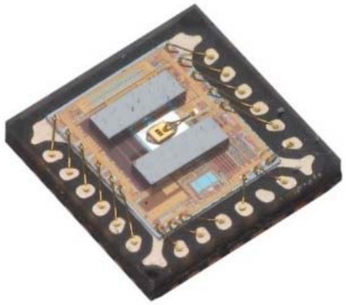
Application Note

AEDR-9940

Three-Channel Reflective Incremental Encoder with Analog or Digital Differential Output (198.4 LPI)



Introduction

This application note offers insight into effectively incorporating the Broadcom® AEDR-9940 into various motor control applications. The encoder provides three channels of digital or analog output configurable to each application, enabling precise monitoring of rotary motion. This document outlines the circuit and schematic design, encoder overview, code wheel design, basic application considerations and practical implementation examples for integrating this encoder into motor control applications.

Description

The AEDR-9940 is a reflective optical encoder which consists of a sensor, the encoder, which outputs a light source onto a rotary disc or code wheel and converts the light patterns reflected into three digital or analog signals (A, B, and Index) that provide information about speed and direction.

Being TTL compatible, the outputs of the encoder can be interfaced with diverse signal processing circuitries, thus providing seamless integration and flexible design-in into existing applications.

The AEDR-9940 encoder is designed to operate best over wide temperature ranges of –40°C to 115°C, which categorizes the application as suitable for commercial, industrial, and automotive.

The encoder houses a custom 660 nm LED light source with photo-detecting circuitry in a single package. The small size of 4.00 mm (L) x 4.00 mm (W) x 0.70 mm (H) allows it to be used in a wide range of miniature applications where size and space is a primary concern.

Features

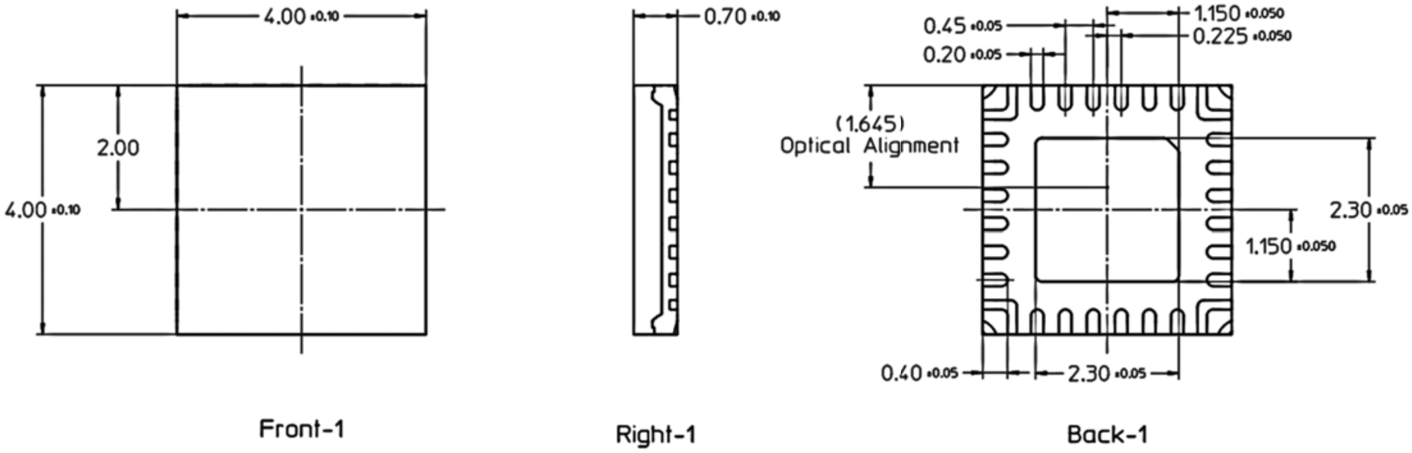
- Analog output option - Three-channel single-ended/ differential output and analog index output
- Digital output option - Three-channel differential or TTL-compatible; two channels quadrature (AB) digital outputs for direction sensing and third channel of index digital output
- Wide selection of built-in interpolation factor
- SPI programmable interpolator from 1X to 1024X
- Surface mount leadless package
- Operating voltage of 3.3V to 5.0V supply
- Built-in LED current regulation
- Temperature range from –40°C to 115°C
- High encoding resolution: 198.4375 LPI (lines/inch) or 7.8125 LPmm (lines/mm)
- Translucent protection compound

Applications

- Closed-loop stepper motor
- Small motors, actuator
- Industrial printer
- Robotics
- Card readers
- Pan-tilt-zoom (PTZ) camera
- Portable medical equipment
- Optometric equipment
- Linear stages

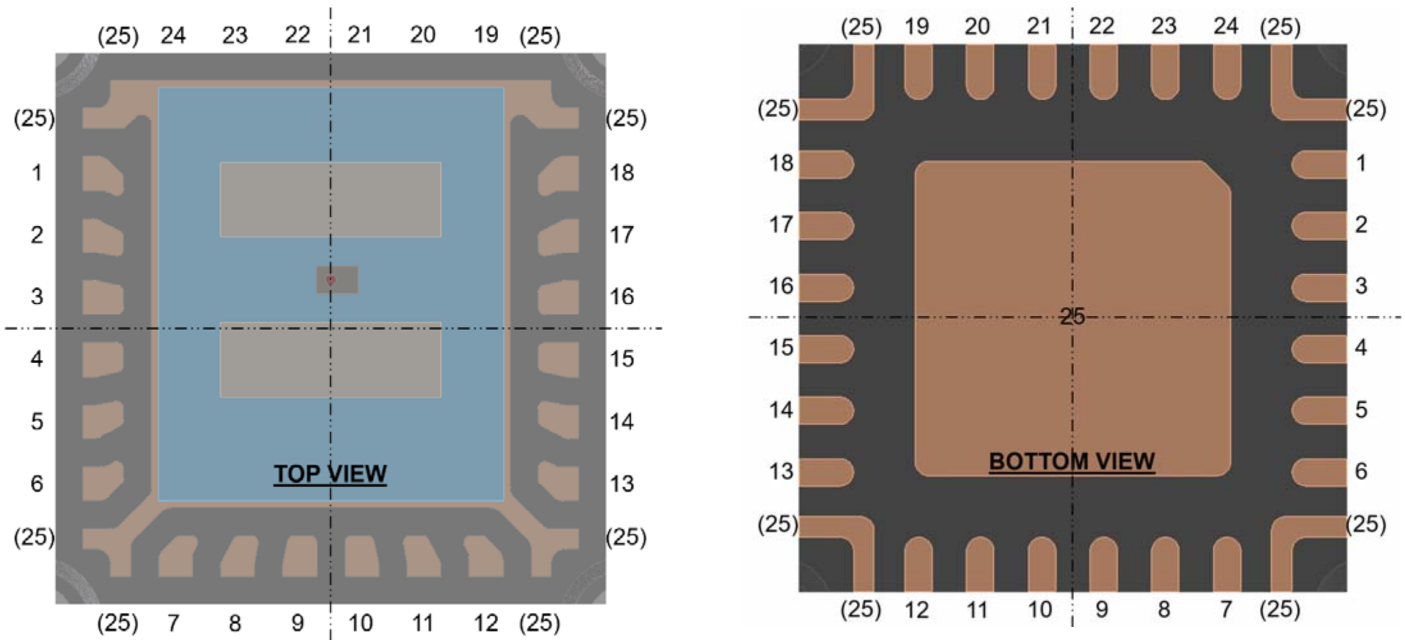
Package Dimensions

Figure 1: Package Outline Dimensions



NOTE: All dimensions in mm with tolerance of ±0.05 mm.

Figure 2: Package Top and Bottom View



NOTE: No connection to all corner pads (25).

Table 1: Pin Functions

No.	Name	I/O	Function	Description
1	CH_A+/Sine+	OUT	Digital/Analog Sine+ output	Digital A output in quadrature mode.
2	CH_A-/Sine-/SPI_DIN	—	Digital/Analog Sine-/ SPI_DIN/ SSI_NSL	Digital A– output in quadrature mode. Inverted output of A. In SPI mode, this is SPI_DIN. In SSI mode, this is NSL.
3	VDD5V	Digital V_{IN}	Digital Supply	+3.0V to +5.5V supply voltage terminal. Digital supply and analog supply must be the same voltage level.
4	VSS	Digital V_{IN}	Digital Ground	Pin must tie to high quality ground, usually a solid PCB plane.
5	CAL	—	Calibration Pin	Normal mode, this pin is tied to ground. To trigger calibration, this pin must be tied to +5V (high) or +2.5V (open).
6	CAL_STAT	OUT	Status Output	This pin provides calibration status information.
7	LEDERR	OUT	Status Output	This pin flags a warning when the LED reaches high, and an error when the encoder is out of spatial tolerance.
8	INDEXSEL	—	Mode Selection Pin	This tri-state pin is used to select ungated/gated output of digital or analog index between 90/180/360°e (electrical degrees). See Configurable Mode Selection - Interpolation Factor.
9	INDEX_I–	OUT	Digital/Analog I–	Digital I– output in quadrature mode.
10	INDEX_I+/ SPI_DOUT	OUT	Digital/Analog I+/ SPI_DOUT/ SSI_DOUT	Digital I+ output in quadrature mode.
11	NC	—	—	This pin has no connection to die.
12	SEL3	IN	Mode Selection Pin	These pins can be configurable to select various available outputs (e.g. analog, digital, and interpolation output). See Configurable Mode Selection - Interpolation Factor.
13	SEL2	IN	Mode Selection Pin	
14	SEL1	IN	Mode Selection Pin	
15	VSSA	Analog V_{IN}	Analog Ground	Pin must tie to high quality ground, usually a solid PCB plane.
16	VDDA	Analog V_{IN}	Analog Supply	+3.0V to +5.5V supply voltage terminal. Digital supply and analog supply must be the same voltage level.
17	CH_B-/Cosine-/SPI_CLK	—	Digital/Analog Cosine–/ SPI_CLK/ SSI_SCL	Digital B– output in quadrature mode. Inverted output of B. In SPI mode, this is SPI_CL. In SSI mode, this is SCL.
18	CH_B+/Cosine+	OUT	Digital/Analog Cosine+	Digital B output in quadrature mode.
19	NC	—	—	This pin has no connection to die.
20	NC	—	—	This pin has no connection to die.
21	NC	—	—	This pin has no connection to die.
22	NC	—	—	This pin has no connection to die.
23	NC	—	—	This pin has no connection to die.

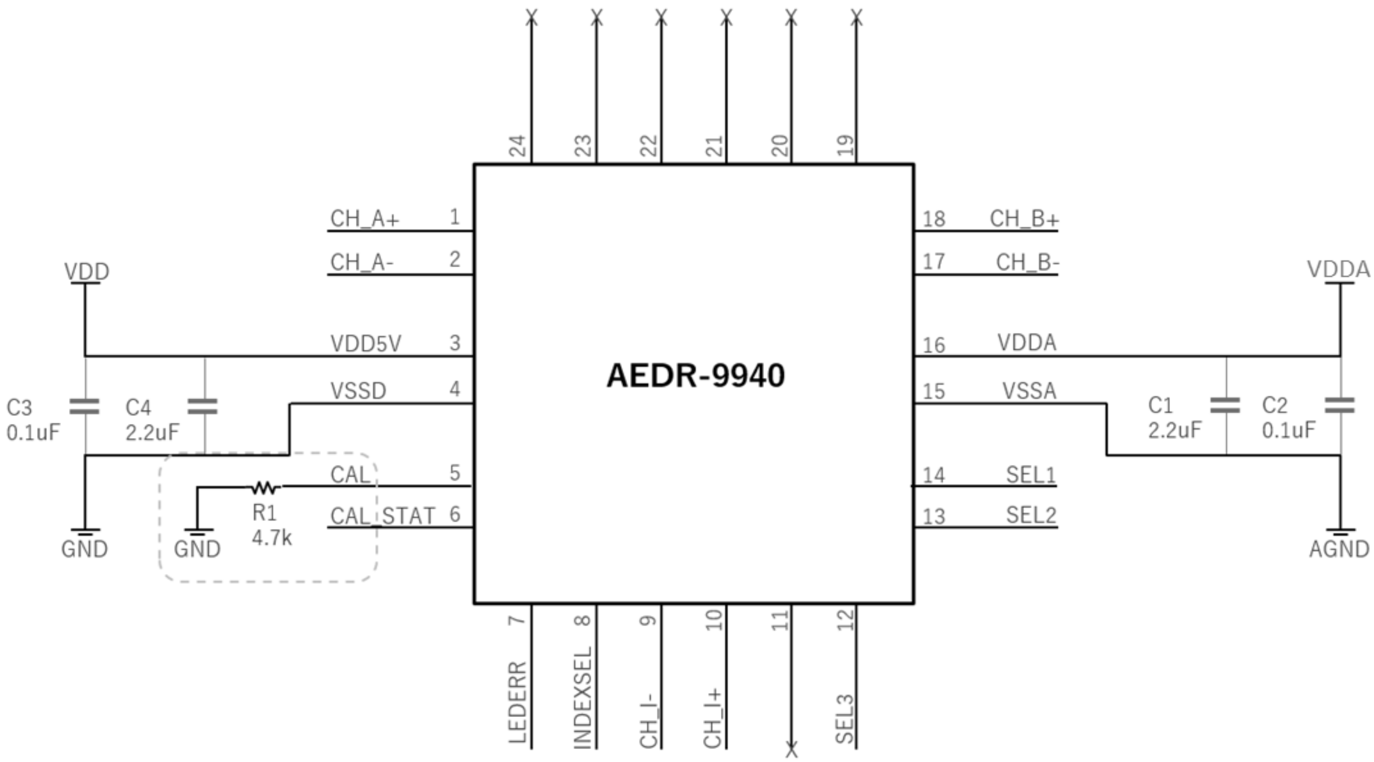
Table 1: Pin Functions (Continued)

No.	Name	I/O	Function	Description
24	NC	—	—	This pin has no connection to die.

Circuit and Schematic Design

This diagram outlines the circuit and schematic design rules for any motor control applications.

Figure 3: Circuit and Schematic Design



NOTE:

1. VDD and VDDA are recommended to be on a same voltage level (+3.0V ~ +5.5V).
2. VSSA and VSS must be connected.
3. Use a pair of 2.2 µF and 0.1 uF capacitors as a bypass filter on VDD and VDDA lines. Place them in parallel as close as possible to the encoder, as shown in Figure 3.
4. Design separate VDD and VDDA traces.
5. Minimize trace or cable length where applicable.
6. For normal operation, place a weak pull-down resistor on the CAL trace; for example, a 4.7-kΩ resistor (as shown in Figure 3).
7. The CAL_STAT and LEDERR pins are encoder status output. Leave the pins unconnected when not in use.

Encoder Placement Orientation, Position, and Direction of Movement

The AEDR-9940 functions with certain spatial placement. For best and optimum performance, tangential, radial positioning as well as a certain gap to the code wheel have been specified.

Table 2: Spatial Tolerance

Parameter	Sym.	Min.	Typ.	Max.	Unit	Note
Tangential Alignment	ET	—	—	±0.35	mm	CPR dependent
Radial Alignment	ER	—	—	±0.35	mm	With AutoCal: 128 CPR = ±0.25 mm 625 CPR = ±0.35 mm 1000 CPR = ±0.35 mm Without AutoCal: >512 CPR = ±0.25 mm
Code Wheel Gap	G	0.85	1.35	2.35	mm	Typical: 625 CPR
		0.85	1.35	1.85	mm	≤128 CPR

NOTE: CPR - count per rotation. See Rotary Code Wheel and Hub Design Concept for more information.

Encoder Placement

AEDR-9940 is designed with both emitter (light source) and detector (photosensor) placed in parallel to code wheel window/bar orientation. The encoder is mounted on top facing down towards the code wheel. With proper alignment, the emitter will be positioned in the center of the incremental track and the index track.

The optical center of the encoder must be aligned tangentially to the code wheel's R_{OP}.

Channel A leads Channel B when the code wheel rotates counterclockwise and vice versa.

Figure 4: Encoder Placement

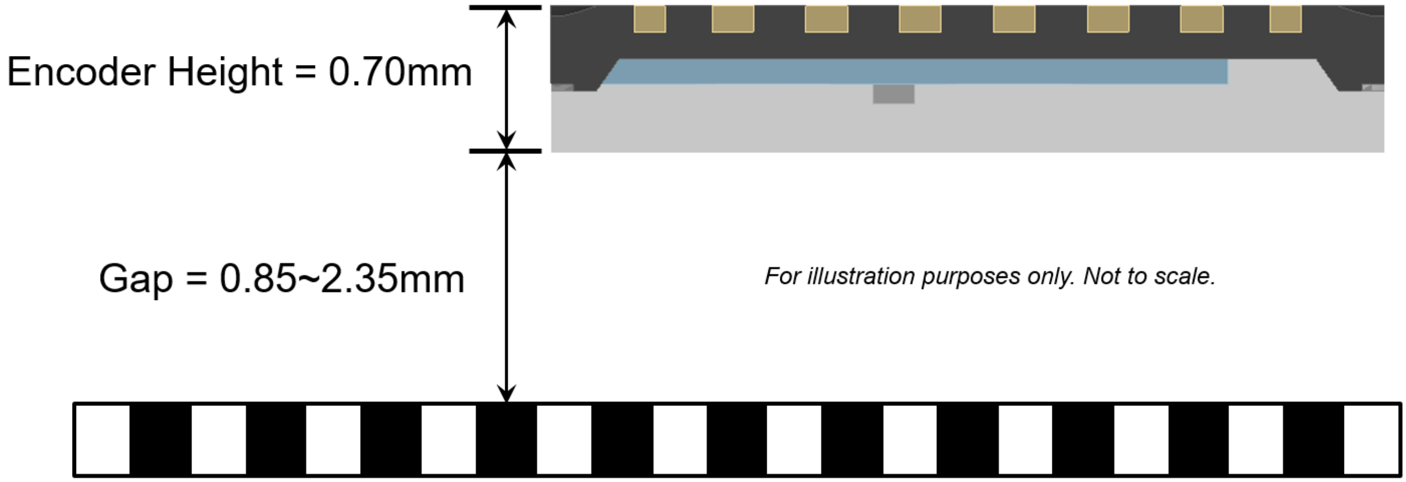
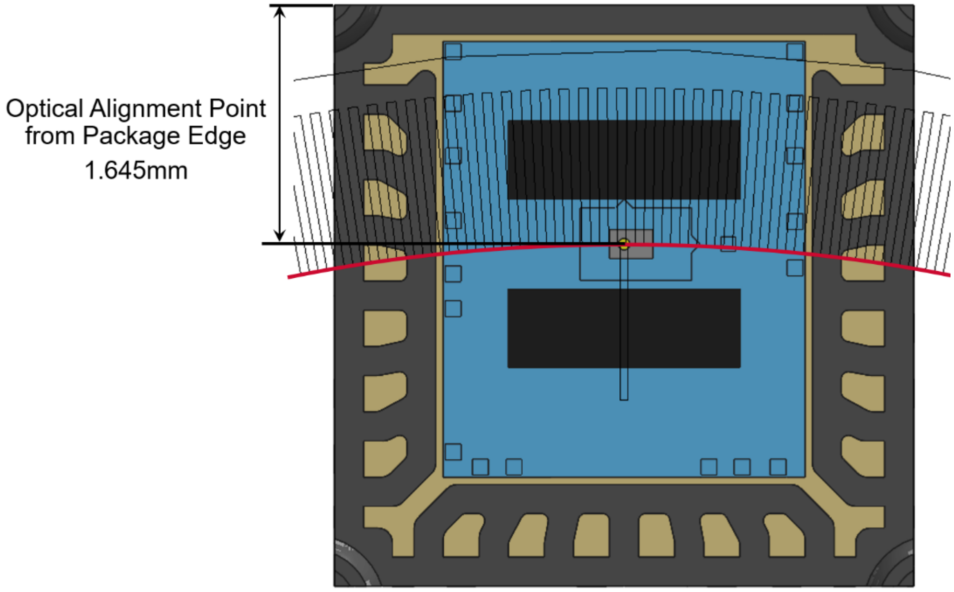


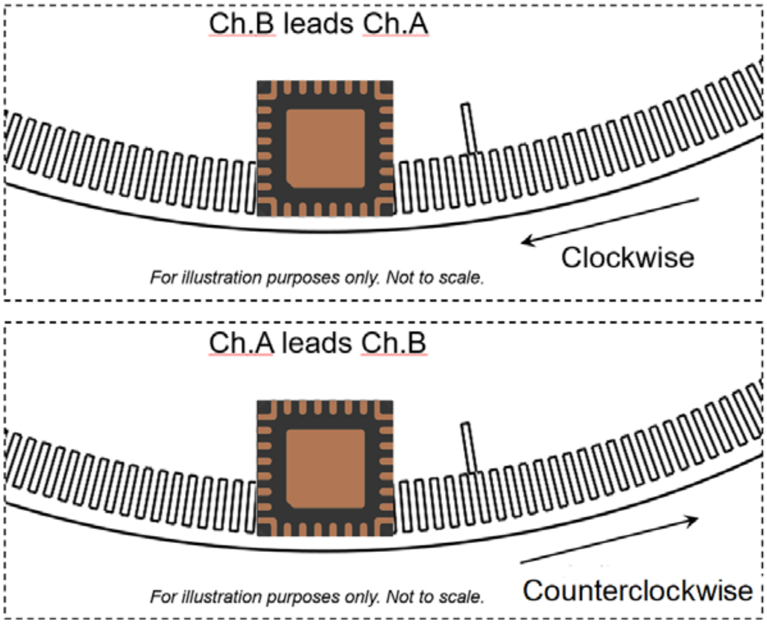
Figure 5 illustrates a top-down view of the encoder's optical center positioned to the code wheel's R_{OP}. The incremental track should cover the top half of the photosensor while the index track covers the bottom half.

Figure 5: Optical Center Positioning



As the code wheel rotates in a clockwise direction, output Channel A will lead Channel B and vice versa as shown in the following figure.

Figure 6: Channel A and Channel B Outputs



Encoder Power Up and Auto-Calibration

Upon the encoder power up, the A, B and Index digital outputs are invalid until the first toggle of either Channel A or Channel B states. This invalid time is specified to be 500 ms upon power up.

Once the AEDR-9940 is properly installed, calibration is required. Auto-calibration can be performed by triggering the CAL pin (pin 5). The CAL pin is a tri-state pin, which has different functions when triggered as HIGH, LOW or OPEN.

Table 3: CAL Pin State

Pin	State	Function	Note
CAL (pin 5)	HIGH	Calibration	
	OPEN	Calibration	
	LOW	Normal Operation	Digital/Analog Outputs

HIGH: Connect CAL pin to either VDD or VDDA (+3.0V ~ 5.5V)

OPEN: Connect CAL pin to half of VDD or VDDA by implementing a voltage divider circuit. See Figure 18, Voltage Divider Example.

Auto-Calibration Step

Perform the auto-calibration process even if the A, B, and I signals appear normal at the first power-on after the encoder assembly. The auto-calibration process helps to optimize the internal encoder ASIC settings, hence enhancing the reliability and performance.

1. Spin the motor at a rotational speed between 1000 to 2000 rpm.
2. Connect the CAL pin to either HIGH or OPEN. Use a high value resistor such as 4.7 kΩ for the connection.
3. Turn on power supply to the encoder.
4. Wait at least 5 seconds.
5. Observe the CAL_STAT (pin 6) output, a pulsing digital signal indicates the auto-calibration has begun and is in progress. Calibration is successful once the CAL_STAT outputs a static HIGH signal.
6. Remove the connection between CAL pin from VDD or VDDA and connect it to GND.
7. Cycle power and the encoder will function as normal.

Table 4: LED Status (CAL_STAT, LEDERR)

Pin	CAL_STAT (PIN 6)	LEDERR (PIN 7)	Status
Pad State	Pulsing (500 ms)	L	Calibrating
	H	L	Calibration done
	L	H	Out of misalignment tolerance
	L	Pulsing (500 ms)	High LED current warning

LED Status (Waveform)

Figure 7: Normal Operation

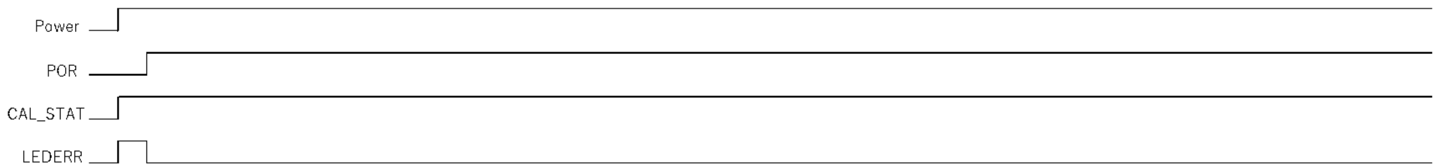


Figure 8: Calibration Mode (Pass)

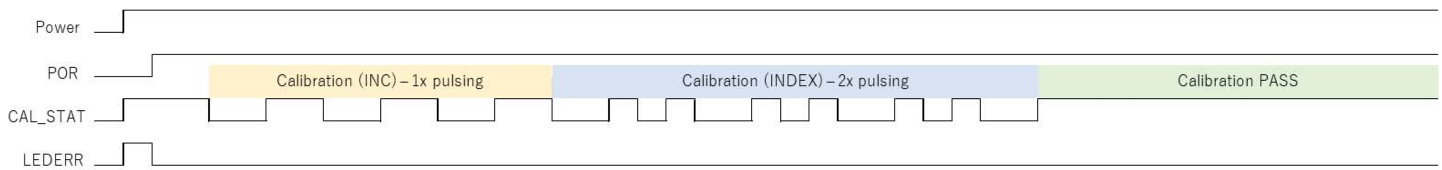


Figure 9: Operation Mode (High LED Current - Warning)

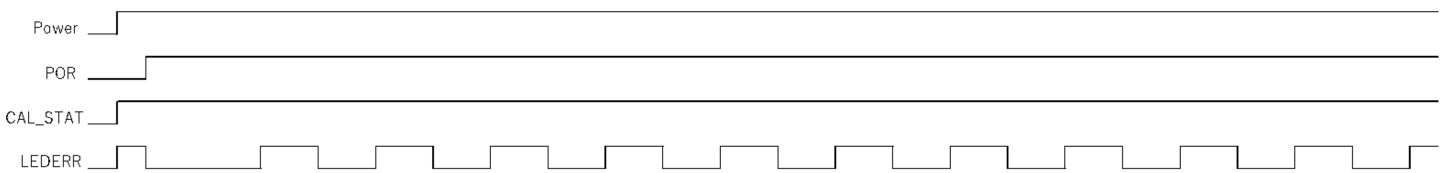
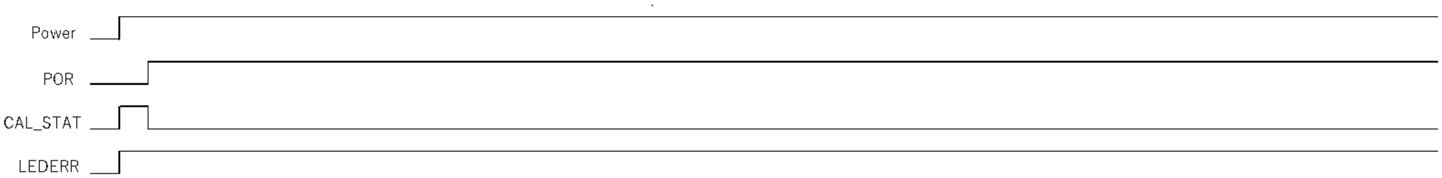


Figure 10: Operation Mode (High LED Current - Error)



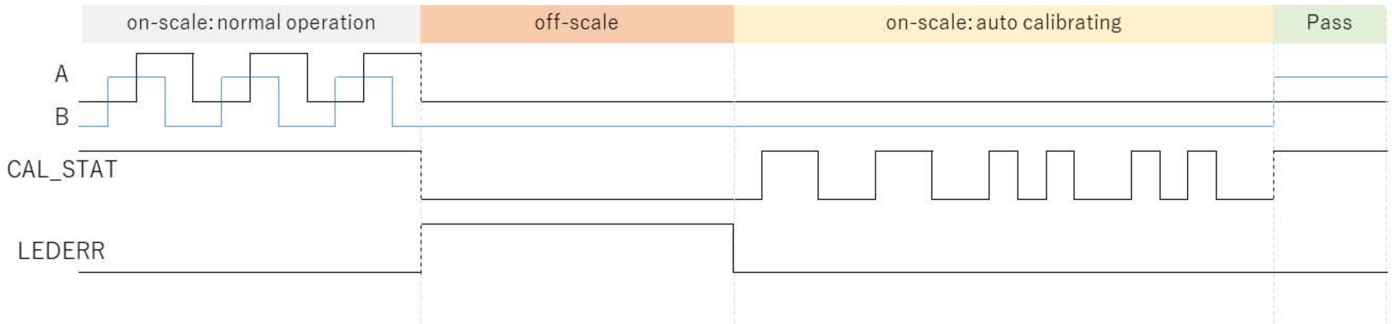
NOTE:

1. POR (Power-On Reset) indicates when the encoder is fully functional after power-up.
2. If CAL_STAT remains pulsing (either 1x or 2x pulsing), perform power cycle and repeat auto-calibration step.
3. LEDERR warning and error status will automatically return low as the LED current returns to normal.

Off-Scale Auto-Calibration Feature

The AEDR-9940 offers a built-in feature which allows auto-calibration to be triggered by moving the encoder from off-scale (invalid spatial range) to on-scale (valid spatial range), without additional wiring or connecting any pins to a certain voltage level (pull high/low/open). This function can also be achieved by temporarily blocking the sensor to the code wheel.

Figure 11: Off-Scale Auto-Calibration



NOTE: Once calibration is completed, cycle power to return to normal operation.

Off-Scale Position Example

NOTE: The following figures are for illustration only.

Figure 12: On-Scale

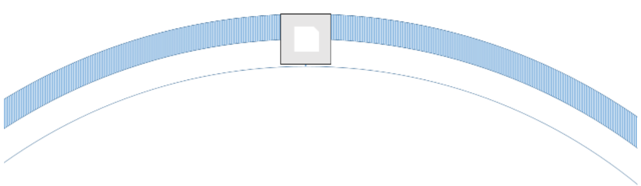


Figure 13: Off-Scale #1

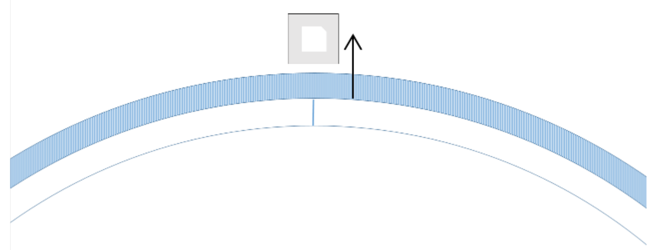


Figure 14: Off-Scale #2

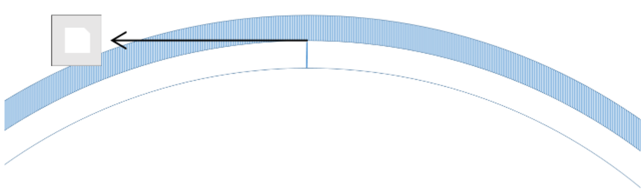
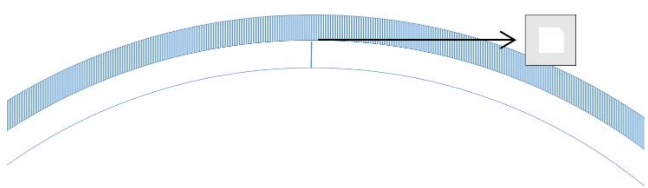


Figure 15: Off-Scale #3



Off-Scale Auto-Calibration Step

1. Power-on in normal operation
2. Move to any of the off-scale position until LEDERR triggers HIGH.
3. Return to on-scale position (any valid spatial range). The auto-calibration will trigger.
4. Once completed, cycle power.

Configuring Interpolation Factor

The AEDR-9940 offers wide selection of built-in interpolation factors which can be configured through; a) SPI programmable interpolator, or b) modes selection by triggering SEL1, SEL2, SEL3, and INDEXSEL pins.

SPI Programmable Interpolation Factor

The AEDR-9940 is configurable using SPI protocol which allows user to select interpolation factor from 1X up to 1024X.

1. To access read and write via SPI, set selection to SPI mode: Program Selection.
2. For signals output after configuration, set selection to SPI mode: Output Enabled.

NOTE: See Configurable Mode Selection - Interpolation Factor (SEL1, SEL2, SEL3, and INDEXSEL).

Table 5: SPI Communication Pin Out

Pin	Name	Function
17	SPI_CLK	SPI Clock
2	SPI_DIN	SPI Data Input
10	SPI_DOUT	SPI Data Output

SPI Read/Write Timing Diagram

The maximum clock frequency is 1 MHz.

Bit	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Read	0	Address [6:0]							Data [7:0]							
Write	1	Address [6:0]							Data [7:0]							

Figure 16: SPI Write

<Write Command = 1><7 bits address><8 bits data>

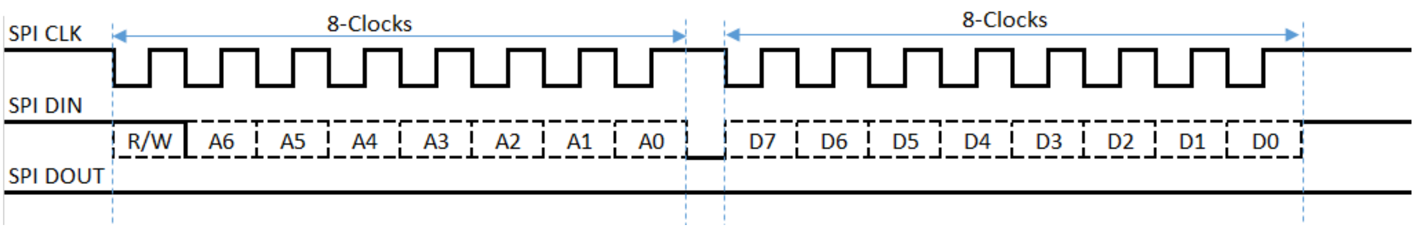
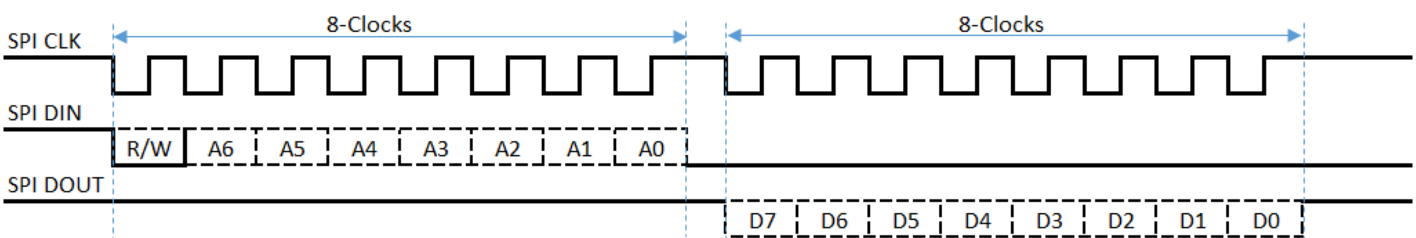


Figure 17: SPI Read

<Read Command = 0><7 bits address><8 bits data>



Unlock Sequence

1. Write to SPI address 0x00 with value of AB (hex) to unlock level 1 registers.
2. Write to SPI address 0x14 with value of 00 (hex) to go to page 0.

Program Memory

1. Write to SPI address 0x01 with value of A1 (hex) to program the memory.

Interpolation Settings and Programming

1. Write to SPI addresses 0x0B and 0x0C with desired value (see Table 6 and Table 7).
2. Once the settings are finalized, write to SPI address 0x01 with value of A1 (hex) to program the memory.

Table 6: Interpolation Settings Descriptions

Byte Address	Page	Bit								Note
[hex]		7	6	5	4	3	2	1	0	
0x0B	0			Iwidth_digital [1:0]		CPR [11:8]				CPR: 0 to 1024
0x0C		CPR [7:0]								

Table 7: Interpolation Settings Programming

Interpolation CPR	0x0B (Hex)	0x0C (Hex)
1	Bit 0 = 0	01
2	.	02
.	.	.
.	.	.
10	.	0A
11	.	0B
.	.	.
.	.	.
255	Bit 0 = 0	FF
256	Bit 0 = 1	00
257	Bit 0 = 1	01
.	.	.
.	.	.
512	Bit 1 = 1	00
.	.	.
.	.	.
1024	Bit 2 = 1	00

Iwidth_digital	Index Width
00	90 degrees
01	180 degrees
10	270 degrees
11	360 degrees

Configurable Mode Selection - Interpolation Factor

By configuring the selection pins, you can select the interpolation factor from 1X to 1000X without accessing through SPI communication.

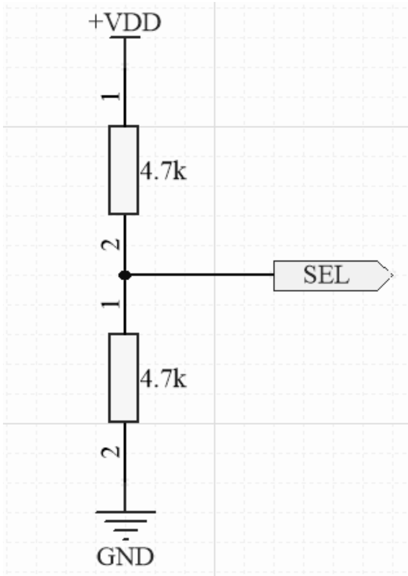
No.	SEL1	SEL2	SEL3	Interpolation Factor	INDEXSEL	Index
1	Low	Low	Low	1X	Low	Interpolation 1X - Index Gated 90 degrees
					High	Interpolation 1X - Index Gated 180 degrees
					Open	Interpolation 1X - Index Raw (Ungated)
2	High	Low	Low	2X	Low	Interpolation 2X - Index Gated 90 degrees
					High	Interpolation 2X - Index Gated 180 degrees
					Open	Interpolation 2X - Index Gated 360 degrees
3	Open[a]	Low	Low	3X	Low	Interpolation 3X - Index Gated 90 degrees
					High	Interpolation 3X - Index Gated 180 degrees
					Open	Interpolation 3X - Index Gated 360 degrees
4	Low	High	Low	4X	Low	Interpolation 4X - Index Gated 90 degrees
					High	Interpolation 4X - Index Gated 180 degrees
					Open	Interpolation 4X - Index Gated 360 degrees
5	High	High	Low	5X	Low	Interpolation 5X - Index Gated 90 degrees
					High	Interpolation 5X - Index Gated 180 degrees
					Open	Interpolation 5X - Index Gated 360 degrees
6	Open[a]	High	Low	6X	Low	Interpolation 6X - Index Gated 90 degrees
					High	Interpolation 6X - Index Gated 180 degrees
					Open	Interpolation 6X - Index Gated 360 degrees
7	Low	Open[a]	Low	8X	Low	Interpolation 8X - Index Gated 90 degrees
					High	Interpolation 8X - Index Gated 180 degrees
					Open	Interpolation 8X - Index Gated 360 degrees
8	High	Open[a]	Low	9X	Low	Interpolation 9X - Index Gated 90 degrees
					High	Interpolation 9X - Index Gated 180 degrees
					Open	Interpolation 9X - Index Gated 360 degrees
9	Open[a]	Open[a]	Low	10X	Low	Interpolation 10X - Index Gated 90 degrees
					High	Interpolation 10X - Index Gated 180 degrees
					Open	Interpolation 10X - Index Gated 360 degrees
10	Low	Low	High	12X	Low	Interpolation 12X - Index Gated 90 degrees
					High	Interpolation 12X - Index Gated 180 degrees
					Open	Interpolation 12X - Index Gated 360 degrees
11	High	Low	High	16X	Low	Interpolation 16X - Index Gated 90 degrees
					High	Interpolation 16X - Index Gated 180 degrees
					Open	Interpolation 16X - Index Gated 360 degrees
12	Open[a]	Low	High	20X	Low	Interpolation 20X - Index Gated 90 degrees
					High	Interpolation 20X - Index Gated 180 degrees
					Open	Interpolation 20X - Index Gated 360 degrees
13	Low	High	High	25X	Low	Interpolation 25X - Index Gated 90 degrees
					High	Interpolation 25X - Index Gated 180 degrees
					Open	Interpolation 25X - Index Gated 360 degrees

No.	SEL1	SEL2	SEL3	Interpolation Factor	INDEXSEL	Index
14	High	High	High	32X	Low	Interpolation 32X - Index Gated 90 degrees
					High	Interpolation 32X - Index Gated 180 degrees
					Open	Interpolation 32X - Index Gated 360 degrees
15	Open[a]	High	High	50X	Low	Interpolation 50X - Index Gated 90 degrees
					High	Interpolation 50X - Index Gated 180 degrees
					Open	Interpolation 50X - Index Gated 360 degrees
16	Low	Open[a]	High	64X	Low	Interpolation 64X - Index Gated 90 degrees
					High	Interpolation 64X - Index Gated 180 degrees
					Open	Interpolation 64X - Index Gated 360 degrees
17	High	Open[a]	High	80X	Low	Interpolation 80X - Index Gated 90 degrees
					High	Interpolation 80X - Index Gated 180 degrees
					Open	Interpolation 80X - Index Gated 360 degrees
18	Open[a]	Open[a]	High	100X	Low	Interpolation 100X - Index Gated 90 degrees
					High	Interpolation 100X - Index Gated 180 degrees
					Open	Interpolation 100X - Index Gated 360 degrees
19	Low	Low	Open[a]	128X	Low	Interpolation 128X - Index Gated 90 degrees
					High	Interpolation 128X - Index Gated 180 degrees
					Open	Interpolation 128X - Index Gated 360 degrees
20	High	Low	Open[a]	160X	Low	Interpolation 160X - Index Gated 90 degrees
					High	Interpolation 160X - Index Gated 180 degrees
					Open	Interpolation 160X - Index Gated 360 degrees
21	Open[a]	Low	Open[a]	256X	Low	Interpolation 256X - Index Gated 90 degrees
					High	Interpolation 256X - Index Gated 180 degrees
					Open	Interpolation 256X - Index Gated 360 degrees
22	Low	High	Open[a]	320X	Low	Interpolation 320X - Index Gated 90 degrees
					High	Interpolation 320X - Index Gated 180 degrees
					Open	Interpolation 320X - Index Gated 360 degrees
23	High	High	Open[a]	640X	Low	Interpolation 640X - Index Gated 90 degrees
					High	Interpolation 640X - Index Gated 180 degrees
					Open	Interpolation 640X - Index Gated 360 degrees
24	Open[a]	High	Open[a]	1000X	Low	Interpolation 1000X - Index Gated 90 degrees
					High	Interpolation 1000X - Index Gated 180 degrees
					Open	Interpolation 1000X - Index Gated 360 degrees
25	Low	Open[a]	Open[a]	Ungated Digital	Low	Analog SIN/COS (500 mVpp), Digital Index (Ungated)
					High	Analog SIN/COS (500 mVpp), Digital Index (Ungated)
					Open	Analog SIN/COS (500 mVpp), Digital Index (Ungated)
26	High	Open[a]	Open[a]	Analog	Low	Analog SIN/COS (500 mVpp), Analog Index (1 Vpp)
				Ungated Digital	High	Analog SIN/COS (1Vpp), Digital Index (Ungated)
				Analog	Open	Analog SIN/COS (1Vpp), Analog Index (1 Vpp)
27	Open[a]	Open[a]	Open[a]	SPI Mode	Low	SPI Mode: Program Selection
					High	SPI Mode: Output Enabled
					Open	SSI 3W Mode[b]

a. Open selection must be connected to the middle of a voltage divider circuit (Figure 18).

b. SSI 3W mode is for monitoring purposes only.

Figure 18: Voltage Divider Example



Use 2 x 4.7-kΩ resistors (V_{DD}-GND).

The digital interpolation factor above is use based on the following equation to cater to various rotational speeds (RPM) and counts per revolution (CPR).

RPM = (Count Frequency x 60) / CPR

CPR (@ 1X interpolation) is based on the following equation that is dependent on radius of operation (R_{OP}).

CPR = LPI x 2π x R_{OP} (inch) or CPR = LP mm x 2π x R_{OP} (mm)

NOTE: LP mm (lines per mm) = LPI / 25.4

Digital Signal Characteristics (Code Wheel R_{OP} @ 12.16 mm, 625 CPR)

The AEDR-9940 outputs three-channel digital signals following certain characteristics and specification limit. These typical values and specifications are based on factory setup conditions at maximum output frequency (4.0 MHz @ interpolation > 16X). The optimal performance of the encoder depends on the motor and system setup condition of the individual customer.

Table 8: Typical Dynamic Performance

Parameter	Symbol	Dynamic Performance								Unit
		Typical								
Interpolation Factor		1X	2X	4X	8X	16X	32X	64X	128X	
Cycle Error	ΔC	±3	±4	±5	±9	±11	±19	±19	±19	°e
Pulse Width (Duty) Error	ΔP	±3	±3	±5	±8	±10	±16	±16	±16	°e
Phase Error	Δϕ	±1	±2	±3	±5	±6	±9	±9	±9	°e
State Error	ΔS	±2	±3	±5	±7	±7	±18	±18	±18	°e
Index Pulse Width (Gated 90°)	P_0	90								°e
Index Pulse Width (Gated 180°)	P_0	180								°e
Index Pulse Width (Gated 180°)	P_0	N/A	360							°e
Index Pulse Width (Raw Ungated)	P_0	330	N/A							°e

Table 9: Digital Parameter Definitions

Parameter	Symbol	Definition
Count	N	The number of bar and window pairs or counts per revolution (CPR) of the code wheel.
Cycle	C	360 electrical degrees (°e), one bar and window pair. One Shaft Rotation: 360 mechanical degrees, N cycles.
Cycle Error	ΔC	An indication of cycle uniformity. The difference between an observed shaft angle which gives rise to one electrical cycle, and the nominal angular increment of 1/N of a revolution.
Pulse Width (Duty) Error	ΔP	The deviation, in electrical degrees, of the pulse width from its ideal value of 180°e.
State	S	The number of electrical degrees between a transition in the output of channel A and the neighboring transition in the output of channel B. There are four states per cycle, each nominally 90°e.
Phase	ϕ	The number of electrical degrees between the center of the high state of channel A and the center of the high state of channel B. This value is nominally 90°e for quadrature output.
Phase	ϕ	The number of electrical degrees between the center of the high state of channel A and the center of the high state of channel B. This value is nominally 90°e for quadrature output.
Optical Radius	R_{OP}	The distance from the code wheel's center of rotation to the optical center (OC) of the encoder module.
Index Pulse Width	P_0	The number of electrical degrees that an index is high during one full shaft rotation.

The following figure illustrates an example of the output waveform digital signals A, B and gated Index of 90, 180, and ungated index 360°e when code wheel rotation is in counterclockwise direction. Also shown is an additional waveform output example for the analog output option with single-ended and differential modes.

Figure 19: Output Waveform Signals

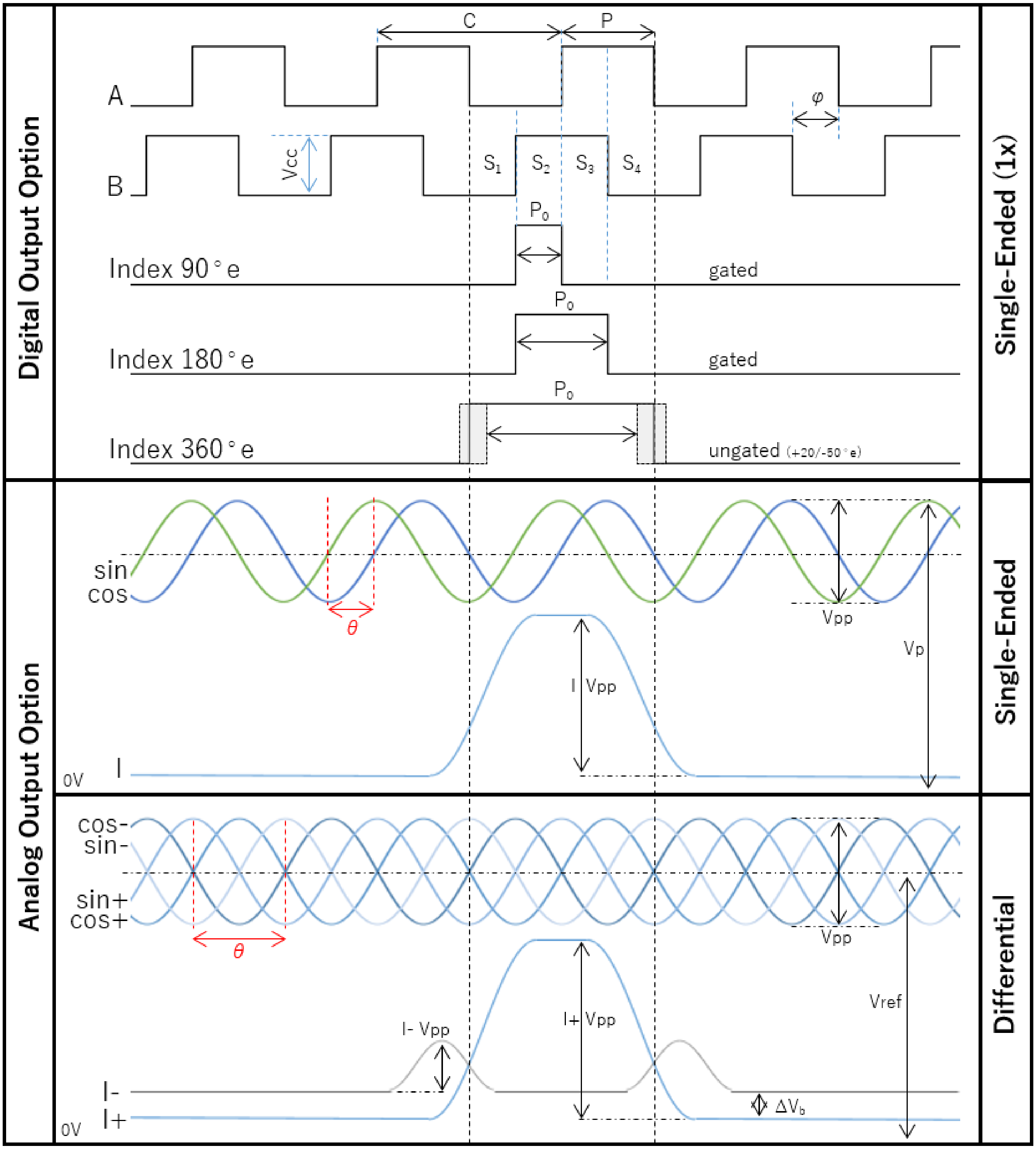


Table 10: Analog Parameter Definitions

Parameter	Symbol	Definition
Analog Peak-to-Peak	Vp	The peak-to-peak signal magnitude of V of the analog signals.
Reference Voltage	Vref	The offset in V of the midpoint of the analog signal's peak-to-peak to zero voltage point. Vref = Vcc/2
Analog Peak Voltage/Valley Voltage	Vp	The value in V of the peak/valley of the analog signals (one-side reading).
Analog Minimum Voltage	Vmin	The value in V of the depth of the analog signals (minimum reading in V). Vmin = Vp – Vpp
Analog Index Vbias (delta)	ΔV_b	The absolute difference of the indexes Vbias = I+Vmin – I–Vmin. The minimum value of ΔV_b is 200 mV.
Phase Shift	θ	The value in °e of the phase between two analog signals. Single-Ended mode: Cosine leads Sine by 90°e. Differential mode: Cosine+ leads Cosine– by 180°e (or Sine– lags by 180°e from Sine+).

Digital Signal Electrical Characteristics

Characteristics of digital output channel A and channel B over recommended operating conditions at 25°C.

Table 11: Digital Signal Electrical Characteristics

Parameter	Symbol	Min.	Typ.	Max.	Unit	Note
High-level Output Voltage	VOH	2.4	—	—	V	IOH = –20 mA
Low-level Output Voltage	VOL	—	—	0.4	V	IOH = +20 mA
Output Current per Channel, Iout	IO	—	—	20	mA	
Rise Time	tr	—	<50	—	ns	CL ≤ 50 pF
Fall Time	tf	—	<50	—	ns	
Jitter	J	—	1.5	—	LSB	For 40k CPR (625 CPR@ 64X)

Jitter

Jitter in digital output refers to the inconsistency in the time intervals between encoded pulses or in other words, the irregularities in the timing of the pulses' edges. It is important to minimize jitter in the digital outputs to ensure accurate and consistent measurement.

Rotary Code Wheel and Hub Design Concept

The window tracks are reflective surfaces with a specular reflectivity of minimum 60%, while the bar tracks are opaque surfaces with maximum of 5% reflectivity. The ideal code wheel design should have high reflectivity window tracks with as lows as possible reflectivity on the bar tracks, generating a finer and precise signal output.

Incremental window/bar tracks are trapezoidal in shape, allowing each window/bar to form identical (in width) repetitive patterns following the curvature of the code wheel, completing one circumference. The number of these patterns depend on the CPR value.

The index window track is a single rectangular-shaped window with a width of 0.0498 mm. There is a slight offset between the incremental window track and the index window track, W_{offset} = 0.648 mdeg (mechanical degree).

Figure 20: Code Wheel Dimensions

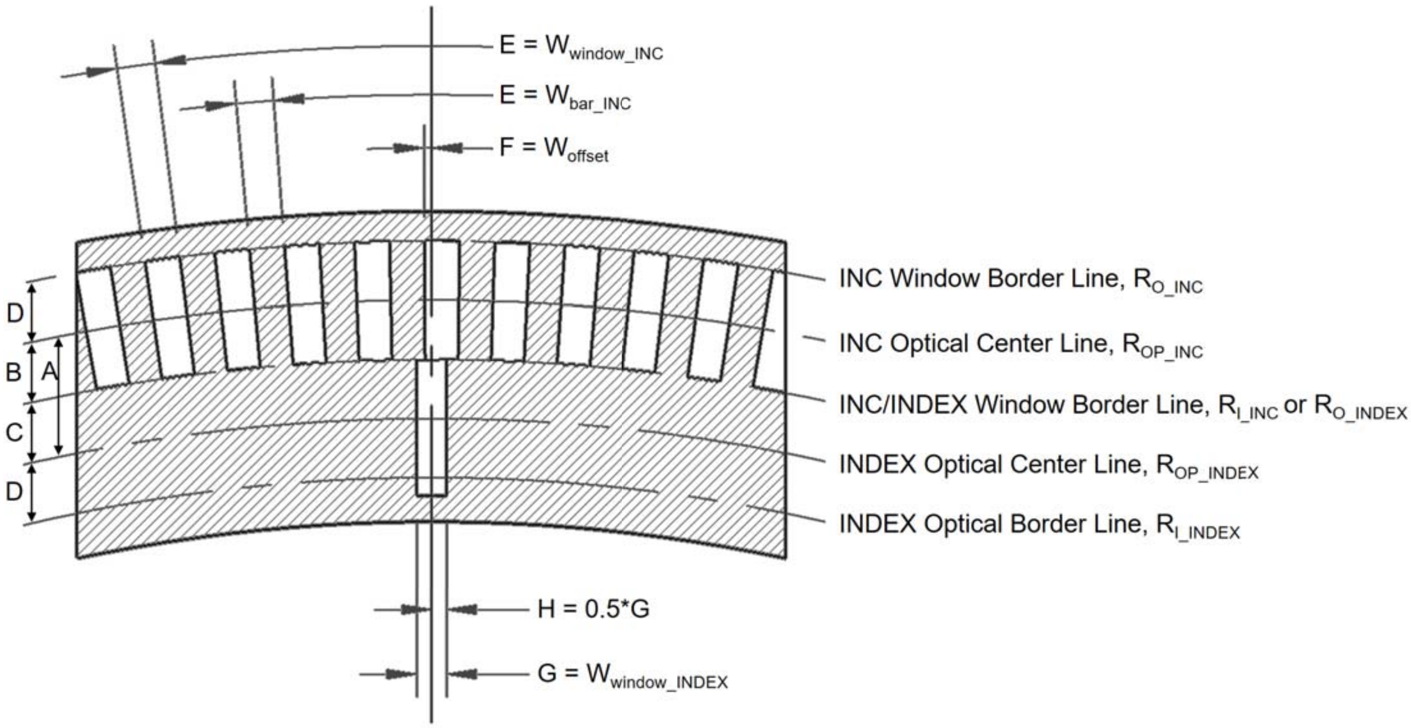


Table 12: Code Wheel Formulas and Values

Dimension	Unit	Formula	Constant (AEDR-9940)	Description
A	mm	$R_{OP\_INC} – R_{OP\_INDEX}$	1.1504	—
B	mm	$R_{OP\_INC} – R_{I\_INC}$	0.5752	—
C	mm	$R_{O\_INDEX} – R_{OP\_INDEX}$	0.5752	—
D	mm	$R_{O\_INC} – R_{OP\_INC}$ OR $R_{OP\_INDEX} – R_{I\_INDEX}$	0.6000	—
E	mdeg	(360 / CPR) / 2	—	INC window/bar width
F	mdeg	2.25 * e	—	W_{offset}
G	mm	—	0.04988	Index window width
H	mm	—	0.02494	Index window half-width

Code Wheel Design Example

Use CPR = 625, LPI = 198.4375 mm. The values for A through E are defined in Table 12.

1. Determine R_{OP_INC}: (25.4 / LPI) * (CPR / 2π) = 12.7324 mm
2. Determine R_{OP_INDEX}: R_{OP_INC} – A = 11.5820 mm
3. Determine R_{O_INC}: R_{OP_INC} + D = 13.3324 mm
4. Determine R_{I_INC}: R_{OP_INC} – B/C = 12.1572 mm
5. Determine R_{O_INDEX}: R_{OP_INDEX} + B/C = 12.1572 mm
6. Determine R_{I_INDEX}: R_{OP_INDEX} – D = 10.9820 mm
7. Determine $W_{window/bar}$: (360 / CPR) / 2 = 0.288 mdeg
8. Determine W_{offset}: 2.25 * E = 0.648 mdeg

Figure 21: Code Wheel Design (Multi-Track)

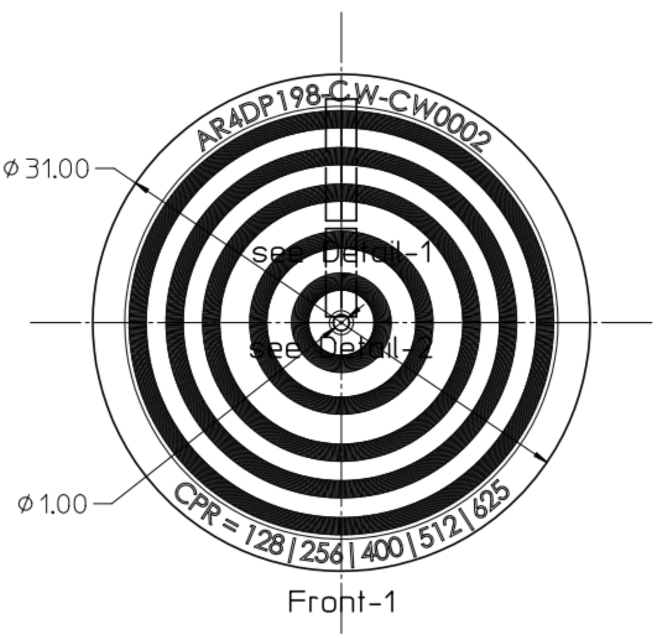
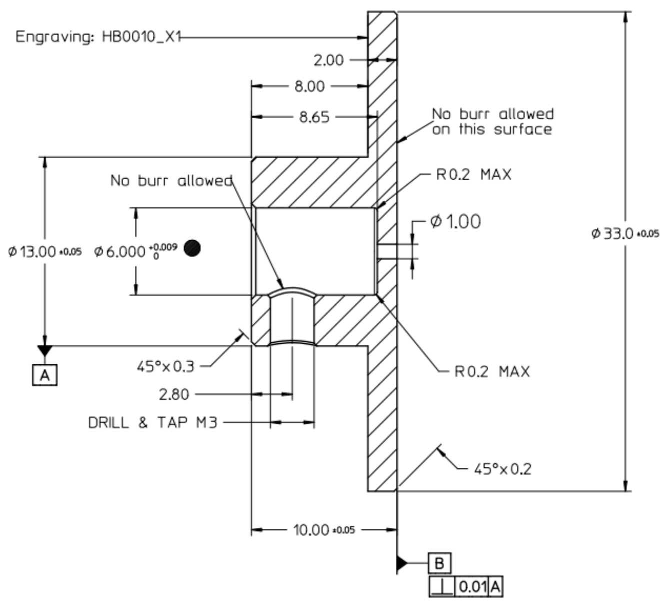


Figure 22: Hub Design



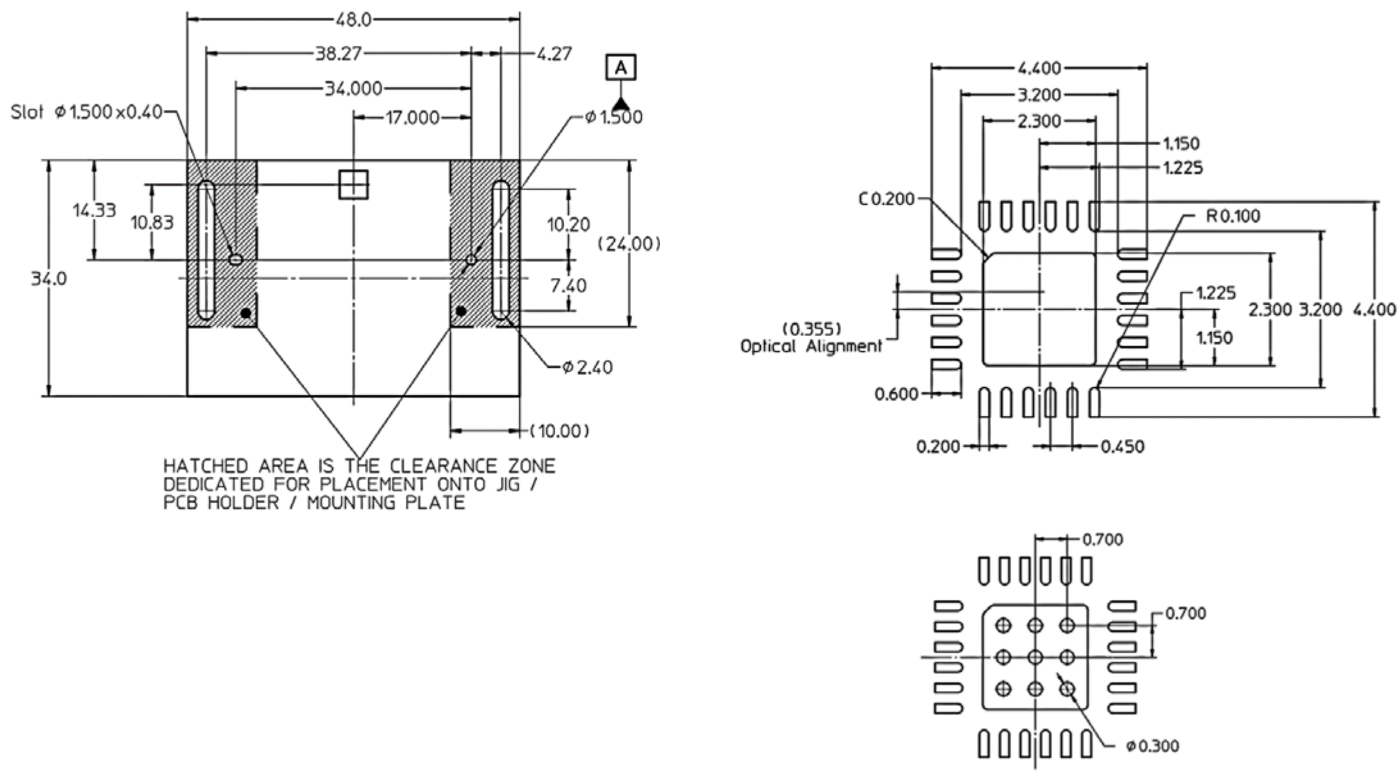
Signal Channel	Track	Window Width	CPR	INC R_{OP} (mm)	INDEX R_{OP} (mm)
INC	1	180° / 128	128	2.608	1.457
INC	2	180° / 256	256	5.215	4.065
INC	3	180° / 400	400	8.149	6.998
INC	4	180° / 512	512	10.430	9.280
INC	5	180° / 625	625	12.732	11.582

Evaluation Board

The AEDR-9940 can be mounted onto an Evaluation Board for testing purposes. The following are recommended design specifications including PCB outline, footprint, and thermal vias.

The Evaluation Board allows user to test, debug and verify certain aspects and features of the AEDR-9940 before integrating into the application system.

Figure 23: Evaluation Board



NOTE:

1. On this board, user can fanout all the I/O pins and manually configure the tri-state pins, SEL1, SEL2, SEL3, and INDEXSEL to get the desired outputs.
2. This PCB should consist of four layers with thermal vias at the center of the encoder for optimum thermal relief. Caution: Long exposure to extreme heat can result in permanent damage to the encoder, thus affecting its performance.

Electrical Characteristics

Table 13: Absolute Maximum Ratings

Storage Temperature, T_S	–40°C to 125°C
Operating Temperature, T_A	–40°C to 115°C
Supply Voltage, V_{CC}	5.5V

NOTE:

1. Proper operation of the encoder is no longer guaranteed if maximum ratings are exceeded.
2. Exposure to extreme light intensity (such as flashbulbs or spotlights) may cause permanent damage to the encoder.
3. Anti-static discharge precautions must be taken when handling the encoder to avoid damage or degradation induced by ESD (Electrostatic Discharge).
4. Take precautions to keep the encoder surface clean at all times.
5. A small amount of dust or particles may be present on the encoder's surface. It does not degrade or affect the performance of the encoder.

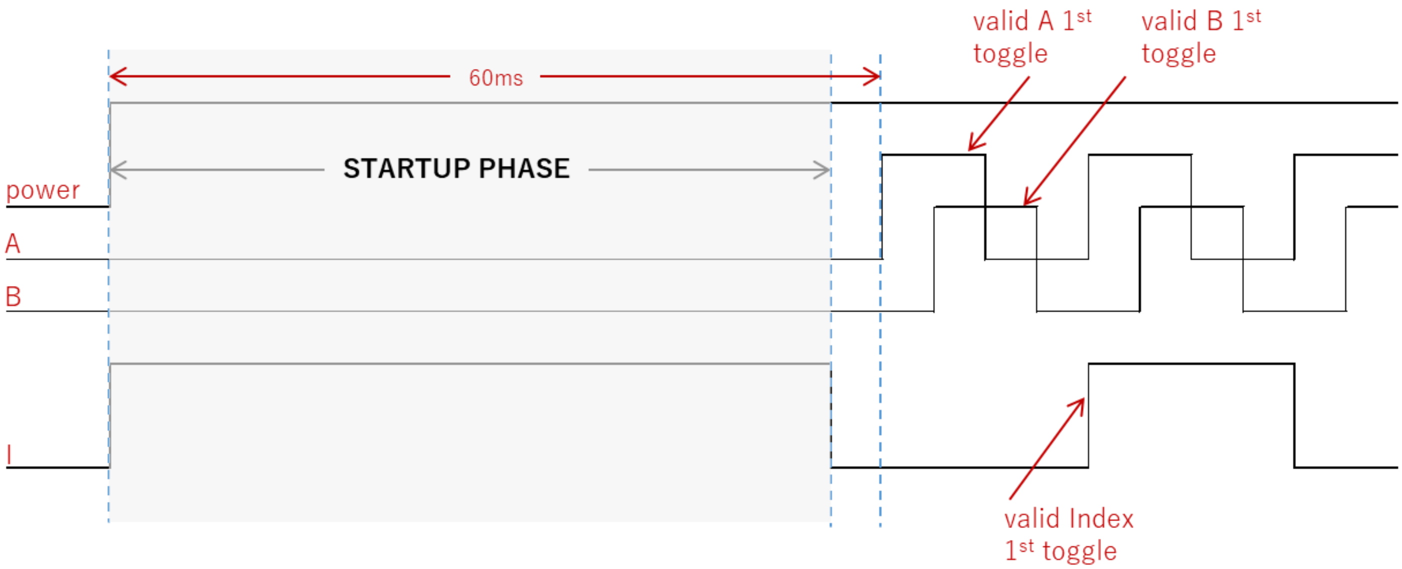
Table 14: Recommended Operating Conditions

Parameter	Symbol	Min.	Typ.	Max.	Unit	Note
Supply Voltage	V_{CC}	3.0	3.3	3.6	V	Ripple < 100 mVpp, $V_{CC} = V_{DD}$
		4.5	5.0	5.5	V	
Current Consumption	I_{CC}	—	45	—	mA	Dependent on spatial position and rotational speed.
Pin Current (all I/O outputs)	I	–20	—	20	mA	
Maximum Output Frequency (External Mode Selection)	f	—	—	0.25	MHz	Interpolation: 1X
		—	—	0.50	MHz	Interpolation: 2X
		—	—	1.00	MHz	Interpolation: 4X
		—	—	2.00	MHz	Interpolation: 8X
		—	—	4.00	MHz	Interpolation: 16X
		—	—	4.00	MHz	Interpolation: 32X
		—	—	4.00	MHz	Interpolation: 64X
		—	—	4.00	MHz	Interpolation: 128X
Maximum Output Frequency (SPI Programmable)	f	—	—	4.00	MHz	Interpolation: ≥ 32X
Tri-state Voltage Threshold	High	90	—	—	$\%V_{CC}$	
	Low	—	—	10	$\%V_{CC}$	
	Open	30	—	70	$\%V_{CC}$	

Startup Behavior

When the AEDR-9940 powers on, digital output A, B, and Index will be in idle state until the first toggle of either the A or B digital signal. This duration is also called the startup phase, where the encoder is in recognition mode to verify the logic as well as the code wheel position.

Figure 24: Startup Behavior



NOTE:

1. The AEDR-9940 is fully functional after the first toggle or pulse of the either A or B digital output.
2. The duration to the first toggle or pulse of the digital output is approximately 60 ± 5 ms.
3. The encoder will remain in the startup phase if it is out of valid spatial range or off-scale.
4. During this phase, A = B = Low while I = High (similar behavior for A–, B– and I–).

Analog Selection Output Waveforms

The AEDR-9940 includes a function to output various settings of analog waveform, configurable through mode selection (see Configurable Mode Selection - Interpolation Factor). The following are some examples of analog output waveforms for each mode selection.

Figure 25: Mode 25: 500 mVpp Analog AB with Ungated Digital Index

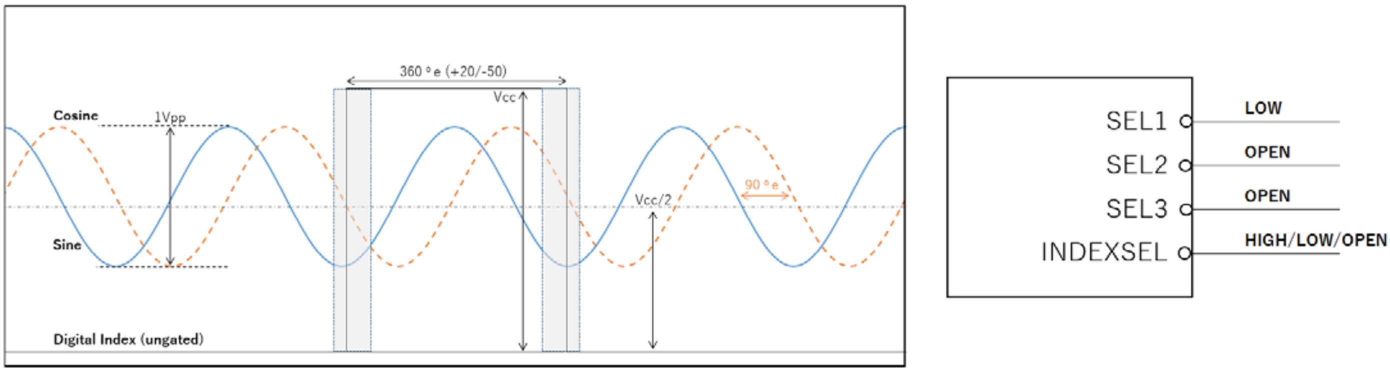


Figure 26: Mode 26a: 500 mVpp Analog AB with 1 Vpp Analog Index+

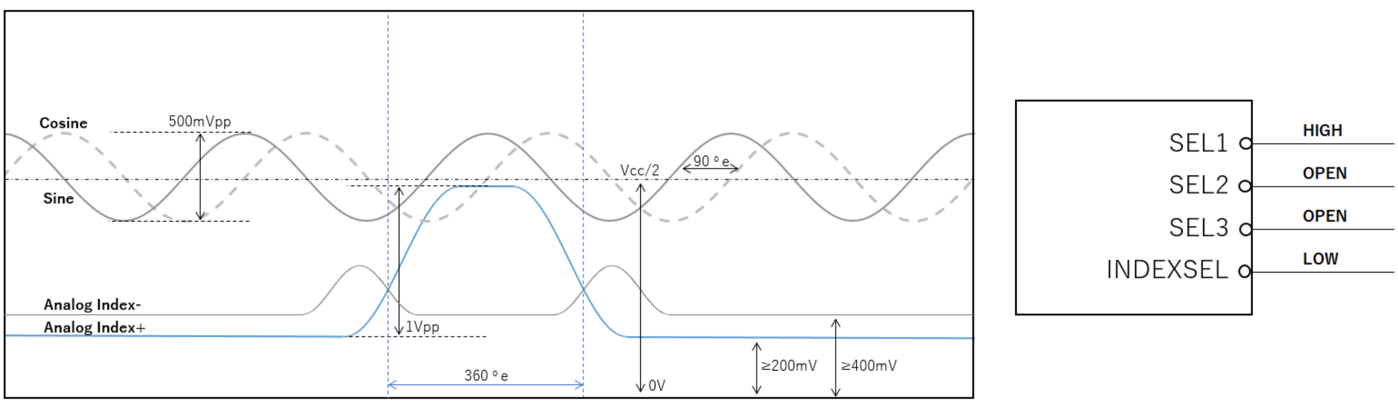


Figure 27: Mode 26b: 1 Vpp Analog AB with Ungated Digital Index

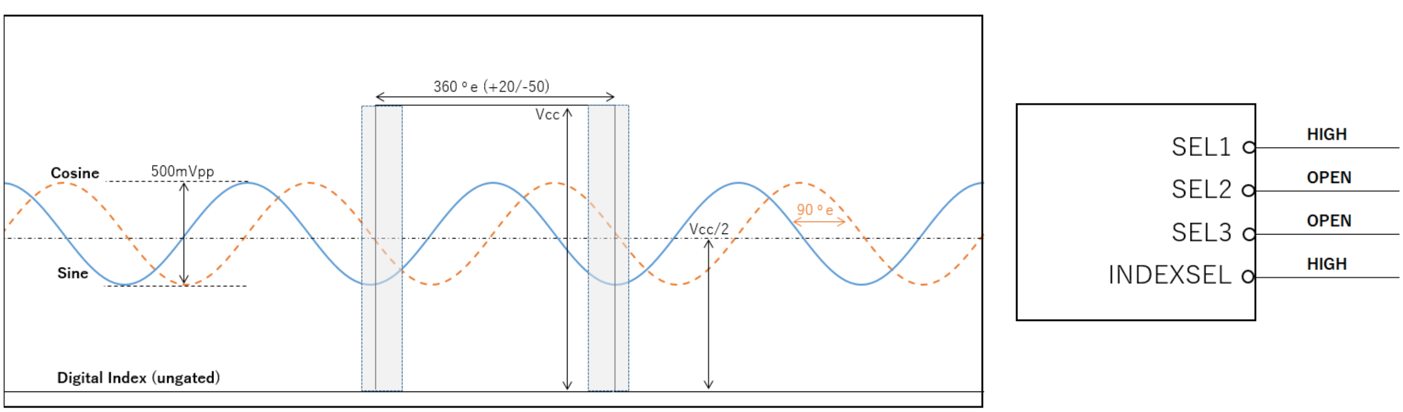
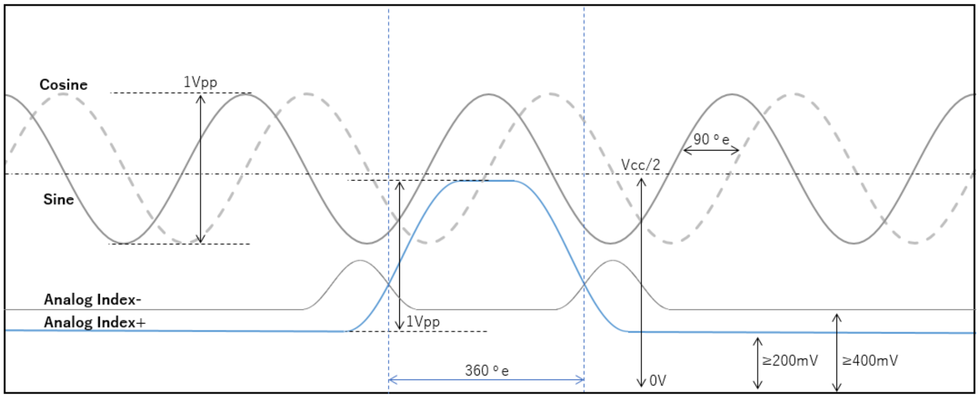
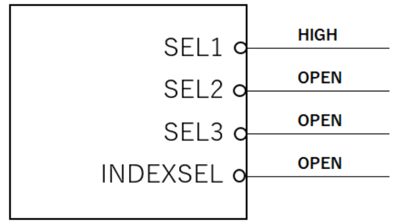


Figure 28: Mode 26c: 1 Vpp Analog AB with 1 Vpp Analog Index+





NOTE: Ungated digital index is raw index at 1X interpolation, 360°e +20/–50.

Ordering Information

A	E	D	R	-	9	9	x_1	0	-	1	0	x_2

x_1	Resolution 4 = 198.4 LPI
x_2	Packaging 0 = 1000 pieces 2 = 100 pieces

Part Number	Description
AEDR-9940-100	AEDR-9940, 198.4 LPI Rotary Incremental Encoder, 1000 pieces
AEDR-9940-102	AEDR-9940, 198.4 LPI Rotary Incremental Encoder, 100 pieces
HEDS-9940EVB	Evaluation board with 2 units of code wheel multiple optical radius 256, 400, 512, 720 CPR base
HEDS-9940EVB1	Evaluation board with 2 units of code wheel multiple optical radius 200, 360, 500, 625 CPR base
HEDS-9940EVBL	Evaluation board with 2 units of code strip 128 µm
HEDS-9940PRGEVB	SPI Programming Kit with Evaluation board bundling, 2 units of code wheel multiple optical radius 256, 400, 512, 720 CPR base
HEDS-9940PRGEVB1	SPI Programming Kit with Evaluation board bundling with 2 units of code wheel multiple optical radius 200, 360, 500, 625 CPR base
HEDS-9940PRGEVBL	SPI Programming Kit with Evaluation board bundling, 2 units of code strip 128 µm

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