INNOVATION WITH PURPOSE

SPEED SENSOR PROTOCOLS

By Syed Bilal Ali
Allegro MicroSystems

INTRODUCTION

Allegro speed sensors offer many different output protocols, each one tailored for specific application requirements and for the information that needs to be transmitted.

This application note provides a detailed description of commonly used output protocols implemented in speed sensors. It also lists the benefits and drawbacks of each and provides information on the safety mechanisms these protocols offer to achieve compliance with the latest automotive safety standards. Table 1 provides a summary of the most commonly used speed sensor output protocols.

Table 1: Summary of the most used output protocols in Allegro speed sensors

Protocol	Applications	Speed	Direction	Maximum Speed	Electrical Interface	ASIL Safe State	Advantages
Speed/ Switching	Applications requiring accurate speed but no direction information	Yes	No	12 kHz	Open Drain	Output Clamping	• Single output • Simple monitoring of open and short conditions by ECU
					Current	Ultra-Low Current State	
Variable Pulse Width	Applications requiring both accurate speed and direction information. Typically employed in Transmission, wheel speed and crank applications.	Yes	Yes	12 kHz	Open Drain	Output Clamping	• Single output • Simple monitoring of open and short conditions by ECU • Can provide information on direction, vibration etc.
					Current	Ultra-Low Current State	
Dual Output Speed and Direction (AB)	Applications requiring high resolution to determine position along with speed and direction. Typically employed in E-motor applications.	Yes	Yes/ Determined by the ECU	40 kHz	Open Drain	Output Clamping	• Allows for high-speed sensing • Provides a level of independence between sensor channels
Dual Output XOR and Direction	Applications which require direction information as a direct output from the sensor along with high resolution output for speed and position.	Yes	Yes	40 kHz	Open Drain	Output Clamping	• Allows for high-speed sensing • Reduces calculation load on ECU by providing direction
AK Protocol	Applications which require additional information other than only speed and direction. This information can be encoded in the bits of the AK message.	Yes	Yes	5 kHz	Current	Designated Current State	• More information transmitted per pulse (e.g. 8 bits)

SPEED/SWITCHING PROTOCOL

Speed/switching protocol is the simplest protocol used to convey speed or position information of a rotating target. The output switches in response to a changing magnetic field produced by the rotating target, thereby reflecting its geometry. The changing magnetic field can be the absolute magnetic field detected by a single Hall element or a differential magnetic field between two Hall elements. A valid output can only exist in two states, OFF (high) or ON (low).

When the magnetic field crosses a certain threshold programmed in the device, the output switches from OFF to ON or vice versa. To avoid switching on noise and to achieve a better jitter/accuracy performance, this switching operation is achieved through two separate comparators which use the same reference point. One comparator has a positive hysteresis B_{HYS1} and the other has a negative hysteresis B_{HYS2}. Therefore, one comparator switches at the threshold crossing on an increasing magnetic signal (B_{OP}) while the other switches on the threshold crossing of the decreasing magnetic signal (B_{RP}). Figure 1 shows an example of this method. Figure 2 shows an oscilloscope capture of the output from a speed only device.

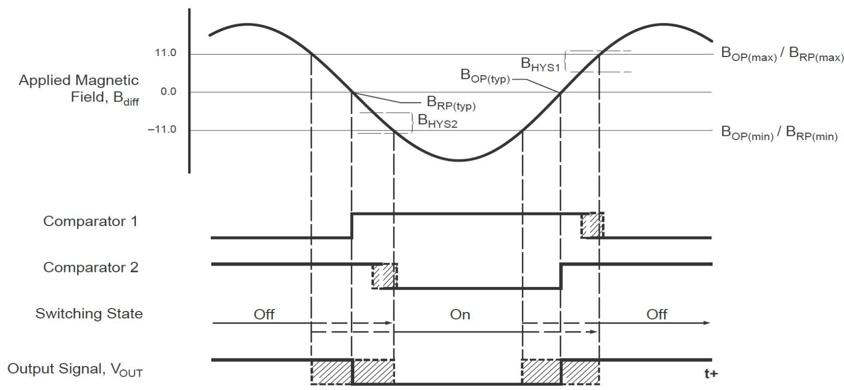

Figure 1: Example of switching scheme for a speed-only sensor

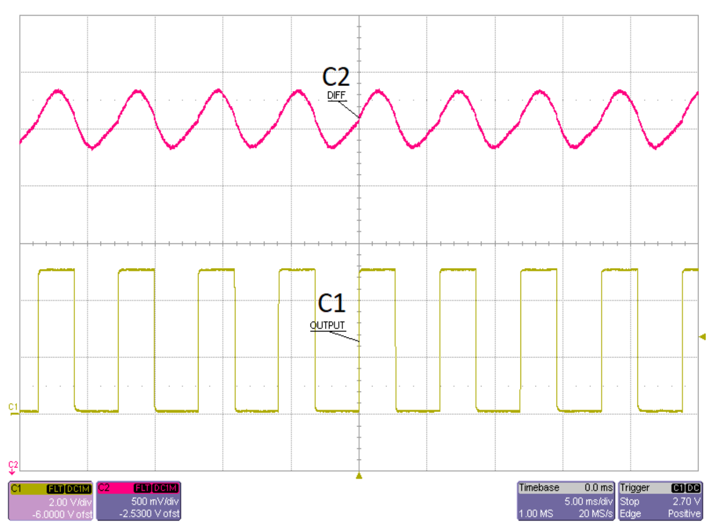

Figure 2: Scope capture of the differential magnetic signal (C2) and the respective speed only output (C1)

Two versions of this protocol exist, one based on an open-drain output, requiring a pull-up resistor, and the other based on a modulation of the component's drawn current. Typical interface application circuits for the two options are shown in Figure 3 and Figure 4. For further information on speed sensor interfaces, refer to AN296233 "Two and Three wire Sensor Interfaces", available on the Allegro website.

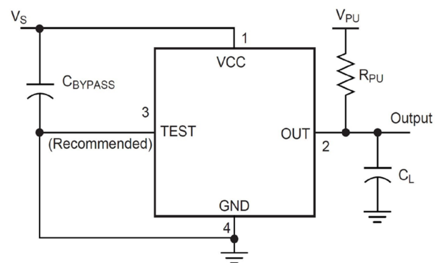

Figure 3: Typical application circuit for an open drain speed-only sensor. Bypass and load capacitors added to meet EMC requirements

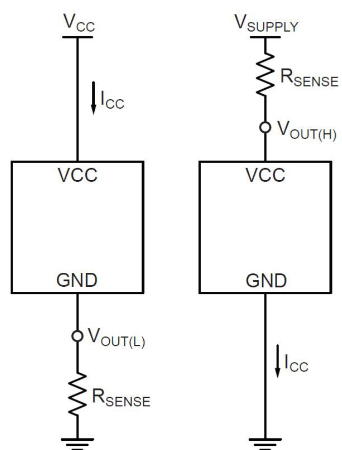

Figure 4: Typical application circuit for a current-interface sensor

Pros and Cons

Allegro devices with speed-only protocol generally consist of two sensing elements. The sensing elements with speed-only protocol can have a larger spacing. Assuming that the sensing element spacing and target pitch are well matched, speed-only sensors may achieve a larger maximum air gap when compared with speed and direction sensors, which generally have three sensing elements that allow the spacing between elements to be smaller and hence having a reduced maximum operating air gap.

Sensors with speed-only protocol can have a minimum of two cables if they have a current interface and can therefore be used for sensing at a remote location to the ECU, e.g., wheel speed and transmission. Monitoring for open and short conditions can easily be performed by the ECU by monitoring the current drawn. Furthermore, a simple comparator-based input circuit can be used in the ECU.

One disadvantage of speed-only protocol is that additional information including information on direction of rotation, calibration or vibration is not available.

PULSE WIDTH OUTPUT PROTOCOL

Pulse width output protocol is implemented in sensors which need to communicate both speed and direction information of the target. When a target spins in front of the sensor, the sensor generates output pulses based on the topology of the target, typically a fixed number of pulses per tooth-valley period. The speed information is provided by the output pulse rate which can be calculated from the time between consecutive rising edges (period) of the output signal. The direction information is encoded in the duration of the output pulses (pulse width). Depending on the sensor and the programming, the output pulses can have different pulse widths. For example:

1. $t_{w(FWD)}$: Duration of output pulse when the target is spinning in forward (FWD) direction, typically around 45 µs.
2. $t_{w(REV)}$: Duration of output pulse when the target is spinning in reverse (REV) direction, typically around 90 µs or 180 µs depending on the sensor programming.
3. $t_{w(ND)}$: Duration of a ND (Non-Directional) pulse. These pulses indicate that the direction information is not available to the device which could be due to device undergoing calibration or detecting vibration, typically around 180 µs or 360 µs depending on the sensor programming.

The direction is defined by the device variant F(FWD) or R(REV). For variant F, target rotation from VCC to GND is referred to as forward, whereas for variant R, target rotation from VCC to GND is referred to as reverse. A forward rotation is indicated by output pulse width $t_{w(FWD)}$, whereas a reverse rotation is indicated by an output with pulse width $t_{w(REV)}$. An 'ND' pulse is generated when direction is ambiguous, for example during calibration or vibration, and is indicated by output pulse width $t_{w(ND)}$. Figure 5 shows an example of the output of such a device with active vibration detection during vibration.

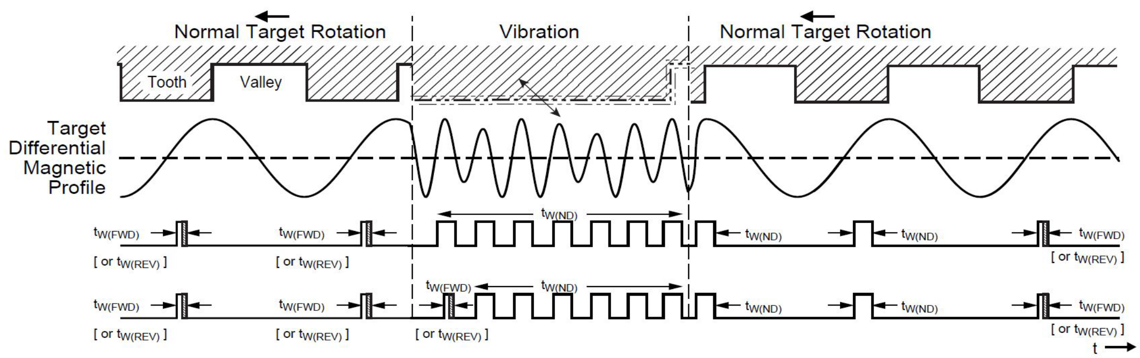

Figure 5: Example output of a device using variable pulse width output during a vibration condition

The variable pulse width output protocol is available in different configuration options. These options are described in detail in the datasheet of the devices. Figure 6 shows an oscilloscope capture of the output from a pulse width device.

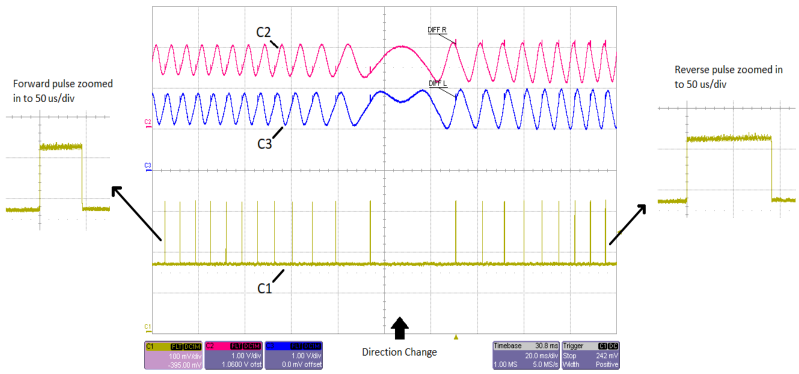

Figure 6: Scope capture of the right and left differential signals (C2, C3) and the respective pulse width output signal (C1) during a direction change from forward rotation to reverse rotation

Pros and Cons

The pulse width protocol can provide more information in addition to only the speed information of a spinning target. This information is encoded in the width of the output pulses as described in the previous section and can be used to determine the direction of rotation or indicate calibration or vibration.

This protocol can be implemented with a minimum of two cables if the sensor has a current interface and therefore it can be used with longer cables for transmission and wheel-speed applications.

DUAL OUTPUT SPEED AND DIRECTION PROTOCOLS

Sensors using a dual output speed and direction protocol have two independent digital outputs which represent the target's mechanical profile. The two outputs together indicate both speed and direction of the rotating target. Three different types of output signals are typically used: SPEED, XOR SPEED, and DIRECTION.

Allegro devices that offer the dual output speed and direction protocols can be configured to output one of the two combinations: the AB speed protocol or the XOR Speed and Direction protocol.

AB Speed Protocol

In the AB speed protocol, both outputs are programmed to provide the SPEED signal from two differential channels. The output switches in response to a changing magnetic field produced by a rotating target, thereby reflecting the geometry of the target. A valid output can only exist in two states, OFF (high) or ON (low).

When the magnetic field crosses a certain threshold programmed in the device, the output switches from OFF to ON or vice versa. Due to the geometric relationship between Hall elements and target features, both channels are phase shifted by ideally 90° to each other [1]. If Ch A leads Ch B, the output indicates rotation in one direction, whereas if Ch B leads Ch A, the output indicates rotation in the other direction. Figure 7 shows channels A and B during a direction change and the resulting incremental counting. Figure 8 shows the oscilloscope capture of the AB speed protocol. This output is like that of a quadrature encoder which can be decoded to get the position and direction of the target.

[1] For further information on the impact of target wheel geometries, refer to the Application Information "Magnetic Encoder Design for Electrical Motor Driving using ATS605LSG", available on the Allegro website at www.allegromicro.com

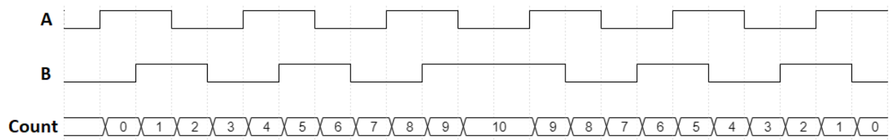

Figure 7: Incremental counting using the AB speed protocol

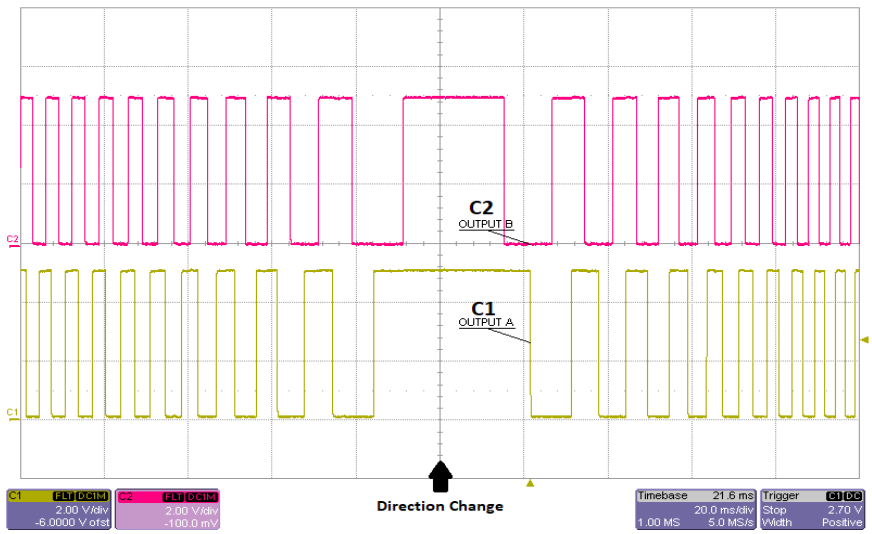

Figure 8: Scope capture of the A and B output signals (C1, C2) from the AB speed protocol during a direction change

If the states of the A and B channel are analyzed, the encoder field (A, B) is Gray encoded since only one of the bits changes for any given state transition. The state transitions can be decoded to get the direction, as shown in Table 2 and Figure 9.

Table 2: Encoding state transition

State	Clockwise Transition	Counterclockwise Transition
0,0	0,1 to 0,0	1,0 to 0,0
1,0	0,0 to 1,0	1,1 to 0,0
1,1	1,0 to 1,1	0,1 to 1,1
0,1	1,1 to 0,1	0,0 to 0,1

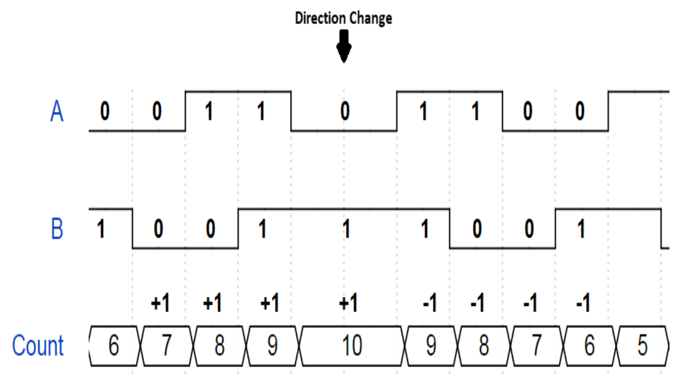

Figure 9: AB protocol encoding state transitions

In addition, if the edges of Ch A and Ch B are examined, there are 4 edges for each period of the target, and it is possible to get 4N resolution from a target with N teeth.

XOR Speed and Direction

XOR speed and direction protocol also consists of two outputs. The first output, XOR Speed provides an XOR'd output of the two speed channels of the AB speed protocol (i.e., XOR Speed = A XOR B) which results in double the speed data rate without making any changes to the controller. The second output is DIRECTION, which is either high or low depending on the direction of rotation of the target. Figure 10 shows a scope capture of the XOR speed and direction protocol. XOR Speed will be updated before DIRECTION and is updated at every transition of both Channel A and Channel B allowing the use of up-down counters without the loss of pulses.

Pros and Cons

The main advantage of using dual output speed and direction protocols is that they can achieve a higher resolution and very high maximum speeds (up to 40 kHz) compared to the pulse width protocols. The AB speed protocol provides an output like that of an incremental encoder and can therefore be used as a cost-effective solution for E-motor position sensing applications. The small space/size requirements and lower cost and complexity allows these sensors to be used as a redundancy or replacement for other high-speed position sensing solutions such as optical encoders and resolvers.

Speed sensors with dual output protocols offer different programming options and can be configured by the user to output an AB signal or XOR Speed and Direction signal.

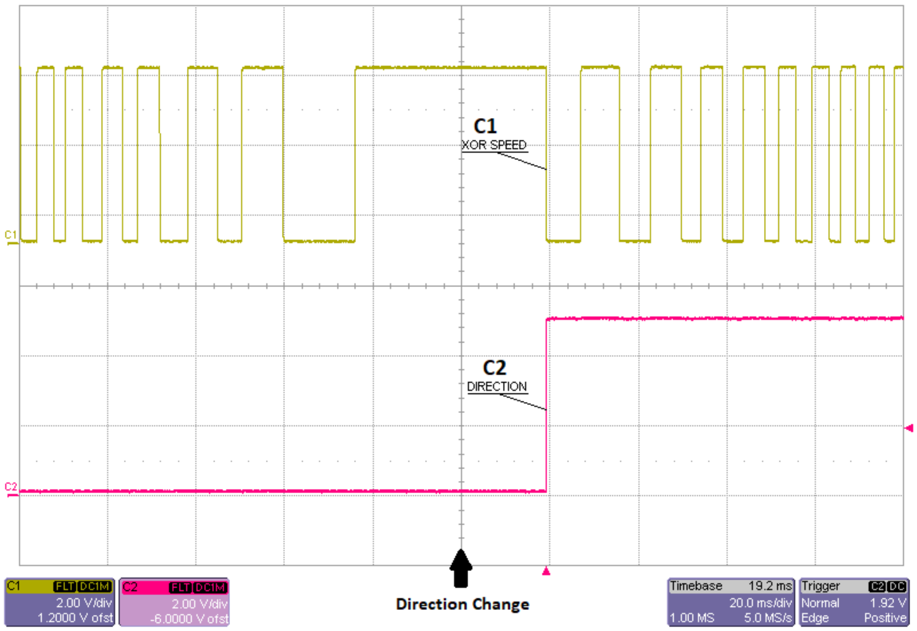

Figure 10: Scope capture of the XOR speed (C1) and DIRECTION (C2) signals during a direction change. Direction is reported on the next edge immediately after direction change

AK PROTOCOL

The AK protocol consists of a series of AK messages, typically a fixed number of messages per tooth-valley period of the target spinning in front of the sensor. Each AK message is called a 'word' which consists of a high-current speed pulse (typically 28 mA) followed by a sequence of mid-current data pulses (typically 14 mA). The data pulses are Manchester encoded which means the bit information is contained in the edge of the signal within a certain time window, tp; for example, a rising edge may represent '1' and falling edge represents a '0'. These bits can be used to encode additional information including direction information, validity of direction, air gap indication, etc.. This encoding is described in detail in the datasheets of Allegro devices supporting AK protocol. Figure 11 shows an example of a single AK message.

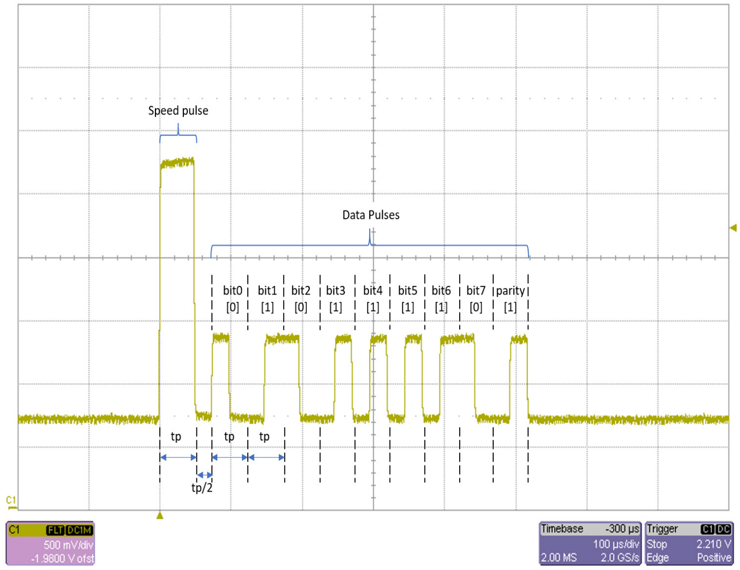

Figure 11: Scope capture of a single AK message showing a speed pulse followed by the data pulses and the decoding of the data pulses to bits

Pros and Cons

The main advantage of the AK protocol is the number of bits that can be transmitted on the output by a single AK message. These bits can be decoded at the ECU to obtain information about the state of the setup or the device. One tradeoff however is that since the AK message is longer in time, the maximum speed at which the target can spin may be limited.

FUNCTIONAL SAFETY SAFE STATES

Sensors developed according to ISO 26262 require a means to communicate that their internal diagnostics have detected a fault condition.

For voltage outputs this is implemented by having a transistor that does not drive the output to either open or closed (high / low) but rather drives the output to a fixed voltage level. Voltages outside defined boundaries around these levels should be interpreted as fault condition by the ECU, as shown in Figure 12. For the specific output voltage level bands, depending on the pull-up resistor used, refer to the individual datasheets and safety manuals.

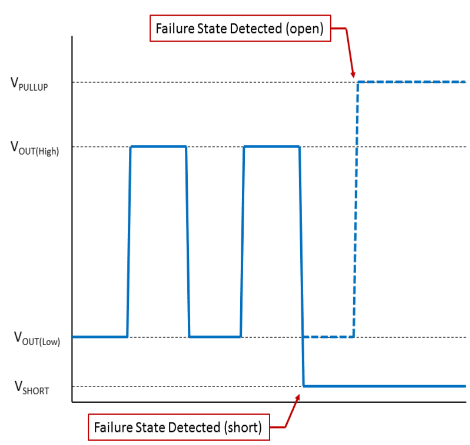

Figure 12: ECU Fault Condition detection

For current interfaces the safe state is implemented by an additional current level below the lowest typical current state. For example, at less than 3.9 mA for a 7/14 mA current interface. The width of the ultra-low-current state can be used to encode further information, for example if a less critical failure (warning) or a critical failure (error) has been detected, as shown in Figure 13. For specific device behaviour, refer to the individual datasheets and safety manuals.

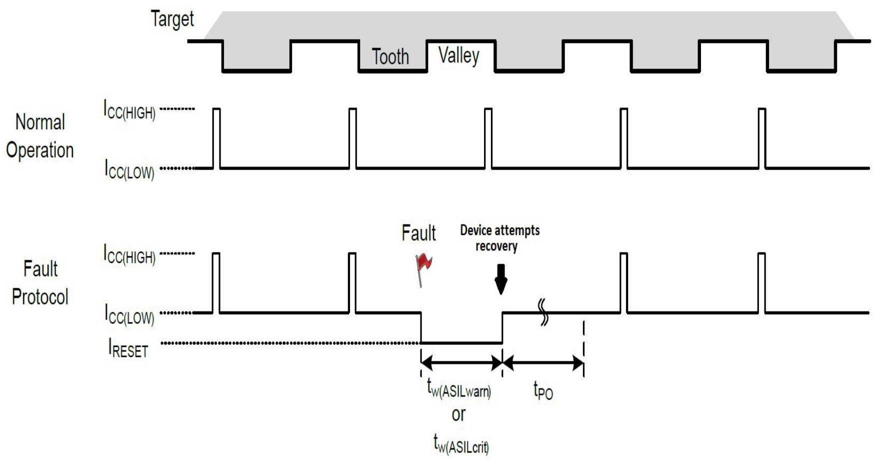

Figure 13: Safe state for 2-wire current interface

CONCLUSION

In this application note, the most commonly used output protocols for Allegro speed sensors are discussed. After analyzing the different protocols and their respective tradeoffs, it can be concluded that each protocol is highly dependent on the application requirements. Depending on the information that needs to be transmitted, one protocol may be better suited than the others. For example, for wheel speed and transmission applications, the pulse width protocol fits best because of its ability to transmit both speed and direction information with a minimum of two wires. Contrarily, for E-motor position sensing applications, the AB speed protocol will be required since it allows incremental decoding with high resolution and at high speeds.

It should also be noted that as the applications and their individual requirements sometimes require a deviation from these standard protocols, it is strongly recommended to consult the device-specific datasheet and if applicable the safety manual for further information.

Revision History

Number	Date	Description	Responsibility
–	August 2, 2021	Initial release	Syed Bilal Ali

955 PERIMETER ROAD • MANCHESTER, NH 03103 • USA
+1-603-626-2300 • FAX: +1-603-641-5336 • ALLEGROMICRO.COM