Hall Teslameter with NMR-like Accuracy

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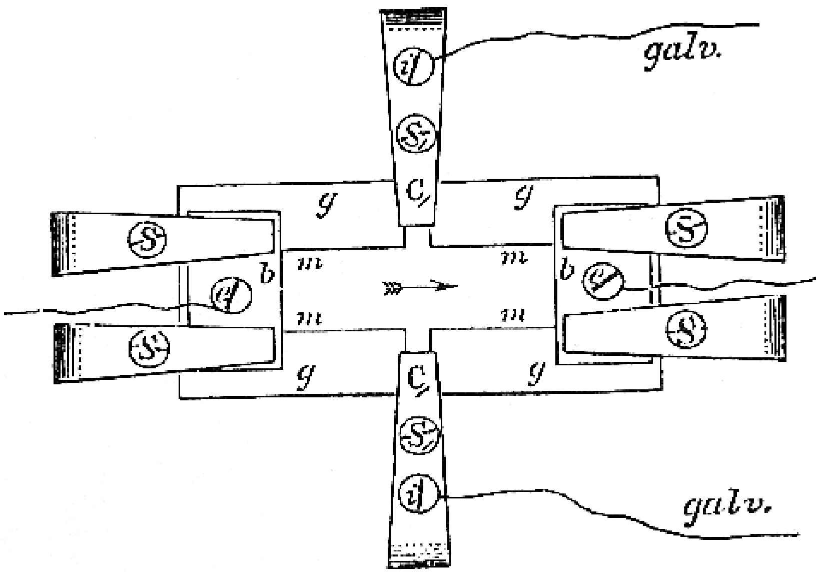
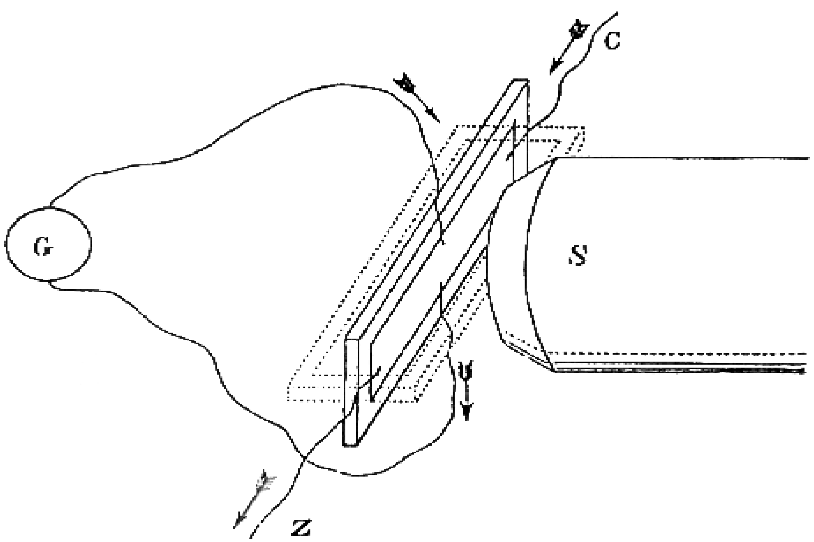
Outline

- Hall Magnetic Sensors
- Offset and noise reduction techniques
- Reduction of the planar Hall effect
- SENIS High-Resolution Hall Transducer
- SENIS High-Resolution Hall Teslameter
- Conclusions and outlook

The Hall Effect



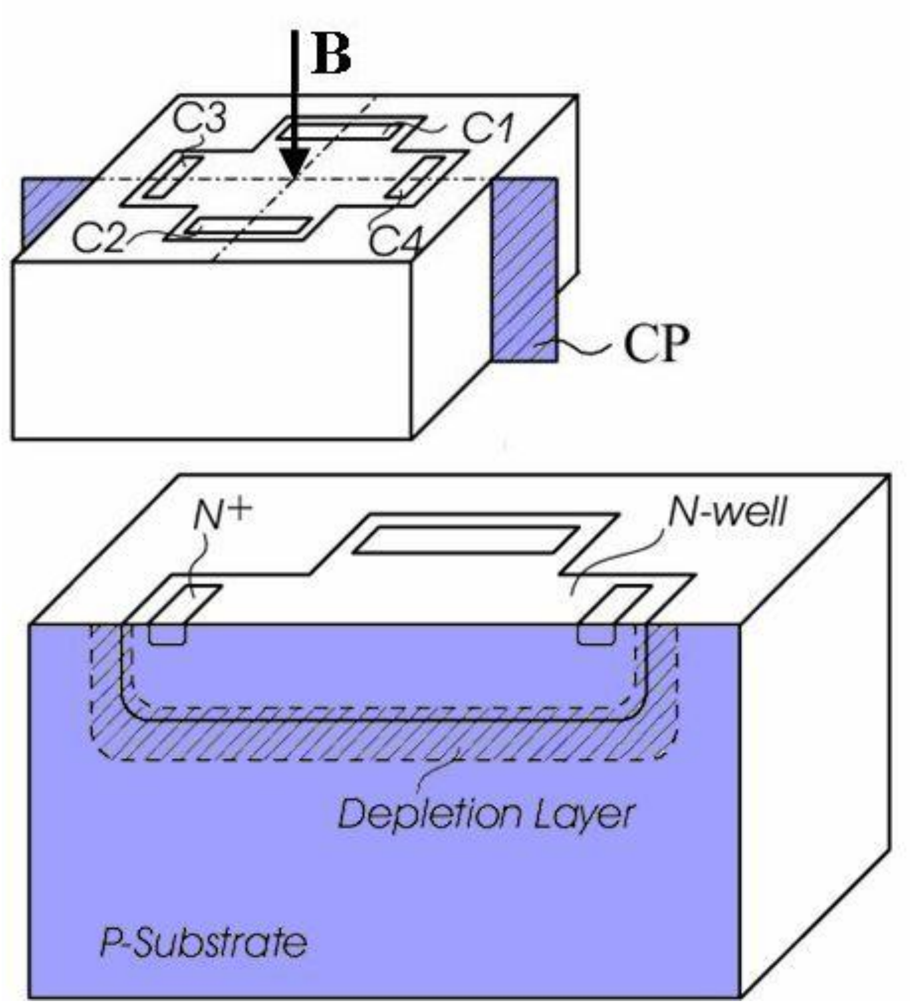


Edwin Hall:
"On a new action of the magnet on electric current" Am.J.Math. **2** (1879) pp.287-92

$$\boldsymbol{V_H \propto I \cdot B}$$

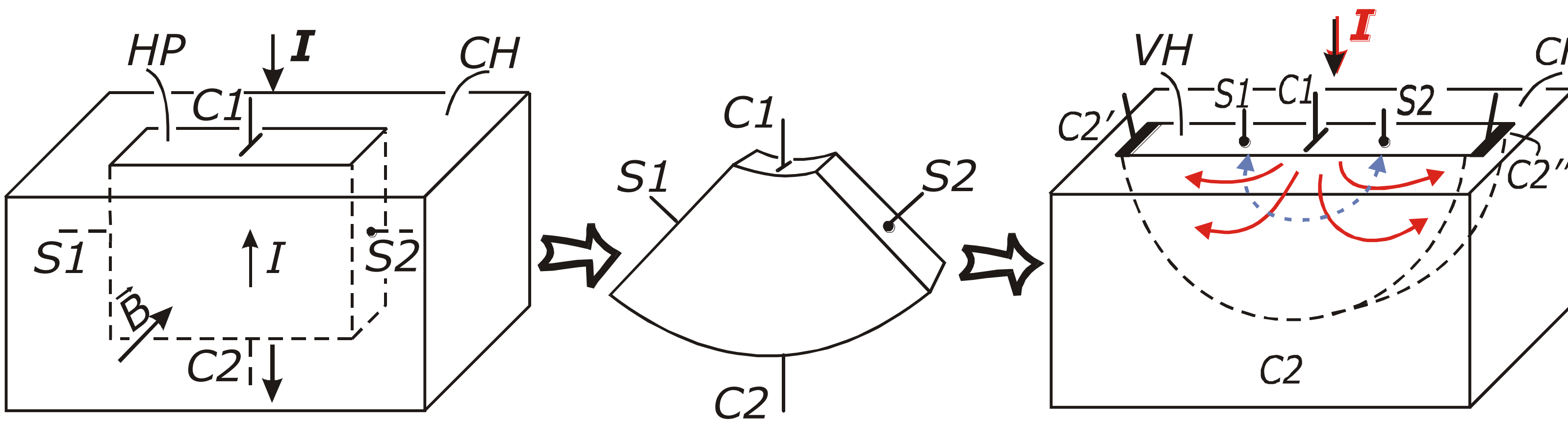
Conventional Integrated Hall Element

- Sensitive to the perpendicular field component B
- CMOS Technology: N-Well
- Depletion layer isolation

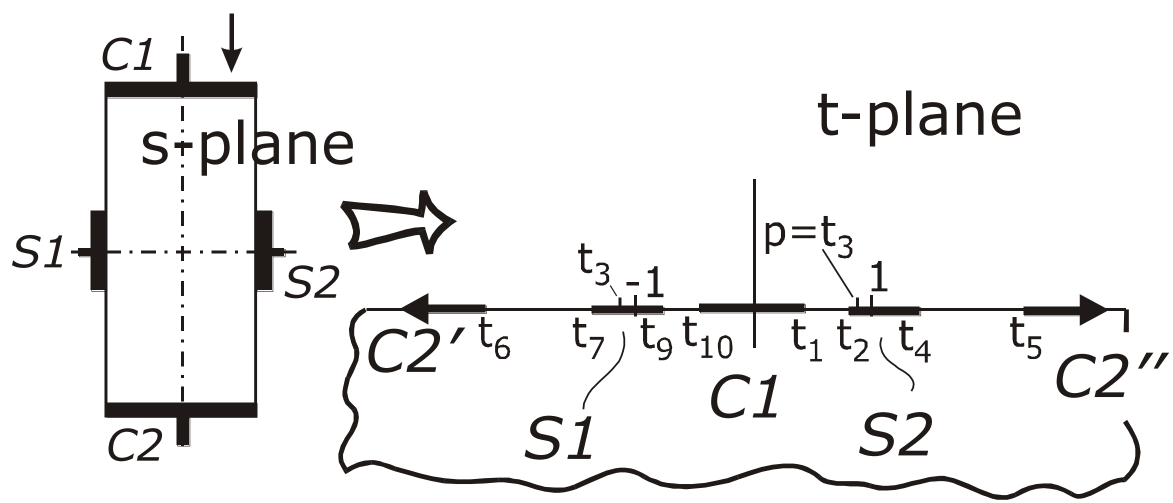


GENESIS OF THE VERTICAL HALL DEVICE

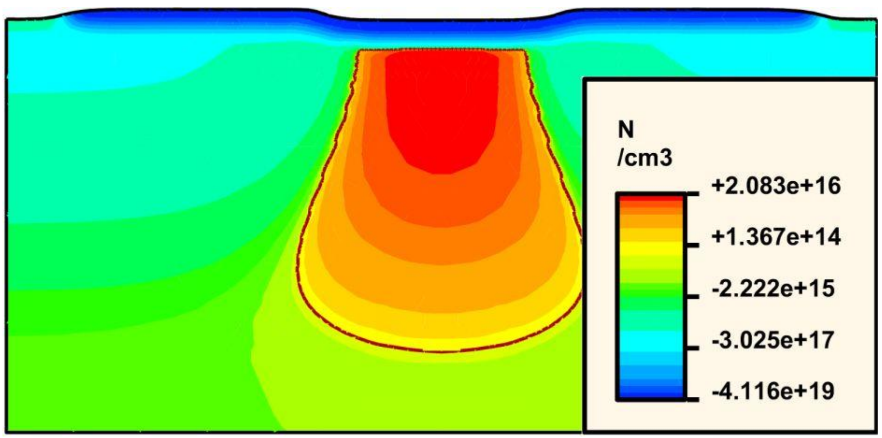
INTUITIVE:

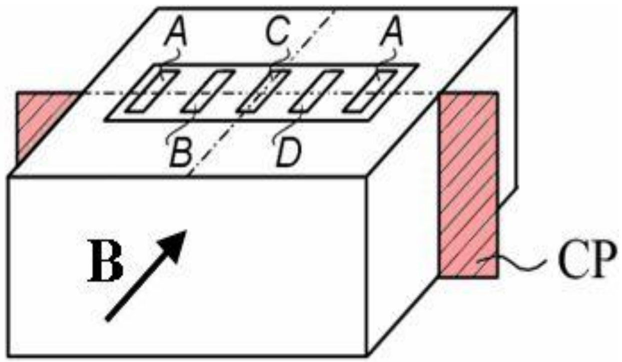


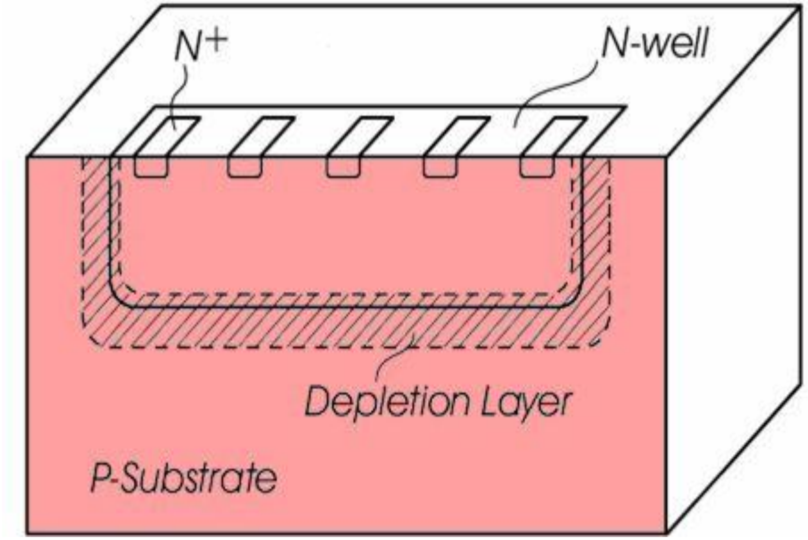
BY CONFORMAL MAPPING:



Integrated Vertical Hall Element

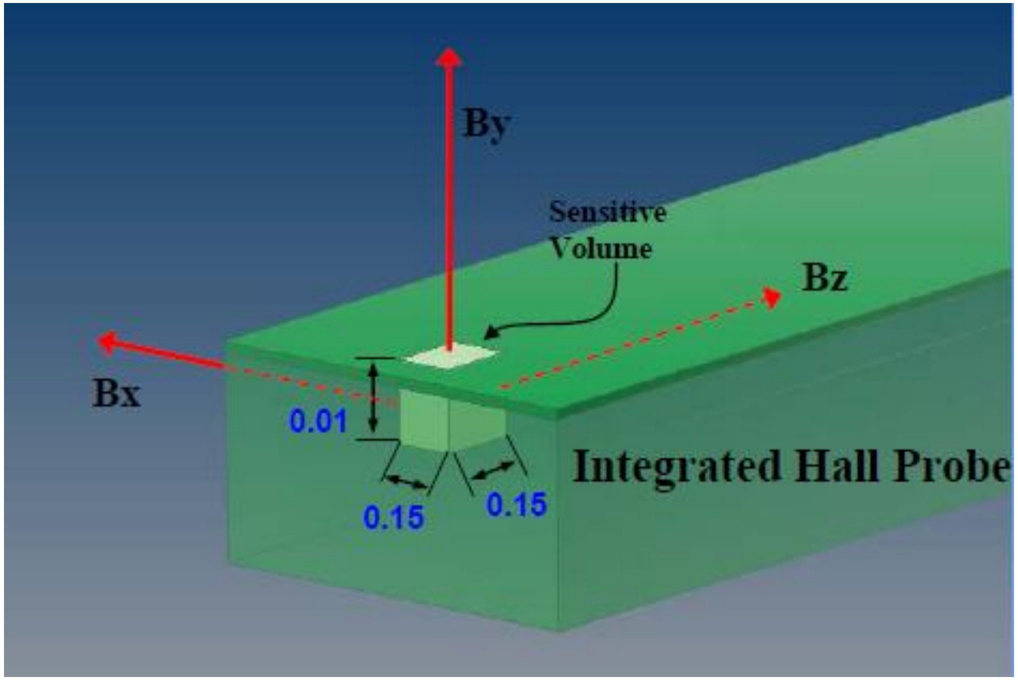






- Sensitive to in-plane field component B
- CMOS Technology: N-Well
- Depletion Layer Isolation

Integrated 3-Axis Hall Probe

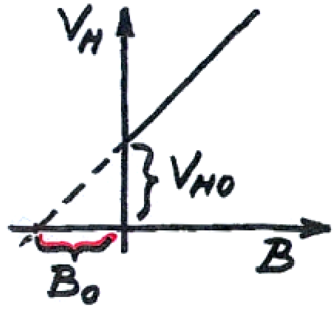


Sensing part composed of two types of micro-Hall sensors

- 4 planar Hall sensor – the perpendicular B-component
- 8 vertical Hall sensors – the in-plane B-components
- Mutual orthogonality: 0.1°

3D spatial resolution: 150 µm

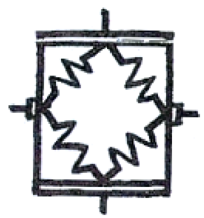
Offset in a Hall Device



$V_{H0} \equiv V_H$ at $B=0$

$B_0 \equiv$ apparent B_{meas} at $B=0$

CAUSES: ASYMETRY DUE TO



- GEOMETRY
- DOPING
- TEMPERATURE GRAD.
- MECHANICAL STRESS
- SURFACE EFFECTS

TYPICAL VALUES:

$B_0 \sim 5 \ldots 50$ mT

Offset fluctuations and Noise

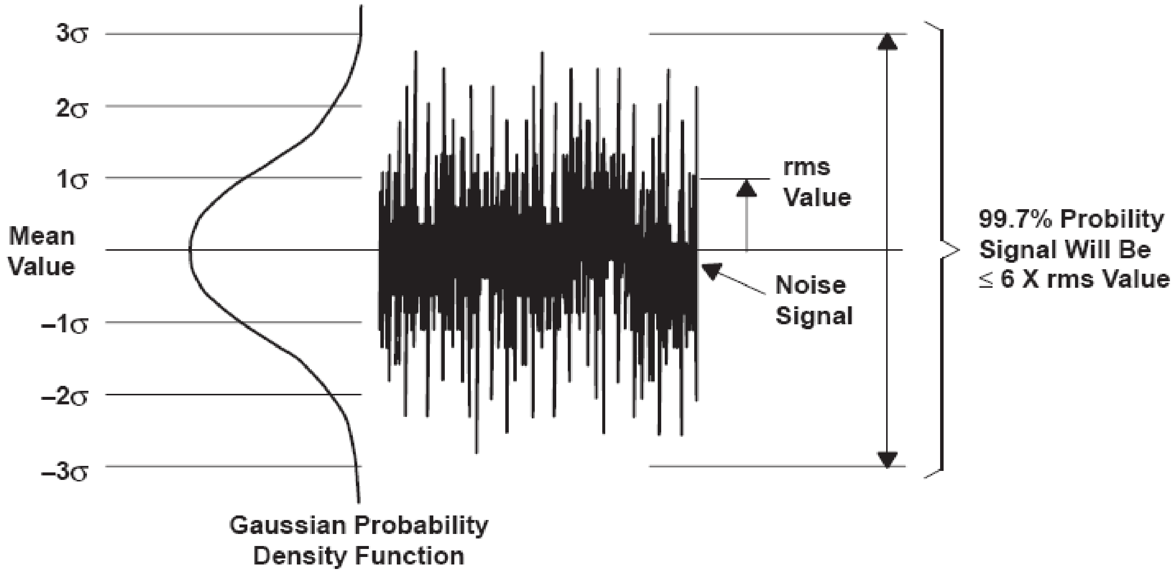


Figure 1. Gaussian Distribution of Noise Amplitude

σ^2: Variance

σ: Standard deviation

v_{nRMS}: Root Mean Square noise voltage

$v_{nP\text{-}P}$: Peak-to-Peak noise voltage

$$v_{nRMS} = \sigma$$

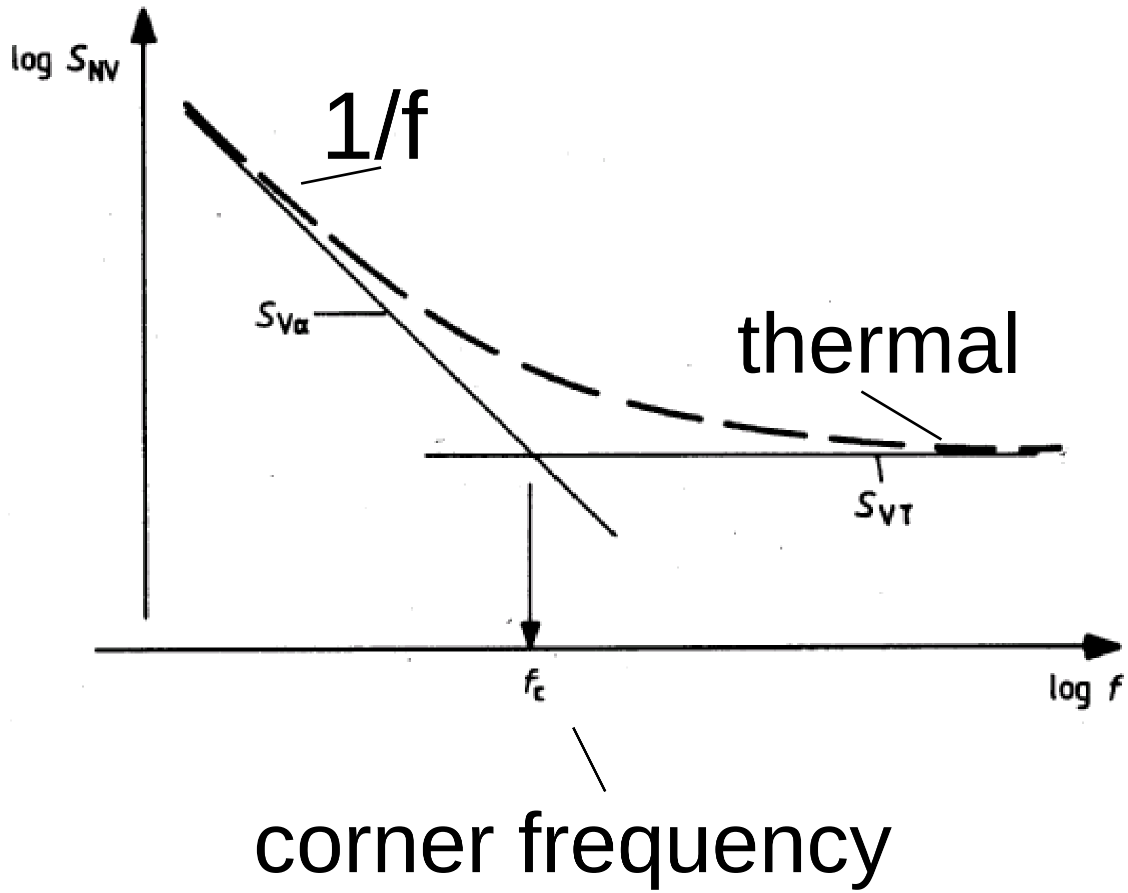
$$v_{nP\text{-}P} \approx 6\, v_{nRMS}$$

Noise voltage spectral density of a Hall Device

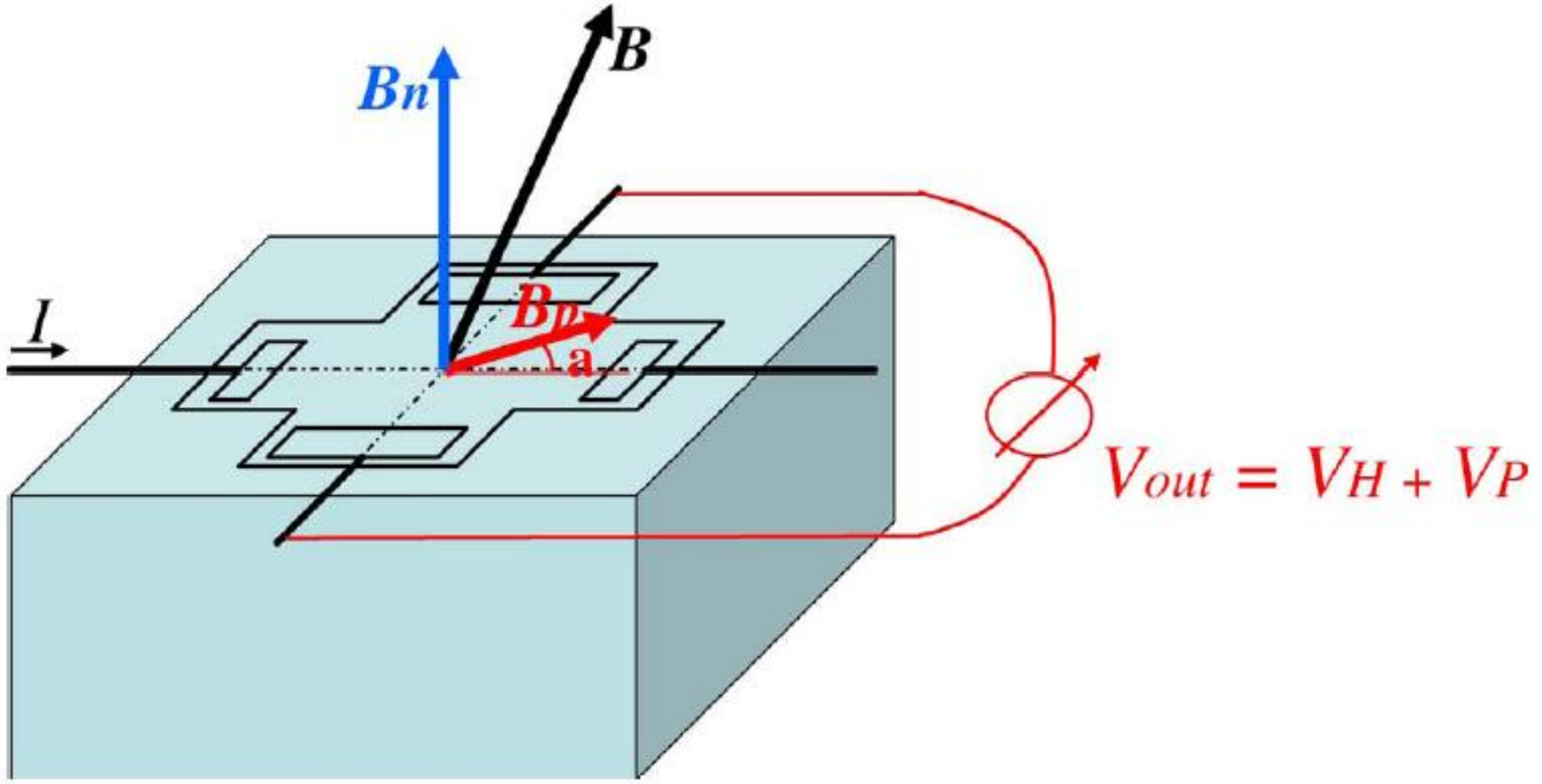
$S_{V\alpha} \propto (I^2 / N) / f$

$S_{VT} \propto kTR$

$f_c \sim 1 \ldots 100$ kHz



The Planar Hall Effect



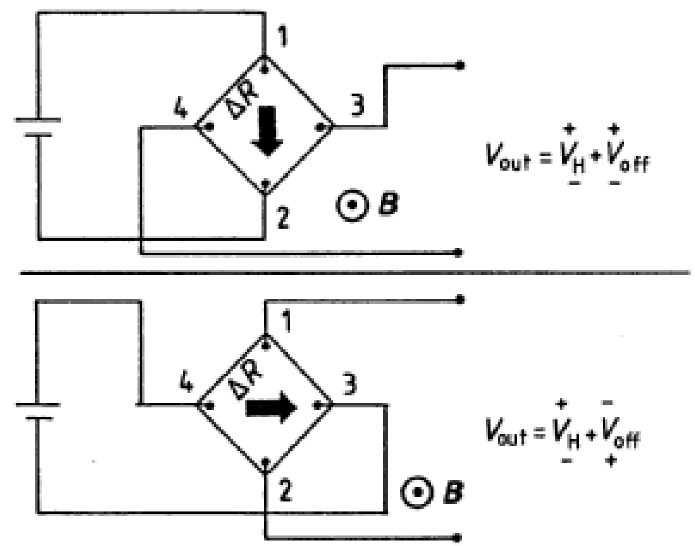
Reducing Offset and 1/f Noise

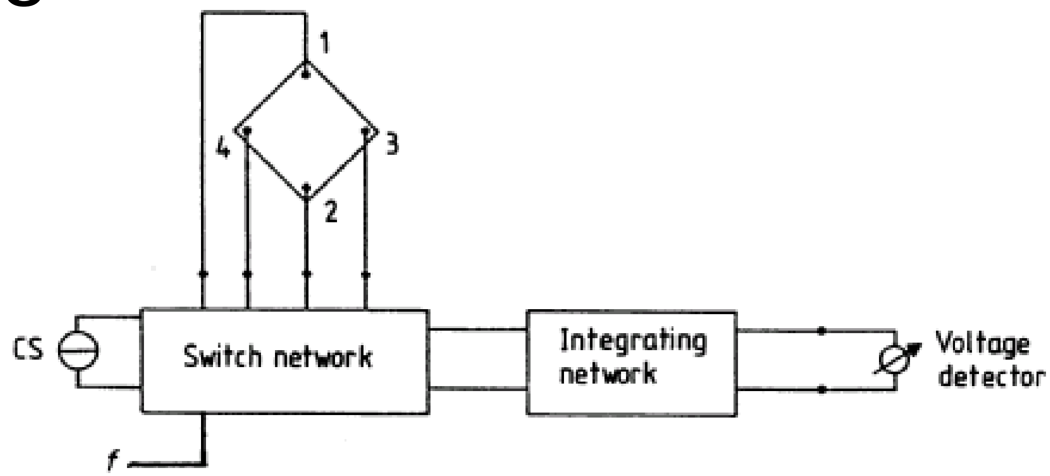
« Switched Hall »

or

« Spinning Current »

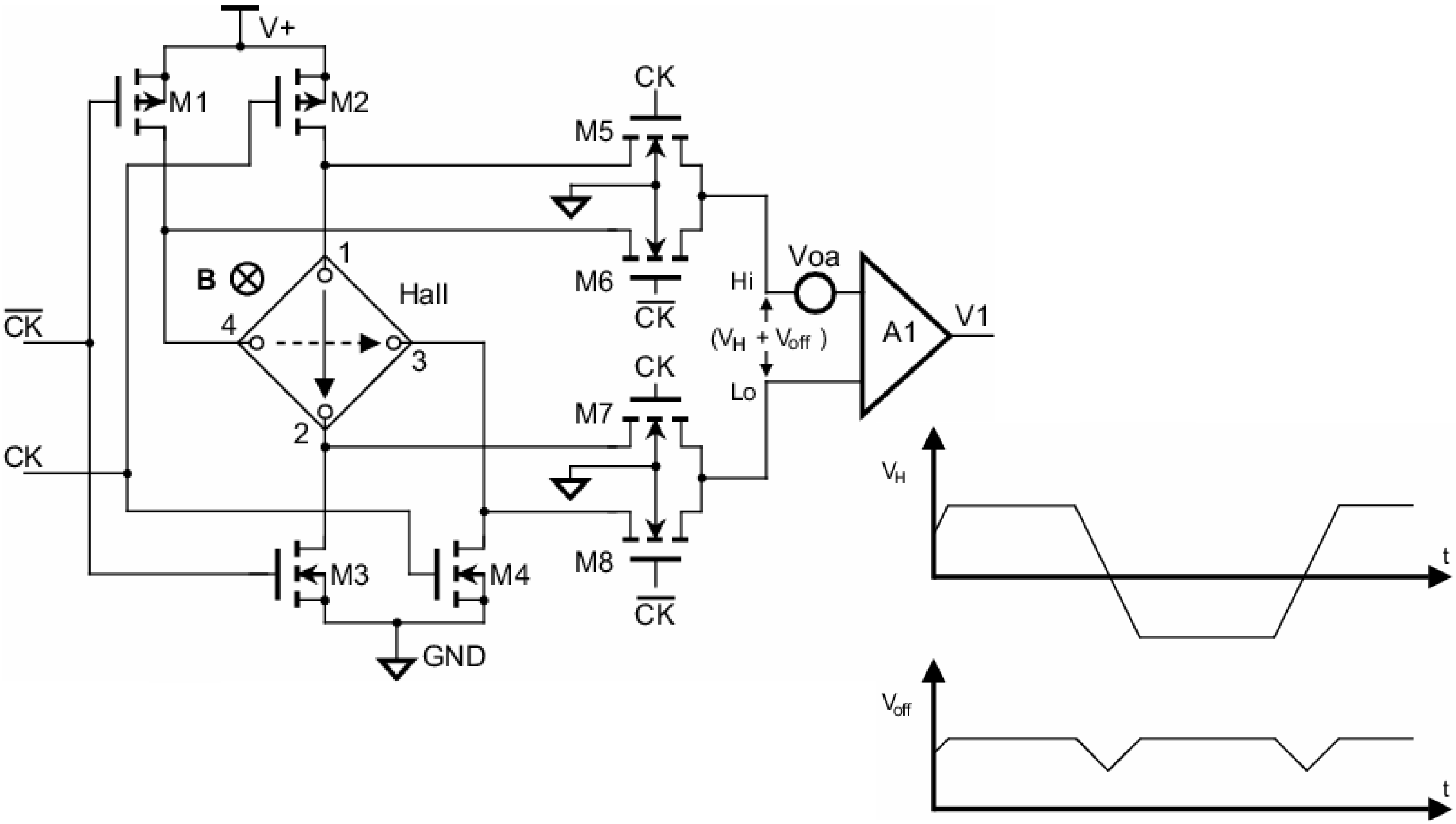
Technique



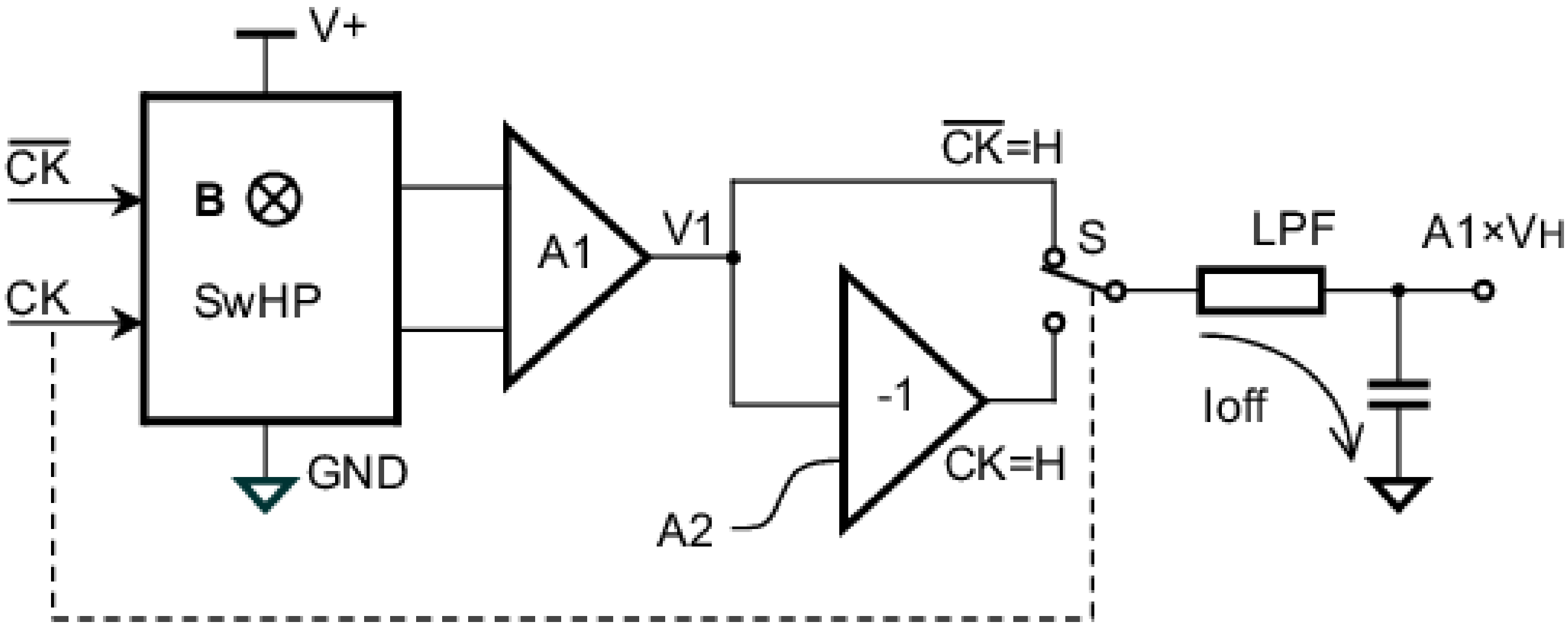


Spinning Current:

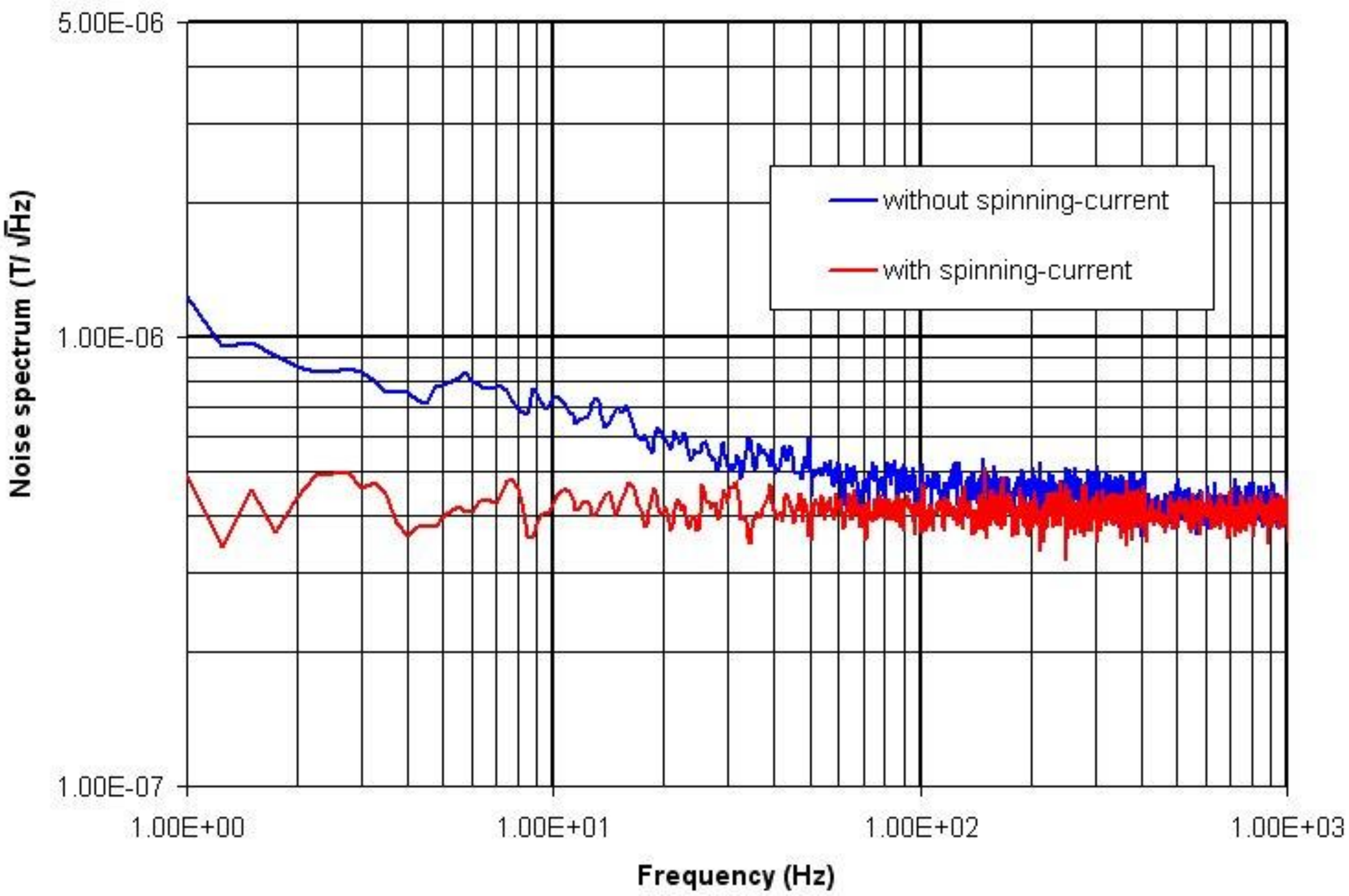
Front-end Circuit



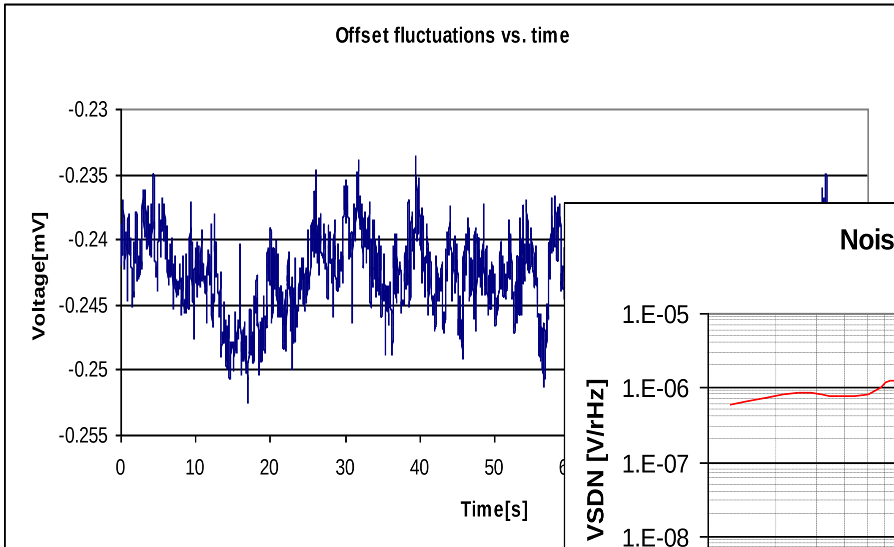
Switched Hall System



1/f noise reduction in a Hall plate by the “spinning-current”

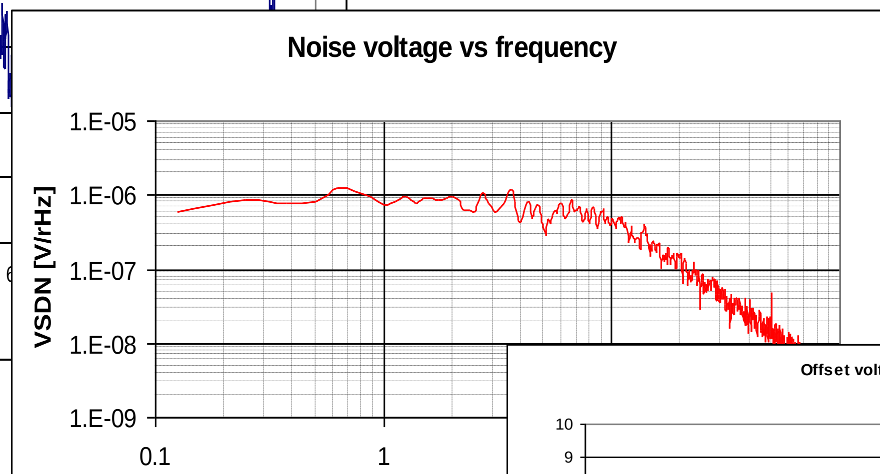


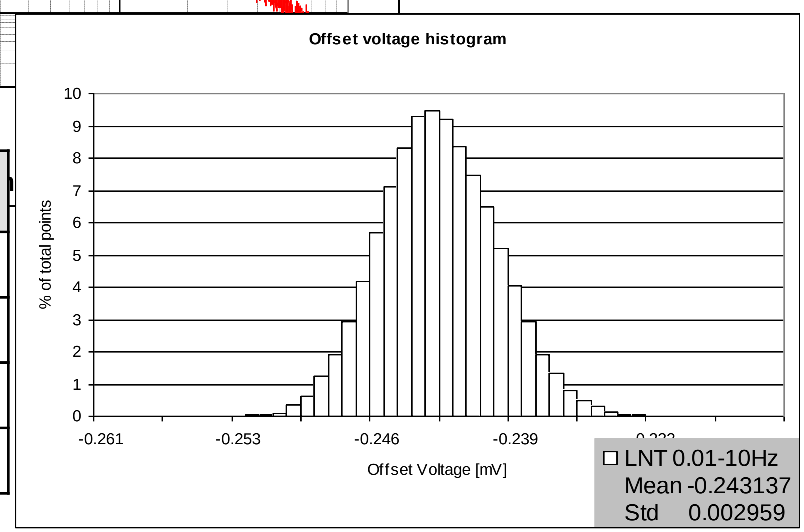
Noise and Offset fluctuations of new SENIS LN Hall Transducers, Range > 0.1T



EXAMPLE:

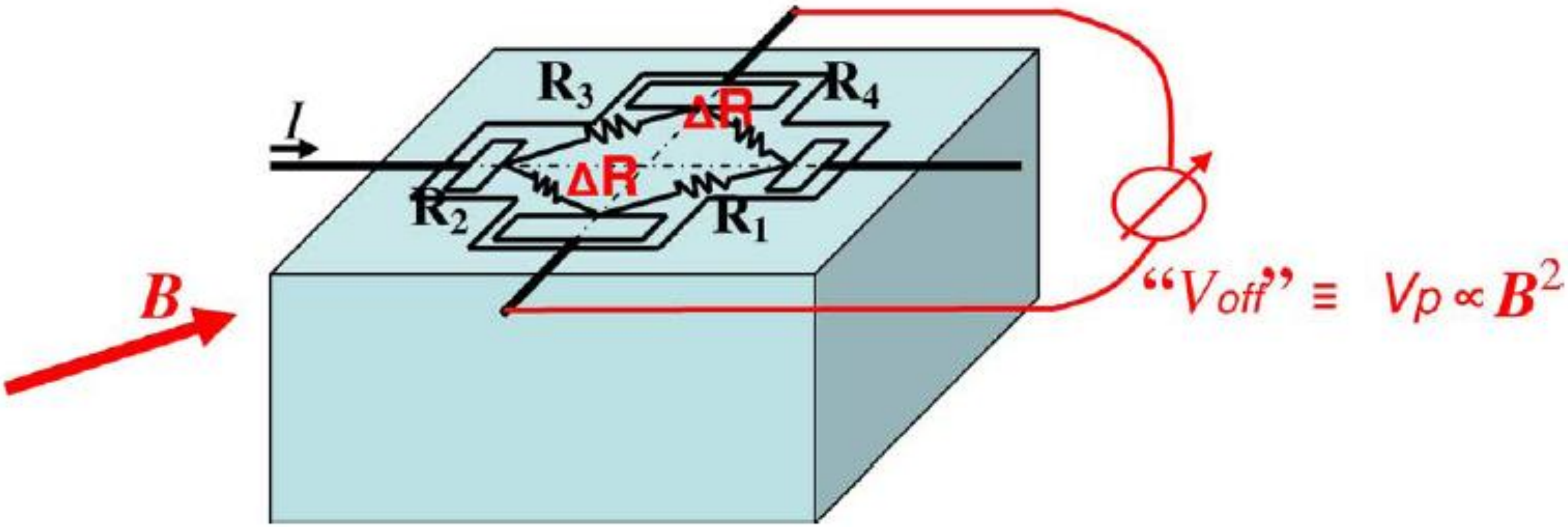
***B*max = 2T, *S* = 5V/T**



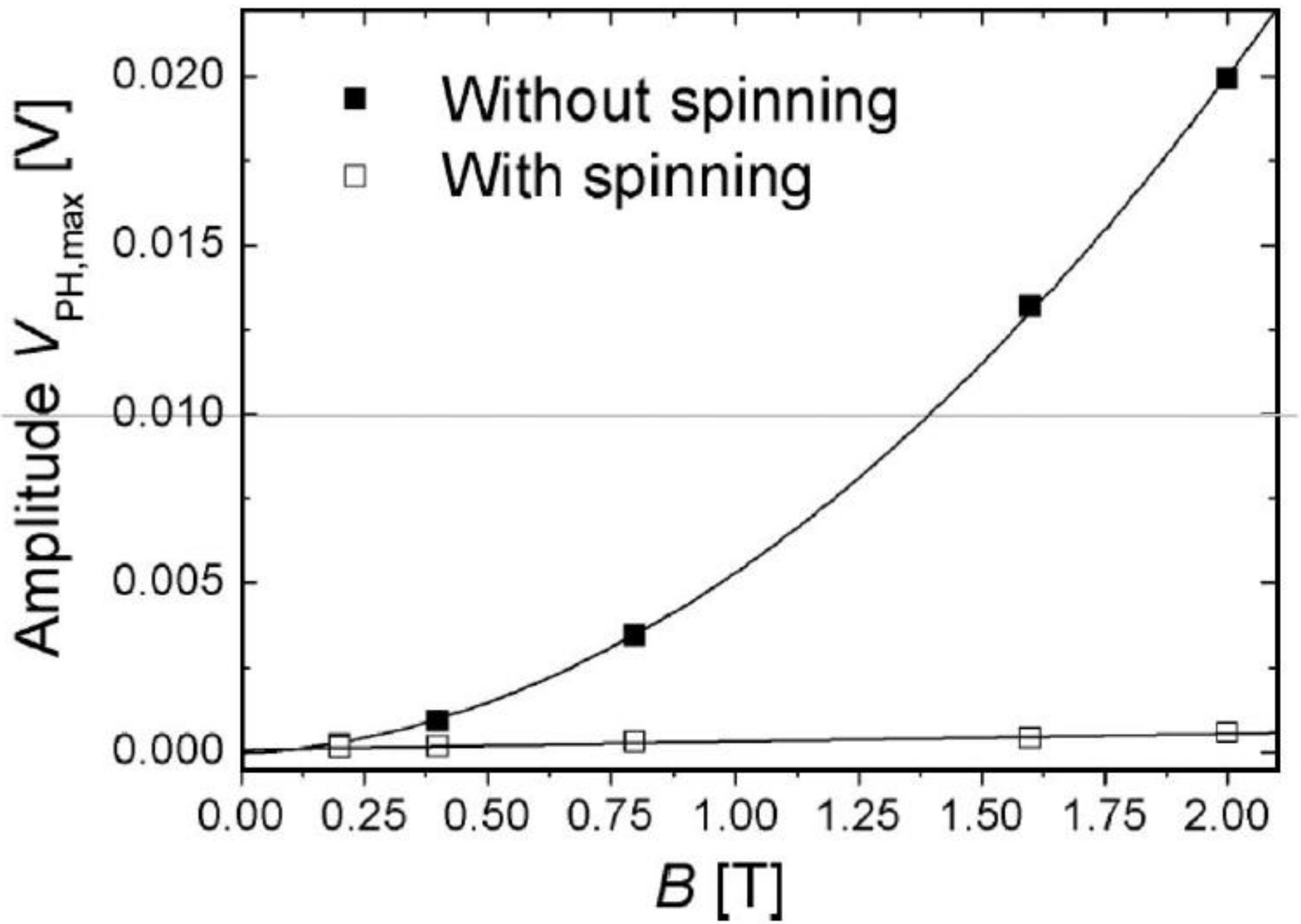


Main Results	
▪ Noise Spec. Dens. / 1Hz	1µV/√Hz (0.2µT/√Hz)
▪ Offset Fluctuation (rms)	3µV (0.6µT)
▪ DC Resolution, BW=10Hz	0.6µT
▪ Resolution / Range	0.3ppm

The Magneto-Resistance Model of the Planar Hall Effect

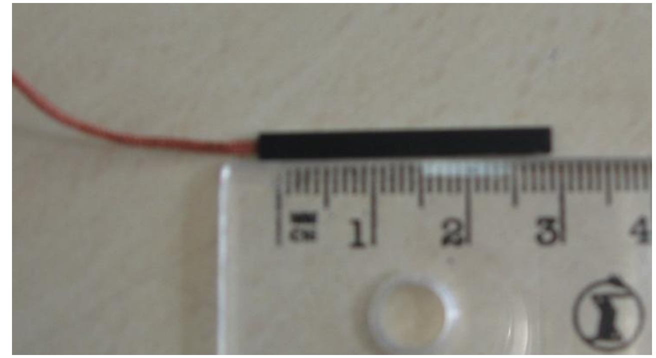


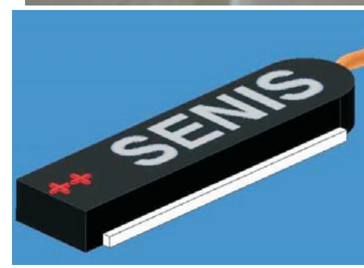
Reduction of the Planar Hall Effect by the "spinning-current"

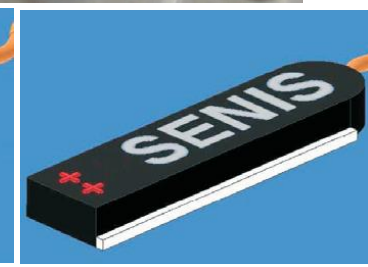


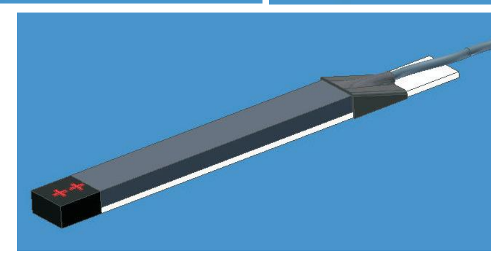
1ppm 2T Two-Axis Hall Transducer

Key Features	
▪ Measurement range	± 2T
▪ Frequency response	DC to 100Hz
▪ Broad-band Noise	$B_{RMS} < 0.5\mu T$
▪ Offset Drift	$B_{OF,RMS} < 0.4\mu T$
▪ Calibration Accuracy	10ppm
▪ Probe dimensions	1.5 x 3 x 30 mm^3

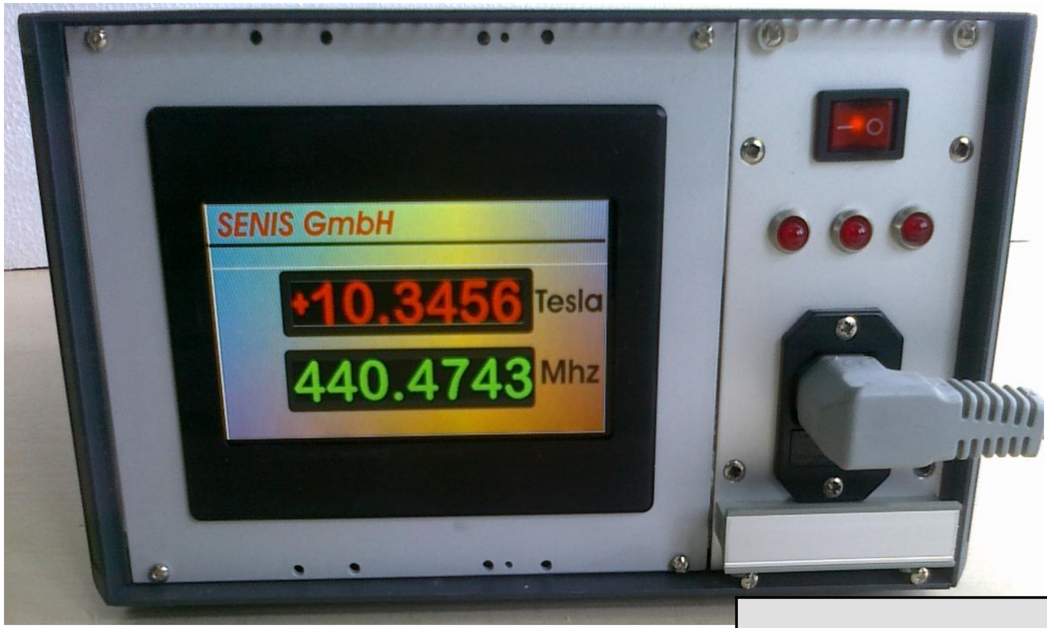


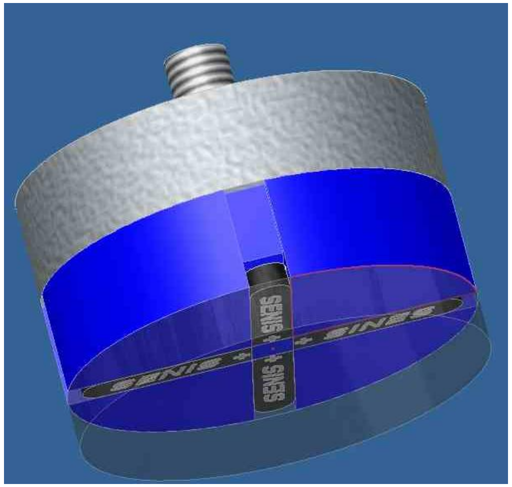






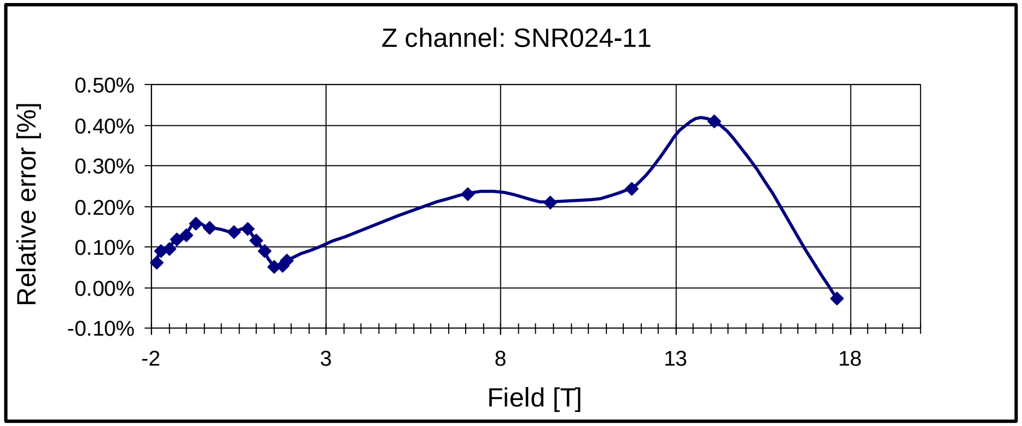
Teslameter 3MH5

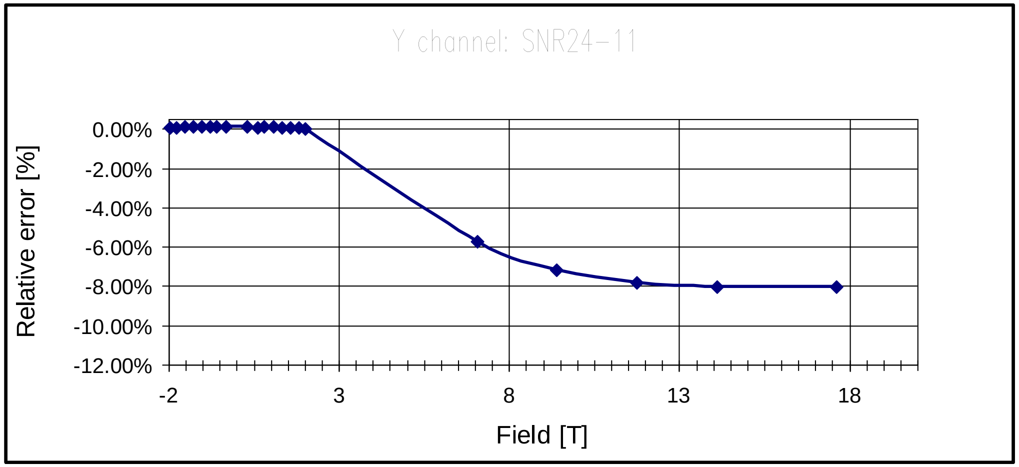




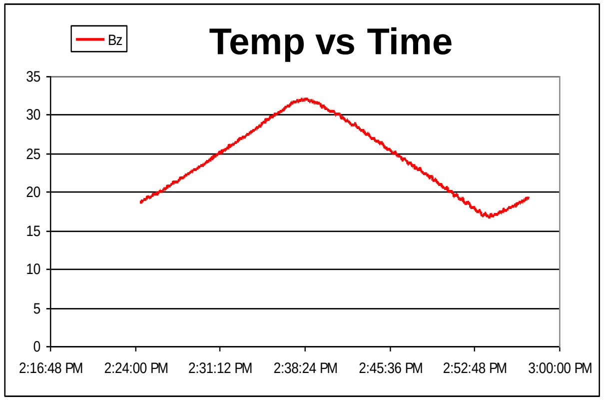
Key Features	
▪ Measurement range	1T, 2T, 5T, 10T, 20T
▪ Integration time	1s, 100ms, 10ms, 1ms
▪ Resolution and stability	< 1 ppm FS
▪ Probe dimensions	Diameter 40 x 15
▪ Digital Interface	USB 2.0; Touch TFT
▪ Analogue out	Connection to DAQ

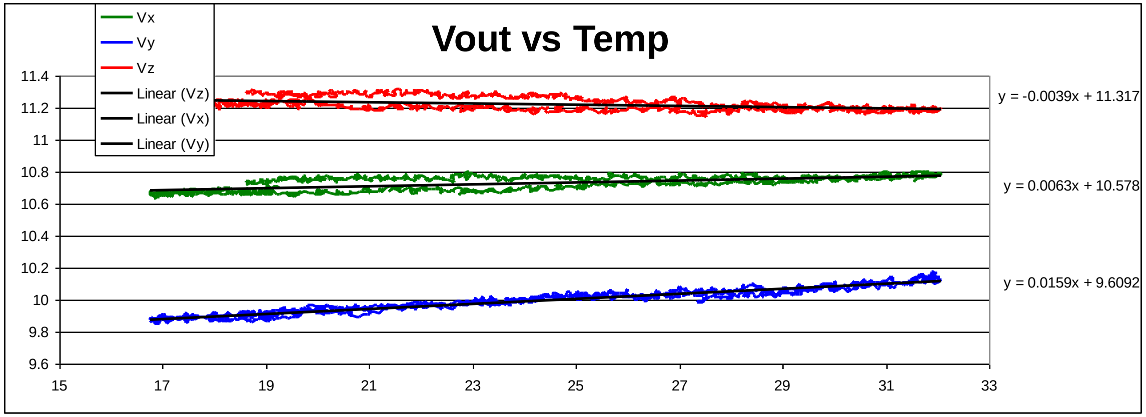
High Field Non-Linearity of SENIS Hall Elements





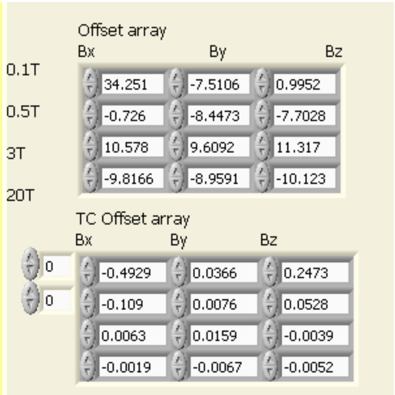
TC offset-compensation





Vout'=Vout –(V$_{offset}$ + TC$_{offset}$ x Temp)

$$Vout' = Vout - (V_{offset} + TC_{offset} \times Temp)$$

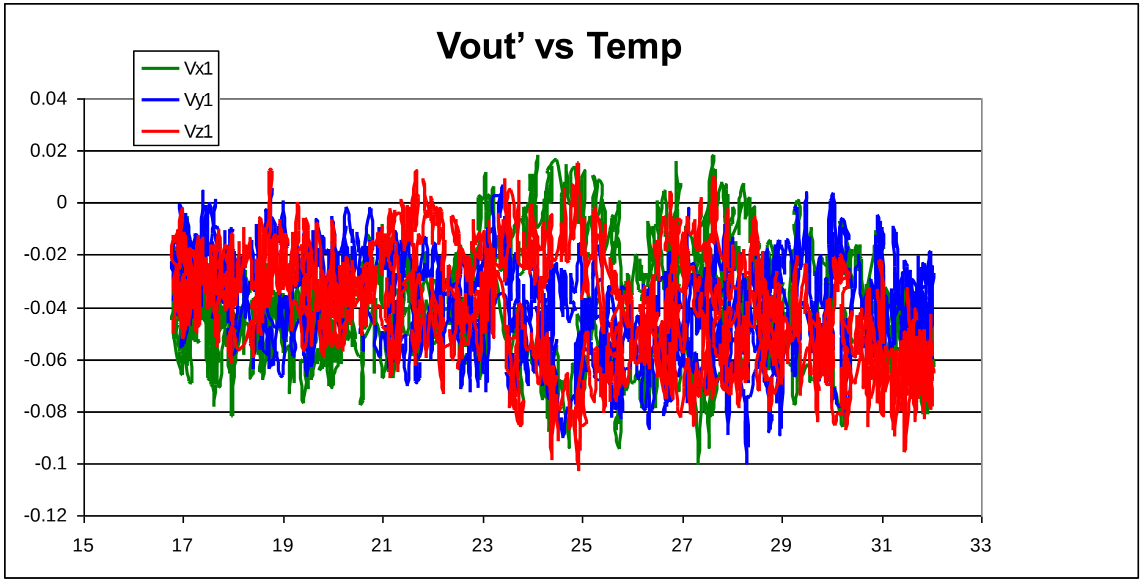


Offset array

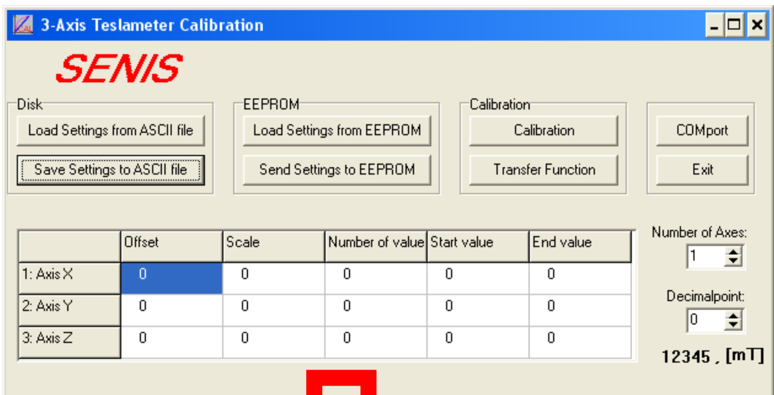
	Bx	By	Bz
0.1T	34.251	-7.5106	0.9952
0.5T	-0.726	-8.4473	-7.7028
3T	10.578	9.6092	11.317
20T	-9.8166	-8.9591	-10.123

TC Offset array

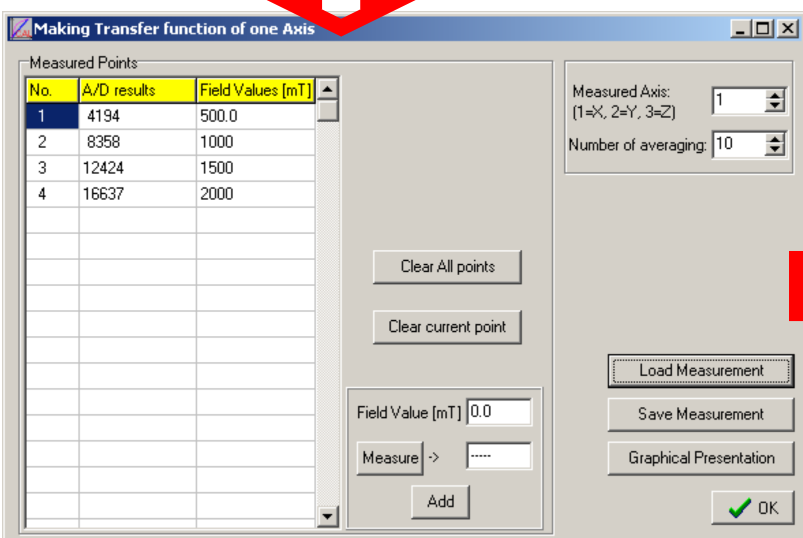
	Bx	By	Bz
0	-0.4929	0.0366	0.2473
0	-0.109	0.0076	0.0528
	0.0063	0.0159	-0.0039
	-0.0019	-0.0067	-0.0052

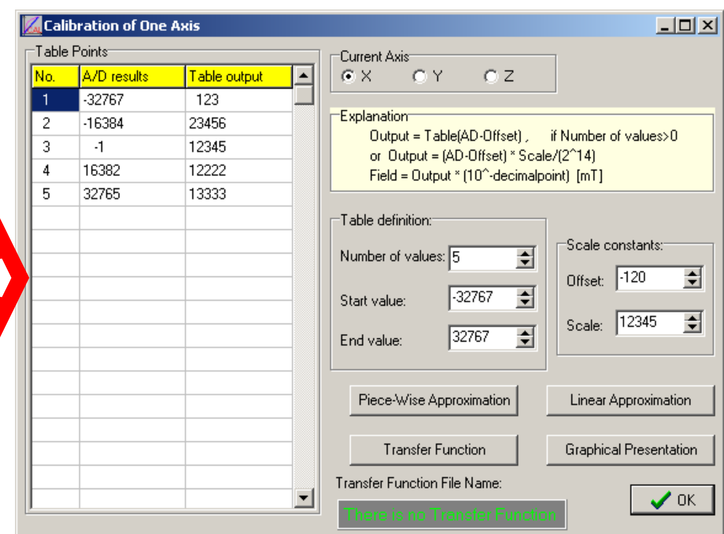


Non-Linearity part I

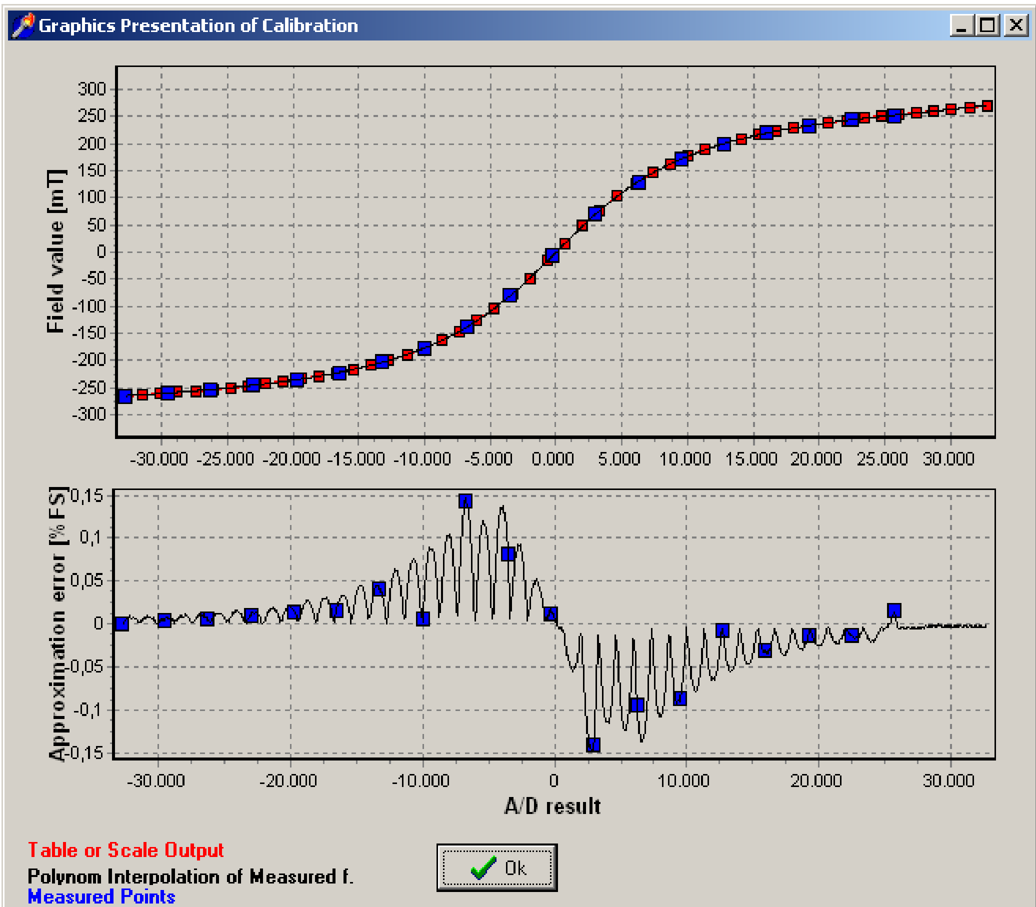


Bout’=f(Vout’)





Non-Linearity part II



Piece- wise approximation:

-Transfer function (blue marker)

-Calibration table values (red marker)

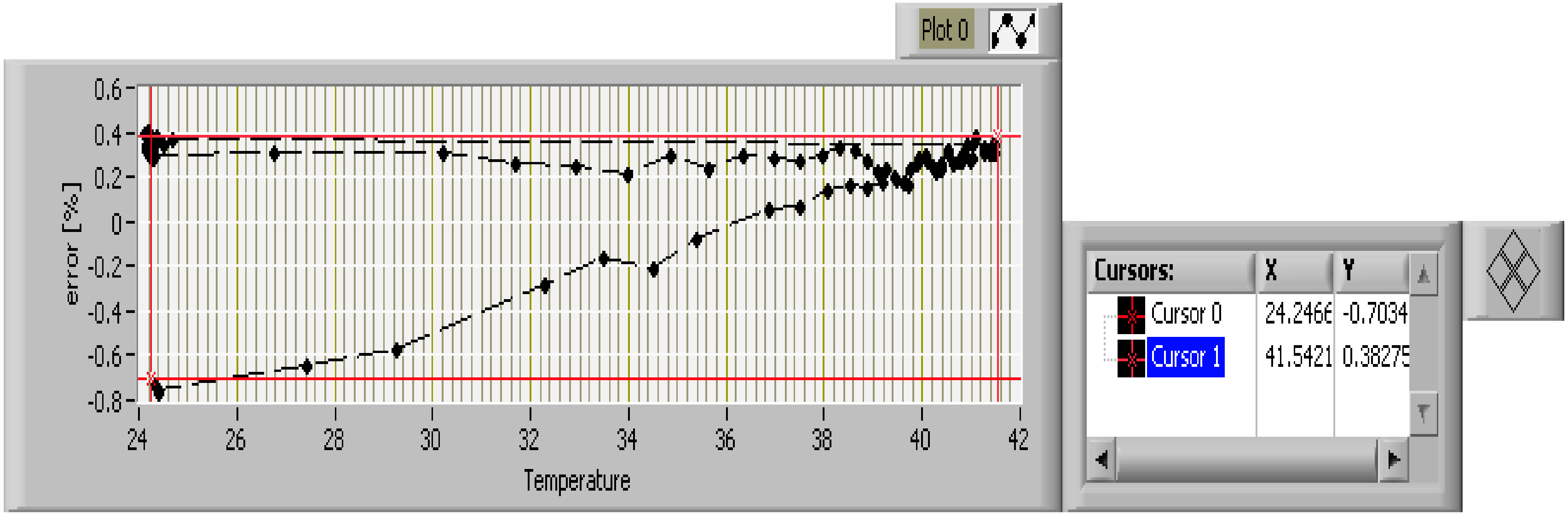
-Approximation error

TCsens with Temp

- At B=0.1 T , initial error because of temperature is 1.2%/18°C=670 ppm/°C

$Bout=Bout'(1 + TC_{sens} \times (T-20°C))$

- After compensation it became less then 10ppm/°C

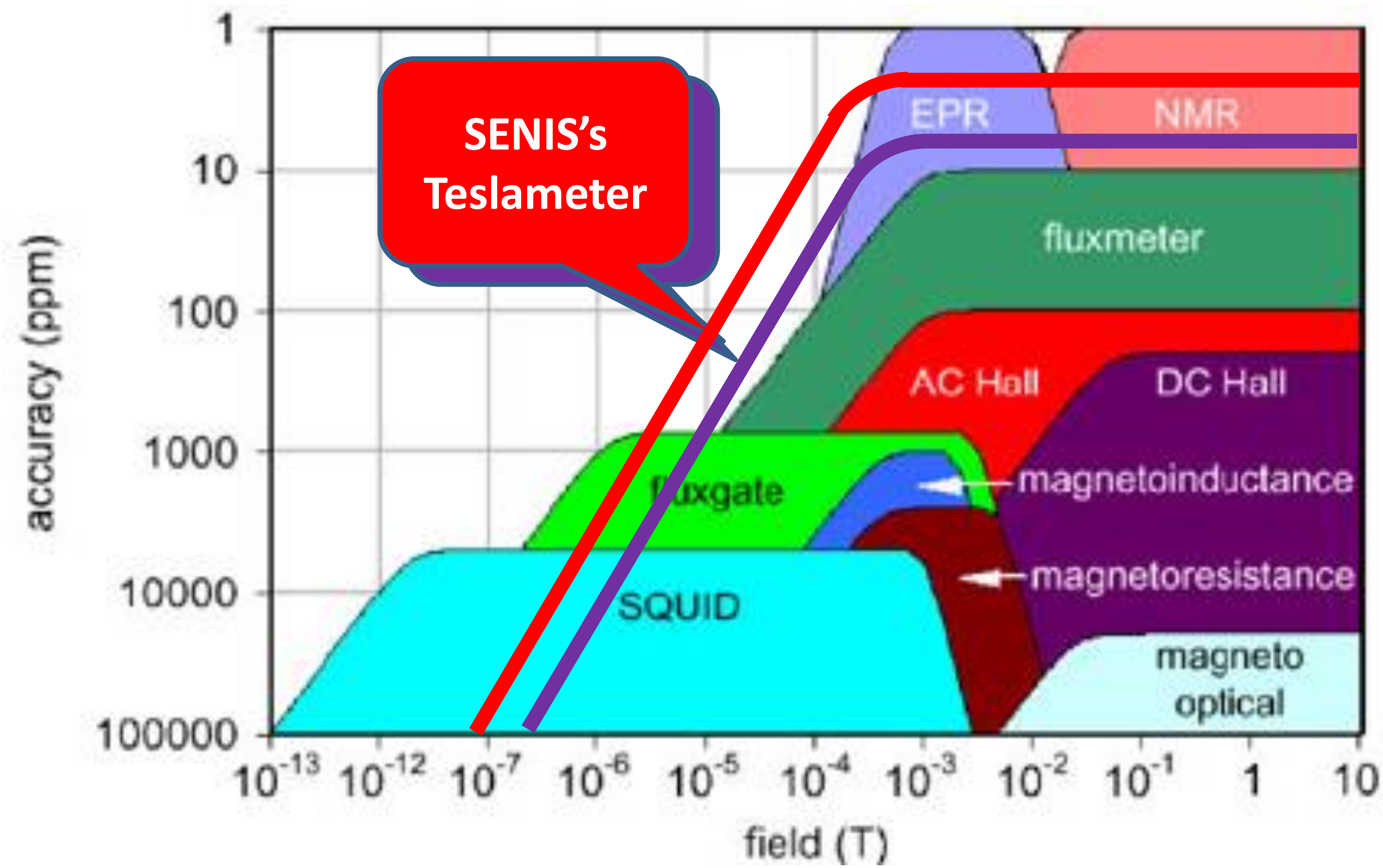


Conclusions

SENIS High-Resolution Teslameter

- **Based on much improved offset and noise reduction technique for analogue part**
- **Resolution at B > 0.5T: < 1ppm**
- **Negligible planar Hall effect**
- **Digital correction of temperature dependence and non-linearity**
- **Accuracy: a few ppm feasible**

Up-dated classification of magnetic measurement technologies*



*Luca Bottura of CERN; Revised by SENIS 2011

Outlook

SENIS High-Resolution Teslameter for relative measurements, such as B homogeneity:

- **Resolution and Error at B > 0.5T: < 1ppm!**