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.

<table>
<thead>
<tr>
<th>Gain</th>
<th>Low field</th>
<th>High field</th>
<th>Very high field</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>6x</td>
<td>3x</td>
<td>1.8x</td>
</tr>
<tr>
<td>Range</td>
<td>10mT</td>
<td>25mT</td>
<td>60mT</td>
</tr>
<tr>
<td>Geometry</td>
<td><img src="image1.png" alt="Low field geometry" /></td>
<td><img src="image2.png" alt="High field geometry" /></td>
<td><img src="image3.png" alt="Very high field geometry" /></td>
</tr>
</tbody>
</table>

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 $0.25\text{mT/A}$.

![Figure 3: Ferromagnetic core geometry and sensor position.](image)

3.2 Linearity error

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

![Figure 4: Linearity error [\(\mu\text{T}\)] vs. applied current [\(\text{A}\)] for the 3 material types.](image)
3.3 Performance overview

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

<table>
<thead>
<tr>
<th>Material type</th>
<th>Sat. current [A]</th>
<th>B_{SAT} (core) [mT]</th>
<th>B_{SAT} (air gap) [mT]</th>
<th>Hysteresis [µT]</th>
<th>Hysteresis [A]</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiFe</td>
<td>750</td>
<td>1500</td>
<td>187</td>
<td>1000</td>
<td>4</td>
</tr>
<tr>
<td>50%NiFe</td>
<td>650</td>
<td>1300</td>
<td>162</td>
<td>≤ 100</td>
<td>≤ 0.4</td>
</tr>
<tr>
<td>ferrite</td>
<td>250</td>
<td>500</td>
<td>65</td>
<td>100</td>
<td>0.4</td>
</tr>
</tbody>
</table>

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-saturated) region.

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

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-saturated) region.

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

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.

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).