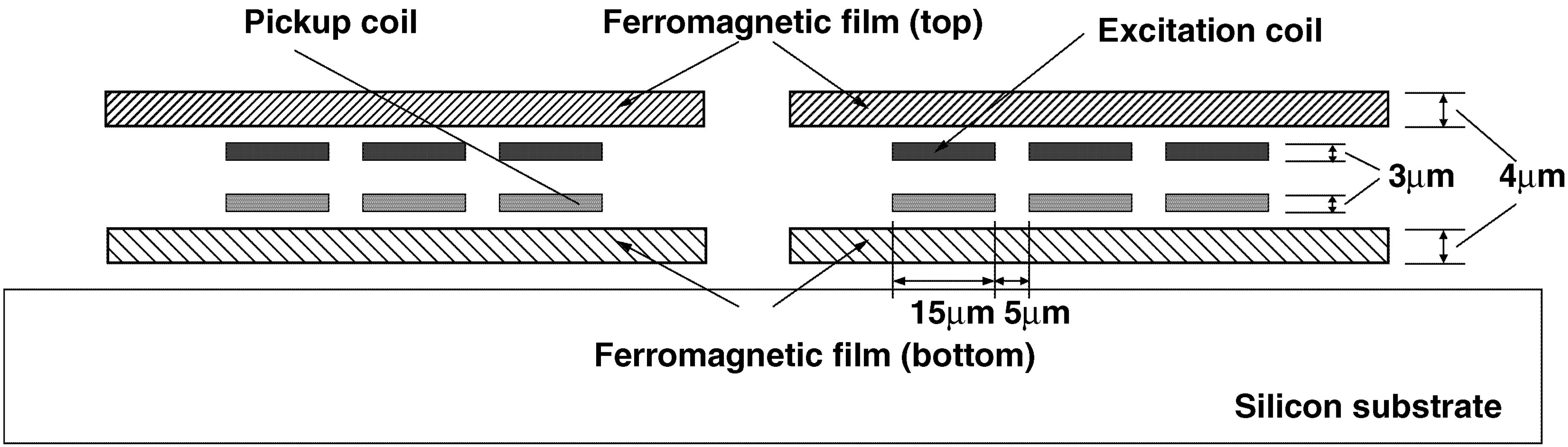
Flat coils

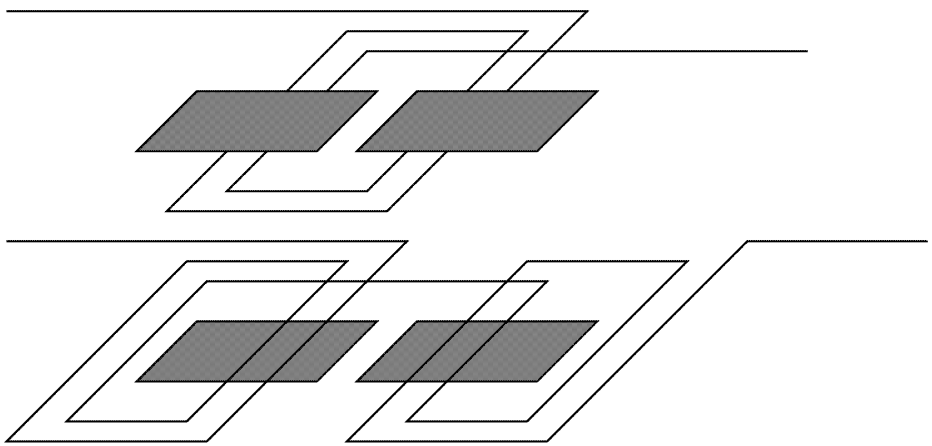


Two-axial sensor with flat coils

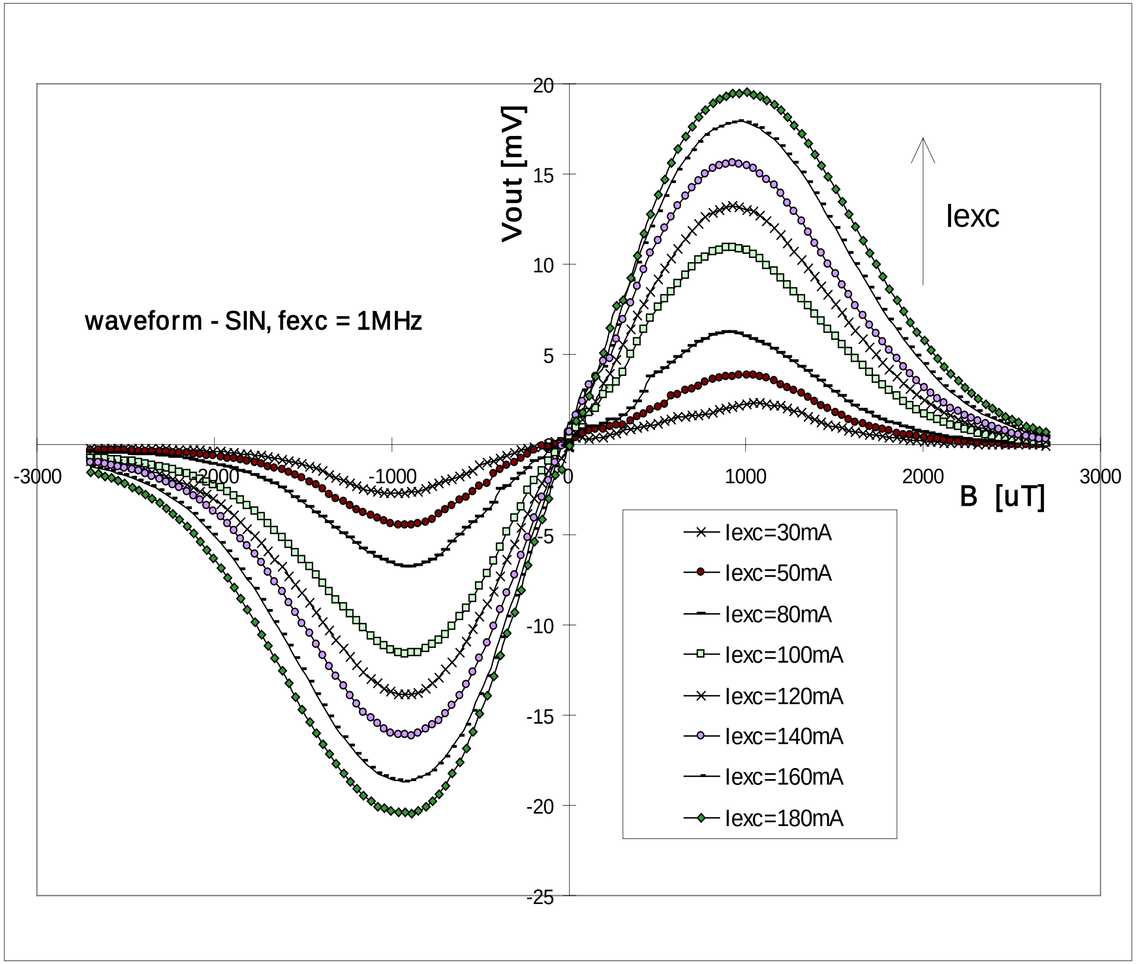


Microfluxgate sensor with symmetrical core

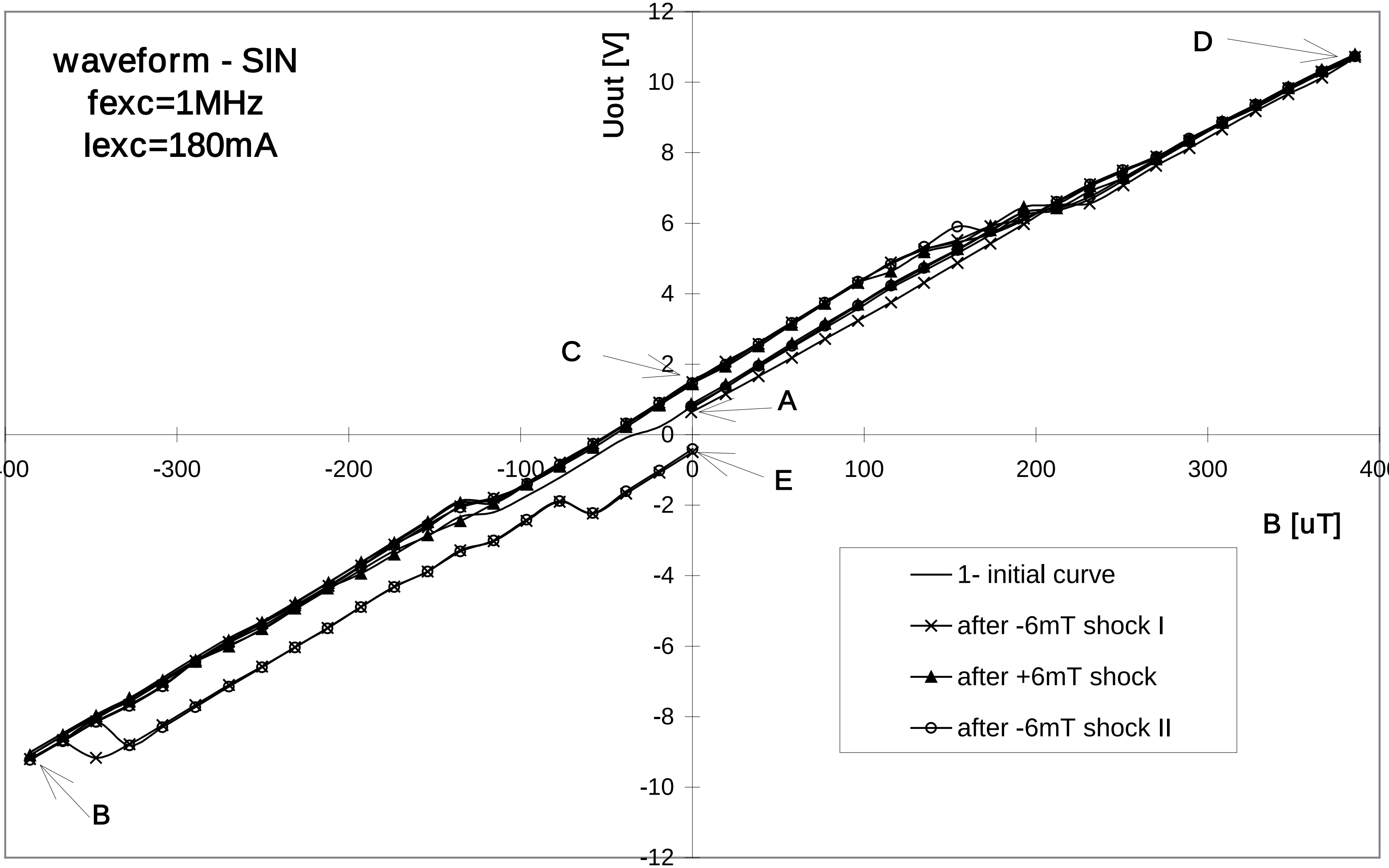




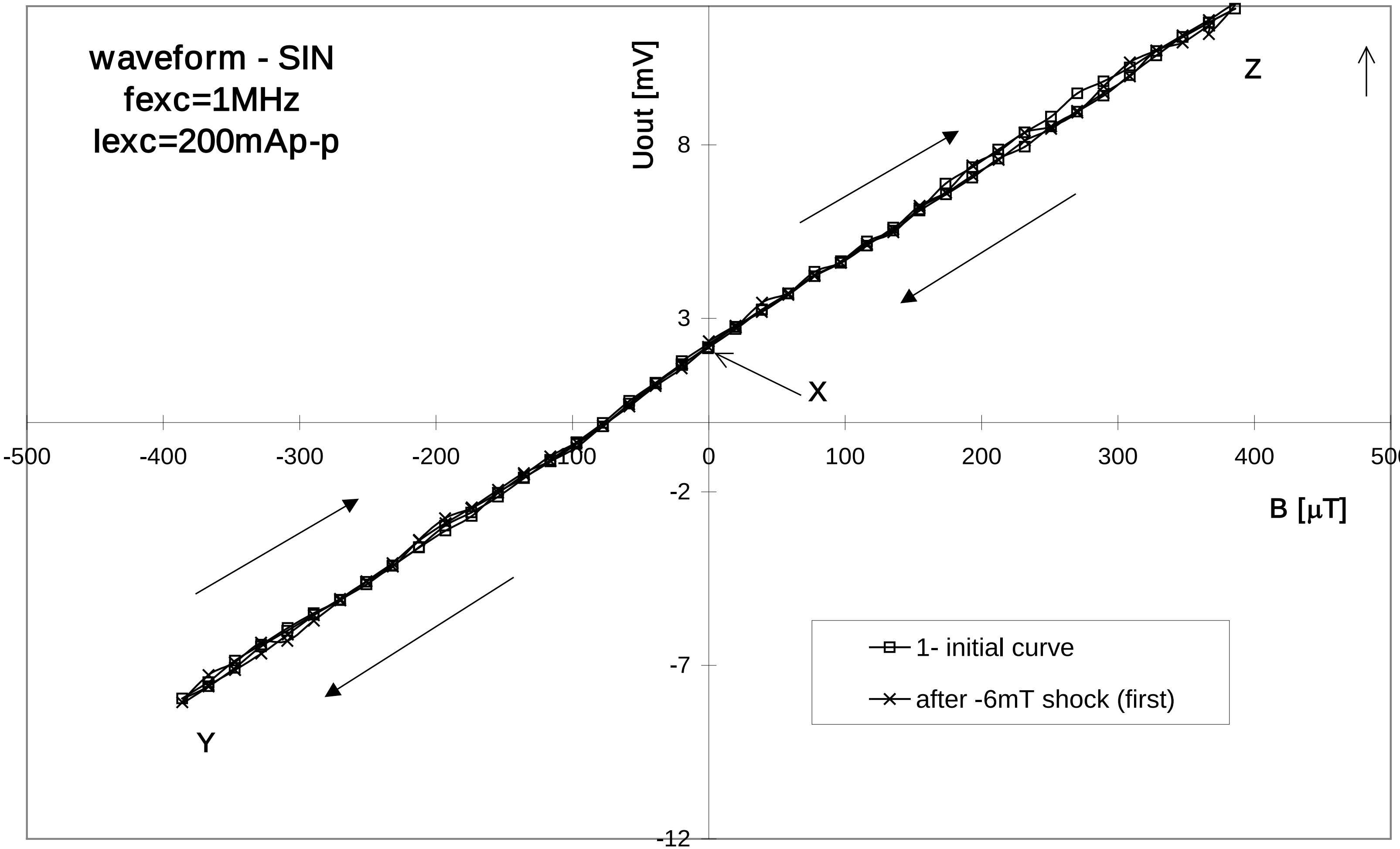
Microfluxgate: Large field characteristics



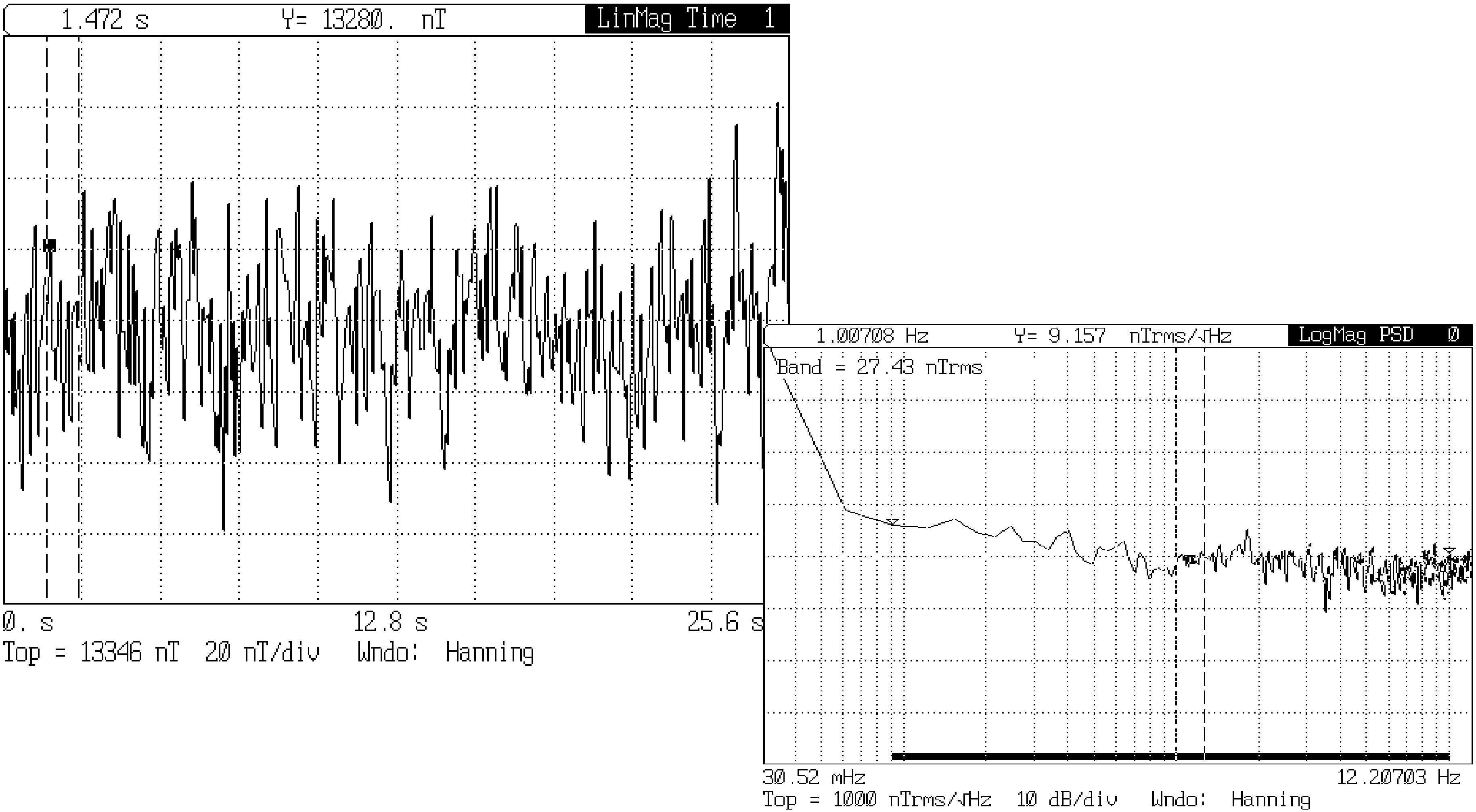
Hysteresis and perming of the single-core sensor in the 400 mT range



Hysteresis and perming of the sensor with double-sided core



Present limitation of microfluxgate: 80 nT p-p noise



Resonance sensors

- Proton magnetometer
  (NMR – Nuclear Magnetic Resonance)
- Overhauser
- Optically pumped – Cesium

All resonance magnetometers are scalar

Proton magnetometer

- based on precession frequency of proton $\omega = \gamma B$
  42 MHz/T ... 42 mHz/nT
- usually free precession after polarization switched off
- absolut precission
- sensitive to gradient and EMC
- slow (1 sec)
- requires 10 ml to 500 ml volume – difficult miniaturization

Overhauser magnetometer

Variation of proton magnetometer

Based on dynamic nuclear polarization: from electrons to protons

0.1 nT resolution 0.5 nT absolute accuracy

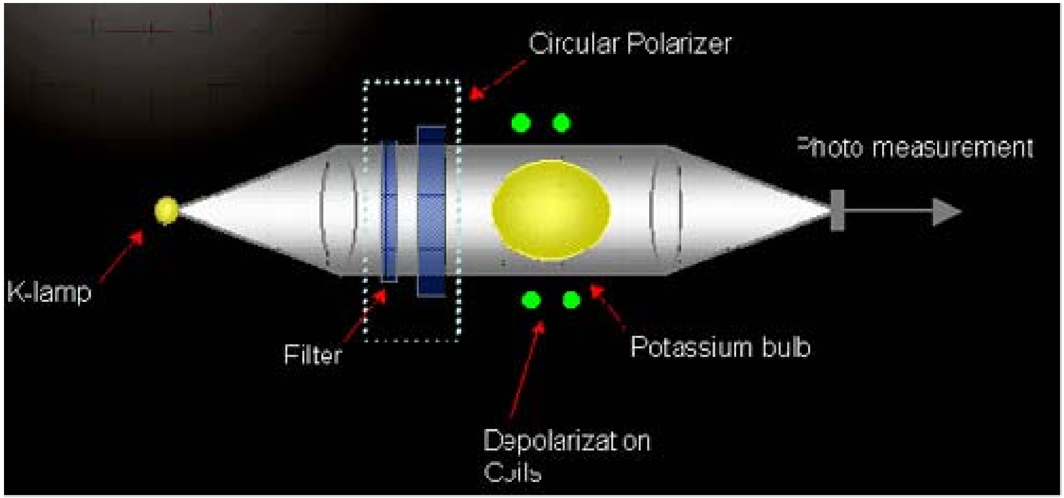
Resistant to field gradients and EMC

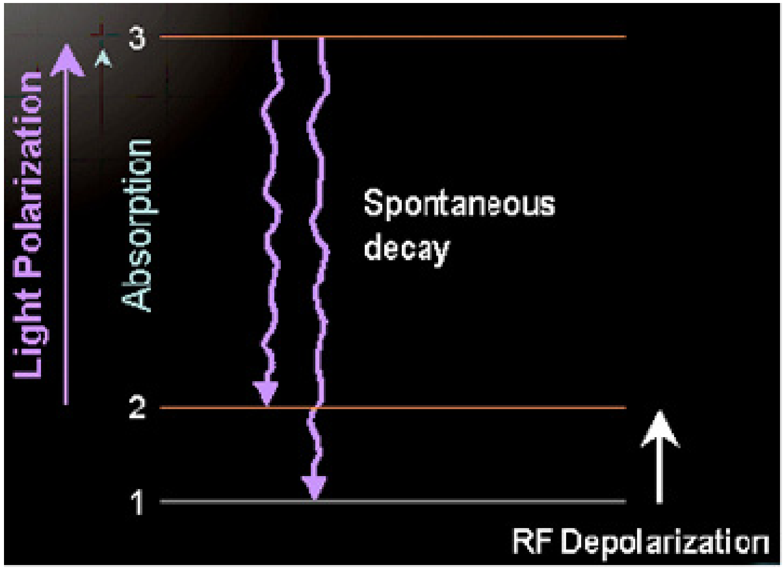
source: GEM

Optically pumped magnetometers

- Cesium, Potassium, Helium
- Based on ESR (electron spin resonance) or Zeeman splitting
- highest resolution: 7Hz/nT
- Requires lamp + RF source

source: GEM





Optically pumped magnetometers

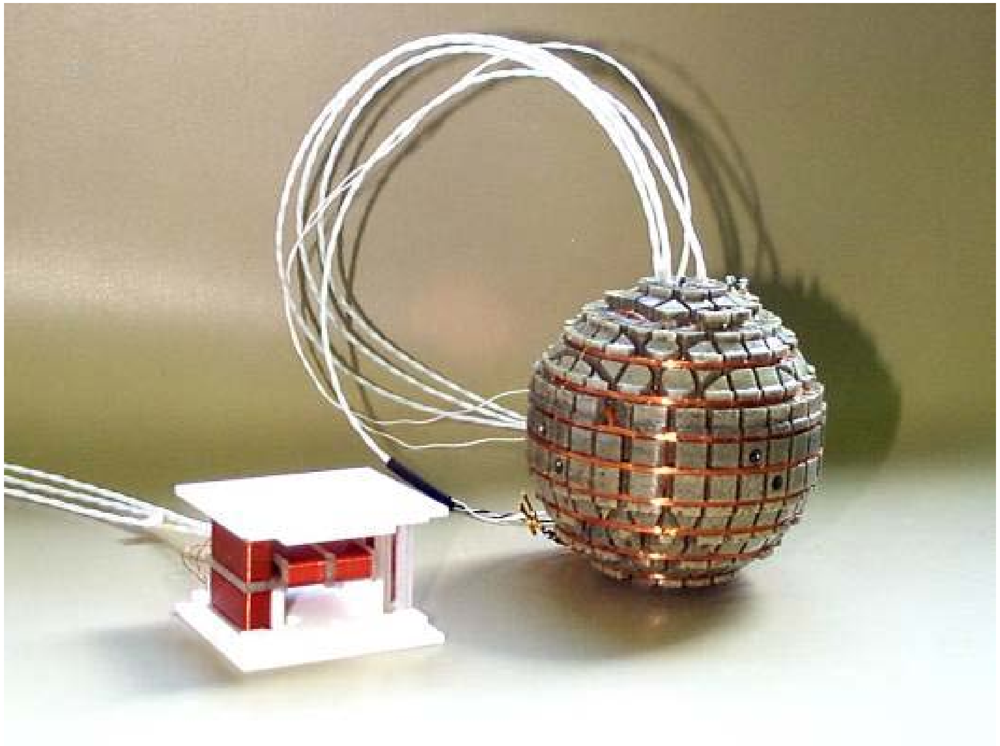
Potassium (GEM)

- 0.2 nT absolute accuracy
- 7 pT resolutin @ 10 Hz sampling

Cesium (Geometrics)

- 1 nT heading error

Precise fluxgate magnetometers



O.V.Nielsen, J.R.Petersen, F.Primdahl, P.Brauer, B.Hernando, A.Fernandez, J.M.G.Merayo, P.Ripka: Development, construction and analysis of the 'Orsted' fluxgate magnetometer Meas. Sci. Technol. 6 (1995), 1099-1115.

P. Ripka, F. Primdahl, O.V. Nielsen, J.R. Petersen, A.Ranta: AC magnetic field measurement using the fluxgate, Sensors and Actuators A, 46-47 (1995), pp. 307-311

Testing and calibration

- Precise coil systems + current sources
- Shieldings
- Non-magnetic thermostats
- Large non-magnetic facilities

Shieldings and calibration coils

Resources

- www.nve.com (GMR)
- www.Sentron.ch (vertical Hall)
- www.ssec.honeywell.com/magnetic/ (AMR)
- www. Micronas.com (Hall)
- www.Infineon.com (Siemens: Hall, GMR)
- www.semiconductors.Philips.com/automotive/sensors_discretes (AMR)
- www.Geometrics.com (resonant magnetometers)
- measure.feld.cvut.cz/groups/maglab (fluxgate)

- P. Ripka (ed.): Magnetic sensors and Magnetometers
  Artech, 2001,www.artechouse.com
- Tumanski S, Thin film magnetoresistive sensors, IOP (2001) ISBN 075030702
- Popovic, R.S., Hall Effect Devices, Bristol: Adam Hilger, 1991.

OSTATNÍ APLIKACE

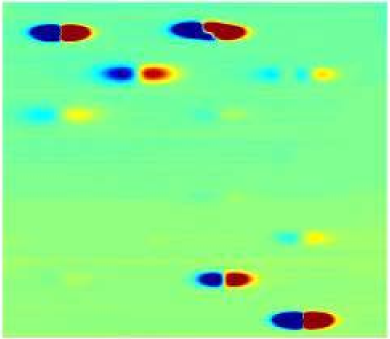
Applications: Metal detectors

Finding small objects: mines, coins, golden nuggets..

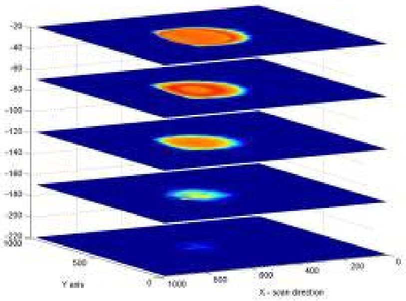
portable instruments… similar to NDT

Finding large and deep objects: scanning, sensor fields …
 -> geophysical methods, image analysis, recognition

Testing fields of European Comission in Ispra, Italy



Gauss laboratory, Ispra



Sensor footprint

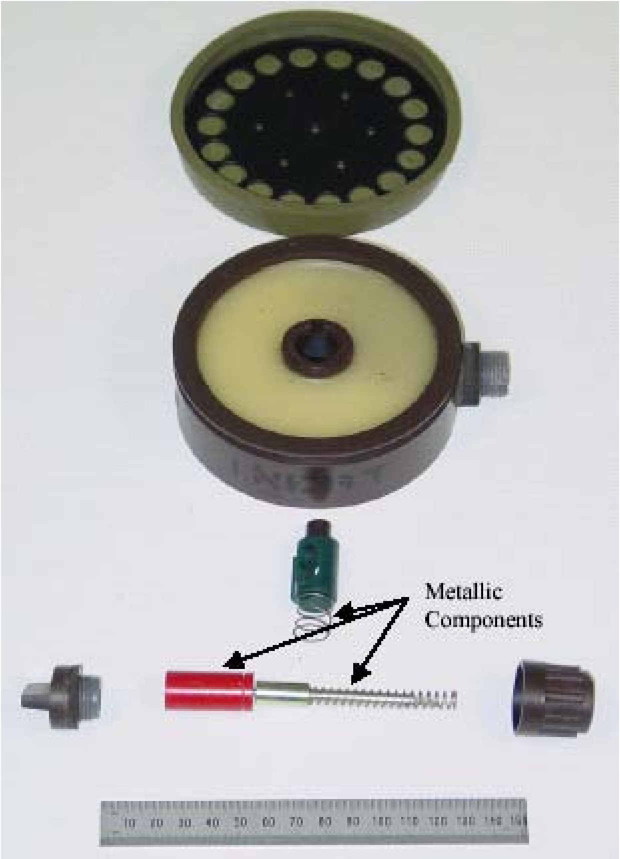
ERW – explosive remnants of war

- Mines and Booby traps
  - AP pressure mines
  - Tripwire activated AP mines
  - AT mines – often protected by AP
    - Active magnetic methods (AC metal detectors) – eddy currents
    - GPR
    - Sniffing of explosive

- Small UXO (unexploded ordnance): projectiles, sub-munition, …

- Deeply burried ERW – mainly bombs
    - Active AC magnetic methods
    - Passive magnetic methods: DC magnetometers – up to 5 m

PMN antipersonnel mine



Small fragmentation bomb (sub-munition)

Humanitarian demining

- HD: all explosive items must be removed or destroyed to a recorded depth.
- military demining: under time pressure, small losses acceptable

Metal detectors: working principles

- **Pulsed induction**
  - Ebinger 420GC
  - Guartel MD8
  - Minelab F1A4 and F3
  - Schiebel AN19 (PSS12)
  - Vallon 1620 and VMH2.
- **Continuous wave**
  - CEIA MIL D1
  - Foerster Minex 2FD
  - Ebinger 420SC

- **(DC)Magnetometers: fluxgate, Cesium**

Pulsed induction detectors

1-coil-systems,

measurements in TD 10^{-5}s - 10^{-3}s.

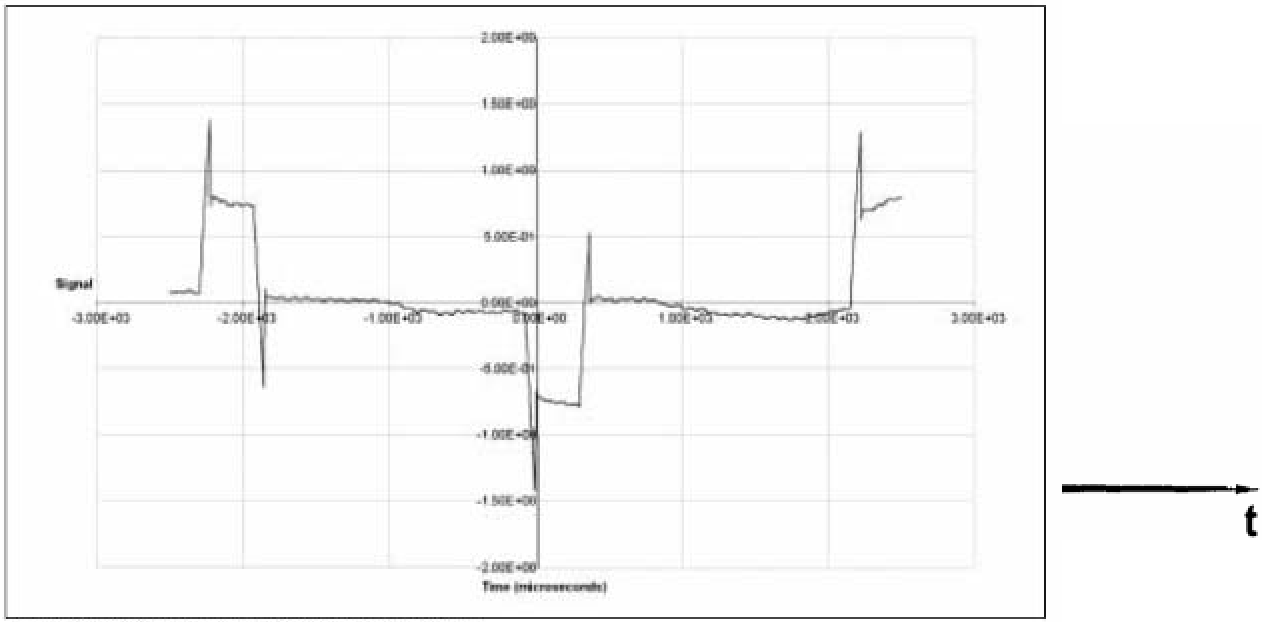
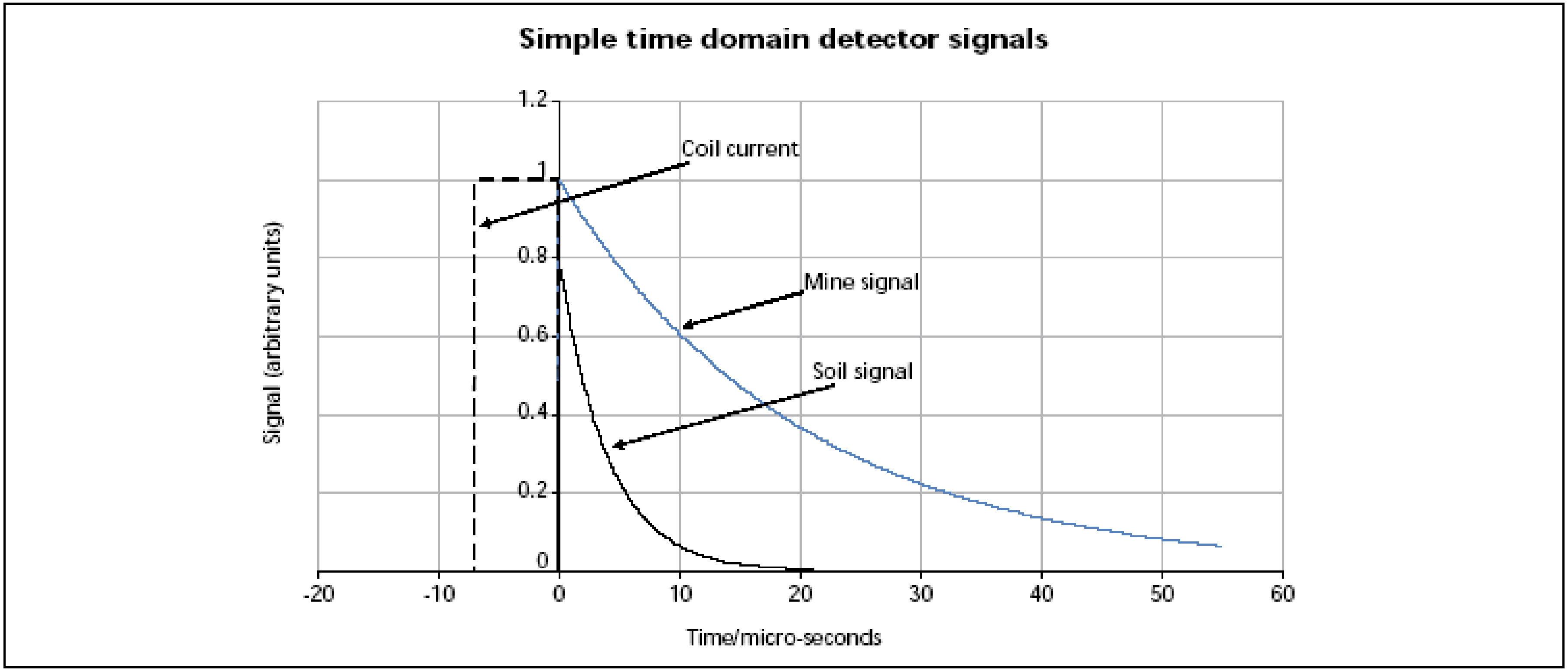


Figure 4.3: Magnetic field measured from a Vallon VMH2 detector

370 µs pulse width

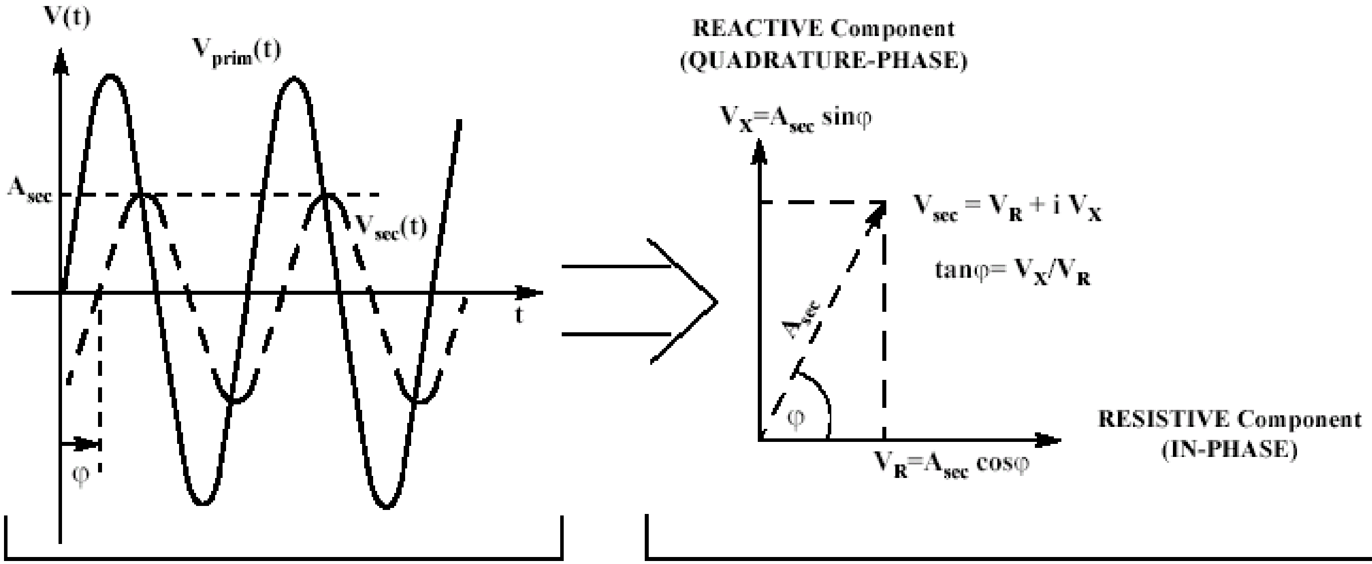
225 Hz repetition freq.

Ground compensation



soil signal decays after 20 µs
Advanced methods: processing multiple samples
and/or using excitation pulses of different lengths.

Continuous wave detector



Transmitted and Received signals as a function of time

Complex (Impedance) Plane representation

Förster Minex 2FD 4500

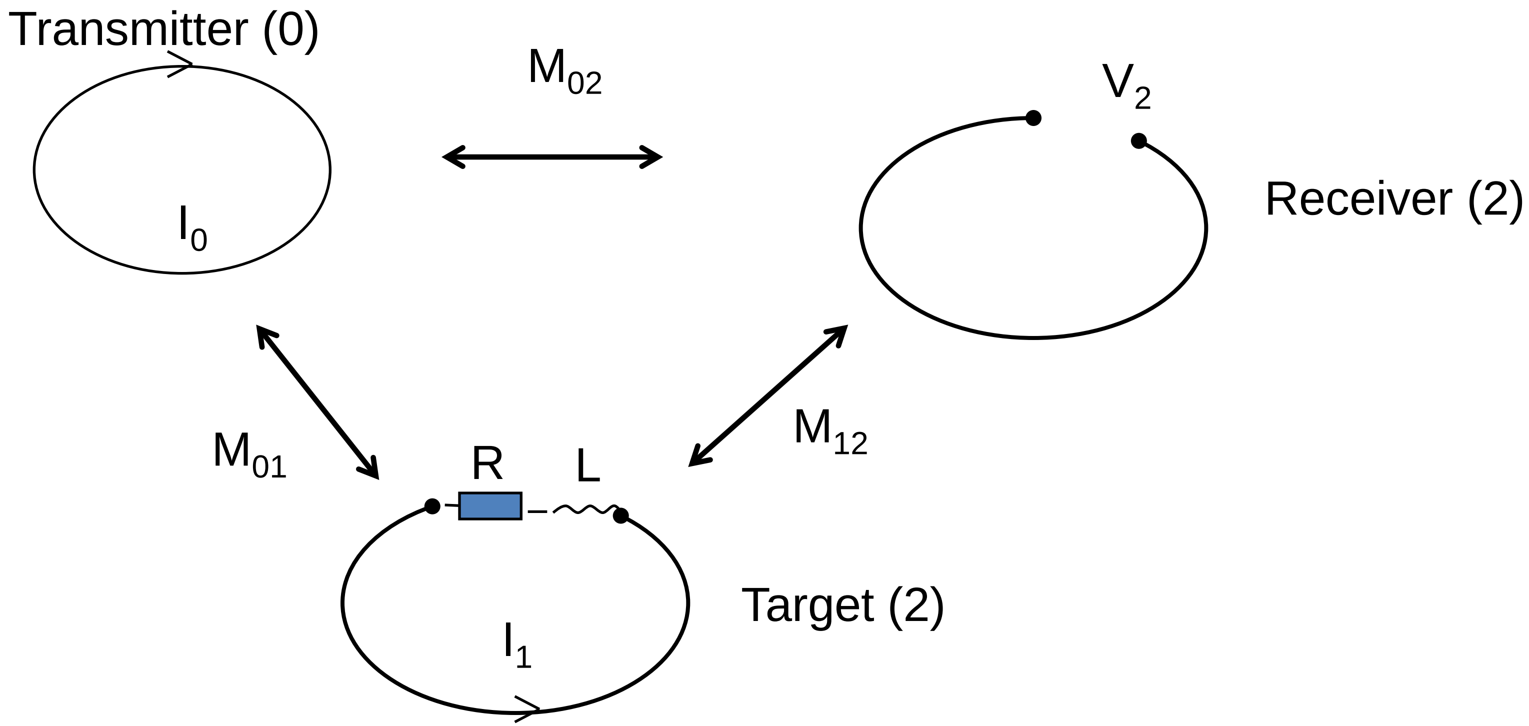
2 or 3 coils:

compensation of the primary field with differencial receiver-coils or bucking coils

Sorce: Jörn Lange,

Institute for Geophysics & Meteorology, Cologne

Basic principle



$$I_1 = -j\omega \frac{M_{01}}{R + j\omega L} I_0 = -j\omega M_{01} \frac{R - j\omega L}{R^2 + \omega^2 L^2} I_0$$

$$V_2(\omega) = -j\omega M_{12} I_1 = \omega^2 M_{12} M_{01} \frac{R - j\omega L}{R^2 + \omega^2 L^2} I_0$$

Basic principle

$$V_2(\omega) = -j\omega M_{12} I_1 = \omega^2 M_{12} M_{01} \frac{R - j\omega L}{R^2 + \omega^2 L^2} I_0$$

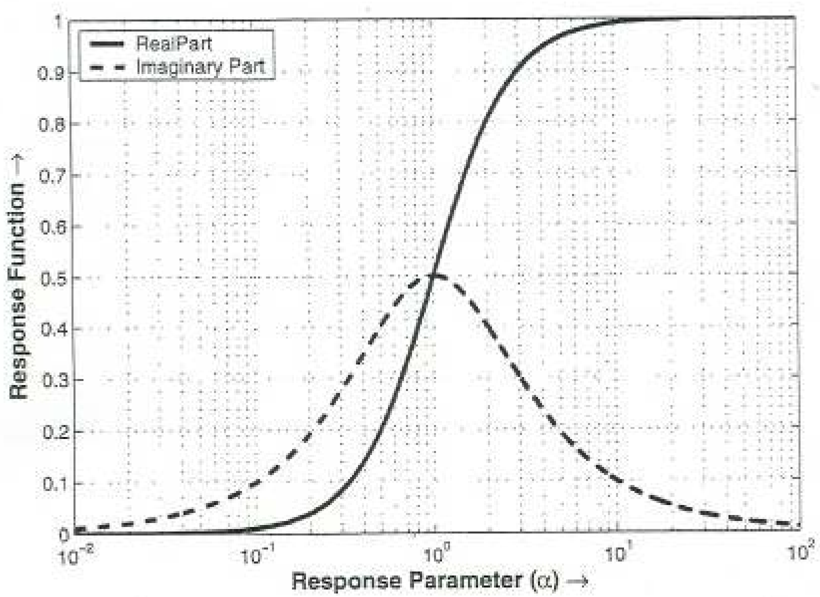
Response function

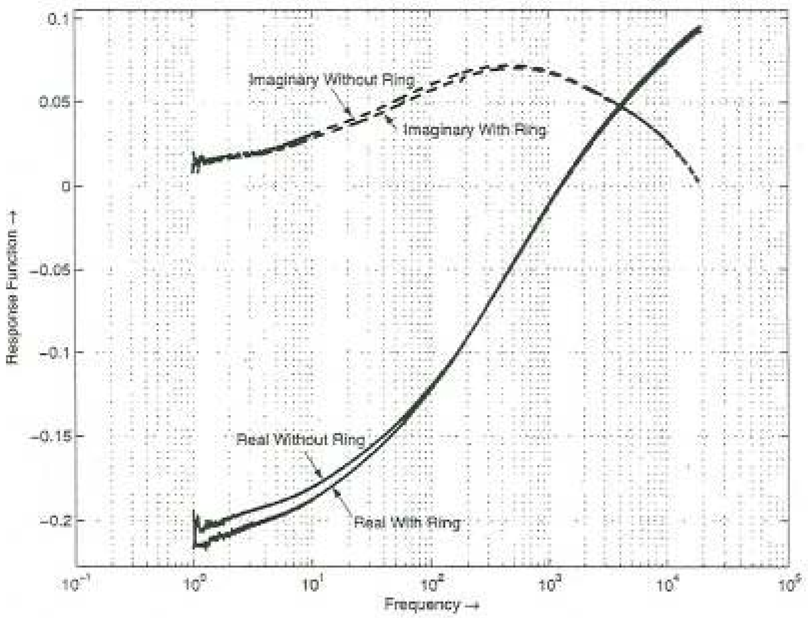
$$F = V_2(\omega)/\omega = \omega M_{12} M_{01} \frac{R - j\omega L}{R^2 + \omega^2 L^2} I_0 = \beta\left(\frac{j\alpha}{1 + j\alpha}\right)$$

Where $\alpha = \frac{\omega L}{R}$ is response parameter for “first order object”

and $\alpha = \sigma\mu\omega a^2$ for metal sphere of diameter a

Response function

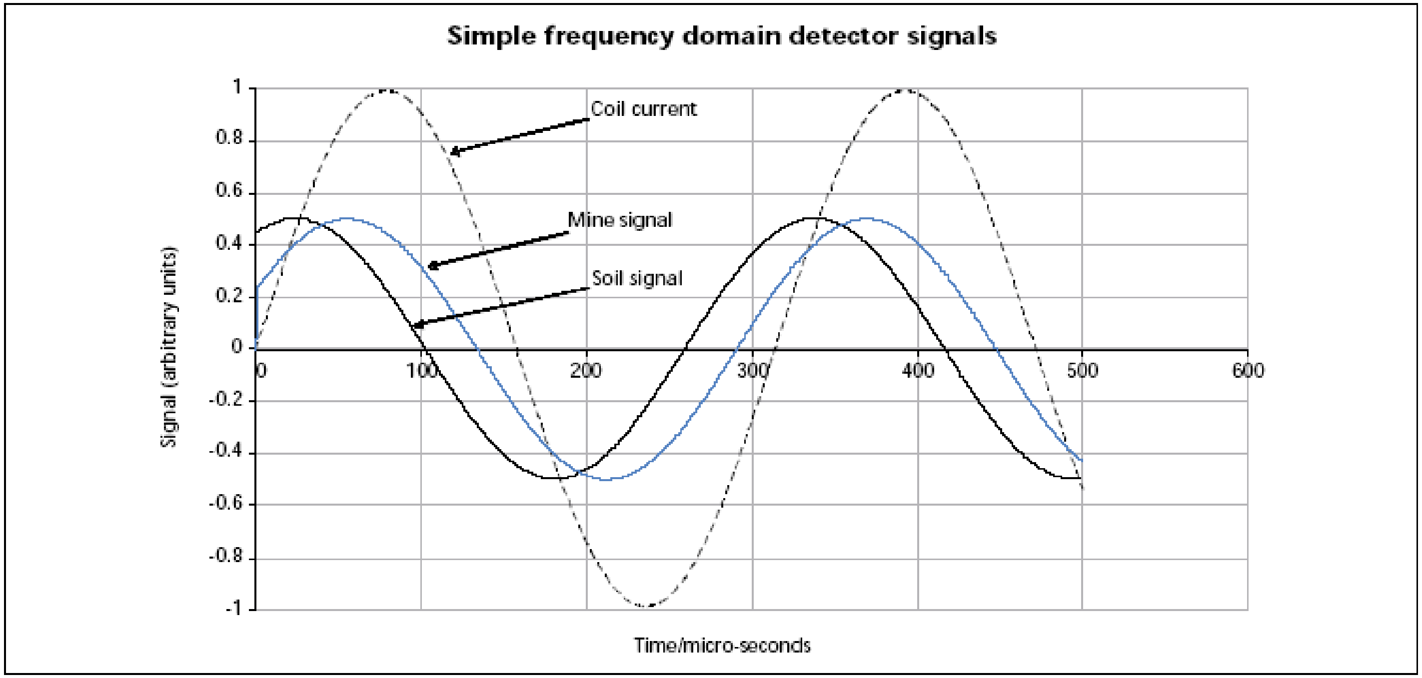




ideal response

12” shell

Chilaka 2004



If the receiver is set up to reject signals of a certain phase the soil signal in this case will be ignored. Even better ground compensation can be achieved by using two or more frequencies.

Continuous wave detector 2 400 Hz + 19 200 Hz.

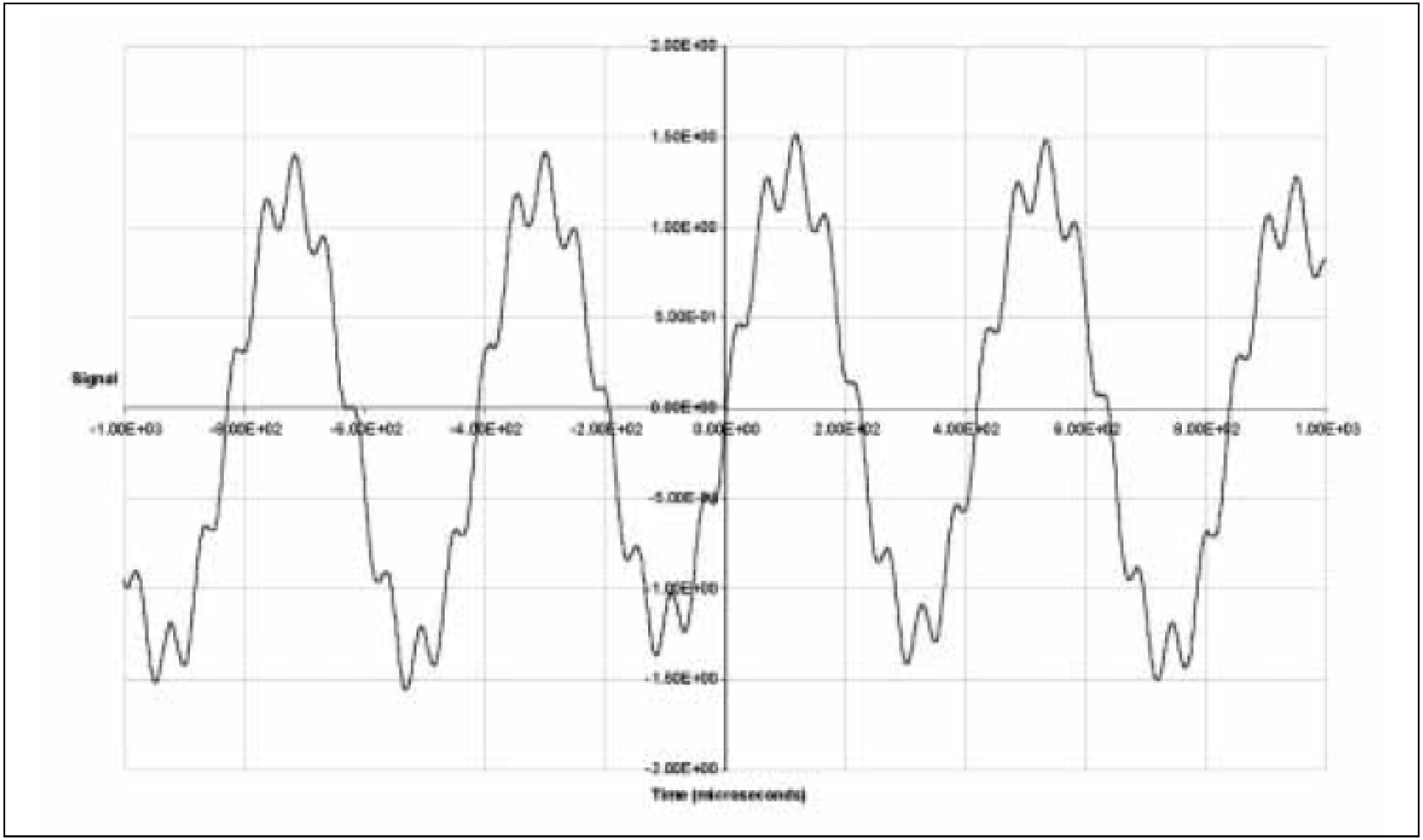


Figure 4.4: Magnetic field measured from a Foerster Minex 2FD 4.500 detector

Magnetic and conductive soils

Many places

Susceptibility 10^{-6} to 10^{-3} … ferrites and other

Conductivity .. Salt water

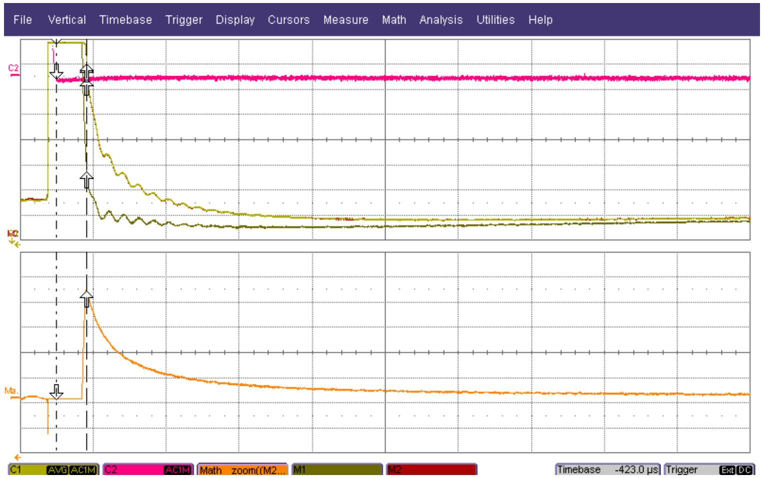
"Difficult soils"

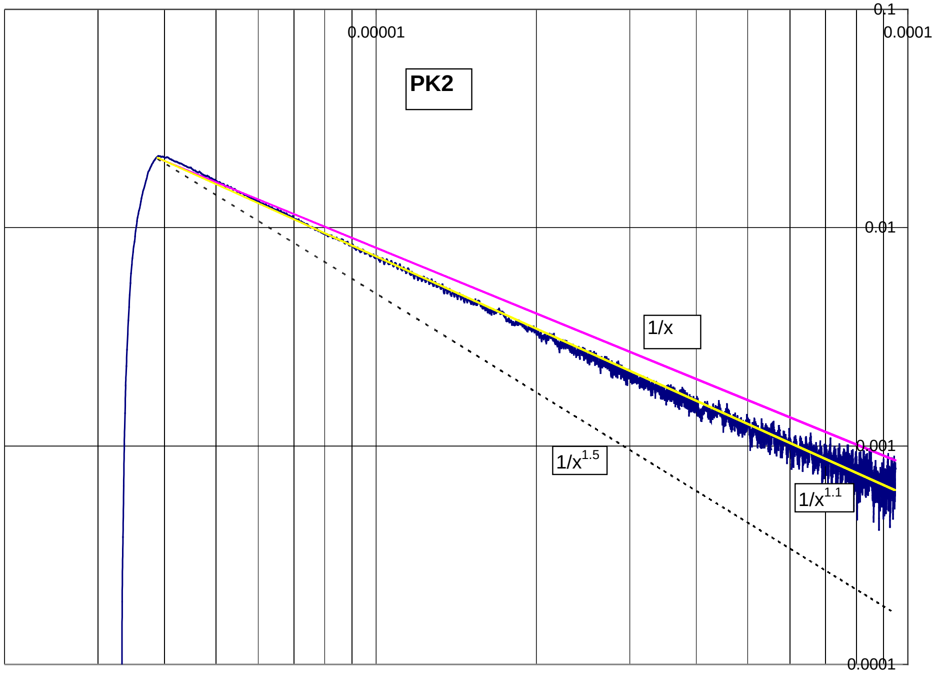
Bosnia, Laos, …

Frequency dependent susceptibility

- mainly due to superparamagnetic nanoparticles

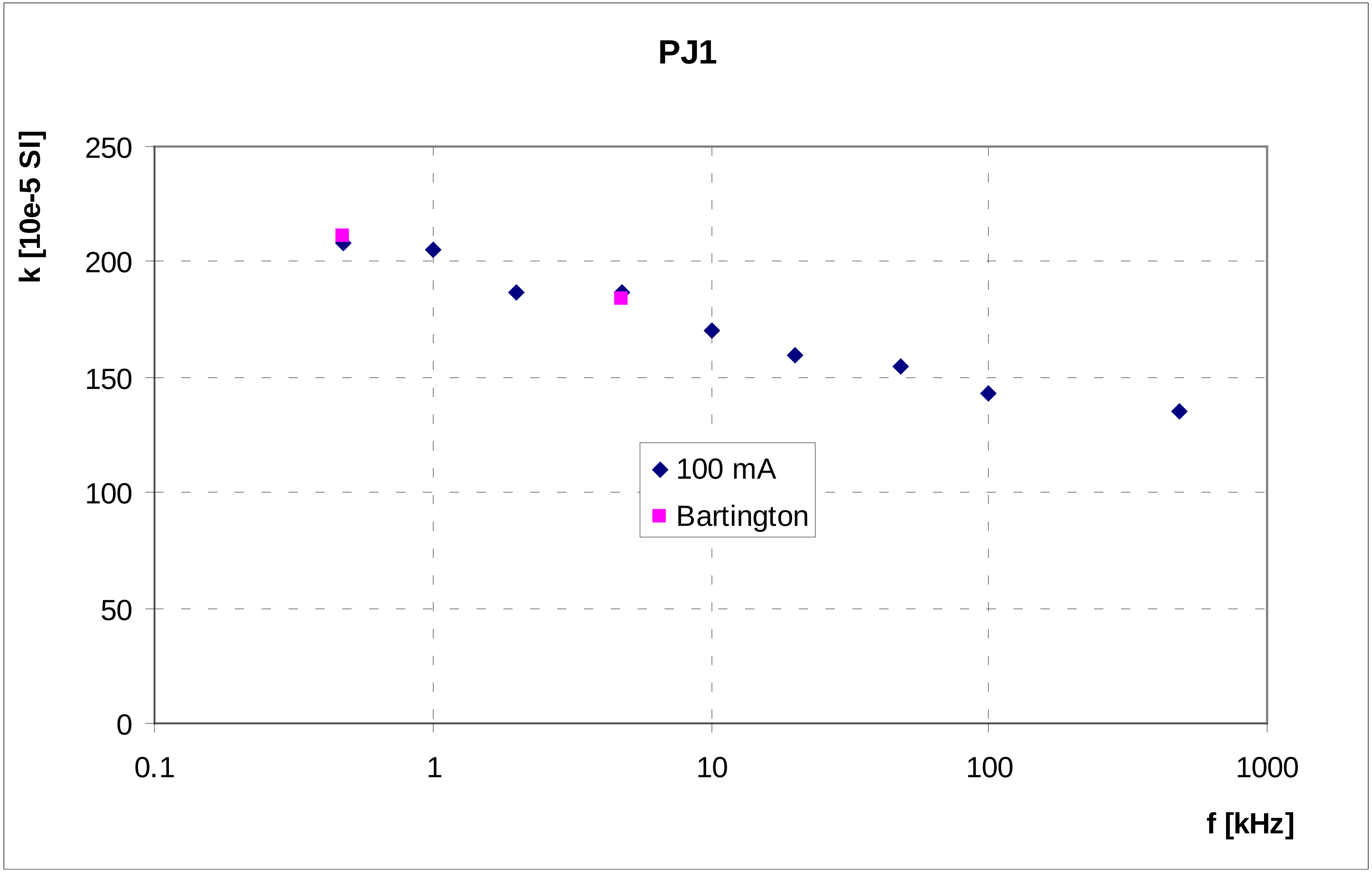
Soil characterisation in time domain





Neel theory of superparamagnetic isolated particles: 1/t time response

Soil characterisation in frequency domain



Frequency-domain versus time-domain

- Time-domain detectors always use pulsed field excitation.
- Frequency-domain detectors: usually continuous wave fields

Static and dynamic modes

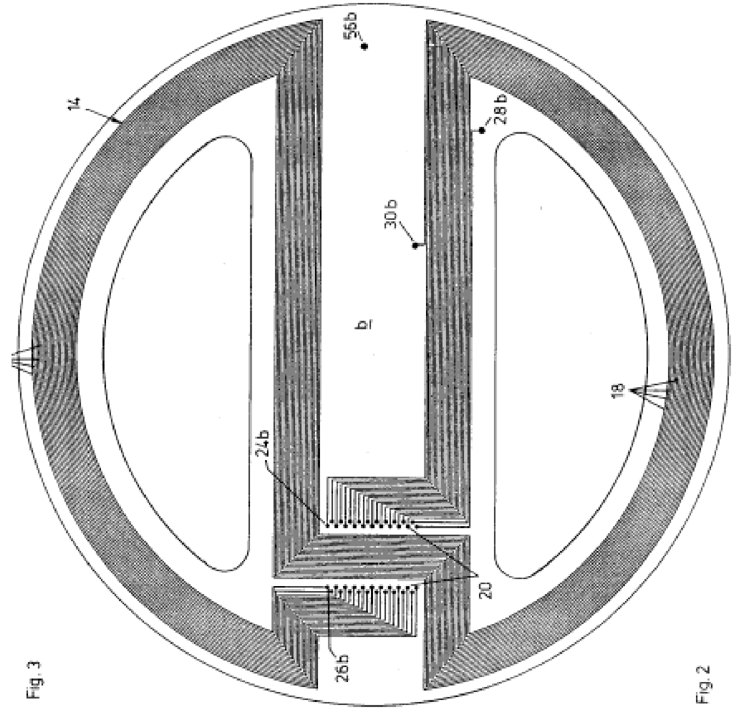
'dynamic mode' detectors:

the alarm turns off after a few seconds

- can help when working in the presence of constant background disturbance, such as alongside a metal rail or fence or when attempting to locate a small AP mine in the vicinity of a large metal-cased AT mine.
- Requires experienced operator
- Dynamic: Guartel MD8, Minelab F1A4 and Vallon detectors
- Selectable Static-dynamic: Ebinger 421GC

Single versus double-D (differential, gradient) receive coils

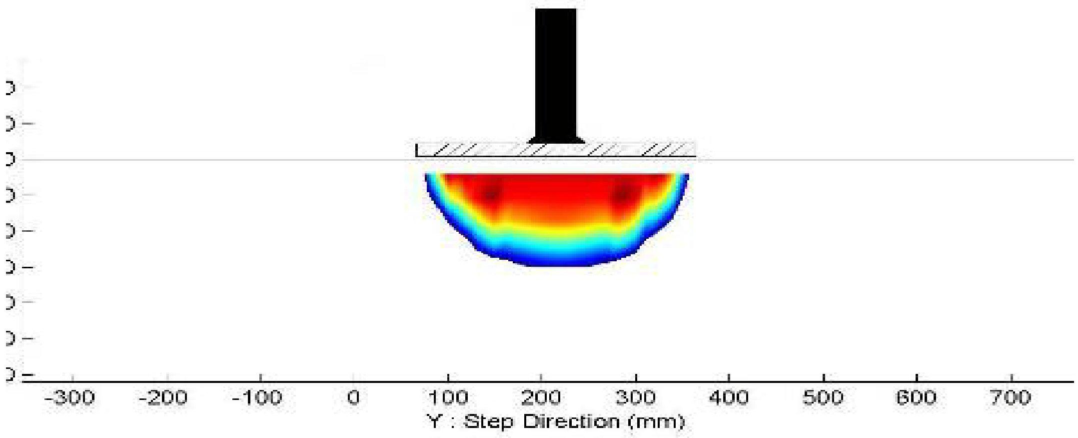
can also be used beside rails and metal fences



CEIA MIL D1
Foerster Minex 2FD
Guartel MD8 detectors.

Size of the coil

- Small objects – small coil
- Deep objects – large coil

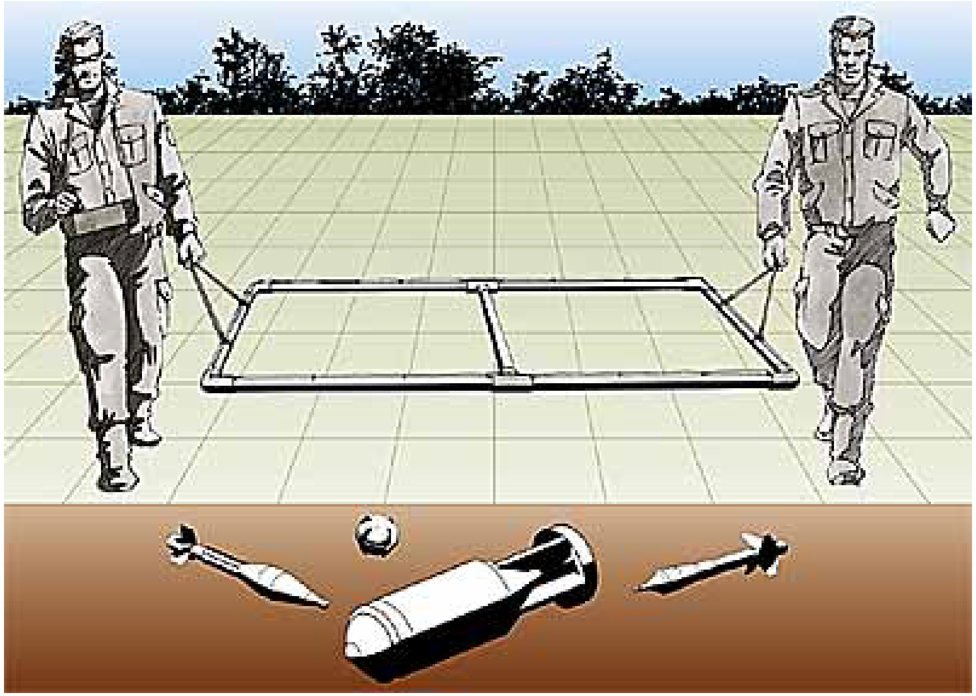


Typical diameters:

Demining detector: 20 cm

UXO detector: 1 m

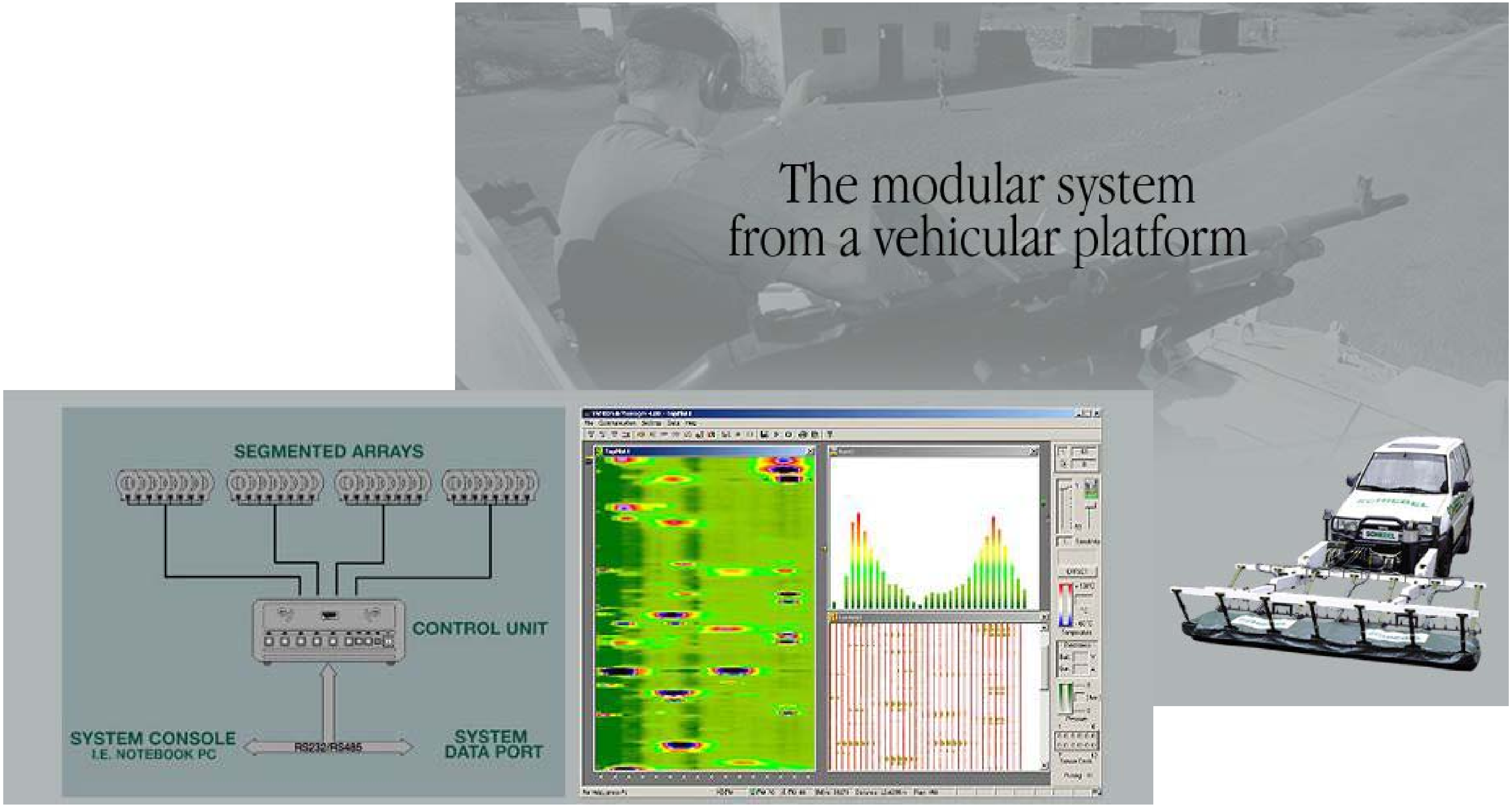
Large-loop detector



Ebinger UPEX 740 M

Geonix EM61

CEIA UXO detector


The modular system
from a vehicular platform
SEGMENTED ARRAYS
CONTROL UNIT
SYSTEM CONSOLE
I.E. NOTEBOOK PC
RS232/RS485
SYSTEM
DATA PORT

Finding large and/or deep objects

- AC methods:

  require artificial source: big coils, 100 A

  sensing coils: up to 10 kg

  Can detect conducting objects

- DC methods:

  use Earth’s field

  Can detect only ferromagnetic objects

DC methods

UXO location

- 155 mm projectile 1.5 m deep ... 10 to 50 nT
- bomb 6 m deep ... 1 to 5 nT

1 nT in 50 000 nT ~ 20 ppm

Vectorial sensors:

angular stability 0.001 deg ~ 0.35 nT

DC Magnetometers

Vectorial:

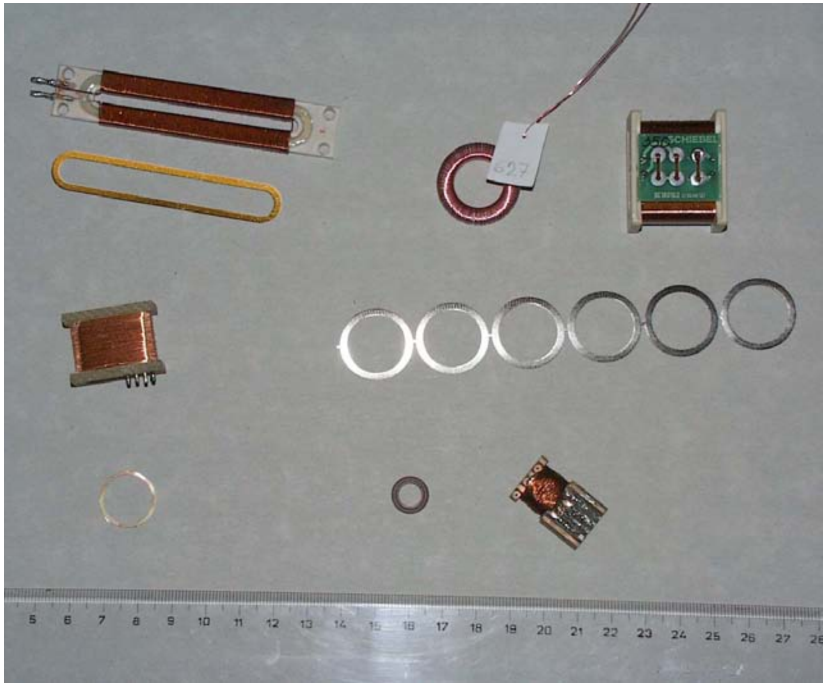
- Fluxgate
  - Ebinger Magnex
  - Foerster Ferex
  - Schiebel Dimads (3-axis)

Scalar:

- Optically pumped: Cesium vapour
- Proton, Overhauser

Why fluxgate and not Hall, AMR, GMR, SDT, GMI..

Classical fluxgates:



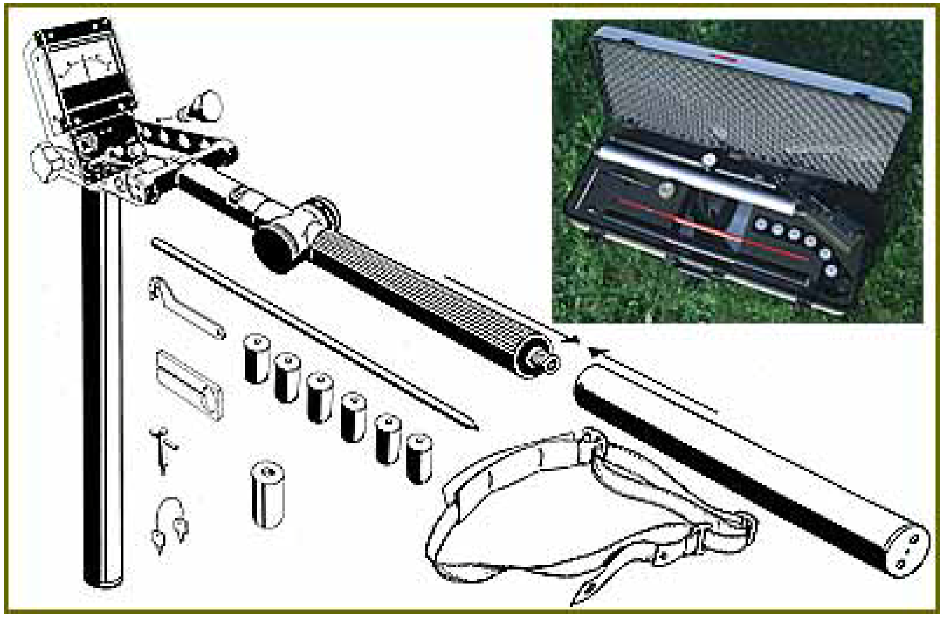
Fluxgates: most precise magnetic sensors

Based on non-linear magnetization characteristics of ferromagnetic core.

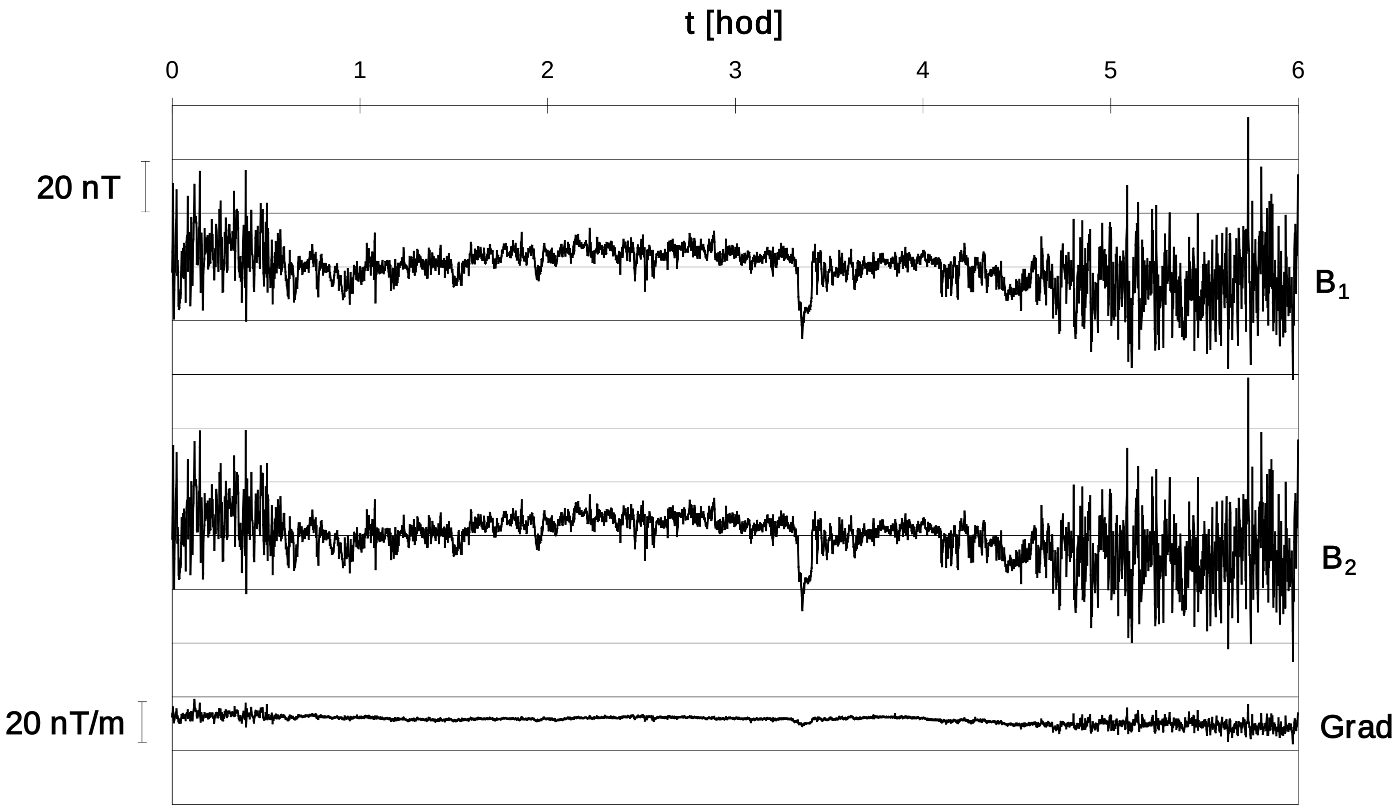
Measure up to 1 mT
with 100 pT resolution (10 pT)

10 ppm linearity

Ebinger Magnex

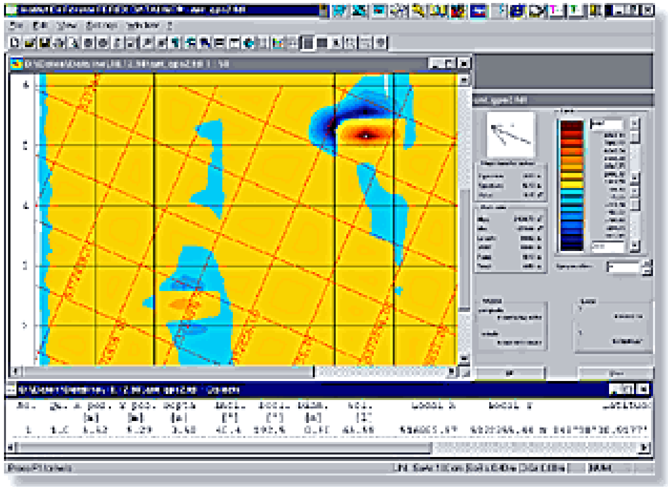


Gradiometer suppresses interferences

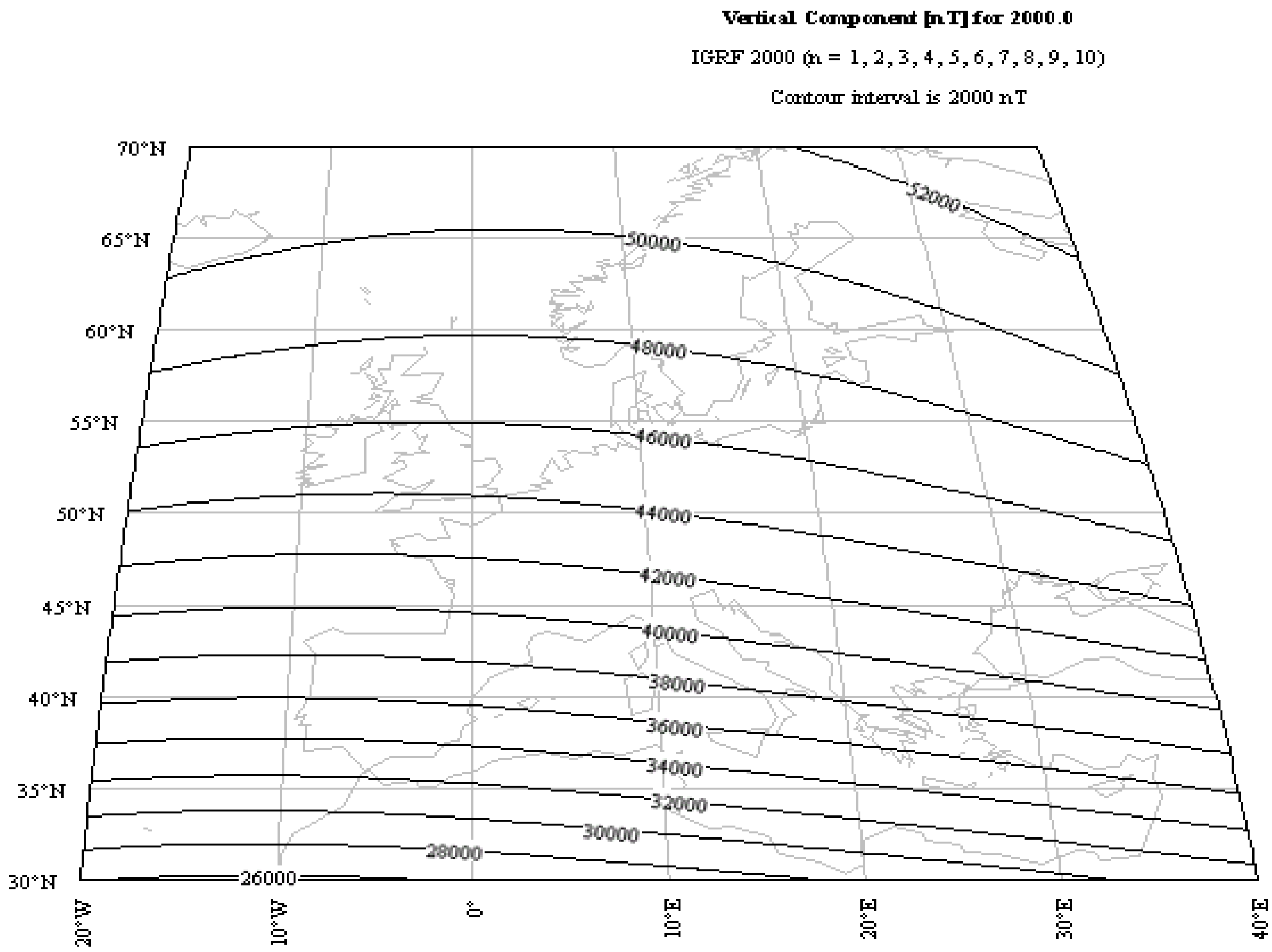


16.2.1999

Foerster Ferex

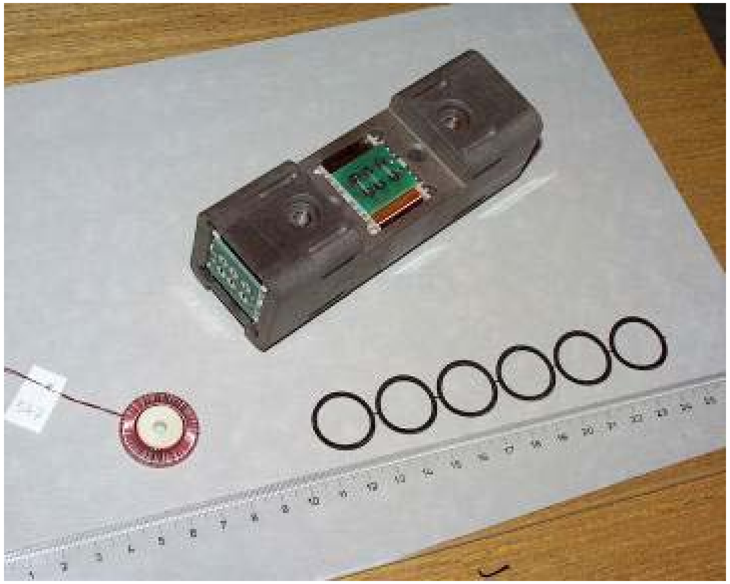


Work nice in Europe, problems in Singapore

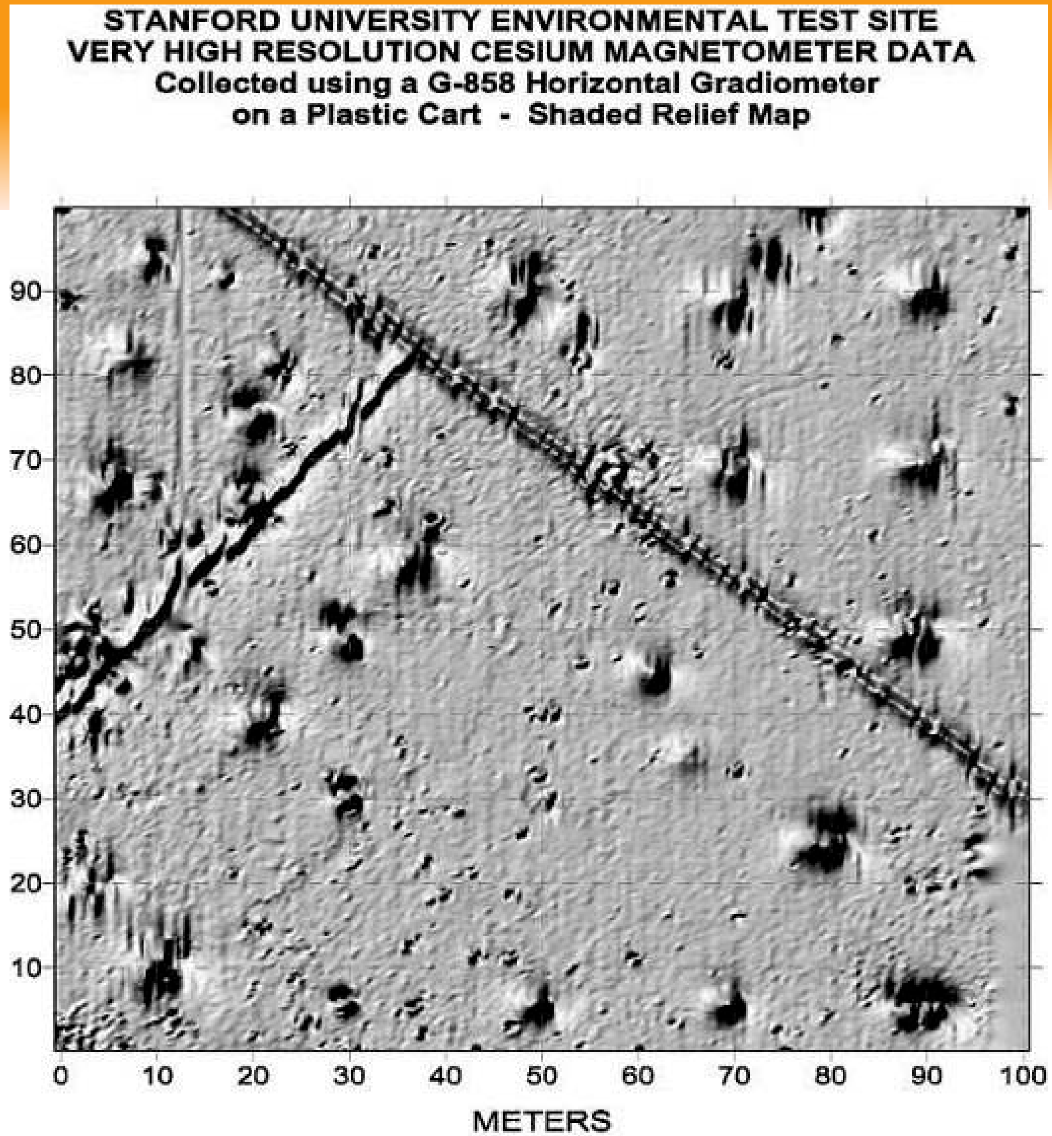


Fluxgate object locator DIMADS

Schiebel Austria,
sensors from Czech Technical University



Geometrics Cesium magnetometer



Buried Drums and Pipes - 1 meter to 3 meters Depth
February 1999 - Geometrics, Inc.

Geometrics Multi-Sensor Towed Array Detection System (MTADS

8 Cesium magnetometers

(3) modified Geonics EM-61 time domain electromagnetic (TDEM) sensors

Other explosive remnants of war detection methods

- Ground-penetrating radar (GPR)
- Electrical impedance tomography
- X-ray backscatter detection
- Infrared and multi-spectral detection
- Acoustic detection
- Detecting explosives

Explosive detecting dogs (EDDs)

A: to run dogs over the suspect area,

B: to take air sample filters in a suspect area and present the filters to dogs later.

Also rats and insects (bees, vasps)

Ground-penetrating radar (GPR)

– dielectric contrast necessary (not plastic mines in dry sand)
– short-wavelength radar waves needed to find small mines (over 800 MHz frequency) do not penetrate wet soil very well.
– Good for metal objects

New mine detectors: Eddy currents + GPR

Primary:

Detect small metal objects

To reduce the response to clutter

GPR imaging system

Noggin 1000 (Sensors and Software Inc.   http://www.sensoft.ca)

Dual technology detectors

AN/PSS-14 : dual technology, audio output

CyTerra Corp. (radar part) http://www.cyterra.com
and MineLab (metal detector part)

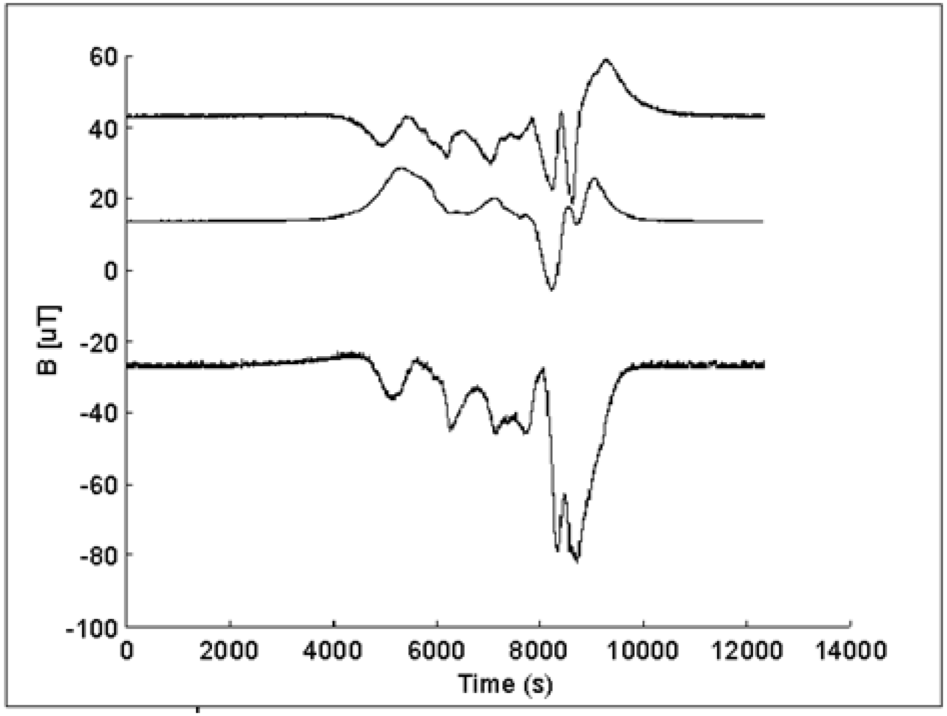
Also Vallon VMR-1

APPLICATIONS

Applications II

- Detection and recognition of vehicles (incl. submersible)
- Detection frames and other sensors for border security
- Magnetic labels and anti-theft system
- Navigation systems
- Magnetic tracking
- Distance measurement
- Distributed sensors and sensor areas

Detection and recognition of vehicles

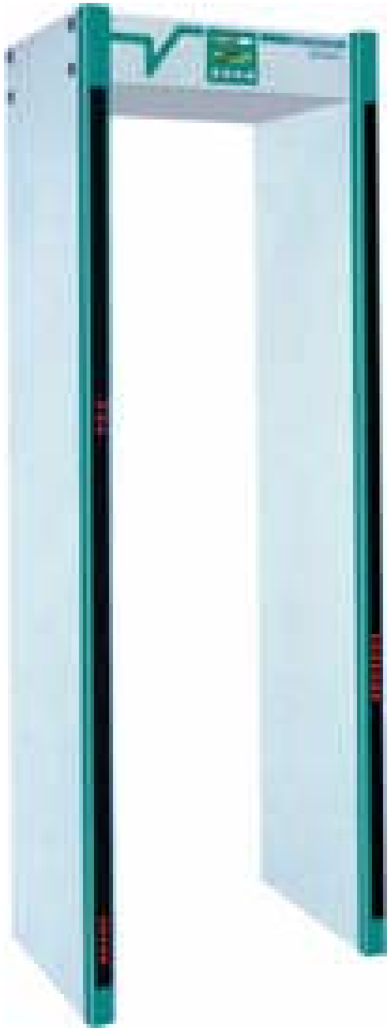


Magnetic field of Skoda car measured by 3-axis CTU fluxgate under the road surface

Vehicles can be identified usig magnetic signature

The same technology is used for detection of ferromagnetic bodies

Detection frames and other sensors for border security

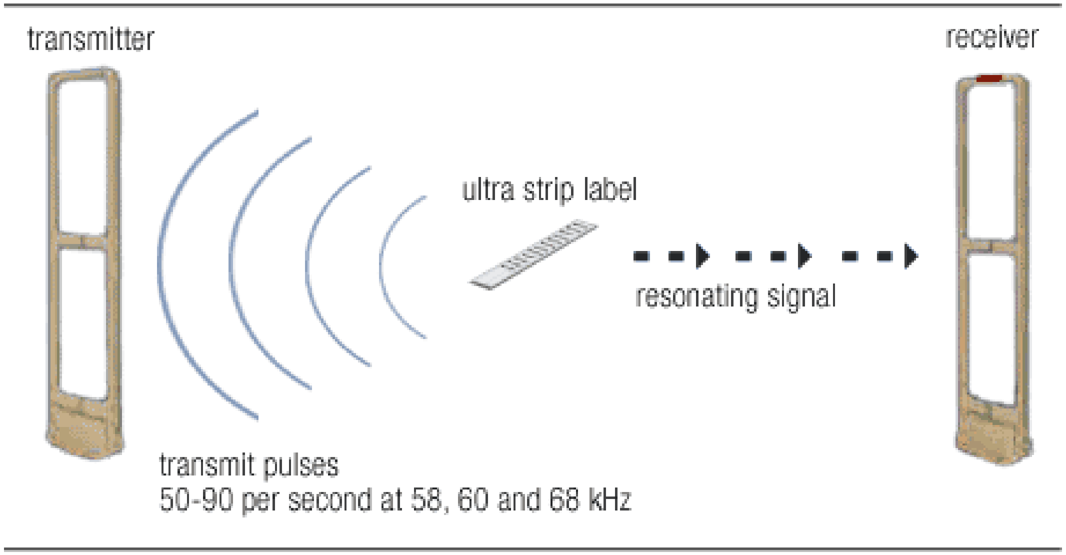


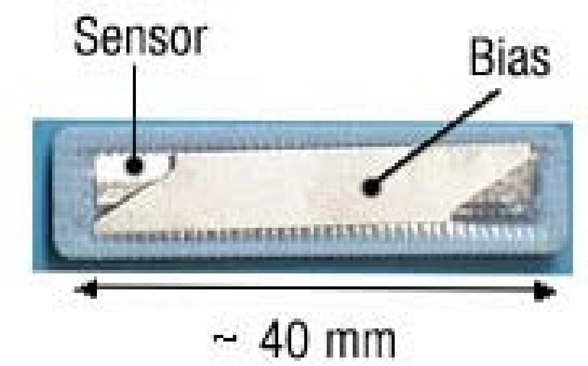
Eddy-current technollogy – multi-pulse

Multi-zone

Ceia, Vallon, …

Magnetic labels and anti-theft system

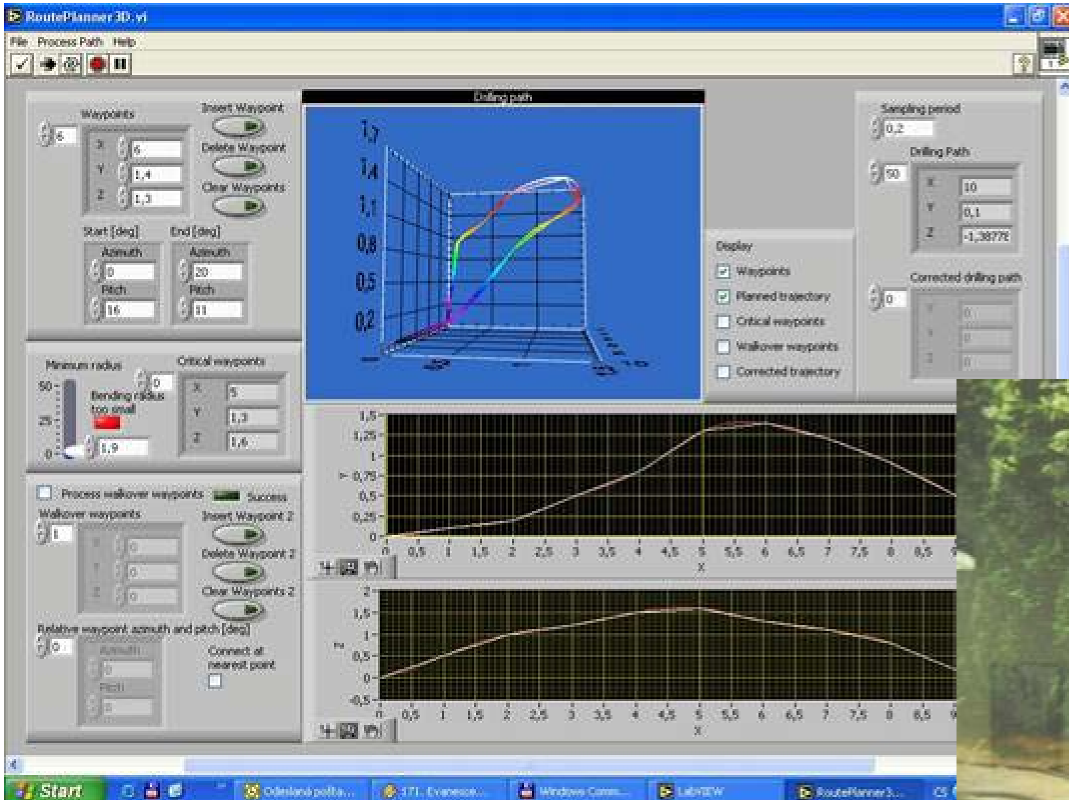




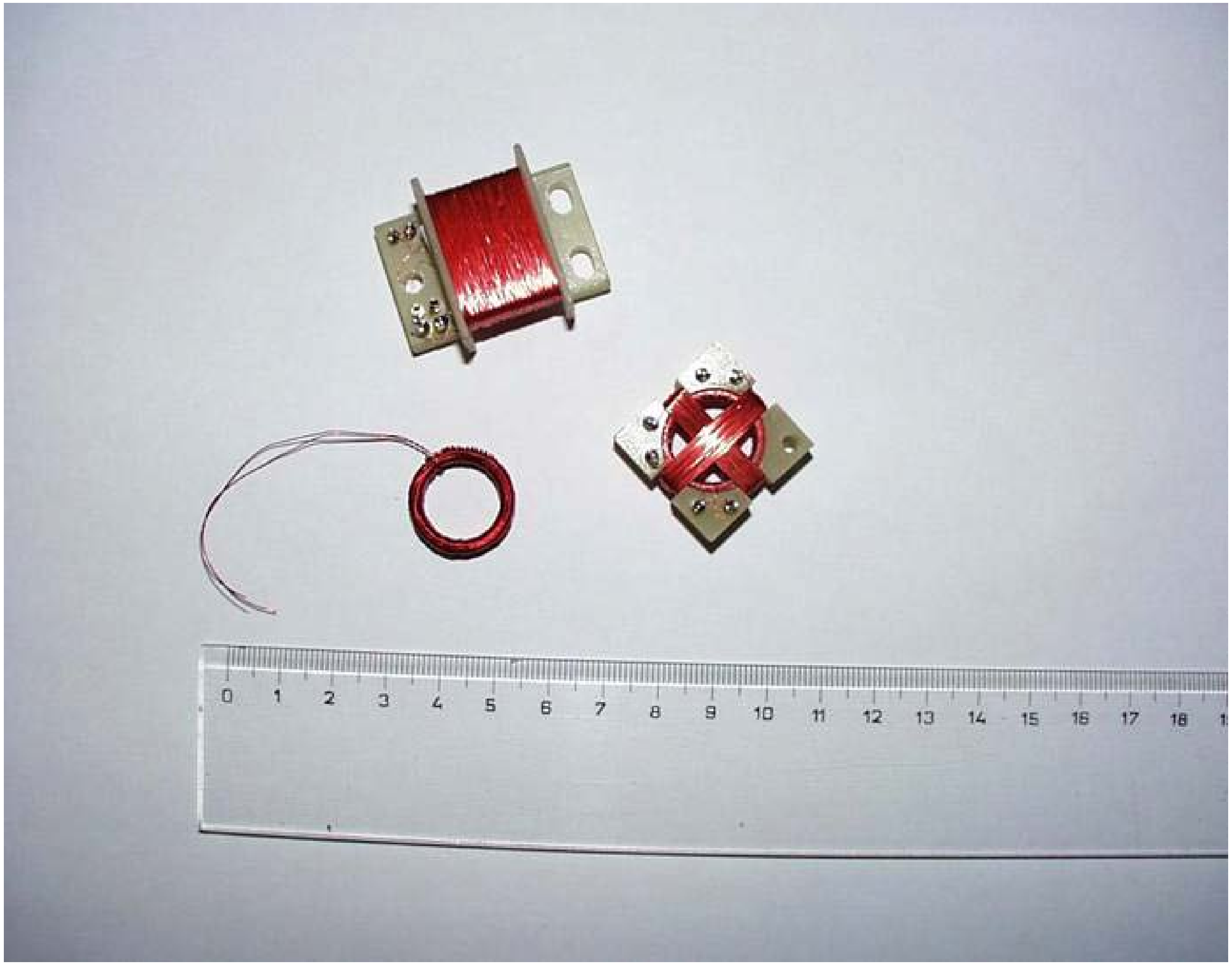
Sensormatic/ Tyco Fire & Security

Magnetoelastic labels
www.vacuumschmelze.de

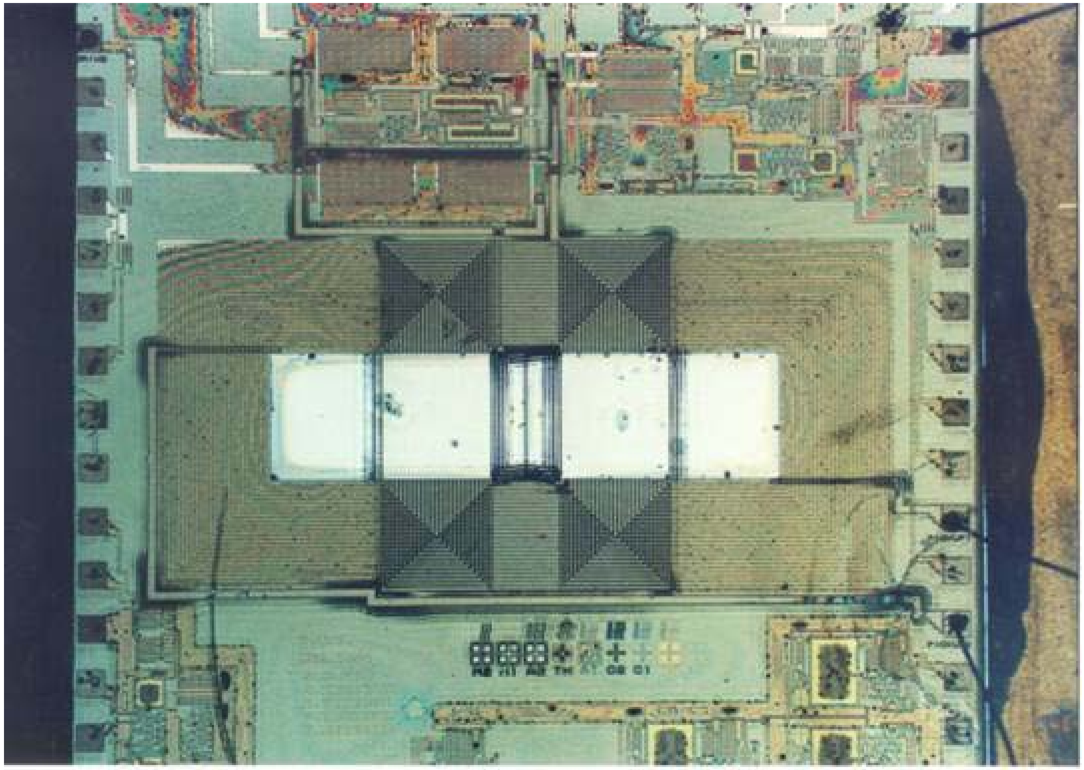
Aplication: Compass



Fluxgate compass: 0.05 deg accuracy



Micro-fluxgate sensors



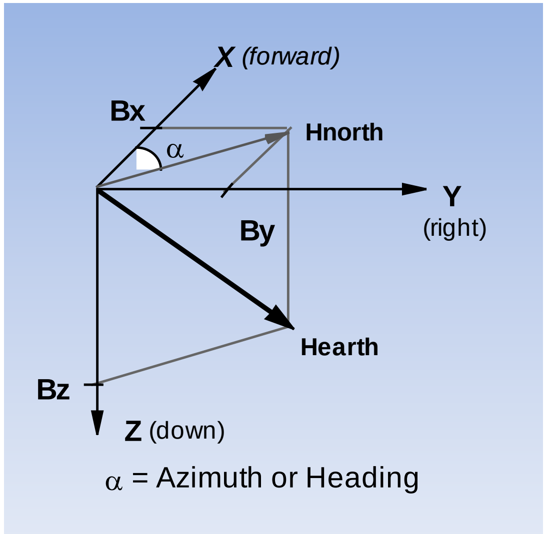
Shizuoka University

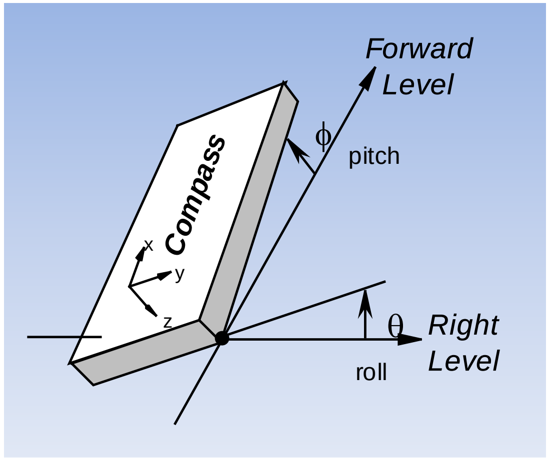
(in development)

- flat coils
- electrodeposited core or amorphous strips
- electronics on chip

- cheap
- resolution still higher than MR

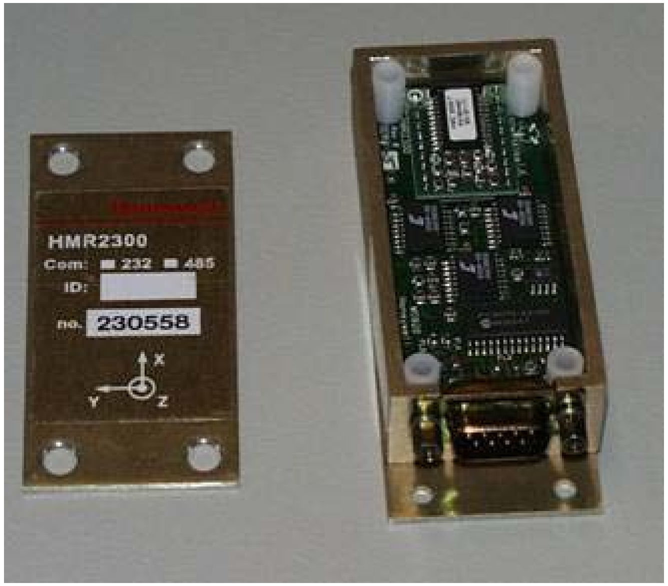
AMR Compass: Honeywell





Magnetic compass + inclinometers

= backup for GPS

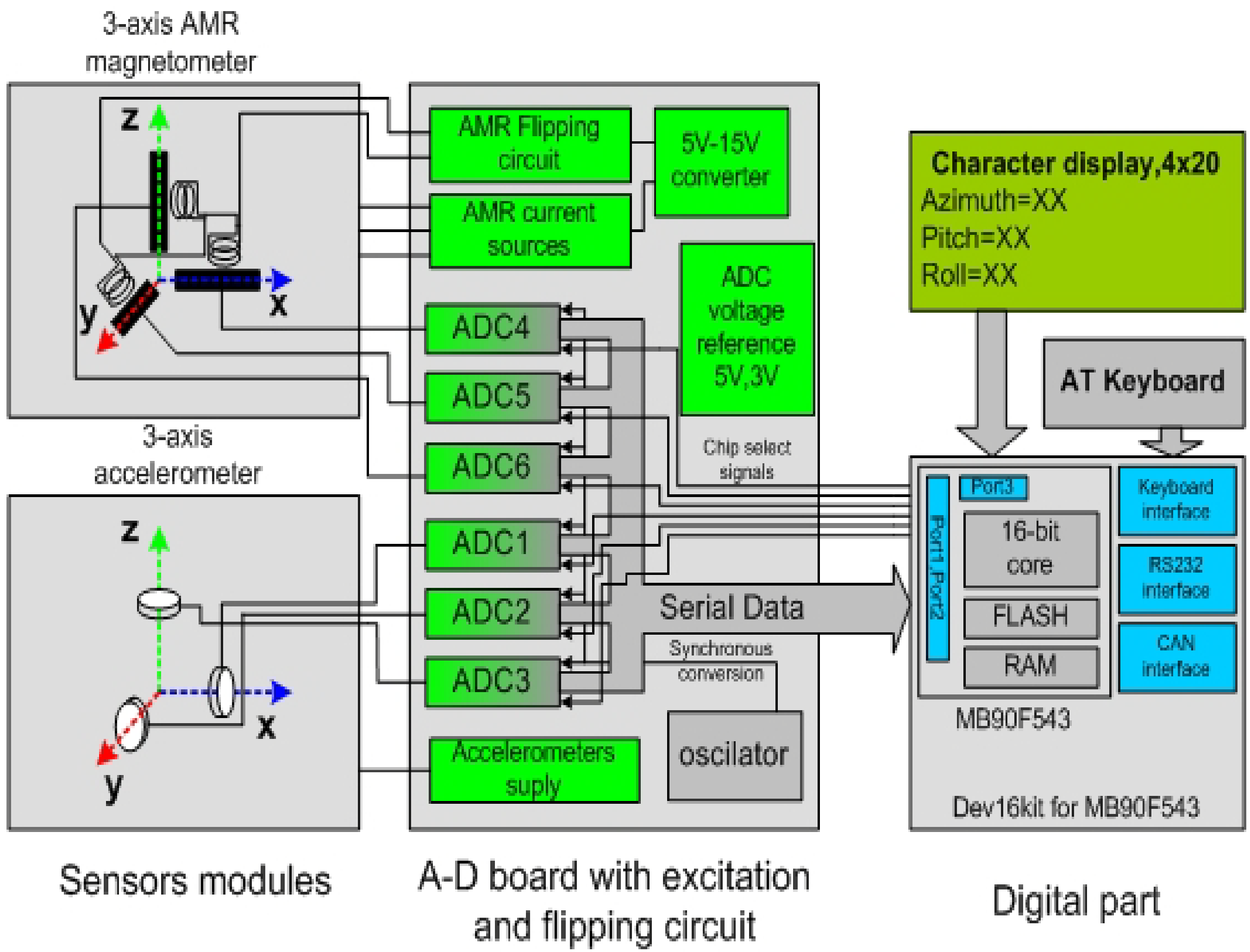


Honeywell 3-axis AMR magnetometer with digital output

AMR Compass: Our experimental system

AMR modules with HMC100X, HMC102X, KMZ51

AMR compass system



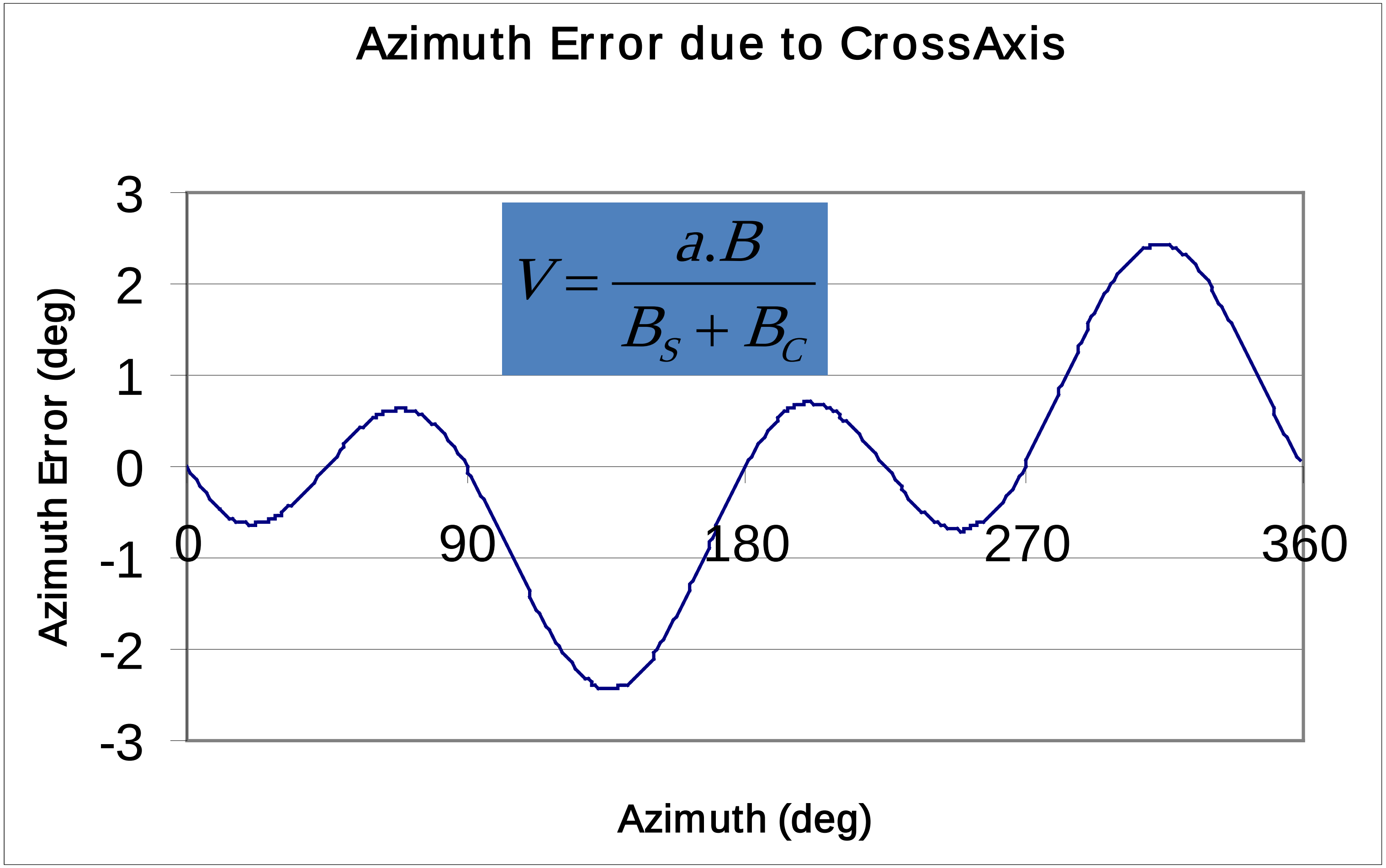
AMR compass system

Obstacles in compass application

- Crossfield sensitivity
- Orthogonality of XYZ sensors
- Horizontality (knowledge of tilt)
- Angular deviations: g sensors
B sensors
reference directions

- Offset, perming, temperature drifts of sensors

Crossfield error - simulation

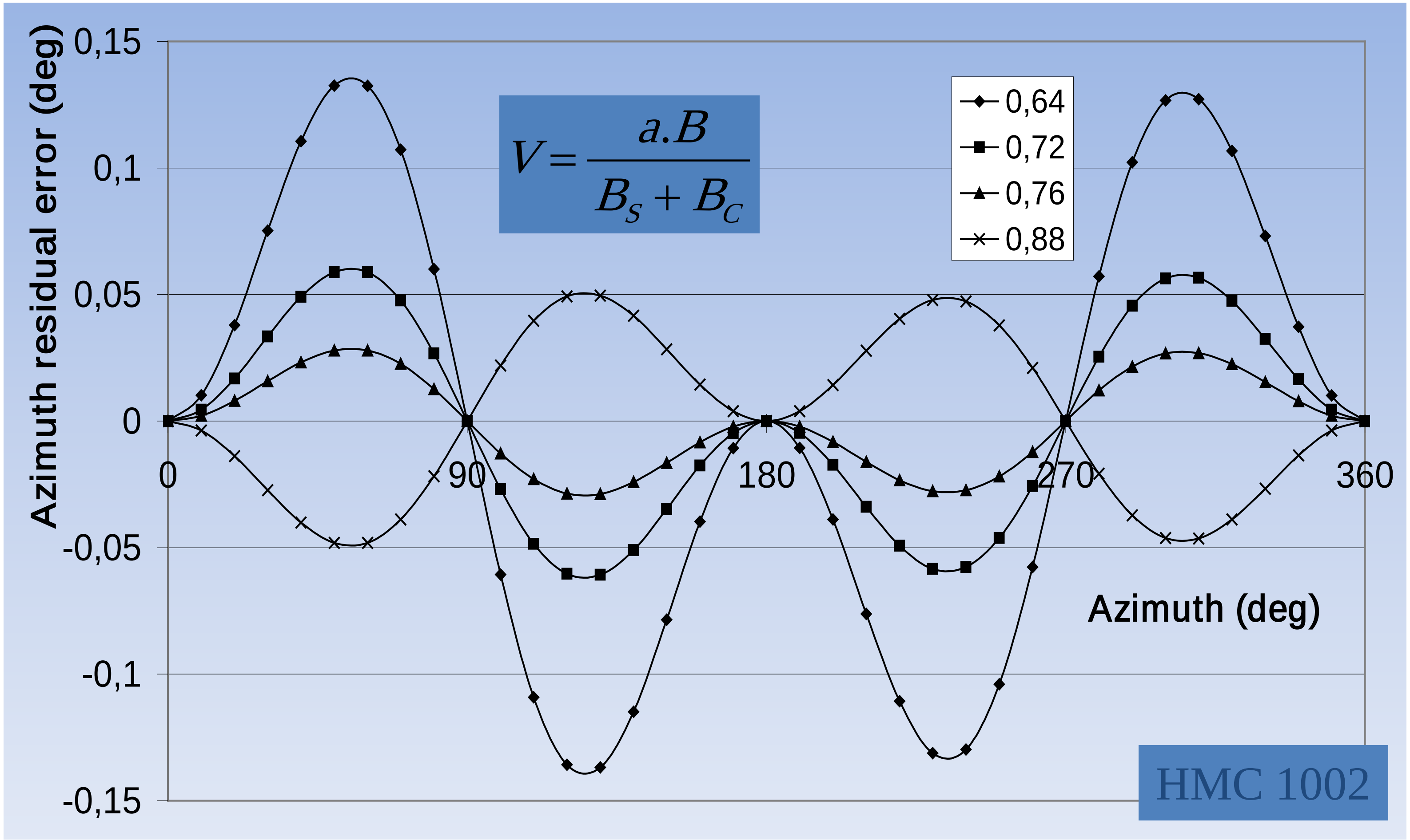


Crossfield error: possible solutions

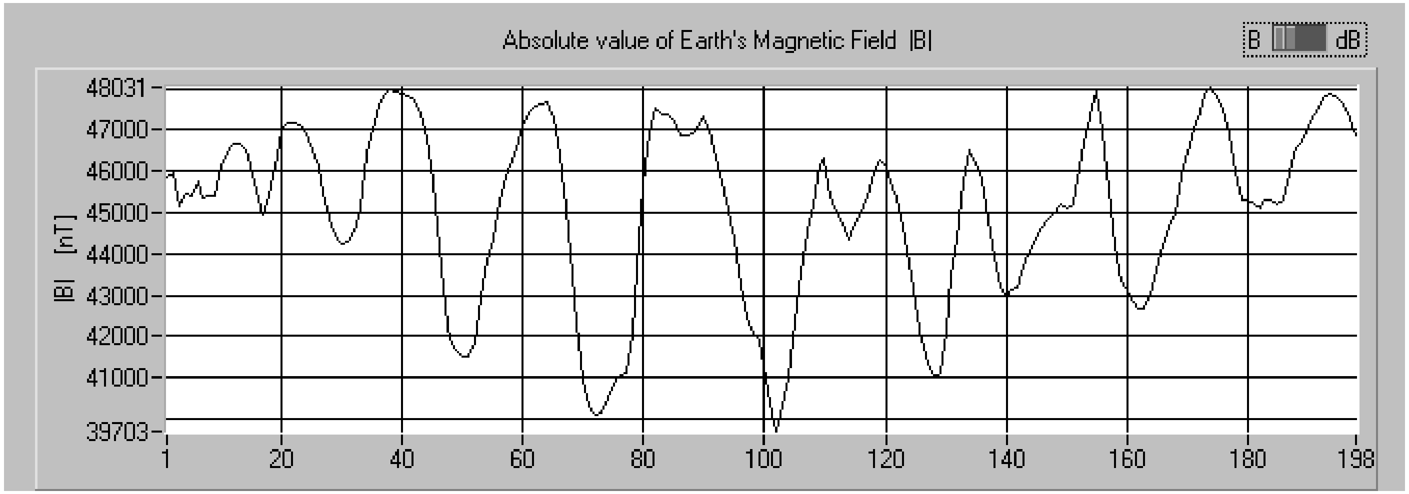
- Feedback compensation
  - power consumption
  - limited bandwidth
  - precision?
- Numerical corrections
  - is the formula precise?
  - how precisely we know Bs?

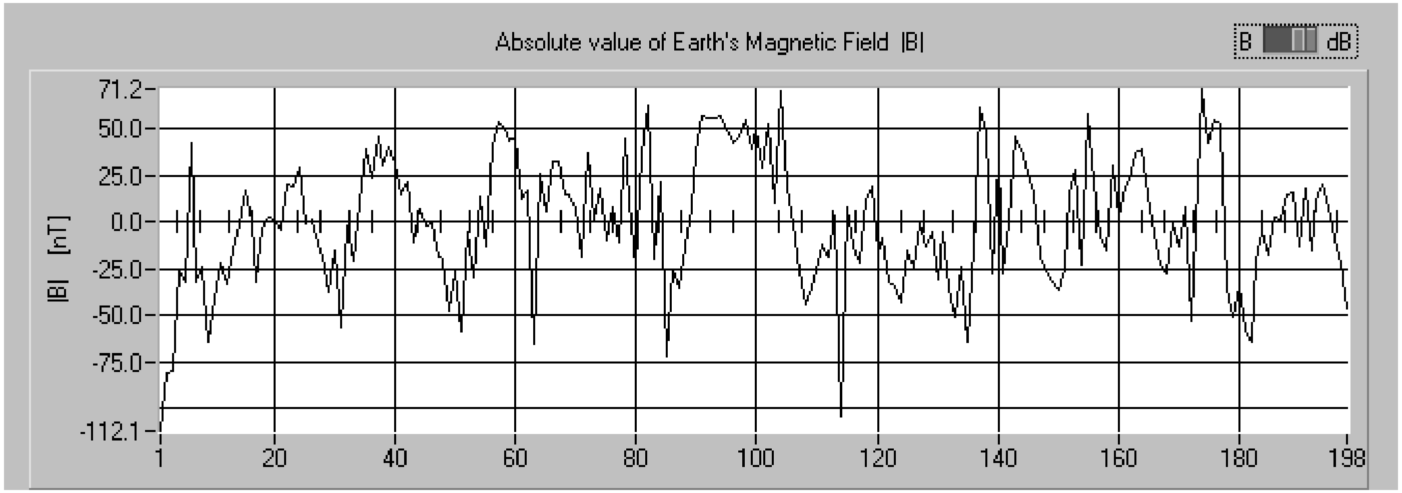
$$V = \frac{a.B}{B_S + B_C}$$

Crossfield error after numerical correction effect of bad estimate of Bs (model)

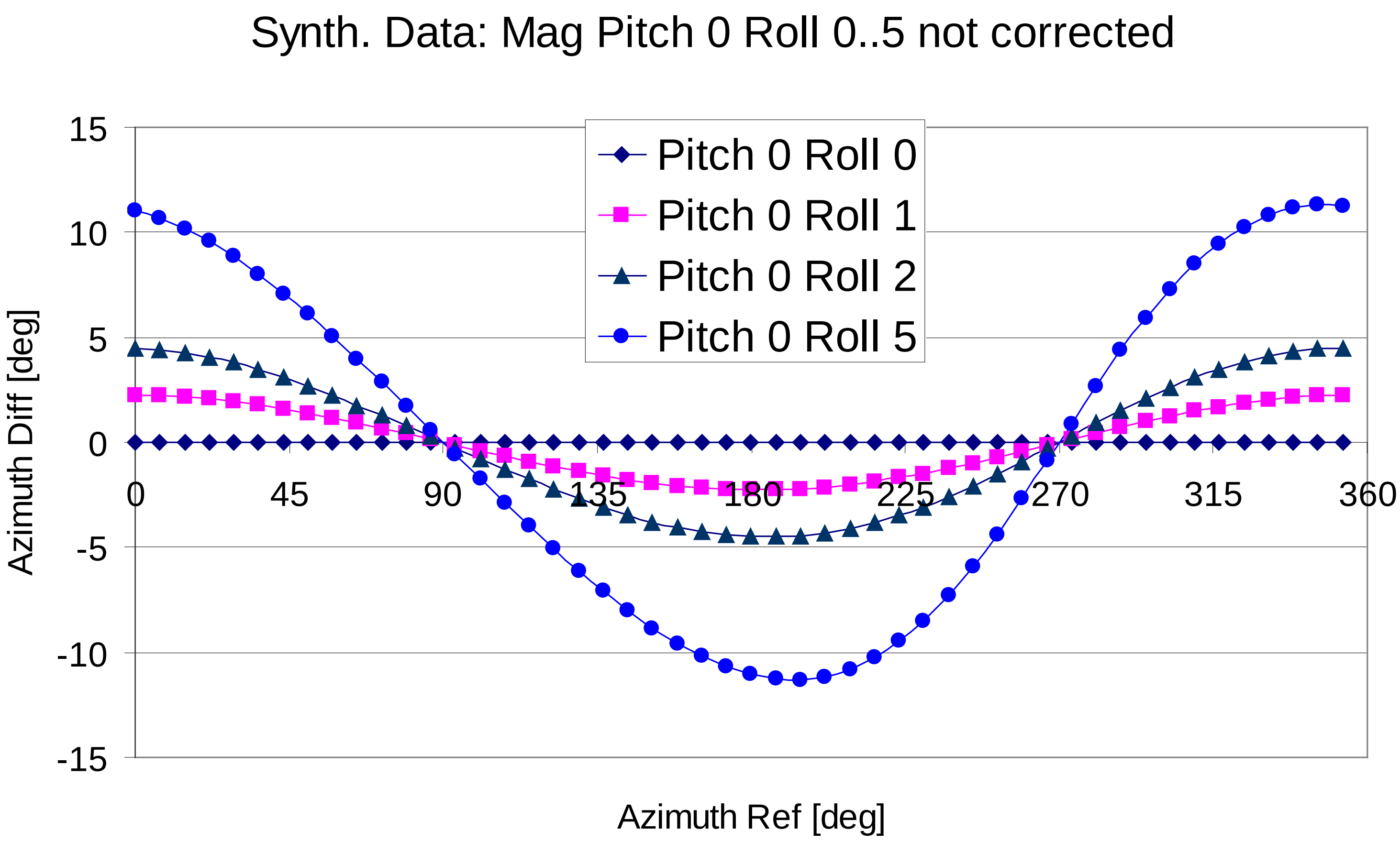


Error due to non-orthogonality

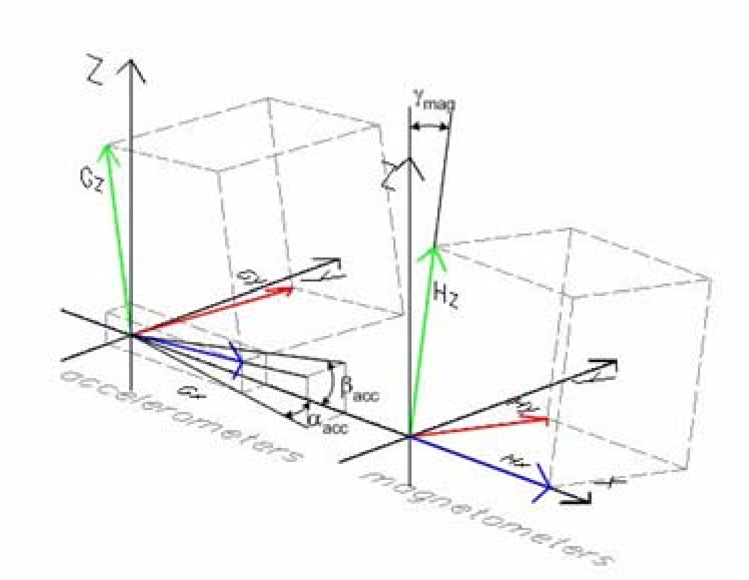




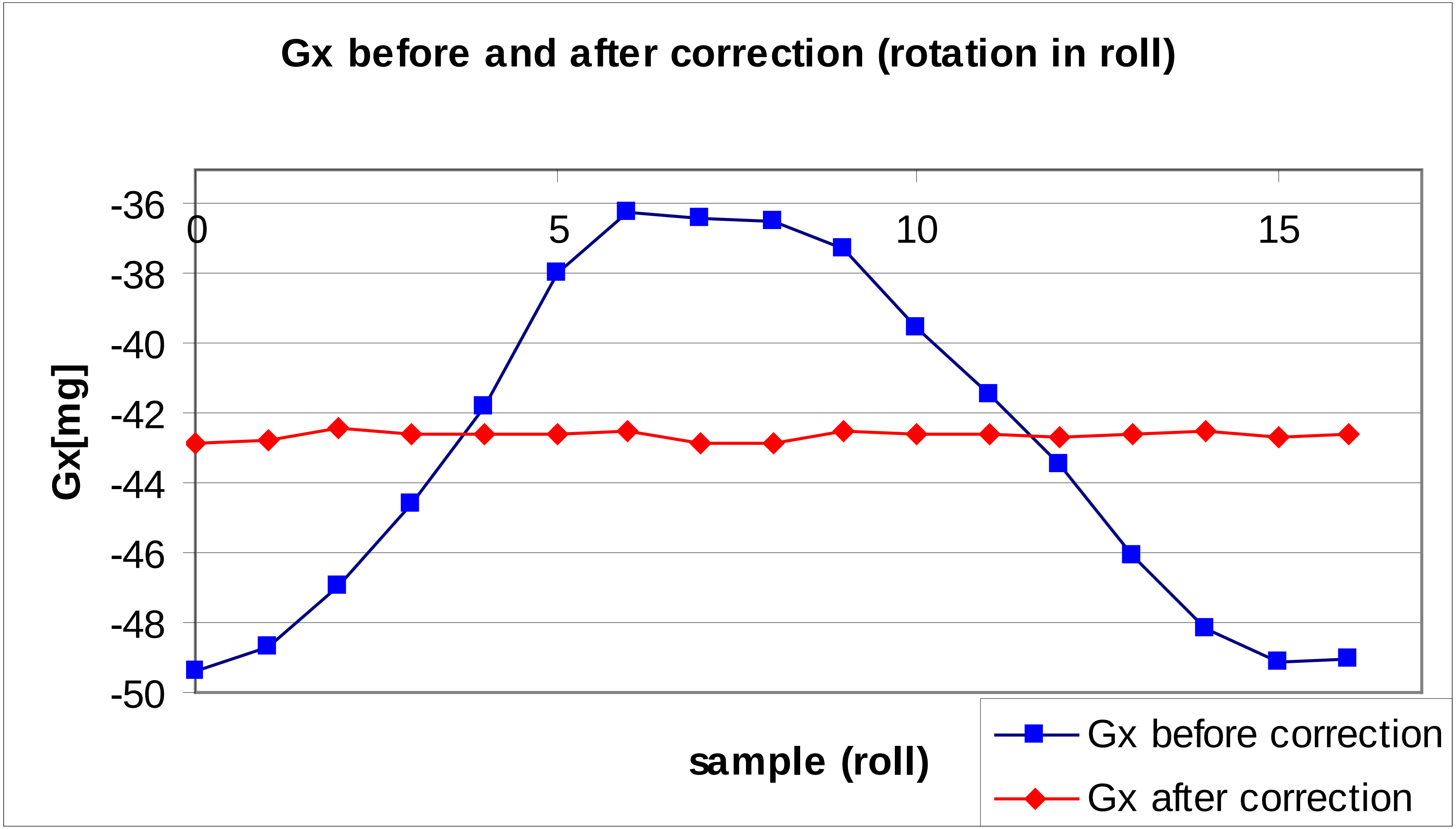
Error due to non-horizontality



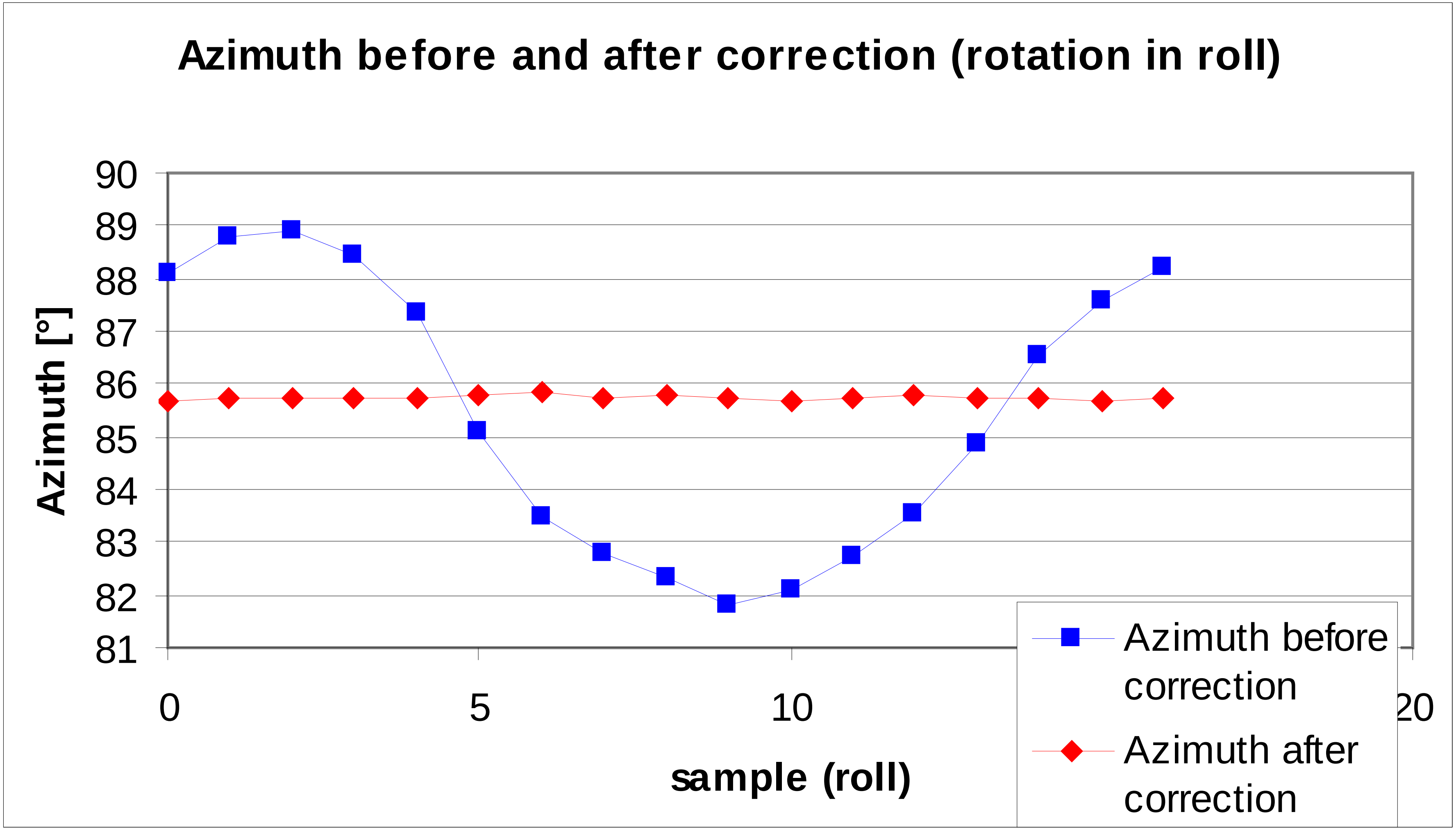
Angular deviations



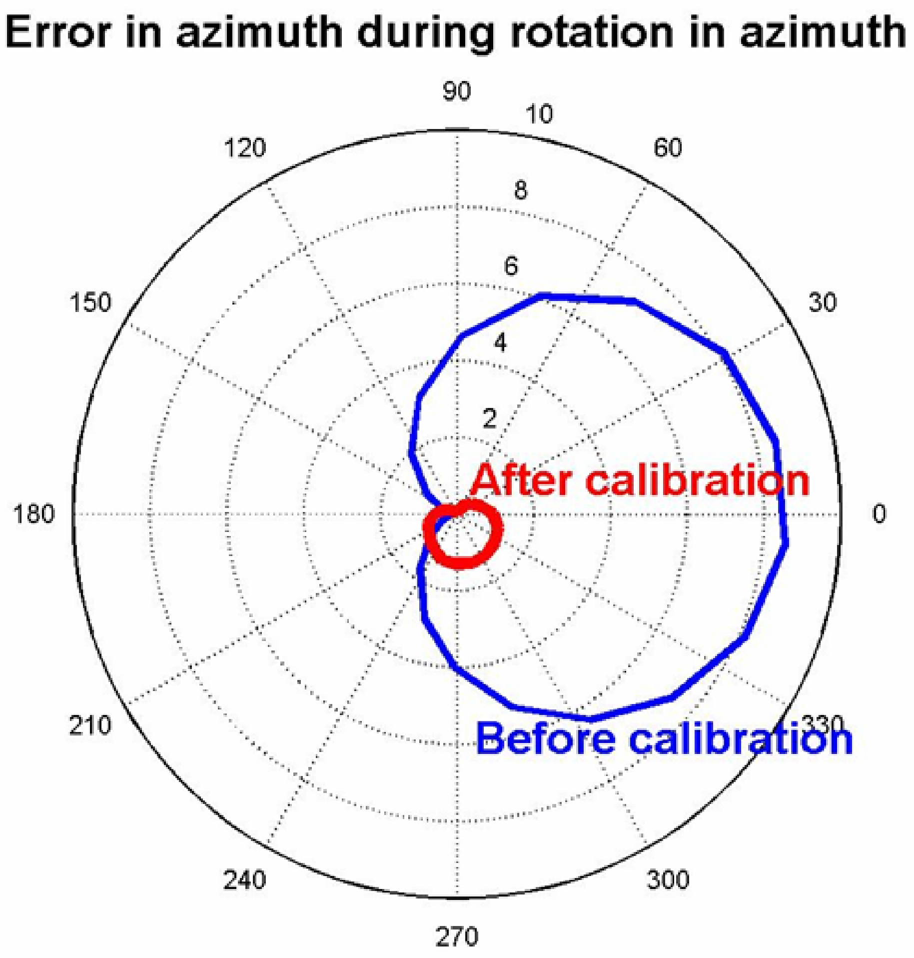
A: rotation in roll … accelerometers



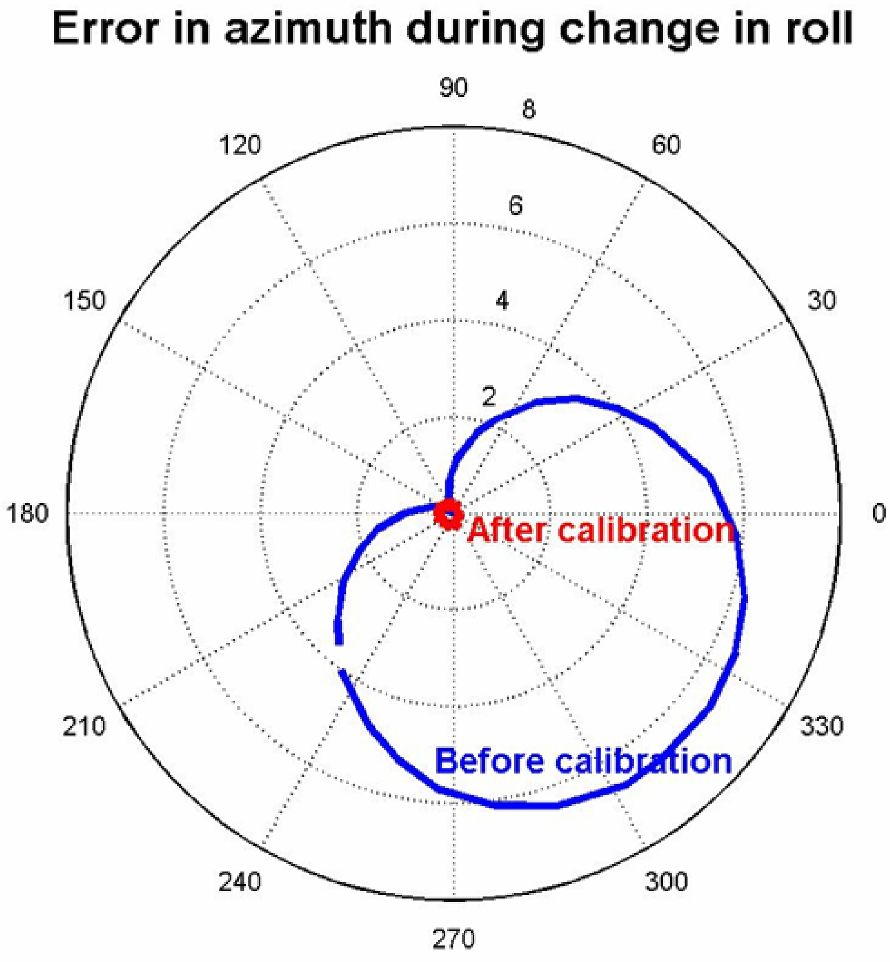
A: rotation in roll … magnetic sensors



Total error


Error in azimuth during rotation in azimuth
90
10
120
60
8
6
150
30
4
2
After calibration
180
0
210
330
Before calibration
240
300
270

Total error



Error in azimuth during change in roll
90
8
120
60
6
150
30
4
2
180
0
After calibration
210
330
Before calibration
240
300
270

Magnetic tracking – moving sensors

Translation Range : 3 m x 3 m

Static Accuracy Position: 1.5 cm RMS

Static Accuracy Orientation: 1.0° RMS

/www.ascension-tech.com/

Magnetic tracking – moving marker

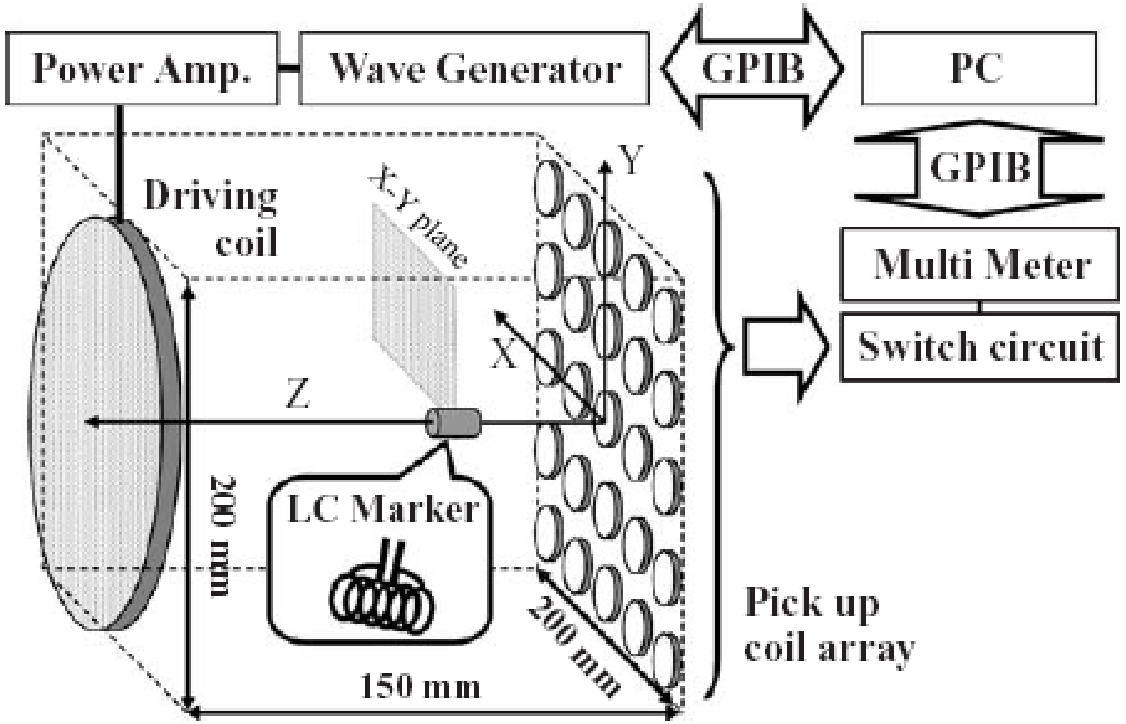


Fig. 1. Schematic diagram for the motion capturing system.

Hashi et al, 2004)

Magnetic tracking – moving marker

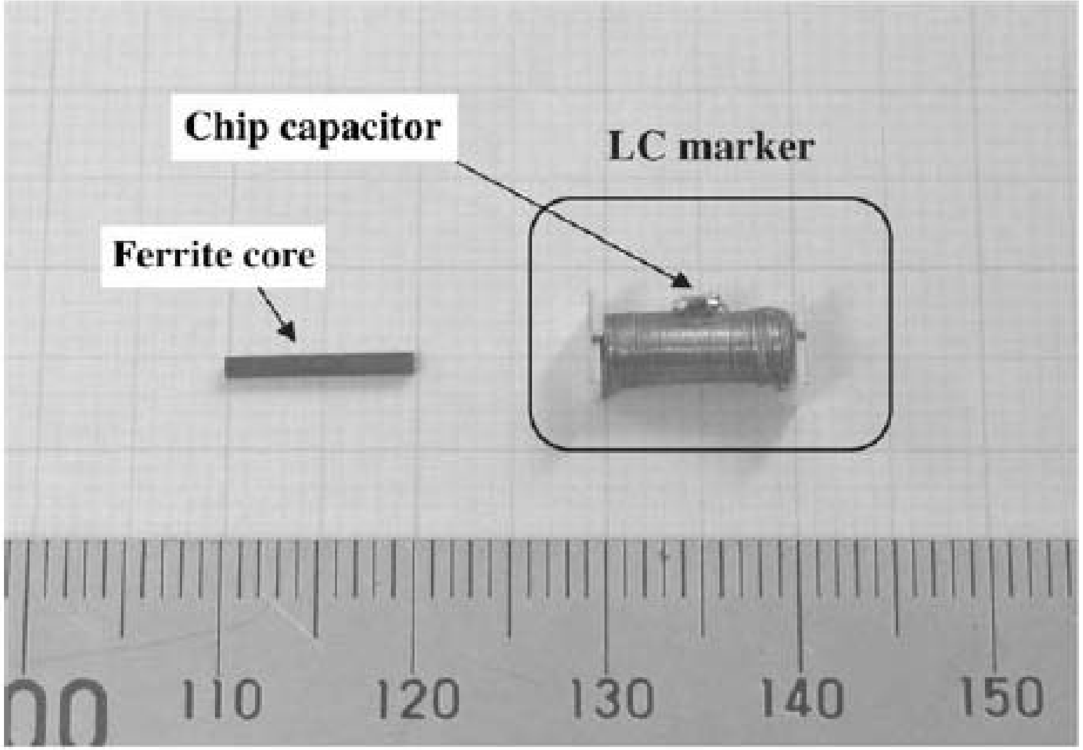
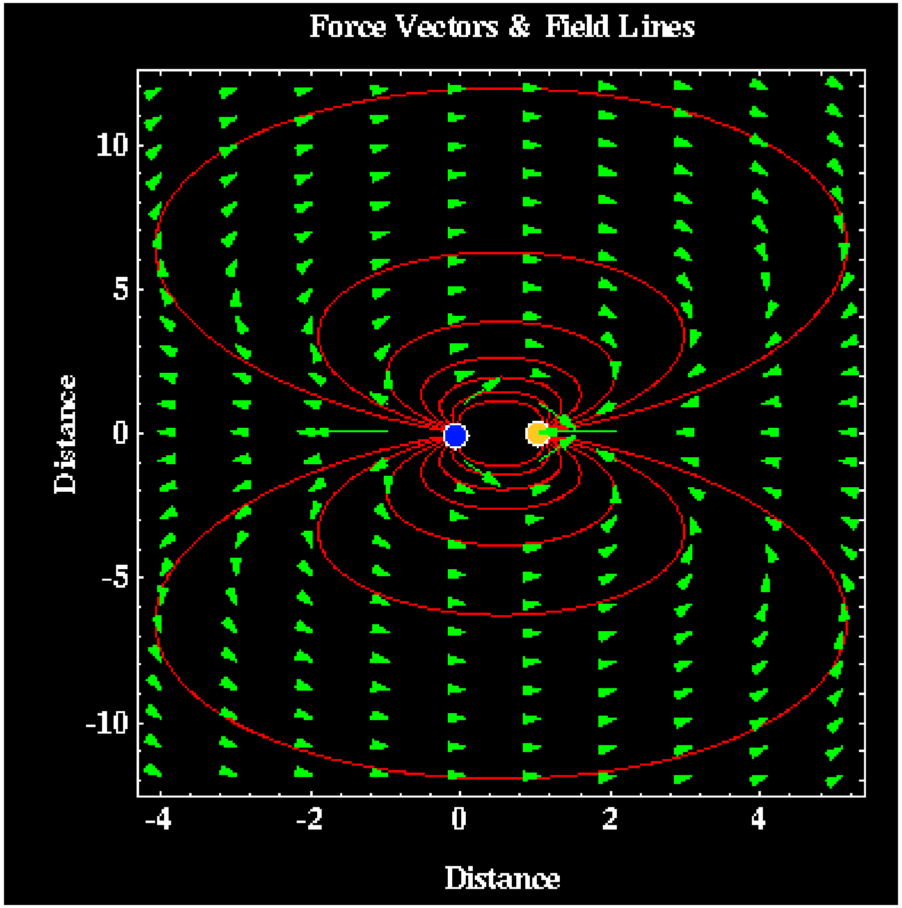


Fig. 2. Photograph of LC resonant marker with high permeability ferrite core.

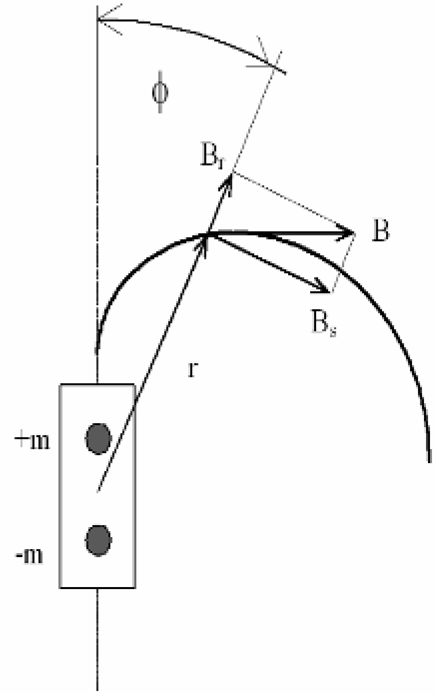
Hashi et al, 2004)

Dipole source

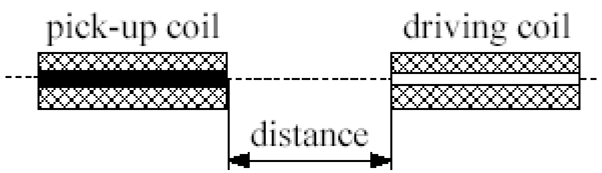


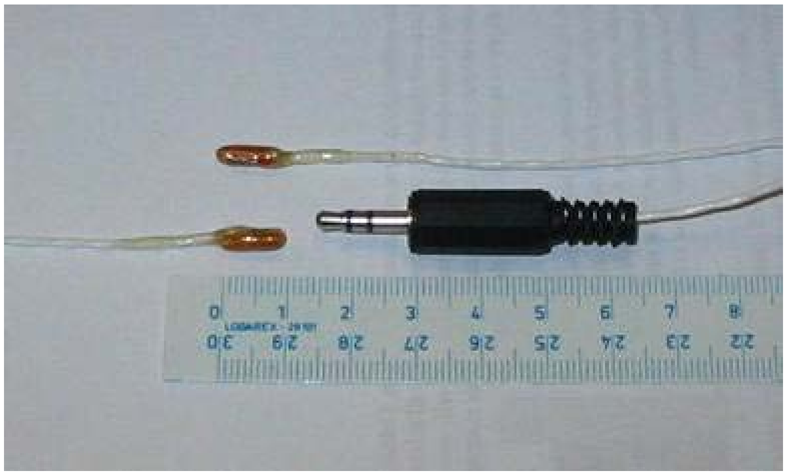
$$B_r = \frac{2}{10^7} \frac{m_m}{r^3} \cos\phi$$

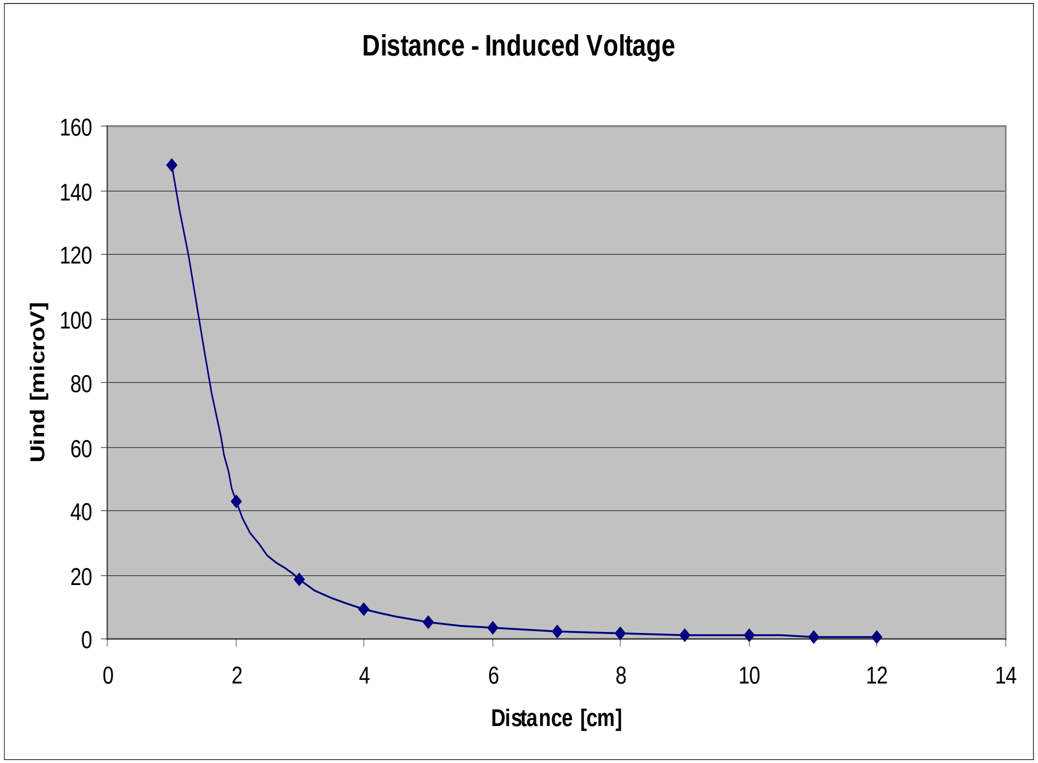
$$B_s = \frac{1}{10^7} \frac{m_m}{r^3} \sin\phi$$



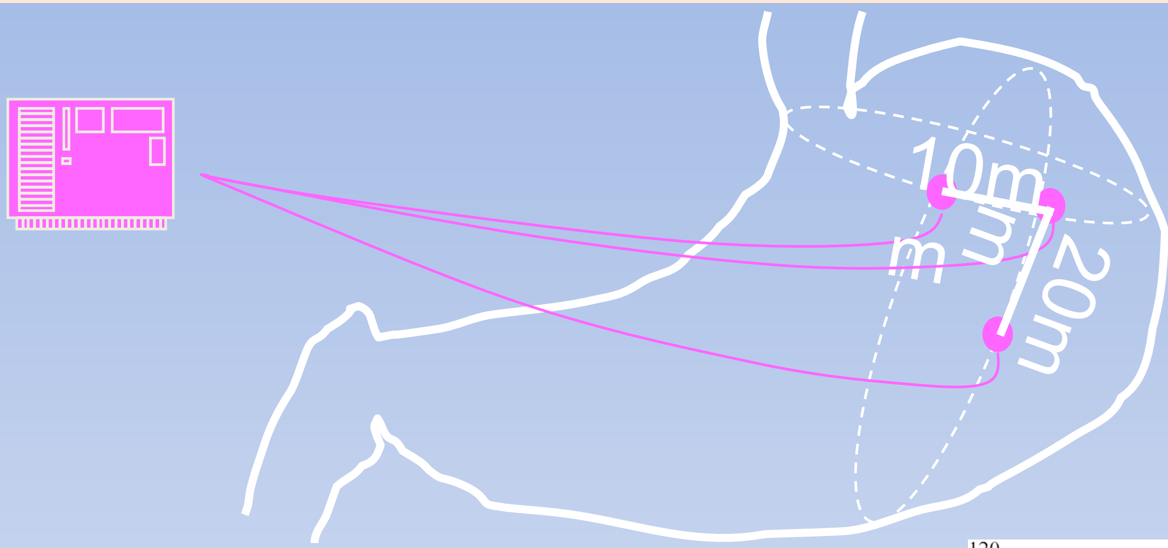
Distance measurement

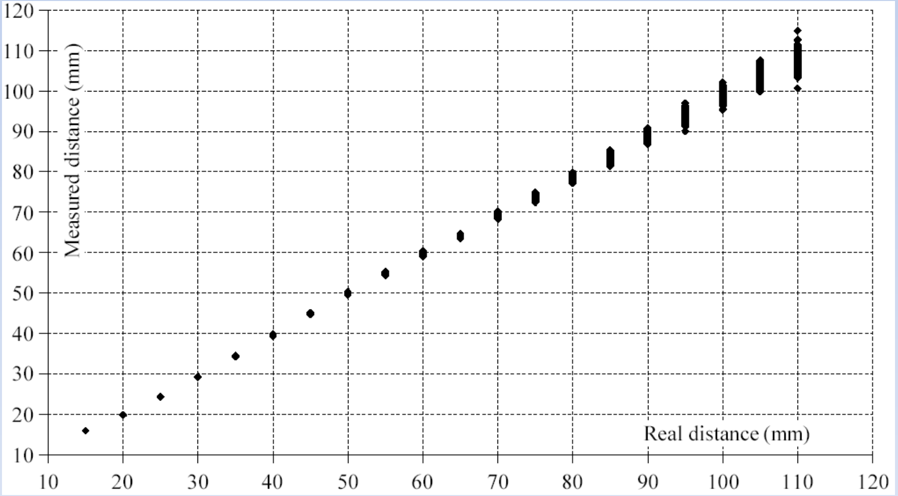






Distance measurement in vivo





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- J. Dirscherl, C. Bruschini: Metal Detectors Catalogue 2005 Geneva International Centre for Humanitarian Demining,
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