LINEARITY & HYSTERESIS

Application Note

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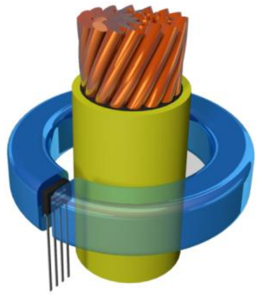
1 Scope

Application note describing the magnetic linearity error and hysteresis of current sensing solutions based on Melexis Hall-effect sensors in combination with ferromagnetic cores or shields. A comparison of various concepts, materials and geometries is presented through simulation and characterization results.

2 Hall-effect current sensors

2.1 Conventional Hall sensors

Conventional Hall sensors are typically used in combination with a ferromagnetic core, to measure the magnetic field proportional to the current flowing in a surrounded wire or bus bar.



Such sensors have no intrinsic magnetic saturation limit or hysteresis. The linearity error is typically below ±0.25%F.S. (±5mV) on the nominal output range (10 to 90%VDD). Outside this range, linearity error increases due to electrical saturation.

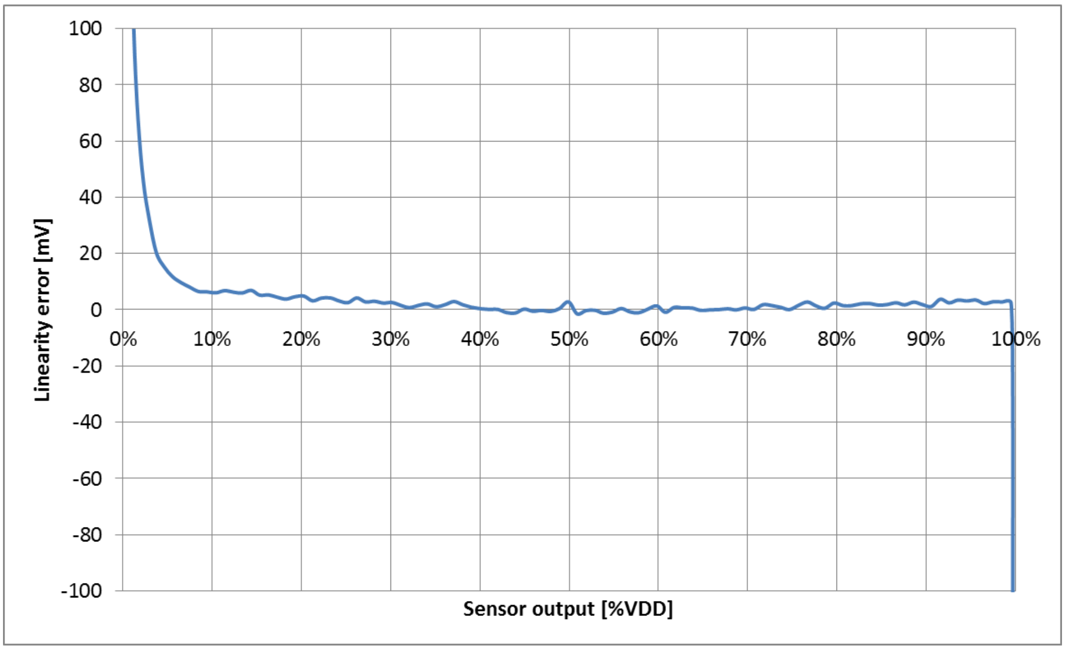
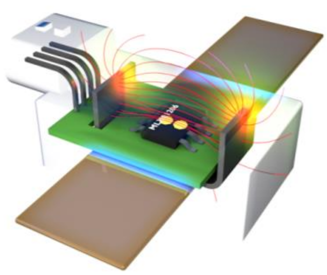


Figure 1: MLX91209 linearity error [mV] vs. output level [%VDD].

2.2 IMC-Hall® sensors

IMC-Hall® current sensors include an integrated magnetic concentrator on-chip made of a high permeability material. They can be mounted directly on top of a conductor to measure the in-plane magnetic field component with high signal-to-noise.



The on-chip magnetic concentrator is available in 3 versions with different gain factors and magnetic operating ranges, as described below.

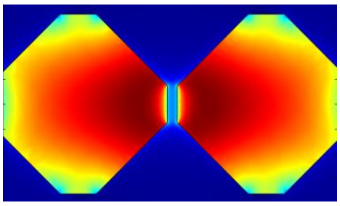
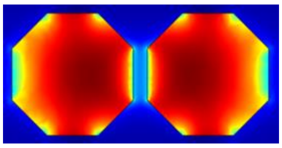
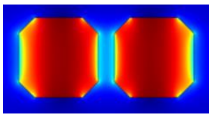
	Low field	High field	Very high field
Gain	6x	3x	1.8x
Range	10mT	25mT	60mT
Geometry			

Table 1: Main properties of each IMC version.

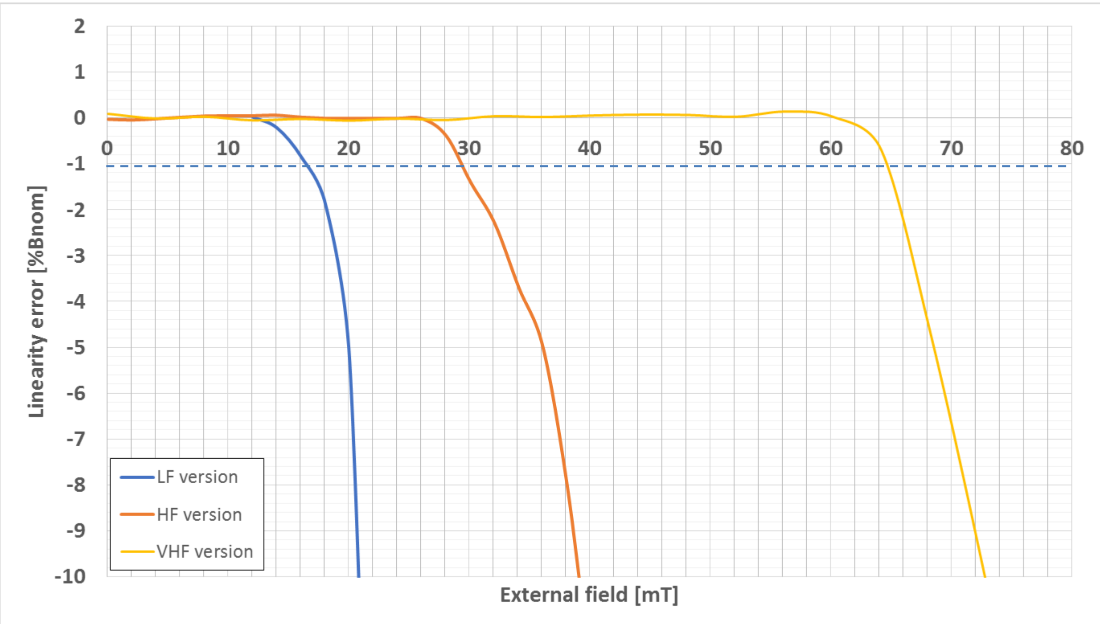


Figure 2: Input-referred linearity error [µT] vs. external field [mT]

3 Ferromagnetic materials

3.1 Reference geometry

In order to compare the performance of the most commonly used ferromagnetic material types (SiFe, 50%NiFe and ferrite), this characterization was performed with cores made of these 3 materials, all with the same geometry (as described on Figure 3).
The magnetic factor of this geometry is **0.25mT/A**.

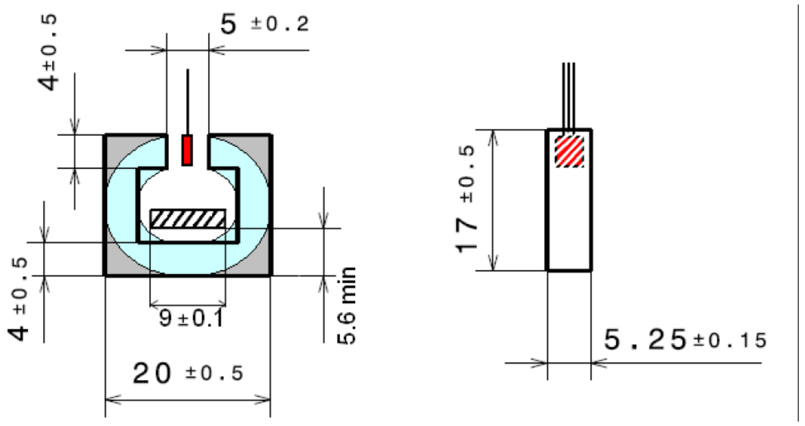


Figure 3: Ferromagnetic core geometry and sensor position.

3.2 Linearity error

Linearity error is computed with reference to a linear forecast on the data set.

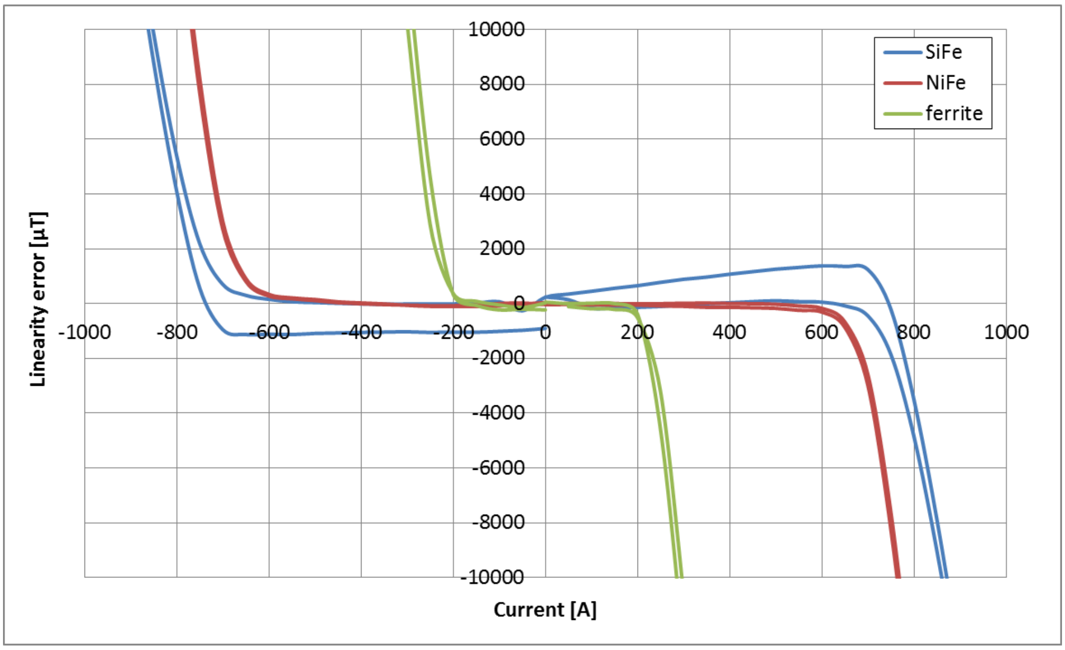


Figure 4: Linearity error [µT] vs. applied current [A] for the 3 material types.

3.3 Performance overview

We typically recommend using 50%NiFe for its wide linear range and very low hysteresis.

Material type	Sat. current [A]	B_{SAT} (core) [mT]	B_{SAT} (air gap) [mT]	Hysteresis [µT]	Hysteresis [A]
SiFe	750	**1500**	187	1000	**4**
50%NiFe	650	**1300**	162	≤ 100	**≤ 0.4**
ferrite	250	**500**	65	100	**0.4**

Table 2: Performance of the 3 material types (geometry-independent values in bold).

Notes

- Hysteresis in µT is roughly inversely proportional to the air gap. Dividing by the magnetic factor in mT/A yields a value in Amps that can be considered geometry-independent (material related).

4 Magnetic circuit

4.1 Core-based solutions

The following equation is a good approximation of the magnetic field *B* seen by the sensor located in an air gap of size *d*, when a current *I* is flowing in the surrounded conductor. The formula holds true as long as the ferromagnetic material is operated in the linear (non-satured) region.

$$B[\mathrm{mT}] = 1.25 \cdot \frac{I[\mathrm{A}]}{d[\mathrm{mm}]}$$

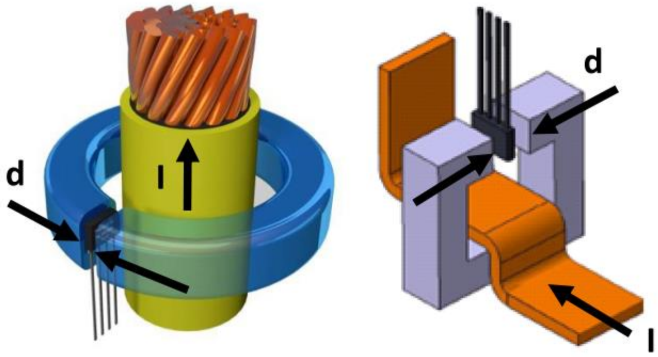


Figure 5 is a comparison of the linearity error for several typical core geometries made of 50%NiFe. These geometries are described by 3 key parameters: air gap size, in-plane, and out-of-plane thickness.

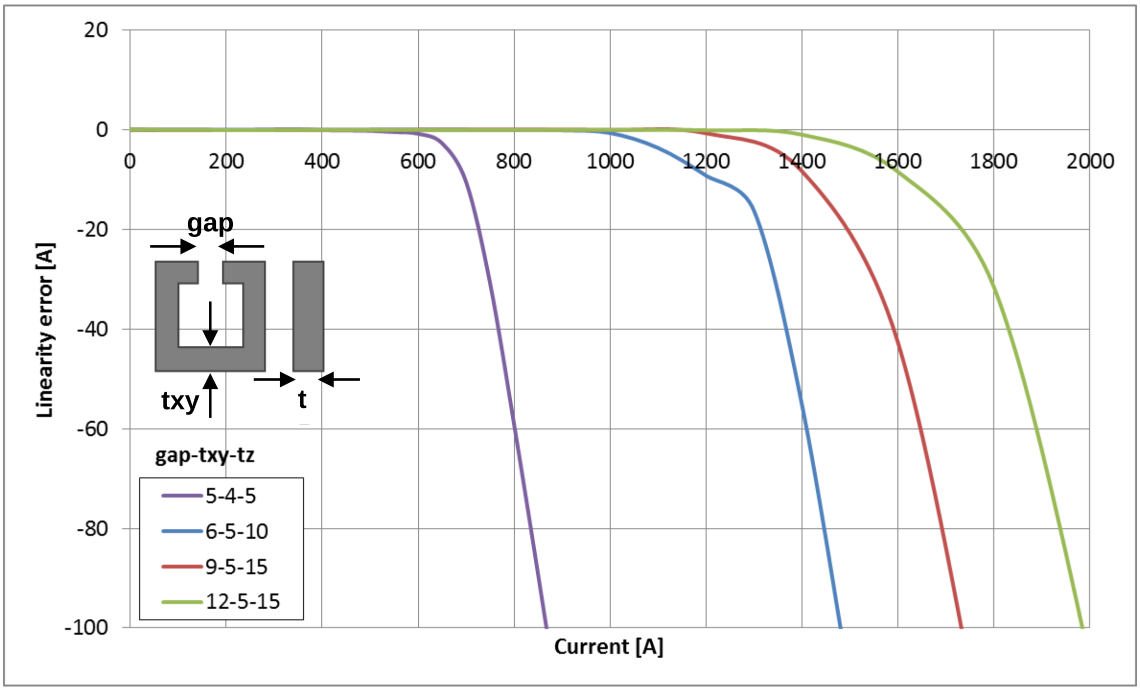


Figure 5: Linearity error [A] vs. current [A] for various core geometries made of 50%NiFe.

Notes

- Although the “perimeter” or average path length of the magnetic circuit has also a direct impact on the saturation limit, it has not been considered here because all the cores had similar diameters.

4.2 Planar (shield-based) solutions

The following equation is a good approximation of the magnetic field *B* seen by the sensor located in a shield with inner width *w*, when a current *I* is flowing in the surrounded bus bar. The formula holds true as long as the ferromagnetic material is operated in the linear (non-satured) region.

$$B[\mathrm{mT}] = 1.25 \cdot \frac{I[\mathrm{A}]}{w[\mathrm{mm}]}$$

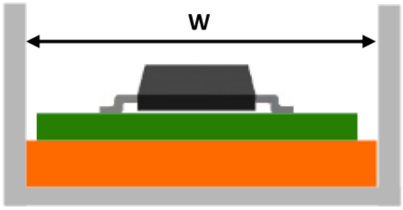


Figure 6 is a comparison of the linearity error for several typical shield geometries made of 50%NiFe. These geometries are described by 2 key parameters: inner width and thickness.

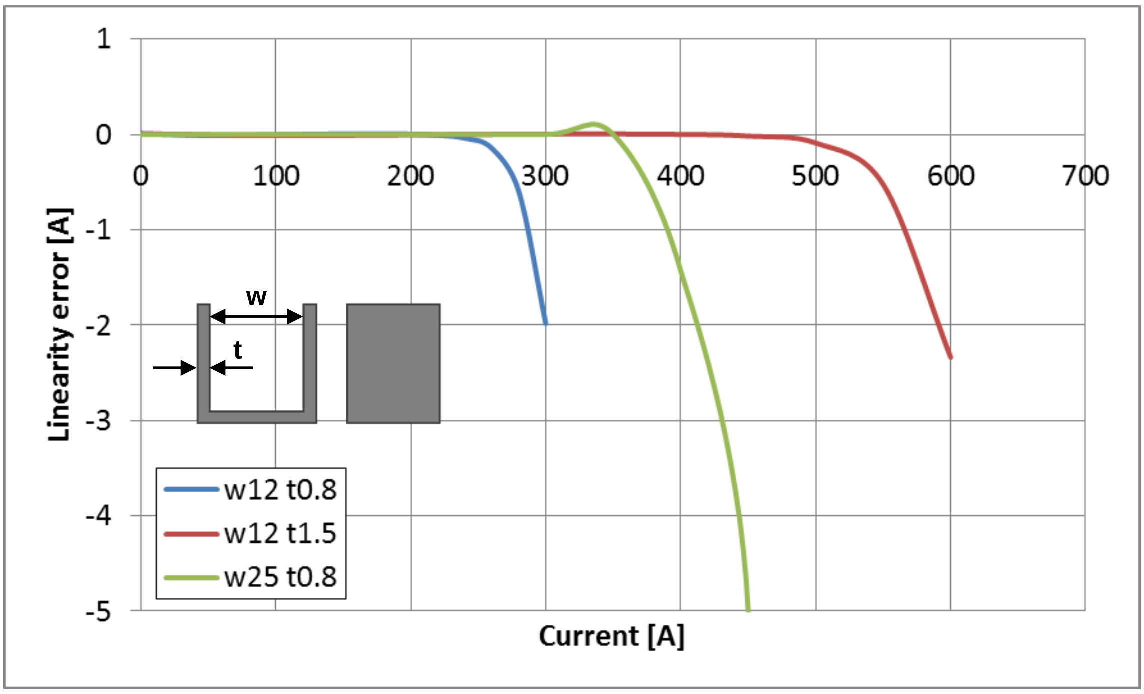


Figure 6: Linearity error [A] vs. current [A] for various shield geometries made of 50%NiFe.

Notes

- The height and depth (out-of-plane) are not considered here, but were of similar dimension for all the shields (12-13mm height and depth).