



# QUADRATURE ERROR CALCULATION IN 2D MULTIPLEXED QUADRATURE SENSORS

By Allegro MicroSystems

## INTRODUCTION

In the realm of advanced sensor design, particularly for two-dimensional (2D) and three-dimensional (3D) applications, multiplexed signal paths are frequently employed. This approach offers significant advantages, primarily because it saves space and simplifies the overall design of the sensor. However, the use of multiplexed signal paths means that the sensor processes one axis (X, Y, or Z) at a time. This results in a sequential update of the output for each channel after a specific multiplexing duration. For instance, in the Allegro APS12626 2D Hall-effect speed and direction sensor integrated circuit (IC), this multiplexing time is 20  $\mu$ s.

While multiplexing offers design benefits, it introduces complexities. Specifically, quadrature sensors that use multiplexed channels are susceptible to two primary sources of error that degrade performance:

- Multiplexing-related error: This error arises directly from the sequential process of channels.
- Mismatch error of the operate and release point channels: This error stems from inherent variations between the sensing elements.

Individually, or in combination, these two errors contribute to an undesired deviation from the ideal quadrature relationship between the two channels, a phenomenon commonly referred to as phase-shift error. This application note delves into each of these error sources and their impact.

## MULTIPLEXING ERROR

The multiplexing error, as its name suggests, attributes directly to the sequential nature of channel updates. It occurs because each channel output updates only after the full multiplexing time has elapsed. Consequently, if a magnetic field threshold, such as the operate point ( $B_{OP}$ ) or the release point ( $B_{RP}$ ), is crossed during the sample time of a given channel, the output of the sensor reflects this change only after that sample period is complete.

To illustrate the worst-case scenario for this type of error in a 2D part with two channels, consider a situation where one channel (e.g., channel A) crosses its  $B_{OP}$  or  $B_{RP}$  precisely at the beginning of the sample time of the other channel (e.g., channel B). In this specific instance, the output change of channel A does not immediately register. Instead, it reflects only after the sample time of channel B finishes plus the subsequent sample time of channel A itself. This effectively means that the output update for channel A delays by twice the sample time.

If channel A crosses  $B_{OP}$  while channel B is undergoing a sample, the output of channel A updates only once its own sample finishes, as shown in Figure 1. This inherent delay directly contributes to an error in the ideal quadrature relationship between the channels. It is crucial to understand that, because this error depends on a fixed duration (the multiplexing time), its impact on the system is directly proportional to the frequency of the magnetic signal. Put simply, the higher the magnetic signal frequency, the more pronounced the effect of this multiplexing error is on the ideal quadrature, as shown in Figure 1.

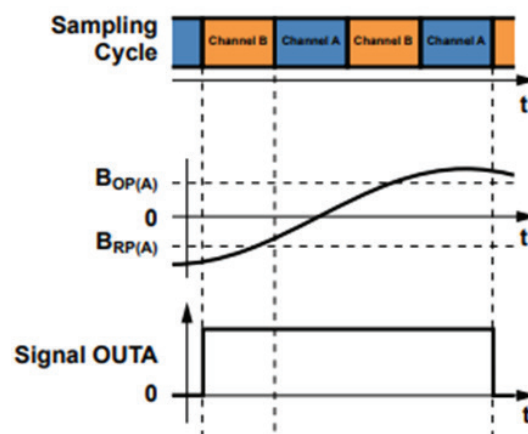


Figure 1: Timing of Operate and Release Points

## MISMATCH ERROR OF OPERATE AND RELEASE POINT CHANNELS

Beyond the effects of multiplexing, another significant source of quadrature error stems from the mismatch that occurs between the operate and release points of different channels within the sensor. This inherent variation is a characteristic of the manufacturing process of the sensor and is typically quantified in datasheets as “operate symmetry” and “release symmetry.” For example, in the APS12626, this mismatch can exhibit a maximum value of 15 G.

This channel mismatch directly translates into quadrature error. However, unlike multiplexing error, its impact is inversely related to the magnetic signal peak value. In other words, the higher the peak value of the magnetic signal, the lower this error becomes. This is because, with higher peak values, the slope of the magnetic signal (rate of change) is steeper. This makes the subtle mismatch in switch points less noticeable relative to the overall signal swing.

The quadrature or shift error, expressed in degrees, is calculated precisely using:

Equation 1:

$$\text{error} = \arcsin(B_{OP1}/\text{Peak}) - \arcsin(B_{OP2}/\text{Peak})$$

where:

- $B_{OP1}$  is the operate point ( $B_{OP}$ ) of channel 1 (or A).
- $B_{OP2}$  is the operate point ( $B_{OP}$ ) of channel 2 (or B).
- Peak is the peak level of the magnetic field.

To illustrate this, consider the worst-case scenario for this mismatch error: when the peak magnetic signal is just barely large enough to cause the channels to switch. For the APS12626, assume the worst-case channel mismatch:

- $B_{OP1}$ : 30 G
- $B_{OP2}$ : 45 G
- Peak: 45 G

When these values are applied to Equation 1, the worst-case error calculates to 48.2 degrees. This angular error also converts into a time error, which depends on the magnetic signal frequency, given that one period of the signal corresponds to 360 degrees.

A visual representation of the worst-case phase error (Y-axis) in degrees versus the magnetic signal peak amplitude (X-axis) in gauss for the APS12626 is shown in Figure 2. The graph clearly demonstrates the relationship described: This error significantly reduces as the magnetic signal level increases.

**IMPORTANT:** It is critical to understand that this mismatch error does not correlate directly to the multiplexing error. Furthermore, this type of error is not unique to multiplexed channel topologies like the APS12626; it is also present in nonmultiplexed topologies, such as the Allegro APS12628.

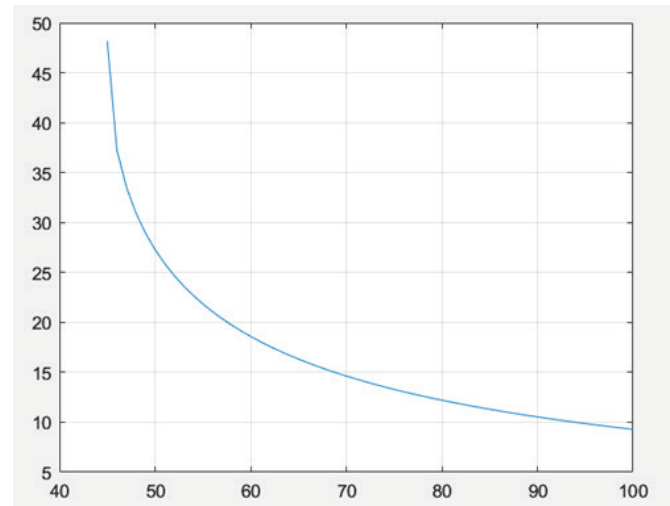


Figure 2: Worst-Case Phase Error vs. Magnetic Signal Peak Amplitude

## EXAMPLE OF ERROR CALCULATION

To offer a practical understanding of how these errors manifest and are calculated, consider a specific set of conditions:

- Magnetic field frequency: 100 Hz
- Magnetic field signal peak: 100 gauss
- Part: APS12626 ( $B_{OP} = 25$  G,  $B_{RP} = -25$  G)

First, quantify the multiplexing worst-case error under these conditions. This error is two times the sample time, which is  $40 \mu\text{s}$  for the APS12626. Given that there are two transitions ( $B_{OP}$  and  $B_{RP}$ ) in one complete cycle (360 degrees) of the magnetic signal, the impact can be determined. For a 100 Hz signal, the period is 10 ms. Therefore, the multiplexing error translates to 0.8% of the period. Expressed in degrees, assuming a 360-degree period, this results in 2.88 degrees of error.

Alternatively, this error can be viewed as a phase-shift error using the timing plot shown in Figure 3, where the phase shift is defined as  $T_{R2}/T_{ON1}$  (where  $T_{ON1} = T_{ON2}$ ). Ideally, if both signals are in perfect quadrature, this ratio is 0.5. Any deviation from 0.5 indicates a phase-shift error. For the given values,  $T_{ON1} = T_{ON2} = 5$  ms. Assume the worst-case multiplexing time error of  $40 \mu\text{s}$ .  $T_{R2}$  can be  $2460 \mu\text{s}$  or  $2540 \mu\text{s}$  (depending on whether the error is negative or positive). This leads to a phase shift of 0.492 or 0.508, respectively, which confirms a 0.8% phase-shift error, as shown in Figure 3.

Because both the multiplexing error and the mismatch error are not fundamentally correlated, their effects can be considered additive in a worst-case scenario. For a direct linear addition, the total error is 5.8%.

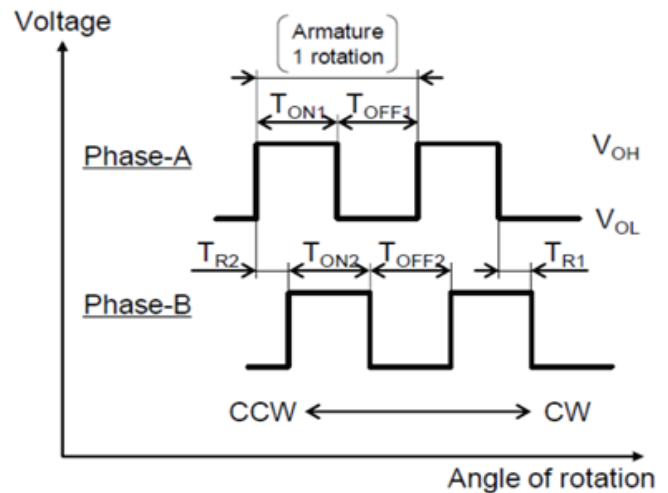


Figure 3: Mismatch Error

## IMPORTANT CONSIDERATIONS

It is crucial to emphasize that the calculated total error presented here represents an extremely unlikely worst-case condition and should be interpreted with caution. In practical applications, the multiplexing error typically has a value closer to the nominal sample time (e.g.,  $20 \mu\text{s}$  for the APS12626). To mitigate this error, operation with low-magnetic-signal frequencies is recommended. Conversely, to minimize the mismatch error of the operate and release point channels, larger magnetic signals (which correspond to smaller air gaps) are recommended. When designers understand these individual error sources and their dependencies, designers can optimize their systems for minimal quadrature error.

*Revision History*

Number	Date	Description	Responsibility
-	September 4, 2025	Initial release	P. Bolsinger

Copyright 2025, Allegro MicroSystems.

The information contained in this document does not constitute any representation, warranty, assurance, guaranty, or inducement by Allegro to the customer with respect to the subject matter of this document. The information being provided does not guarantee that a process based on this information will be reliable, or that Allegro has explored all of the possible failure modes. It is the customer's responsibility to do sufficient qualification testing of the final product to ensure that it is reliable and meets all design requirements.

Copies of this document are considered uncontrolled documents.