BUSBAR DESIGN GUIDELINES FOR CORELESS CURRENT SENSING WITH ACS37610 OR ACS37611

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INTRODUCTION

Accurate measurement of current is a critical function in a wide range of applications, from electric vehicle (EV) powertrains to industrial motor drives. The coreless Hall-effect current sensor, such as the Allegro ACS37610 or ACS37611 (ACS37610/1), is a leading solution that offers a compact, lightweight, nonintrusive method to sense current. This method uses a differential sensing architecture, and the magnetic field is measured at two separate points. This enables rejection of common-mode stray magnetic fields, a crucial capability in modern densely packed power-electronic systems.

Compared to a shunt-and-operational amplifier (Shunt-OpAmp) system or a system that uses a magnetic concentrator, a coreless system has a reduced system size, weight, and bill of materials (BOM). However, the designer of a coreless system needs to pay attention to the following parameters:

- **Coupling Factor:** An increase in the coupling factor achieves better resolution of small currents.
- **Gain Errors:** Mechanical displacements cause gain errors over the life of the device.
- **Crosstalk:** Adjacent busbars produce crosstalk error. To reduce this error, three phases are commonly measured.
- **Busbar Resistance:** Higher resistance leads to thermal losses.
- **AC Performance Degradation:** Gain and phase errors occur at high frequency due to the skin effect.

Although a coreless sensor is functional with a simple conductor, the most critical factor to optimizing these performance parameters is the busbar geometry. This application note compares four common busbar designs (Figure 1) for use with coreless current sensors: notched busbar, S-notch busbar, dual-bridge busbar, and plain busbar

This analysis empowers an engineer to select the optimal busbar for a specific application.

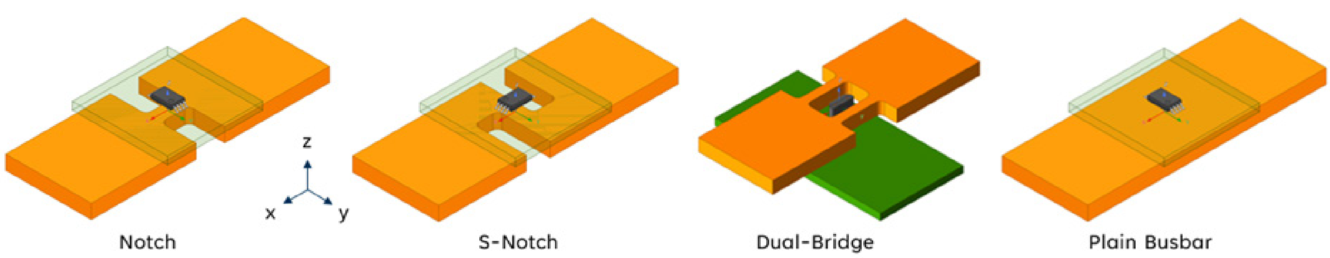

Figure 1: Overview of Compared Busbar Designs

COMPARISON OF BUSBAR DESIGNS

This comparison of busbar designs uses magnetic simulations performed in Ansys Maxwell.

To ensure consistency, all designs use a copper busbar with standardized dimensions of 18 mm × 3 mm × 50 mm (width × thickness × length).

- The notch, S-notch, and plain busbar configurations use a sensor in an eight-lead thin-shrink small-outline package (TSSOP-8). The sensor is placed on top of a 1.6 mm-thick printed circuit board (PCB). The resulting magnetic air gap between the sensing element and the busbar surface is 2.16 mm, as shown in Figure 2. Typically, the sensor is soldered onto the PCB with a solder thickness of 0.1 mm. For simplicity in this model, this solder thickness is ignored.
- The dual-bridge design uses a sensor in a single in-line package (SIP).

Detailed geometries are shown in Figure 3. For a more in-depth analysis of the notch, S-notch, and dual-bridge geometries, refer to the respective application notes available on the Allegro website. [1][2][3]

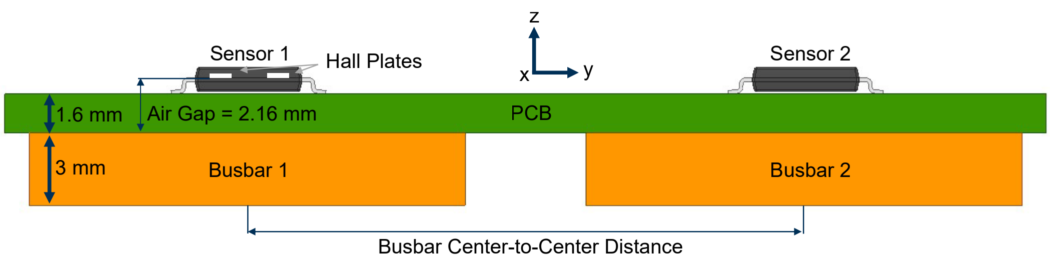

Figure 2: Cross Section of Simulated Geometry

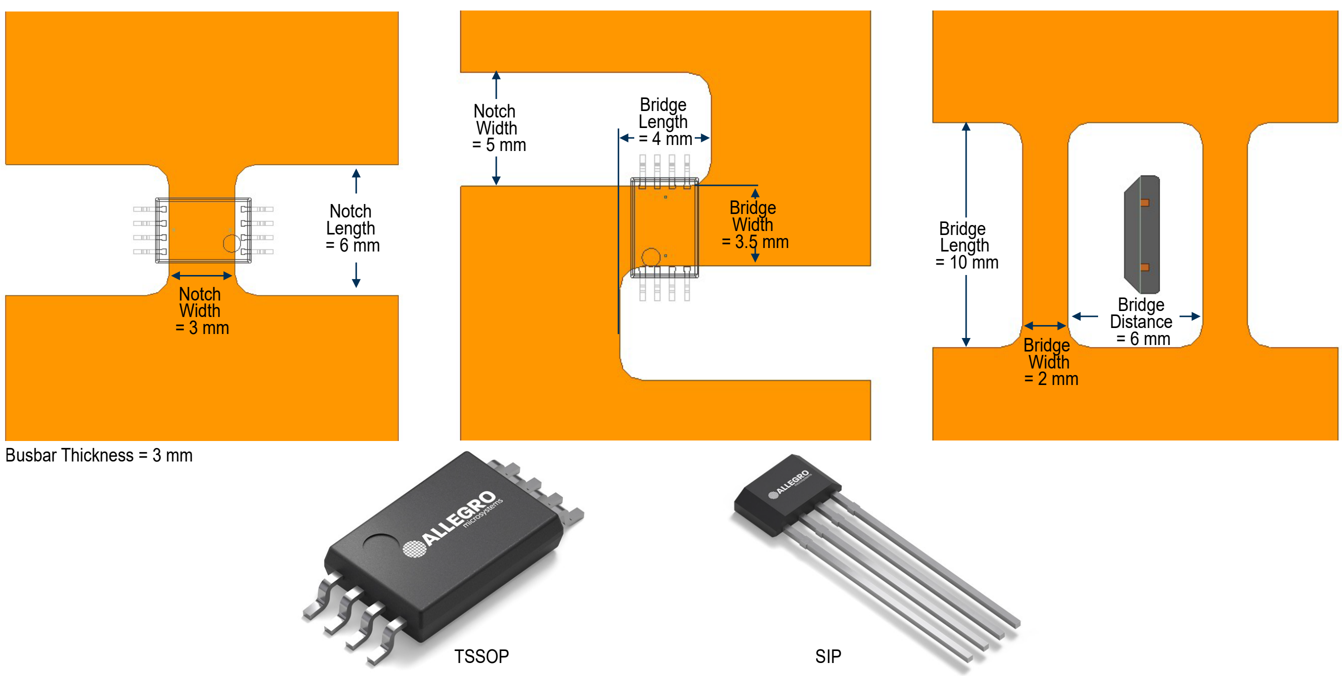

Figure 3: Detailed Geometry of Notch, S-Notch, and Dual-Bridge, and Drawings of Available Packages

[1] https://www.allegromicro.com/-/media/files/application-notes/an296231-acs37610-busbar-notch-guidelines.pdf?sc_lang=en
[2] https://www.allegromicro.com/-/media/files/application-notes/an296292-acs37610-crosstalk-error-busbar-design.pdf?sc_lang=en
[3] https://www.allegromicro.com/-/media/files/application-notes/an296337-dual-brdige-design-for-acs37610s.pdf?sc_lang=en

KEY PERFORMANCE METRICS

Key performance metrics of each busbar design are summarized in Table 1.

Coupling Factor

Coupling factor, measured in G/A, is the ratio of the magnetic field generated at the sensor to the current flowing through the busbar. A higher coupling factor is paramount because it directly improves the system signal-to-noise ratio (SNR), enabling accurate measurement of smaller currents. While a plain busbar is functional, geometric modifications significantly enhance measurement resolution by concentrating the magnetic field.

Performance

- The notch design and S-notch design yield the highest coupling factors (0.33 and 0.35 G/A, respectively).
- The dual-bridge design offers a moderate coupling factor (0.26 G/A).
- The plain busbar provides the lowest coupling factor (0.05 G/A) by a significant margin.

Table 1: Overview of Key Performance Metrics of Analyzed Busbar Designs

Parameter	Condition		Notch	S-Notch	Dual-Bridge	Plain Busbar	Units
Coupling Factor			**0.33**	**0.35**	0.26	0.05	G/A
Gain Error	1 kHz		**0.1**	0.4	–1.2	–43	%
Phase Shift	1 kHz		**–0.3**	–0.7	–1.5	–40	°
Crosstalk	48 mm (center to center)		0.8	**<0.1**	1.0	4.8	%
Noise RMS (Input Referred)	at 250 kHz		**1.7**	**1.6**	2.2	10.4	A
Max Current [1]	5 mV/G		1212	1143	1538	8000	A
	10 mV/G		606	571	769	4000	A
	20 mV/G		303	286	385	2000	A
Sensitivity Error Due to Mechanical Displacement	dx =	0.1 mm	<0.1	–0.1	–0.1	<0.1	%
		0.3 mm	–0.1	–1.1	–1.2	<0.1	%
	dy =	0.1 mm	–0.2	<0.1	<0.1	<0.1	%
		0.3 mm	–1.4	–0.3	<0.1	<0.1	%
	dz =	0.1 mm	–4.8	–4.8	**0.1**	–0.8	%
		0.3 mm	–13.6	–13.3	**1.2**	–2.3	%
Busbar Resistance			30	38	30	16	μΩ
Sensor Package			TSSOP	TSSOP	SIP	TSSOP	–

[1] ACS37610 is also available in a 50 mV/G variant.

Gain and Phase over Frequency

The AC performance of a coreless current sensing system depends on both the sensor characteristics and the geometry of the busbar due to the skin effect. As frequency increases, the current is forced to the edges of the busbar. This changes the magnetic field profile that is measured by the sensor.

For the highest accuracy, the system gain and phase should remain constant across the entire operating frequency range. The gain and phase performance of the busbar geometries shown in Figure 4 demonstrates that they can be specifically engineered to minimize the impact of the skin effect.

NOTE: At the –3 dB gain point, the measured bandwidth of the ACS37610/1 is 240 kHz. For any sensor with such a bandwidth, a –0.9 dB gain and a 60-degree phase shift are observed at 100 kHz.

Performance

- The notch and S-notch designs exhibit the best AC performance, showing minimal gain error and phase shift at 1 kHz.
- The dual-bridge design follows with moderate AC performance.
- The plain busbar, however, exhibits significant gain error (–43%) and phase shift (–40°), which limits its use to low-frequency applications.

The system response time, often measured as the response to a quick input current step with a rise time of 1 µs, is impacted by the system frequency response. The ACS37610/1 both feature 240 kHz bandwidth leading to a response time of < 2 µs. The notch, S-notch, and dual-bridge designs add less than 0.5 µs to the sensor response time, ensuring that the overall system speed is dominated by the sensor itself.

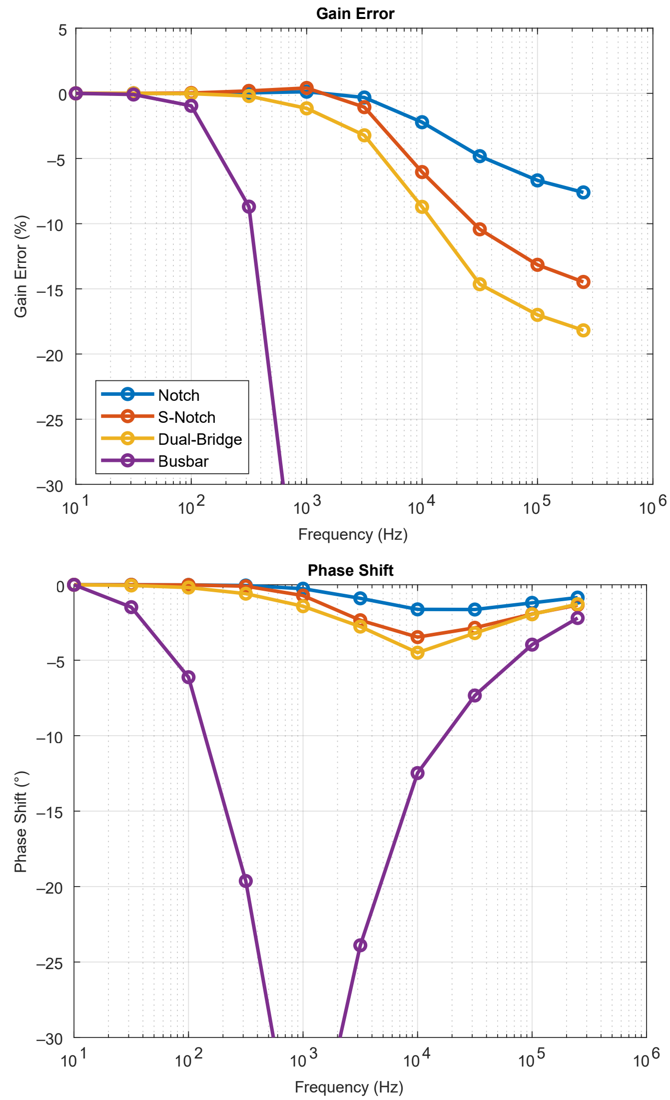

Figure 4: Frequency Response of Busbar Designs

Crosstalk Immunity

The ACS37610/1 uses differential sensing to reject uniform stray magnetic fields. However, if a magnetic field has a gradient, a measurement error results. To address this issue, coreless sensors are often used to measure the phase current of a three- or six-phase motor. This results in a system with adjacent busbars/sensors for each phase. The error introduced from the adjacent phase is the crosstalk error.

Performance

- The S-notch design provides superior immunity to stray fields from adjacent conductors by rotating the sensor by 90°, causing the field from the adjacent sensor to be sensed uniformly by both Hall elements in the sensor. At a distance of 48 mm (center to center), this results in a crosstalk error of less than 0.1%.
- The notch and dual-bridge designs offer moderate crosstalk performance (0.8% and 1.0%, respectively). Reducing the air gap helps to reduce the crosstalk error.
- The plain busbar is the most susceptible to crosstalk error, at 4.8%.

A more detailed comparison of crosstalk error is shown in Figure 5. The plain busbar is omitted because it shows crosstalk of greater than 20% at a distance of less than 30 mm.

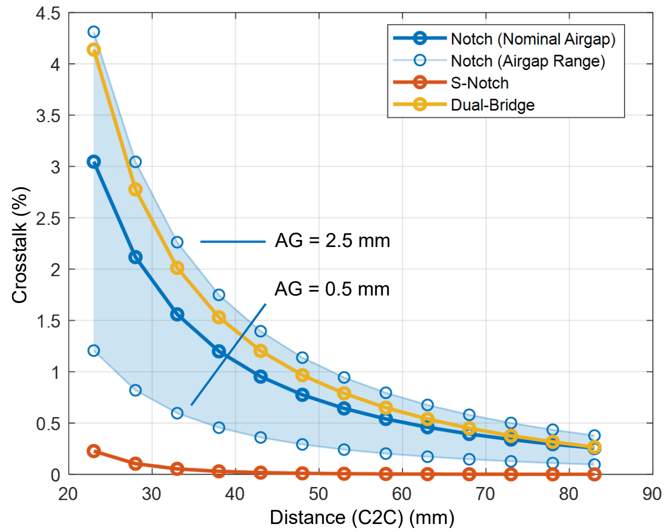

Figure 5: Crosstalk versus Busbar Distance for Notch, S-Notch, and Dual-Bridge Designs

Sensor Displacement Error

Sensor displacement relative to the busbar contributes to a variation of the coupling factor, which causes a sensitivity error. Displacement is primarily caused by:

Mechanical tolerances of the assembly process: These errors can be eliminated by the user by conducting an end-of-line calibration. In this calibration, the sensor sensitivity and offset are calibrated to achieve the desired coupling factor, mechanical displacement during operation due to vibration, aging, etc.

Performance

- The dual-bridge geometry is specifically engineered to minimize errors from sensor displacement.
- The plain busbar, with its uniform field gradient, also shows good tolerance to displacement.
- In contrast, the high-field concentration of the notch and S-notch designs results in significant displacement error, particularly along the z-axis (vertical). To maintain accuracy over life, stable mechanical mounting is required. Although traditionally challenging, many Allegro customers have already achieved this.

A more detailed comparison of the sensor displacement errors per axis of the busbar designs is shown in Figure 6.

Thermal Considerations

Modifying the busbar geometry to concentrate the magnetic field causes a small increase in its electrical resistance. This increase in resistive heating must be factored into the thermal management design of the system.

Performance

Compared to the plain busbar:

- The notch and dual-bridge designs shows an increase in resistance of 14 μΩ.
- The S-notch shows an increase in resistance of 22 μΩ.

To reduce the busbar resistance, a short notch/bridge length is recommended.

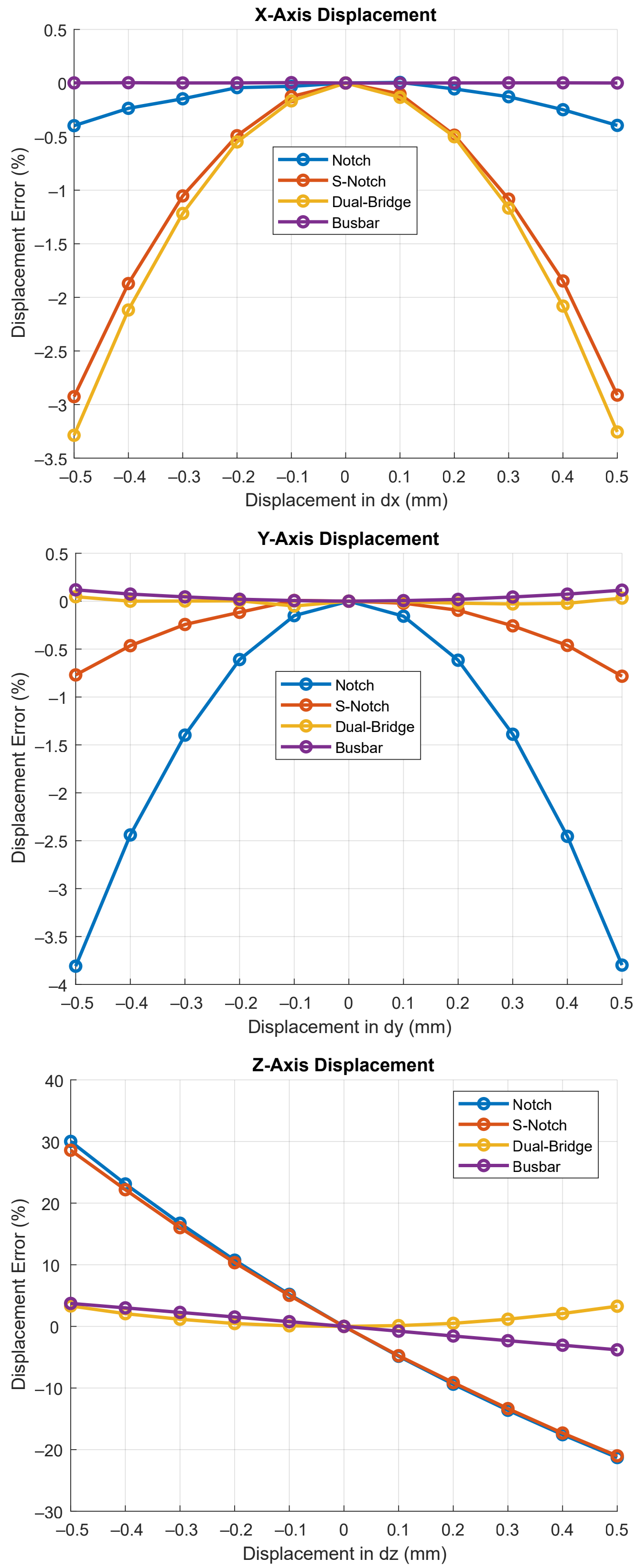

Figure 6: Comparison of Sensor Displacement Error per Axis

INFLUENCE OF DESIGN PARAMETERS ON KEY PERFORMANCE METRICS

This section is intended to help designers understand how to deviate from the reference design (see Figure 3) to achieve specific performance targets. The focus here is on gain error at 1 kHz, coupling factor, and busbar resistance. The trends for the gain errors at higher frequencies are typically similar, but with a larger magnitude. The influence on crosstalk error is not specifically shown but is mainly influenced by the coupling factor: higher coupling factor leads to lower crosstalk error. Changes to the notch or bridge width improve the sensor displacement error but degrade the AC performance significantly.

Notch

See Figure 7.

Thickness: The busbar thickness shows minimal influence on the gain error. A thinner busbar increases coupling factor, and a thicker busbar one reduces resistance.

Notch Length: A longer notch drastically improves gain error and slightly increases coupling factor and resistance.

Notch Width: A notch width of greater than 3 mm increases the magnitude of the gain error and decreases the coupling factor and resistance.

Air Gap: The air gap has a small effect on the gain error. The optimal air gap is approximately 2 mm. It has a very strong effect on the coupling factor. A smaller air gap leads to a higher coupling factor and does not affect resistance.

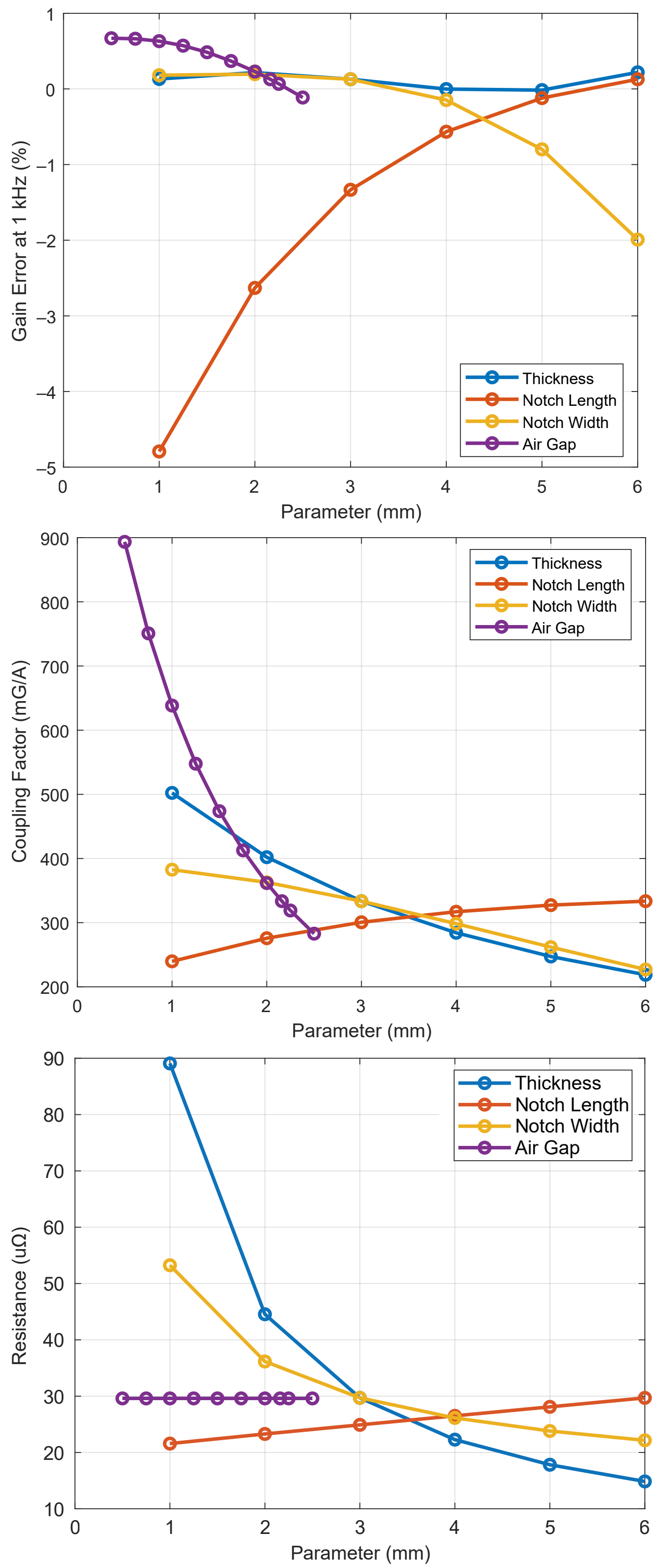

Figure 7: Influence of Notch Parameters on Key Performance Metrics

S-Notch

See Figure 8.

Thickness: The busbar thickness shows minimal influence on the gain error. A thicker busbar reduces the coupling factor and the resistance.

Bridge Length: A longer bridge increases the magnitude of the gain error when its length exceeds the optimum of approximately 2 mm. A longer bridge also slightly increases resistance but has minimal effect on the coupling factor.

Bridge Width: Increasing the bridge width to greater than 3 mm increases the magnitude of the gain error and decreases the coupling factor and the resistance.

Air Gap: The air gap has a small effect on the gain error and a very strong effect on the coupling factor. A smaller air gap leads to a higher coupling factor and does not affect resistance.

Notch Width: Reducing the notch width to less than 3 mm drastically increases the magnitude of the gain error. The coupling factor and resistance both are only slightly affected.

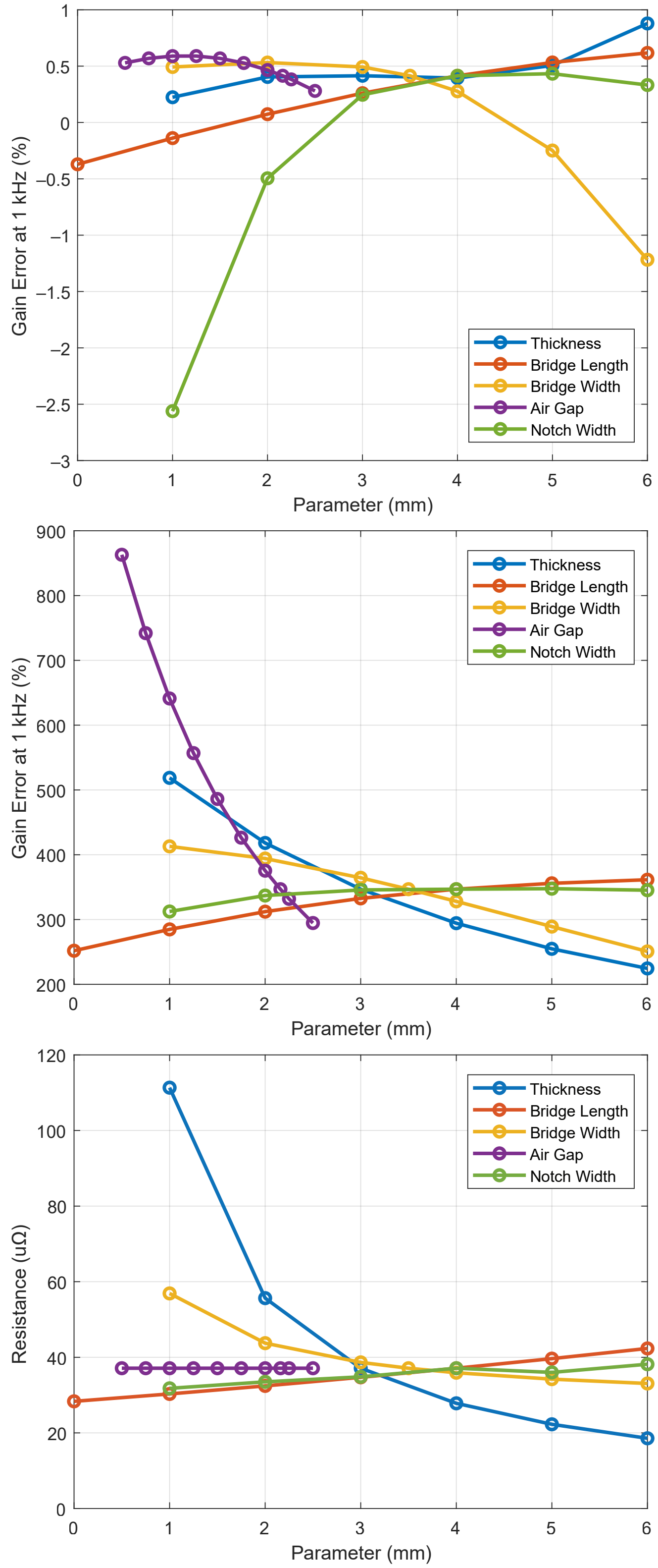

Figure 8: Influence of S-Notch Parameters on Key Performance Metrics

Dual-Bridge

See Figure 9.

Thickness: The thickness has a strong effect on gain error. A thinner busbar leads to a lower magnitude of the gain error, the coupling factor is increased, but also the resistance.

Bridge Length: A longer bridge drastically improves the magnitude of the gain error, barely affects the coupling factor, and slightly increases the resistance.

Bridge Width: Reducing the bridge width strongly decreases the magnitude of the gain the error, increases the coupling factor, and increases the resistance.

Bridge Distance: The bridge distance has a small effect on gain error. However, reducing the bridge distance strongly increases the coupling factor. Bridge distance does not affect the resistance.

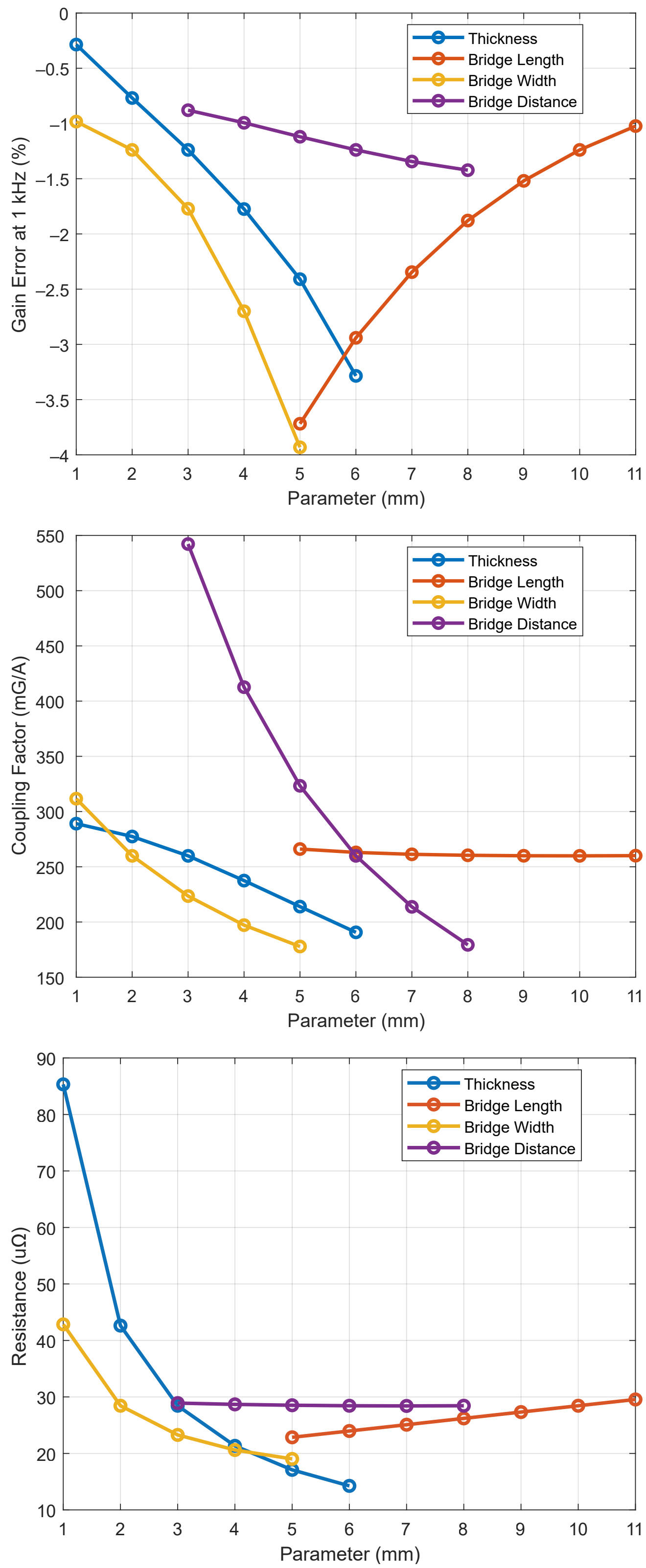

Figure 9: Influence of Dual-Bridge Parameters on Key Performance Metrics

APPLICATION GUIDANCE AND CURRENT RANGE

To aid in sensor and busbar selection, the nominal sensitivity of the Allegro coreless sensor is mapped to the measurable current range in Table 2, for each of the four busbar designs. The coupling factor of each busbar directly influences the minimum, nominal, and maximum current that can be resolved by a sensor with a given sensitivity trim range.

CONCLUSION

Selecting the appropriate busbar geometry is a critical step in the design of a high-performance coreless current sensing system. Each design presents a unique set of tradeoffs:

- Plain Busbar: Offers the lowest resistance and good tolerance to sensor displacement but suffers from a very low coupling factor, poor AC performance, and high susceptibility to crosstalk. It is best suited for high-current DC applications where component density is low.
- Notch or S-Notch Busbar: These designs provide the highest coupling factor and the best AC performance, making them ideal for applications that require high accuracy and wide bandwidth. If crosstalk from adjacent conductors is a concern, the S-notch design is the superior choice. However, both designs are sensitive to sensor placement, particularly in the vertical (z-axis) direction, and have higher resistance.
- Dual-Bridge Design: A dual bridge design represents a strong compromise: It offers moderate coupling factor and AC performance with exceptional robustness to sensor placement errors. This makes it an excellent choice for applications where manufacturing tolerances and mechanical stability are primary concerns.

By understanding these tradeoffs, engineers can confidently choose the busbar design that best aligns with specific application requirements through a balance of accuracy, bandwidth, density, and manufacturability. From this data, it is clear that busbars with higher coupling factors, such as the notch and S-notch, enable lower-current measurements. Conversely, the plain busbar is suited for very high-current applications, where lower resolution is acceptable.

Table 2: Measurable Current Range vs. Sensor Sensitivity for Different Busbar Designs

Nominal Sensitivity (mV/G)	Trim Range (mV/G) [1]	Busbar Design	Coupling Factor (G/A)	Min Current (A)	Nominal Current (A)	Max Current (A)
5	3 – 7	Notch	0.33	861	1205	2008
		S-Notch	0.35	816	1143	1905
		Dual-Bridge	0.26	1099	1538	2564
		Plain	0.05	5291	7407	12346
10	6 – 14	Notch	0.33	430	602	1004
		S-Notch	0.35	408	571	952
		Dual-Bridge	0.26	549	769	1282
		Plain	0.05	2646	3704	6173
20	12 – 28	Notch	0.33	215	301	502
		S-Notch	0.35	204	286	476
		Dual-Bridge	0.26	275	385	641
		Plain	0.05	1323	1852	3086
50	40 – 60	Notch	0.33	100	120	151
		S-Notch	0.35	95	114	143
		Dual-Bridge	0.26	128	154	192
		Plain	0.05	617	741	926

[1] Nominal sensitivity can be changed by ±20% without affecting the sensitivity and offset drift over temperature. If different sensitivities are needed, contact Allegro MicroSystems

Revision History

Number	Date	Description	Responsibility
–	February 26, 2026	Initial release	C. Kasparek
1	August 11, 2026	Initial release to the Allegro website with updated busbar resistance parameter (page 3), updated Performance in Thermal Considerations section (page 6), and updated plots in Influence of Design Parameters on Key Performance Metrics section (pages 7–9)	C. Kasparek