

Application note

U-shield choice for IMC-Hall current measurement

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2 Scope

The scope of this application note is to describe how to design and choose U-shields applied to IMC-Hall sensors ([Figure 1](#)), to obtain a current sensing solution with optimal performances. The shield's functions are to concentrate the magnetic field at the sensor's location, to protect the sensor from external magnetic disturbances and to increase the resilience to mechanical vibrations by creating a homogenous horizontal field in the middle of the U-shield ([Figure 2](#)). The parameters of the U-shield affecting the performances of the sensing system are the geometrical dimensions and the ferromagnetic properties of the material.

To replicate a complete measurement setup, the following components are required:

- Copper busbar (with a center hole preferred, for better frequency behaviour)
- Ferromagnetic U-shield (NiFe, SiFe, laminated steel)
- PCB with Melexis IMC-Hall current sensor
- Plastic holder for fixing all the elements together

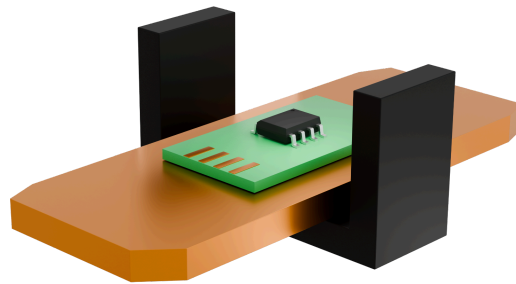


Figure 1: A IMC-Hall type of current sensing assembly containing a U-shield (black), a current busbar (orange) a PCB (green) and an IMC-Hall sensor.

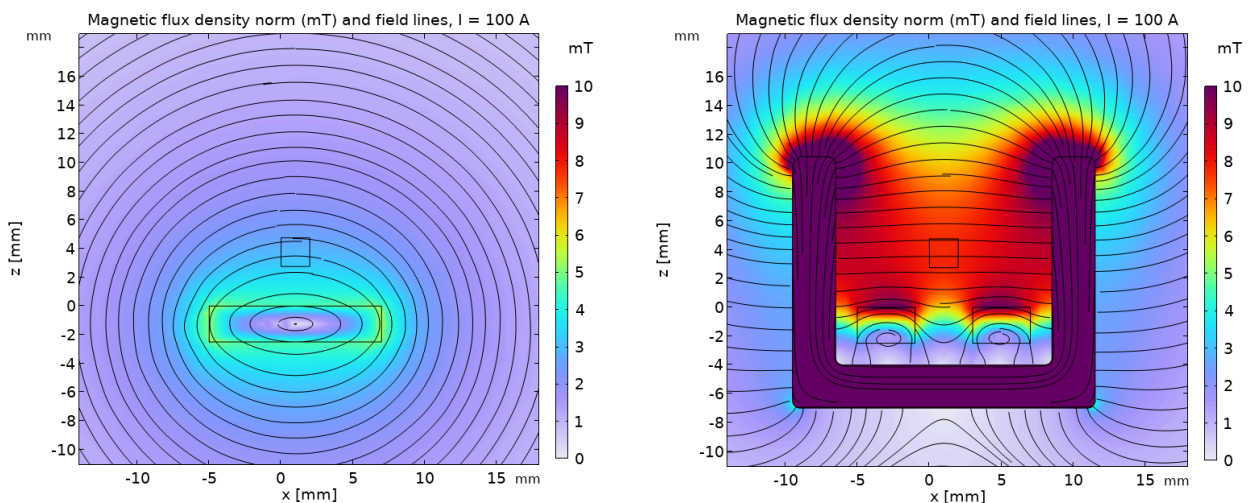


Figure 2: Magnetic flux density and field lines generated by 100A in a busbar without and with a shield

3 U-shield geometrical dimensions

Significant performance variations in U-shields come from modifications in their size and shape ([Figure 3](#)).

Dimensions changes affect several key aspects, including:

- The gain or field factor
- The magnetic saturation
- Residual magnetic flux density and hysteresis
- Shielding capabilities and cross talk immunity
- Resilience to mechanical displacements
- The frequency response

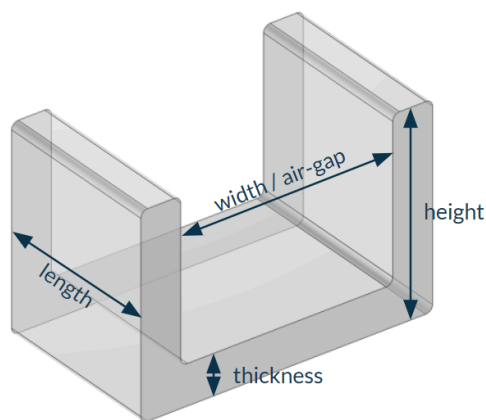


Figure 3: U-shield dimension names.

3.1 Gain / field factor

The field factor (FF) of a U-shield is its capacity to convert the current flowing through its busbar (A) into a magnetic flux density (mT), at the sensor's position. It primarily depends on the **U-shield width**, also referred to as the air-gap, which is the internal distance between the two vertical arms of the U-shield. This region is where the magnetic field maintains a mostly homogeneous horizontal direction.

The field factor in the horizontal direction of a sensor centered in a U-shield can be estimated using the following equation:

$$FF[mT/A] = \frac{1.25}{d[mm]}$$

Where:

- FF is the field factor in mT/A
- d is the air-gap of the U-shield in mm

Careful considerations with the IMC saturation:

IMC-Hall sensors use different Integrated Magnetic Concentrators (IMCs) that saturate at different levels depending on the magnetic field strength. The maximum magnetic field at the sensor must not

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exceed the IMC's saturation field, specified in the sensor's datasheet (or in [Figure 4](#)). Shield gain selection must therefore account for the IMC type.

In the end, the selected U-shield width will depend on your busbar width constraints (a local neckdown can be used to reduce it), the saturation of the U-shield and of the sensor's IMC. [Table 1](#) presents Melexis' recommended air-gap depending on your current sensing range.

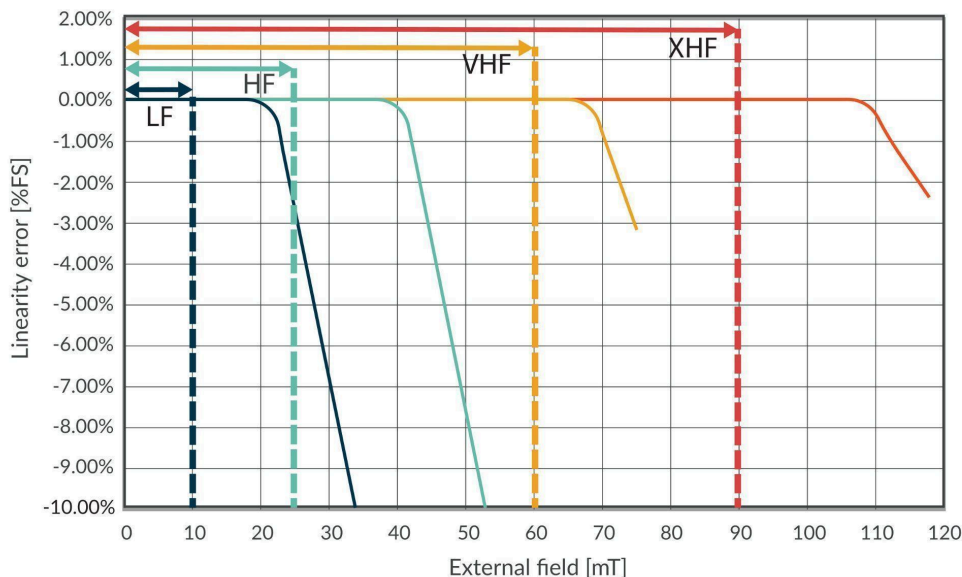


Figure 4: the different IMC linearity limits

U-shield width	Ideal current sensing range (A)
12 mm*	300–600
15 mm	500–1100
20 mm	1000 - 1600
25 mm	1400–2000

* non laminated, for DC currents only

Table 1: Ideal U-shield air-gap (width) depending on the current sensing range

3.2 Magnetic saturation

U-shields concentrate the magnetic field linearly up to a certain threshold set by both their dimensions and the material's saturation flux density ([Section 4, Material properties](#)).

For accurate current measurements, the shield must operate within its linear region. At Melexis, we consider that a shield starts to saturate when its field factor deviates by more than 0.5% from its ideal linear behaviour at lower currents. This deviation is referred to as the non-linearity error (NLE).

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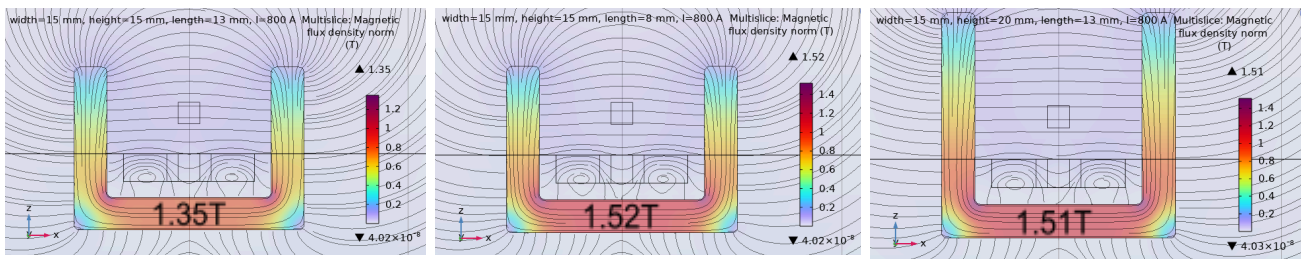


Figure 5: Magnetic flux density (T) repartition in three different U-shields and its maximum value with 800A in the busbar for: the reference (left) with 15mm height and 13mm length, a shorter U-shield (middle) with 8mm length and a higher U-shield (right) with 20mm height.

In [Figure 5](#), the magnetic flux generated by the busbars is attracted and concentrated by the U-shields. It follows the path of least reluctance (or highest permeance), which crowds the flux mainly in the inner corners of the U-shield. Looking at the structure of the U-shield, we can list the parts that compose it in order of magnetic concentration (the of the list being the part where the magnetic field density is the highest), as follows:

- Inner corners
- Bottom or base
- Vertical arms (with decreasing magnetic flux density when going higher)
- Outer corners of the U-shield
- Top of the vertical arms

Increasing the volume of the U-shield's inner corners and bottom increases the volume for magnetic flux, so decreases magnetic flux density and delays the U-shield's saturation point.

The left plot in [Figure 5](#) shows that a higher U-shield leads to higher magnetic flux density at its bottom. This is because a taller shield attracts and concentrates flux that is further from the busbar.

Summary for the saturation:

- Increasing the thickness of the base of U-shields (or the overall thickness of the U-shield) delays the saturation point.
- Increasing the shield width or air-gap delays the saturation point.
- Increasing the height of U-shields makes them saturate sooner.
- Some parts of the U-shields can be cut (outer corners, external sides of the top of vertical arms) with minimal influence on the saturation point.

3.3 Shielding capabilities and cross talk immunity

A design may require high immunity to magnetic cross-talk. For instance, when the U-shields are positioned side by side in a three-phase inverter, parasitic magnetic fields from adjacent phases primarily couple into the U-shields in the vertical direction ([Figure 6](#)). Improving the shielding of the magnetic field component in the vertical direction (B_z) is the most important to increase cross-talk immunity. The parameters that play a role in the shielding are the following: placement of the sensor (especially in the horizontal direction), shield height, width and length.

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[Figure 7](#) illustrates the magnetic field strength in the IMC-Hall sensing direction for different U-shield dimensions under a 1 mT vertical external field. Key observations are that:

- A perfectly centered IMC sensor is not affected by the external field since the external field component is only vertical.
- If the sensor is moved along the x axis, cross talk appears due to the induced B_x component.

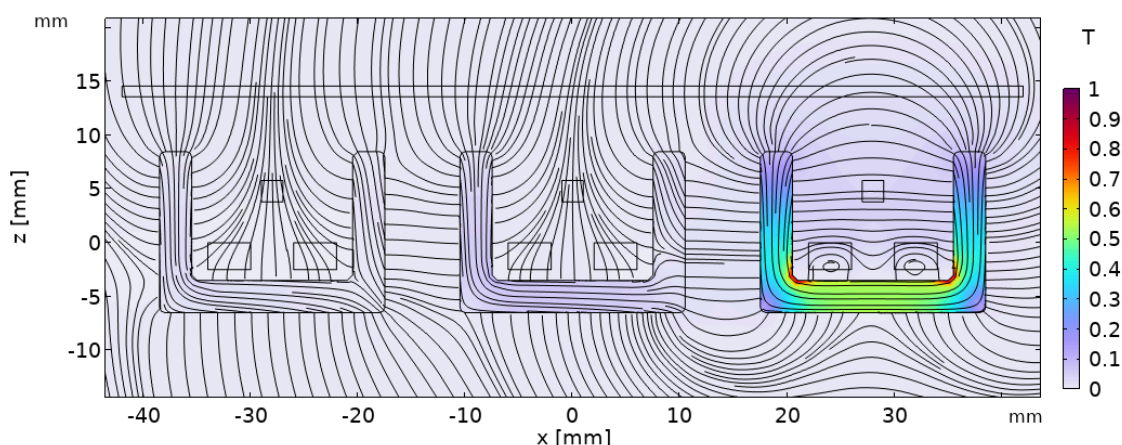


Figure 6: Magnetic field direction in a 3 phase system when only one phase is active.

Increasing the U-shield height has:

- Minimal effect on the field factor itself, but increases the shield saturation.
- A significant positive impact on immunity to external fields in both the vertical ([Figure 7](#)) and horizontal ([Figure 8](#)) directions.

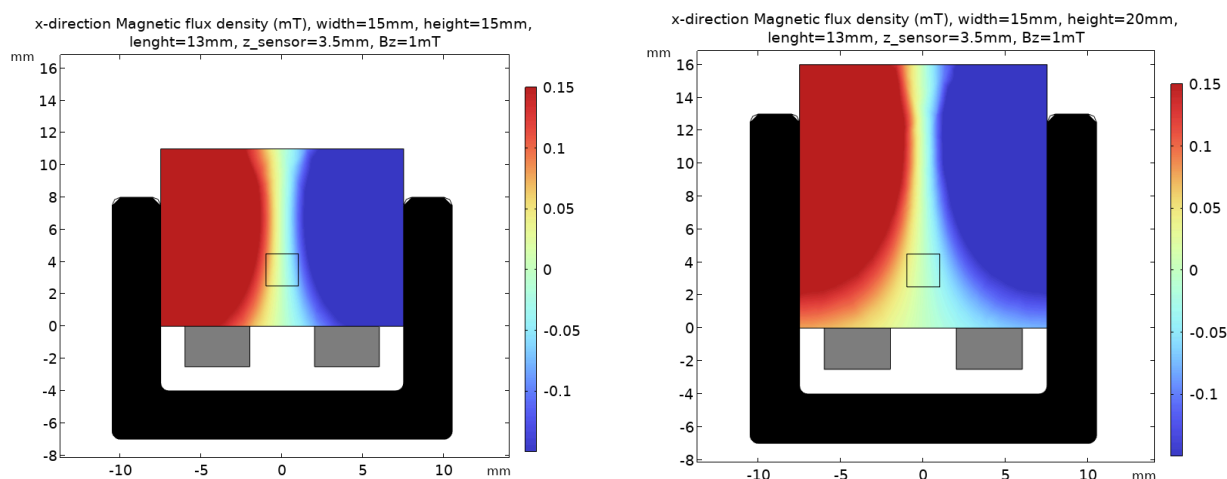


Figure 7: Magnetic field strength in the x direction (mT) for different U-shield heights with a 1 mT vertical external magnetic field

U-shield width: Because a wider U-shield provides less field factor for the internal field, the ratio of external to internal magnetic fields increases, which results in stronger crosstalk in %.

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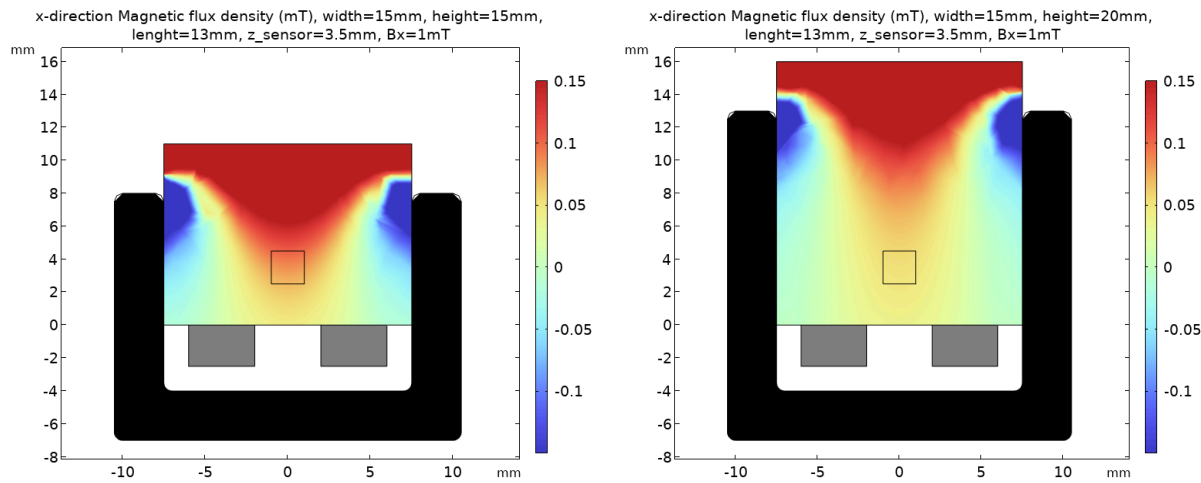


Figure 8: Magnetic field strength in the x direction (mT) for different U-shield heights with a 1 mT horizontal external magnetic field

U-shield length: Reducing the U-shield length has a minimal impact for a vertical direction external field, but greatly affects the response to horizontal fields. Therefore, this will also increase the cross talk in some cases ([Figure 9](#))

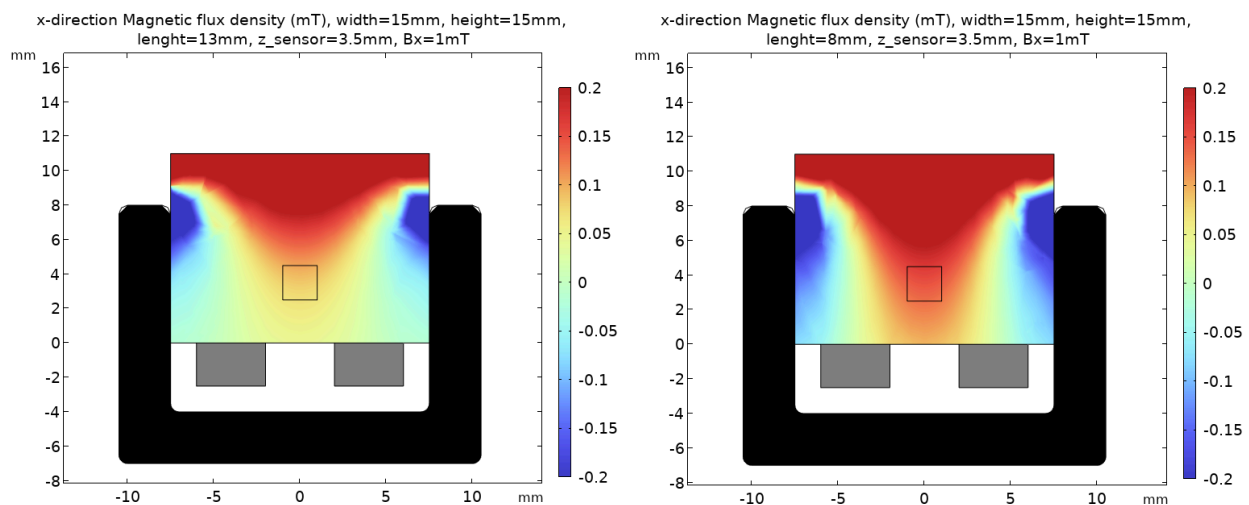


Figure 9: Magnetic field strength in the horizontal direction (mT) for different U-shield length with a 1 mT horizontal external magnetic field

Summary for cross talk

- To reduce the cross-talk impact, increasing the U-shield height is most effective. However, this must be done with consideration for magnetic saturation limits.
- Decreasing the width or air-gap of the shield improves cross talk as well. However, the resulting changes in U-shield gain and magnetic saturation must be carefully considered.
- Increasing the shield length will partially improve the cross talk immunity by improving the shielding in the horizontal direction.

3.4 Resilience to mechanical displacements

U-shield dimension adjustments can help reduce measurement errors caused by sensor displacement within the same inverter phase. Increasing the U-shield height and length lowers sensitivity to mechanical offsets by making the internal magnetic field more uniform. However, the most significant improvements depend on sensor placement and busbar design rather than on the U-shield itself.

3.5 Frequency response

All U-shields will have a field factor reduction and phase shift over frequency (Figure 10), as varying magnetic fields create Eddy currents that in turn, create dephased counter fields, whose intensity is proportional to the frequency.

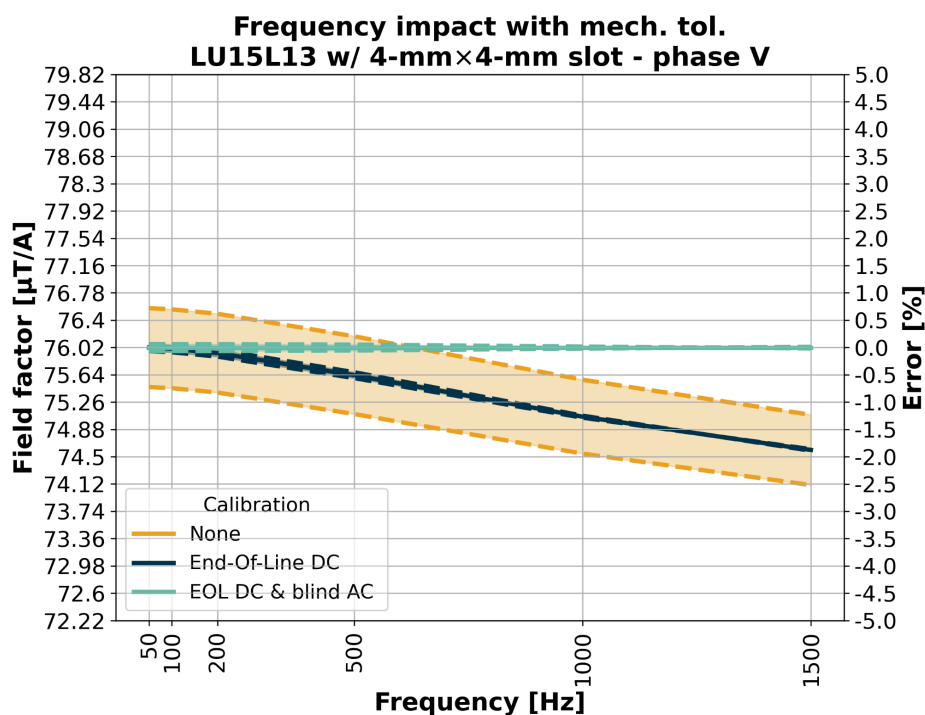


Figure 10: Simulation of the field factor reduction over frequency of a laminated 15mm air-gap U-shield (LU15), along with different calibration outcomes.

To minimize the gain and phase changes over frequency, the Eddy currents in the U-shield should be minimized by:

- Choosing a material with lower conductivity.
- Decreasing the Eddy currents surface by laminating the U-shield. Laminations are typically 0.5 or 0.35mm thick, depending on the steel sheets chosen by the U-shield manufacturer.

4 Ferromagnetic material properties

The second part of this application note explains the inherent properties of the ferromagnetic materials that need to be considered when designing a U-shield. To understand these properties, it is important to understand how a ferromagnetic material is structured at a smaller scale ([What is a Ferromagnetic Material?](#)) and which information we can get from a B-H curve. Following this, the document covers properties and characteristics inherent to the material itself: material saturation, residual magnetic flux density, curie temperature, the difference between grain oriented and non oriented materials, and laminations manufacturing process. The section concludes by detailing the most common materials and their properties.

4.1 What is a Ferromagnetic Material?

Ferromagnetic materials strongly react to an external magnetic field, concentrating it inside the material, and its surroundings. Their atoms have magnetic moments, which align within microscopic magnetic domains. When no field is applied, and in absence of any remanent magnetization, the domains' moments are randomly oriented (resulting in zero net magnetization). Once an external magnetic field is applied, the domain's moments align, creating a strong net magnetization ([Figure 11](#)). B-H curves help understand the material's precise response to an external magnetic field.

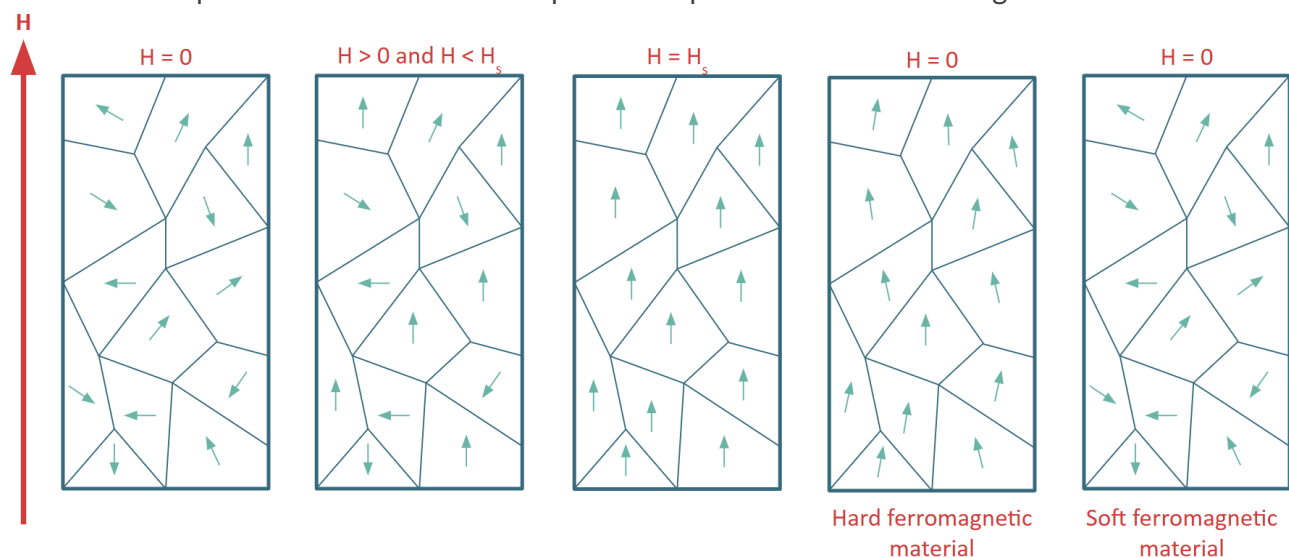


Figure 11: Magnetization of soft (for U-shields) and hard (for magnets) ferromagnetic materials

4.2 The B-H curve

The B-H curve describes the nonlinear behavior of the magnetic field flux density inside a material (B) in response to an applied magnetic field (H).

Applying a magnetic field aligns the material's magnetic domains, increasing the magnetic flux density until saturation B_{sat} . Removing the field leaves a remanent flux density B_r , (i.e. the domains are still slightly aligned to the previous magnetic field direction) which depends on the maximum applied magnetic field and its direction. By cycling the magnetic field between B_{sat} and $-B_{sat}$, a hysteresis loop is created and can be seen in [figure 12](#).

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For relatively small magnetic field strength and without considering hysteresis, the magnetization response of the material stays linear. The slope of this line is the permeability of the material as expressed in the formula:

$$B = \mu_0 \mu_r H$$

With B the magnetic flux density in T, μ_0 the permeability of vacuum in H/m, μ_r the relative permeability of the material and H the magnetic field strength in A/m.

Thus, the shape and size of the B-H curve reveal key magnetic properties (remanence, permeability, saturation) which affect the performance of the final U-shield.

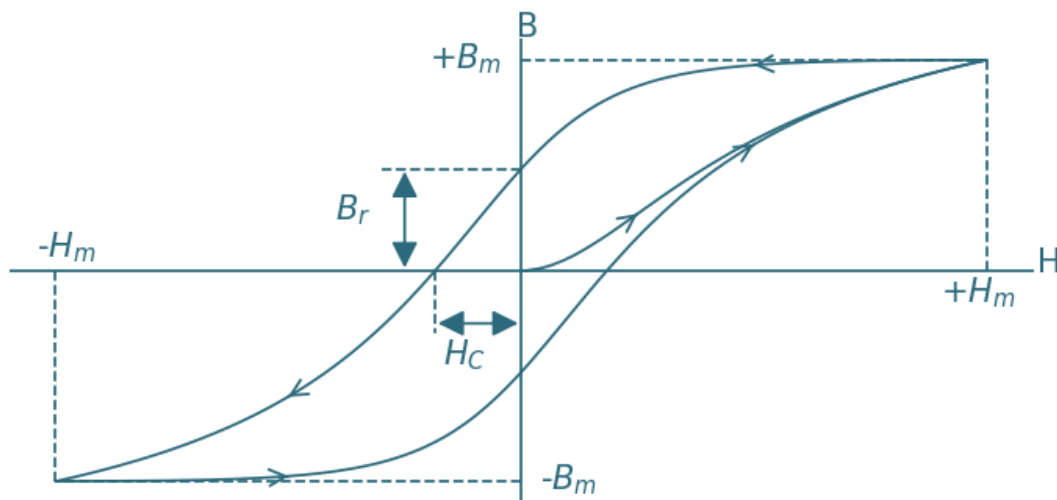


Figure 12: A B-H or hysteresis loop curve showing B_r the remanent field, and H_c the coercive force, dependent on the maximum applied field H_m .

4.3 Material saturation

The saturation flux density (B_{sat}) represents the maximum magnetic flux that a ferromagnetic material can carry. A material is considered saturated when all of its magnetic domains are aligned. Beyond this point, increasing the magnetic field strength (H) results in only a minimal rise in magnetic flux density (B).

Melexis Applications engineers can evaluate the saturation point of a specific U-shield (to stay within 0.5% NLE), provided that you have the B-H curve of its raw material. An example of this data can be seen in [table 2](#).

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H [A/m]	B [mT]	H [A/m]	B [mT]	H [A/m]	B [mT]	H [A/m]	B [mT]
0	0	100	0.84	900	1.46	10000	1.79
10	0.04	150	1.055	1000	1.47	20000	1.9
20	0.06	200	1.17	2000	1.55	30000	1.95
30	0.13	250	1.24	3000	1.6	40000	1.98
40	0.23	300	1.285	4000	1.64	50000	1.995
50	0.36	400	1.345	5000	1.675	60000	2.005
60	0.49	500	1.385	6000	1.705	70000	2.015
70	0.6	600	1.41	7000	1.73	80000	2.025
80	0.695	700	1.43	8000	1.75		
90	0.775	800	1.445	9000	1.77		

Table 2: example of B-H curve needed for material saturation simulation, in this case of SiFe 35C270

4.4 Residual magnetic flux density and hysteresis

Very low hysteresis is generally less critical in inverter applications, where the current rapidly oscillates from positive to negative, but it becomes crucial in battery measurement systems for accurate coulomb counting.

Residual magnetic flux density is the remaining flux density inside the material when no external magnetic field is applied. This introduces errors in low current measurements. While it is unavoidable with a ferromagnetic concentrator, proper U-shield material and manufacturing can mitigate it (see [Example of ferromagnetic materials](#)).

4.5 Curie temperature

When the U-shield approaches the Curie temperature (T_c) it faces structural changes that make the permeability of the material change and the guiding properties of the material degrade. Ferrite materials, which typically have a Curie temperature around 200 °C, are not recommended for high-temperature automotive environments that can reach 150 °C.

4.6 Grain oriented materials

Soft ferromagnetic materials are classified as grain-oriented (GO) or non-grain-oriented (NGO). GO materials have aligned crystal structures that maximize permeability and minimize hysteresis in one direction. NGO materials have no preferred crystallographic direction, offering uniform magnetic properties no matter the magnetic field orientation. NGO is preferred due to the non-unidirectional field within U-shields, while GO is mostly beneficial for wound cores (outside this application note's scope).

4.7 Laminations manufacturing process

For a clearer understanding of the fabrication process and issues linked to them, an example of a laminated U-shield manufacturing process is described below:

1. Manufacturing the core from multiple sheets (typically 0.5 or 0.35mm) of ferromagnetic material. These are typically bought from a gross electrical steel manufacturer and have precise B-H curve characteristics and datasheets available.
2. Stamping the raw material into the required shape. This step creates mechanical stress in the material, degrading the magnetic properties.
3. The pieces are coated to provide electrical insulation and (sometimes) oxidation resistance.
4. Stacking the layers together to form the final U-shield shape.
5. Annealing of the U-shields to release mechanical stress and optimize magnetic properties.
6. Application of an external insulating coating again, since the original coating is often degraded during annealing (but preserved inside the laminations.).

The annealing phase can be very different from one manufacturer to another. They can last from less than one hour to around 10h, with different chemical compositions of the gases in the oven and temperature profiles.

4.8 Example of ferromagnetic materials

Silicon-iron (SiFe) and nickel-iron (NiFe) are the most common ferromagnetic materials used for U-shields (and C-cores). Silicon iron is the most widely used material for inverter or AC applications. Its performances are widely sufficient for most cases.

Nickel-iron is more expensive and is chosen when high accuracy is needed across the entire current range, due to its low hysteresis. Measurements done in our lab show that for identical U-shield dimensions, NiFe can have more than 8x less hysteresis compared to a SiFe core. Relevant applications for NiFe cores are, for example, battery monitoring systems. [Table 3](#) summarises the important parameters to consider.

Material	Price/kg (approx.)	Relative Permeability	Hysteresis Loss (relative)	Saturation Flux Density (T)	Curie Temperature (°C)
NiFe (48% Ni)		10,000–30,000	Low	~1.6 - 1.7 T	~550 °C
SiFe (3% Si)	5x cheaper than NiFe	2,000–6,000	Medium	~2.0 T	~750 °C
Ferrite	Cheaper than SiFe	2,000–15,000	High	0.3 - 0.5T	~200 °C

Table 3: Soft ferromagnetic materials used for cores in the automotive industry and comparison of their main characteristics.

5 Conclusion

Using a ferromagnetic U-shield is a key element for achieving robust and accurate IMC-Hall sensor applications. The **U-shield geometry**, **choice of material**, and **manufacturing process**, play an important role in the current measurement system's overall performance (including accuracy, AC behavior, cross-talk immunity, and mechanical stability).

From a **design perspective**, the U-shield dimensions must be optimized alongside material choice. U-shield air-gap, height, length and thickness directly influence gain, saturation behavior, and immunity to cross talk and mechanical displacements error.

- The field factor of the U-shield at the sensor position is proportional to the inverse of the airgap.
- Reducing the air-gap also improves the protection to horizontal external fields but leads to an earlier saturation.
- Increasing the thickness of the base delays the magnetic saturation threshold.
- Increasing height and length improves immunity to cross-talk and mechanical displacement, but advances the saturation.
- The frequency response is managed by reducing Eddy currents, primarily through the use of laminations.

A **high-quality material selection** is essential. Reliable data on B-H curves, permeability, electrical conductivity, and Curie temperature are required to accurately model and predict U-shield behavior.

Understanding the **manufacturing process** is also important. Improper annealing and residual mechanical stress introduced during fabrication can significantly degrade performances and increase part-to-part variability. When possible, a close collaboration with material suppliers is needed, to verify and understand their manufacturing steps and ensure that the magnetic properties are optimal.

With proper material selection, verified processing, and well-dimensioned geometry, Melexis IMC sensors have delivered **accurate and stable current sensing solutions for several years** for demanding environments such as EV inverters, DCDC converters, power monitoring, HVAC, etc.

6 Related Melexis Products

IMC-Hall current sensors:

- MLX91208
- MLX91216
- MLX91218

7 Revision history

Revision	Date	Change history
001	03-Dec-25	Document creation

Table 4 – Revision history

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