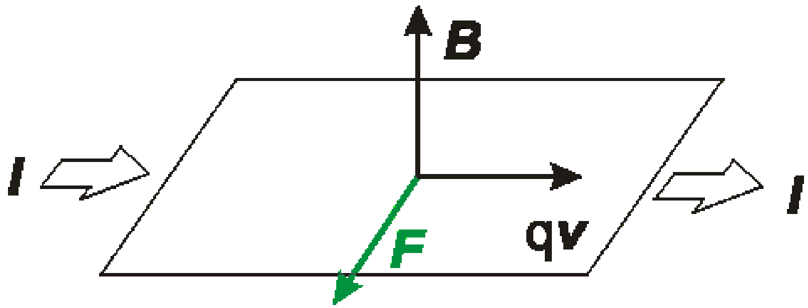
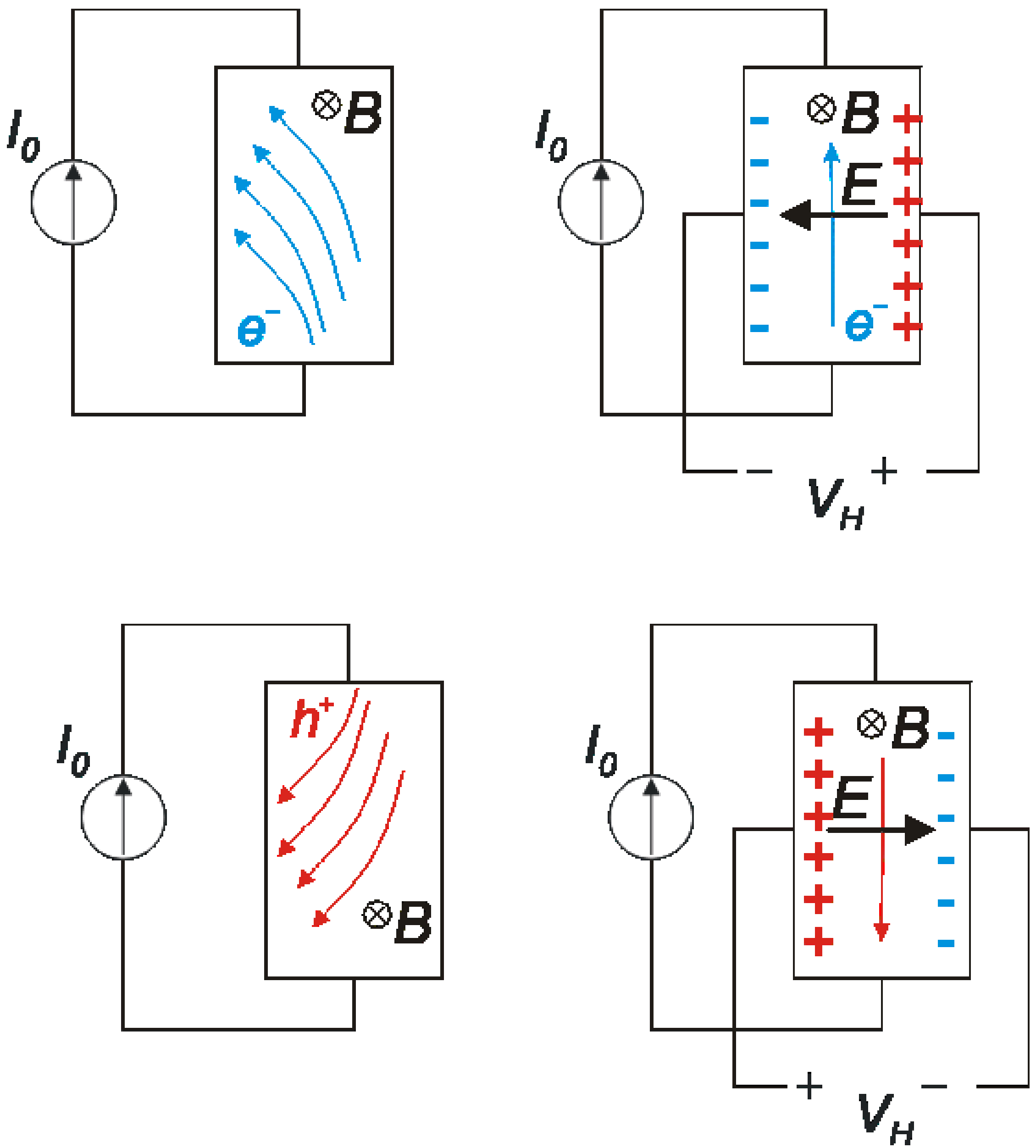
Magnetic Sensors

1) Hall sensors

Hall effect: Discovered by Edwin Hall in 1879





I_0
⊗B
e^-
I_0
⊗B
E
e^-
V_H
I_0
h^+
⊗B
I_0
⊗B
E
V_H

Resistive Magnetic Sensors

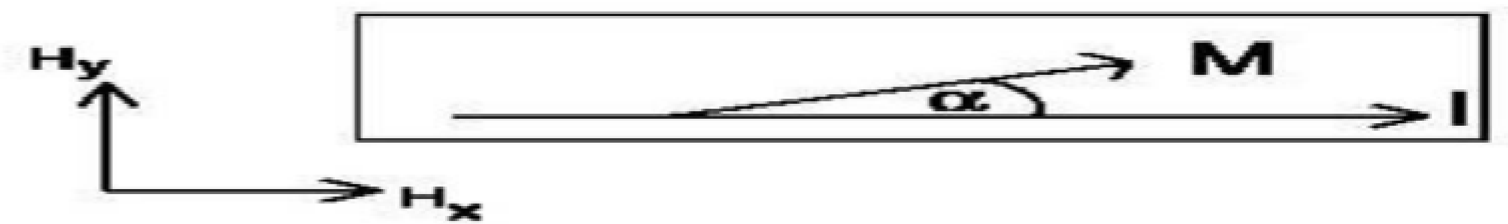
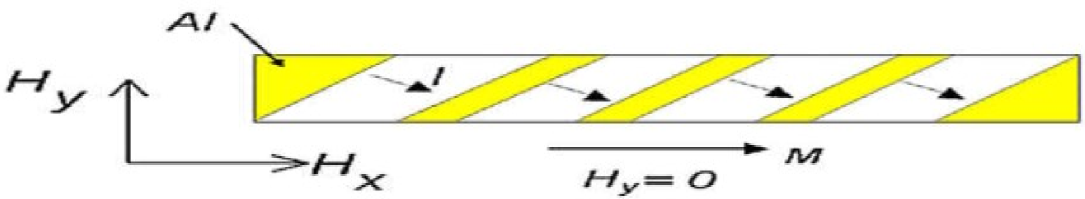


Fig. 1: *The geometry of a Hunt element*

e change in resistivity is found experimentally to be

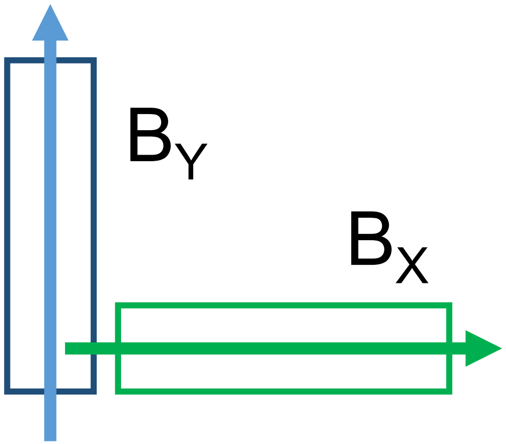
$$R = R_0 \cdot (1 + \frac{\Delta R}{R} \cdot \cos^2 \alpha) \qquad (1)$$



Ex. 1: Electronic Compass

Earth's Magnetic Field Intensity : 25-65 μT (0.25–0.65 G)

Horizontal component in Pisa (from map) 23300 nT ~ 23 μT



Sensor arrangement:
Two orhogonal sensors that measures the X and Y (horizontal components) component of the magnetic field B

Angular resolution:

$$\theta_e = \frac{B_e}{|B_H|}$$

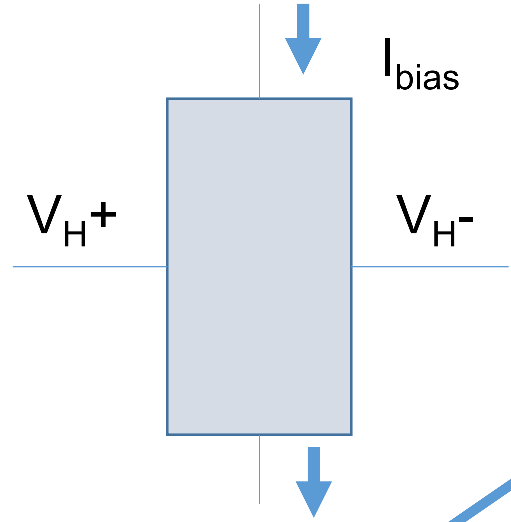
Let us consider a maximum error of 5° :

$$\theta_e = \frac{5}{180}\pi = 0.087 \ \ \text{rad}$$

$$\max(B_e) = \max(\theta_e)|B_H| = 0.087 \cdot 28 \times 10^{-6} \ \text{T} \cong 2 \ \ \mu\text{T}$$

Case 1: Use a couple of orthogonal Hall effect based on crystalline silicon

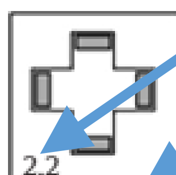
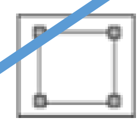
$$S_A = \frac{V_H}{B} = \frac{G \cdot r_H}{nqt} I_{bias}$$



R_0=2.2 kΩ

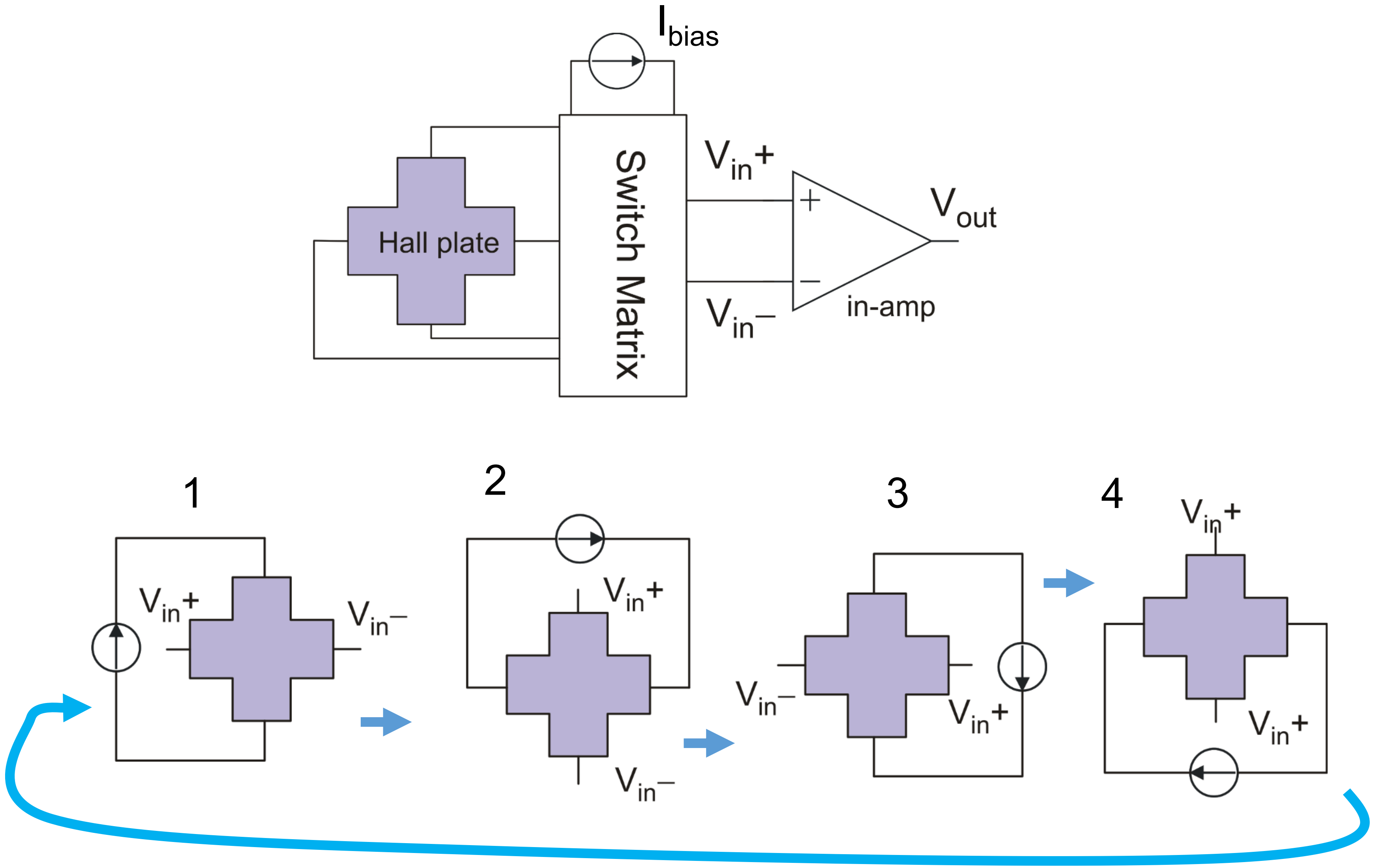
S_A=0.0412 V/T

Table 1
Hall cells design parameters.

Hall cell	XL	Square
Geometry (planar representation)		
R_0 (kΩ) @ T=300 K, B=0 T	2.2	4.9
S_A (V/T) @ I_{bias}=0.5 mA	0.0412	0.0467
L (μm)	43.2	20
W (μm)	19	20
L/W	2.27	1
Contacts dimensions s (μm)	18.3	2.3
Geometrical correction factor (G)	0.86	0.96

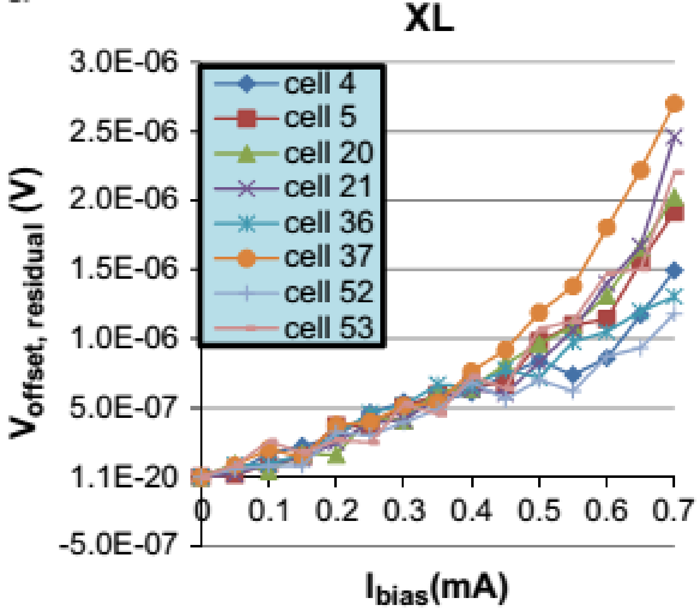
Typical readout approach for precise measurements:

Current Spinning

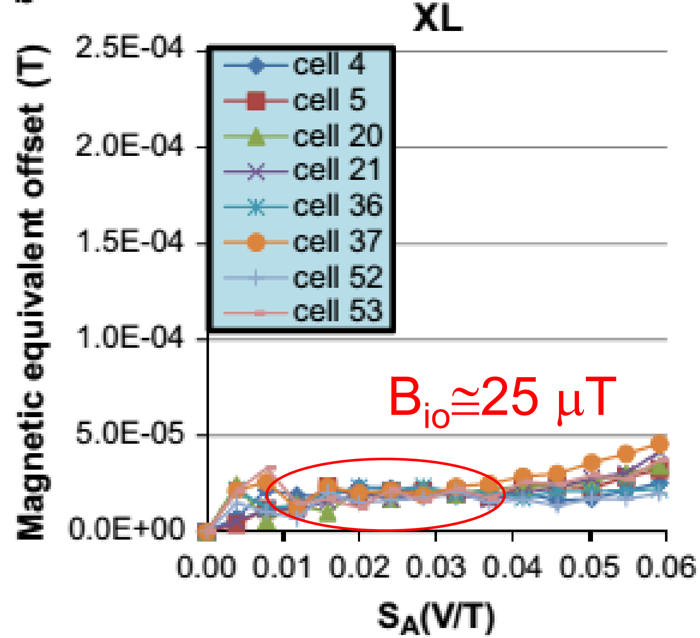


Sensor offset

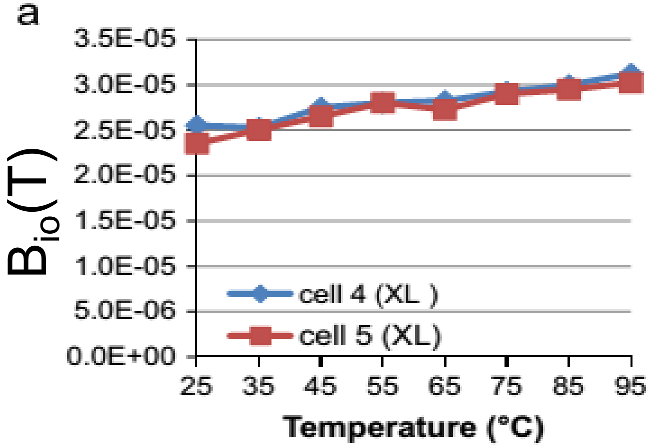
a



b



a



$\Delta B_{io} < 5\ \mu T$ (between 25 and 35 °C)

since 2 μT -> 5° angular error then:

Offset: -> 62.5° angular error

Drift: -> 12.5° angular error

Sensor noise

BW=0.1-100Hz

$$S_{vR} = 4kTR_0$$ R_0=2.2 kΩ

$$\sqrt{S_{vR}} = \sqrt{4kTR_0} = 5.93 \ \ \mathrm{nV}/\sqrt{\mathrm{Hz}}$$

over 100 Hz BW:

$v_{nS\text{-}rms}$=59.3 nV

$v_{nS\text{-}pp}$=237 nV

$$B_{nS-pp} = \frac{v_{nS-pp}}{S_A} = 5.75 \quad \mu\mathrm{T}$$

Amplifier contribution to the angular error (1)

Case 1: AD 620. Offset: accuracy
Noise: Resolution

Offset voltage (typ.) Input: 15 μV Output 200 μV
$V_{io\text{-}total} = V_{osi} + V_{oso}/G$ with G=1000 $V_{io\text{-}total} \cong V_{osi}$=**15 μV**
V_{osi} drift (typ.) : 0.1 mV / °C (**1 μV** between 25 and 35 °C)

Offset current contribution: $I_{io}R_0$= 0.3 nA x 2.2 kΩ =0.66 μV << $V_{io\text{-}total}$

Noise: BW 0.1-100 Hz

Broad Band noise: $e_{ni}=\sqrt{S_{VBB}}$=9 nV $\sqrt{}$ Hz → Integrated over BW=100Hz:
$v_{nBB\text{-}rms}$=90 nV -> $v_{nBB\text{-}pp}$=360 nV
Low frequency (Flicker) noise over 0.1-10 Hz -> 280 nV
Total noise voltage of the amplifier:

$$v_{nA-pp} = \sqrt{v_{nBB-pp}^2 + v_{nF-pp}^2} = 456 \text{ nV}$$

Amplifier contribution to the angular error (2)

Current noise: Broad-band component

$$S_{VI} = 2 S_I R_S^2 \qquad R_S = \frac{R_0}{2} = 1.1 \ \text{k}\Omega$$

$$\sqrt{S_{VI}} = \frac{\sqrt{S_I} R_0}{\sqrt{2}} \qquad \sqrt{S_I} = 100 \ \text{fA} / \sqrt{\text{Hz}}$$

$$\sqrt{S_{VI}} = 0.155 \ \text{nV} / \sqrt{Hz}$$

Flicker component:

$$v_{ni-f-pp} = i_{n-pp} \frac{R_0}{\sqrt{2}} = 22 \ \text{nV}$$

Noise voltage components due to the input bias current noise are negligible with respect to the input noise voltage components.

Design of an electronic compass using the HMC 1002 Magneto-resistive sensor (2 axis)

Sensor characteristics:
V supply (typ) = 5 V
Output resistance: 850 Ω
Sensitivity: 3.2 mV/V/gauss SA=160 μV / μT (with V_{supply} =5 V)
Noise: $\sqrt{S_{VBB}}$= 30 nV/ √Hz ; $\sqrt{K_f}$=30 nV
Offset max: 60 mV

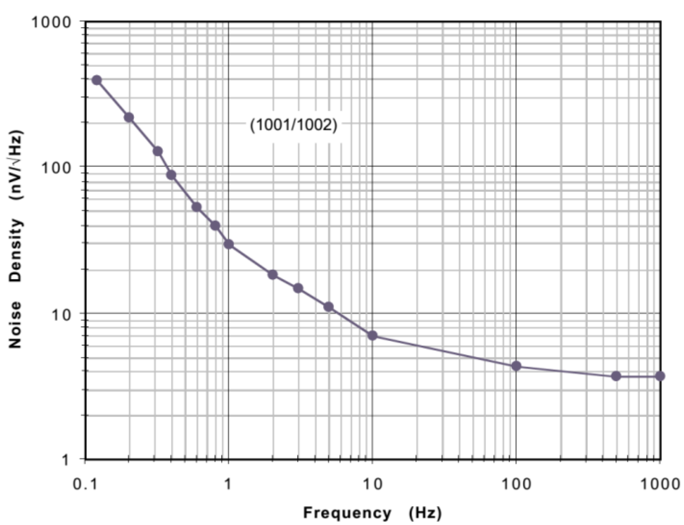


Figure 3—Typical Noise Density Curve

Offset: can be strongly reduced using the set-reset measurement cycle (see datasheet).
The residual offset can be assumed to be given by the set-reset repeatability: 2μV

Noise:

BW 0.01 – 100 Hz (four decades)

$$v_{n-pp} = 4 \cdot e_n \cdot \sqrt{BW} \cong 1.6 \ \ \mu\text{V}$$ thermal

$$v_{n-pp} = 4\sqrt{k_f \, 2.3 \cdot n_{dec}} \cong 363 \ \ \text{nV}$$ flicker

V_n=1.64 μV p-p (total)

Equivalent errors on the magnetic field:

$$B_{n-pp} = \frac{v_{n-pp}}{k_S} = \frac{1.6 \times 10^{-6}}{32 \times 10^{-6}} = 0.05 \ \ \mu\text{T}$$ Noise

$$B_{io} = \frac{v_{io}}{k_S} = \frac{2 \times 10^{-6}}{32 \times 10^{-6}} = 0.062 \ \ \mu\text{T}$$ Offset

Conclusion

The offset and noise errors on the measured magnetic field is much smaller than the initial specification (2.4 μT).

Therefore the sensor is suitable to obtain angular accuracies much better than the 5° specification.