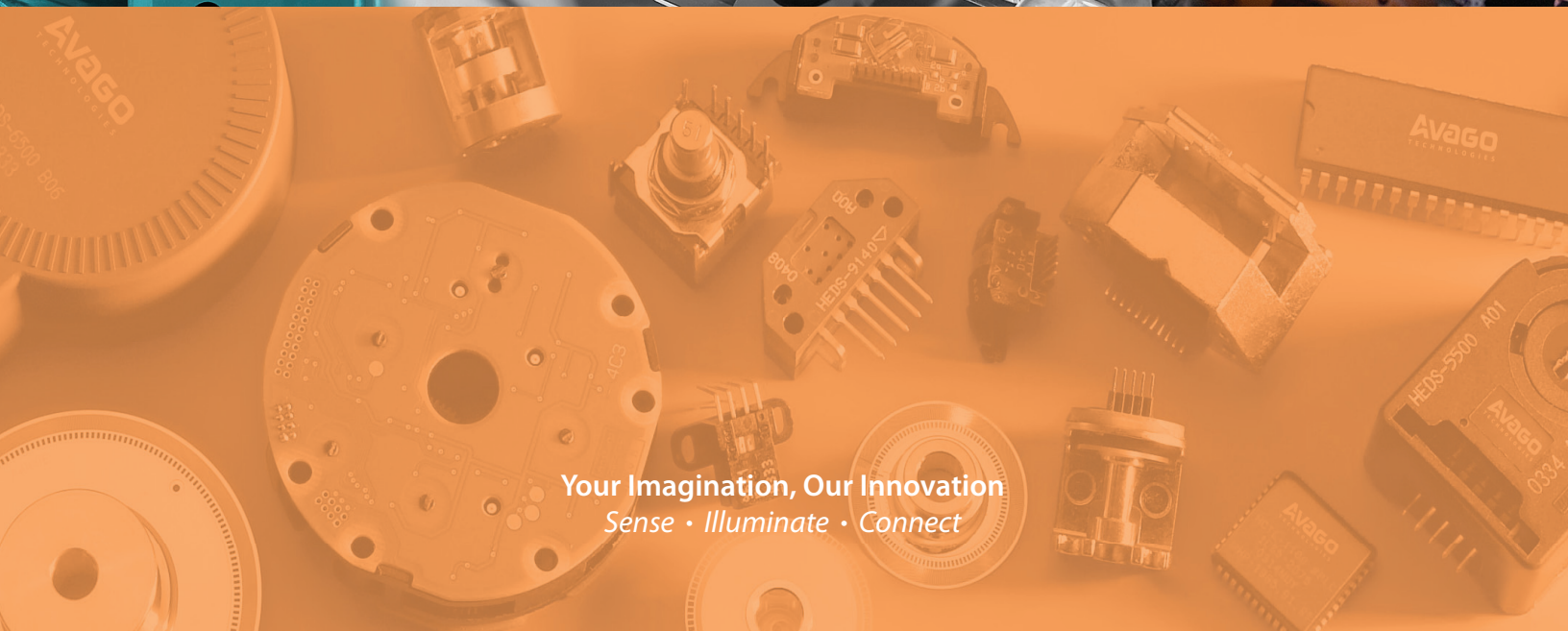
# Motion Control Encoders in Electrical Motor Systems

## Design Guide



# Contents

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### 1.0 Introduction
As the market becomes increasingly driven by consumer demands, businesses are forced into an intensified effort of meeting those demands to ensure their survival. It is a free-for-all in a business landscape that is filled with unpredictable sentiment and unforgiving circumstances. From suppliers to manufacturers, distributors to sales channels, all mechanisms involved in supporting the end products are faced with the seemingly unreasonable task of delivering products that are record-breaking miniature sizes; complete with extended capacities, high quality, while continuously maintaining a cost-down price structure.

Avago Technologies, a leading supplier of motion control products, for industrial and office automation and consumer applications, understands these needs. With a presence that began over 40 years ago from its Agilent/Hewlett-Packard roots, coupled with the technical competency and innovation excellence, Avago continues to offer products that have assisted thousands of automation-enablers throughout the world, in achieving the highest level of efficiency in their equipment.

With a focus towards improving the capabilities of electrical motor systems that will ultimately drive the automation landscape, Avago offers the most comprehensive line of motion control encoders to meet the needs of its customers. Avago's motion control encoders come with a variety of options and characteristics that include, high operating temperature, a wide range of resolutions, multiple channels, various output options, and more.

### 2.0 What are motion control encoders?
Motion control encoders are electro-mechanical devices that are designed to translate mechanical motion such as position change and direction, into electrical signals.

### 2.1 Type of encoders available at Avago Technologies
Avago Technologies offer several types of motion control encoder solutions to meet the needs of different electrical motor systems. These encoders are divided into two categories: **Incremental and Absolute**.

At the core of the encoder design is the use of proprietary optical or magnetic-based technology for sensing purposes. The optical technology is further expanded by providing two different position sensing approaches: **transmissive or reflective sensing technology**.

#### 2.1.1 Incremental and Absolute Encoders
Incremental encoders provide relative position, where the feedback signal is always referenced to a start or home position. On an incremental encoder, each mechanical position is uniquely defined. The current position sensed is only incremental from the last position sensed.

Absolute encoders generate a unique code for each position. It has the distinctive feature of being able to provide positional information instantly upon power-up.

#### 2.1.2 Transmissive, Reflective and Magnetic Sensing Technology
Optical-based encoders use light to sense speed, angle and direction of a rotary shaft. These encoders are further separated by differences in their sensing technology.

In **transmissive** optical encoders, light from a light source penetrates a moving codewheel and is sensed by the photo-detector on the opposite side of the codewheel.

In a **reflective** encoder, light from a light source bounces back from a moving codewheel and is sensed by the photo-detector, which is located on the same side of the codewheel as the emitter.

**Magnetic-based** encoders typically utilize the Hall effect or magneto-resistive (MR) effect to sense the positional information. Avago's magnetic encoder with an integrated Hall sensor requires a permanent magnet that is rigidly mounted on the rotating shaft of a motor.

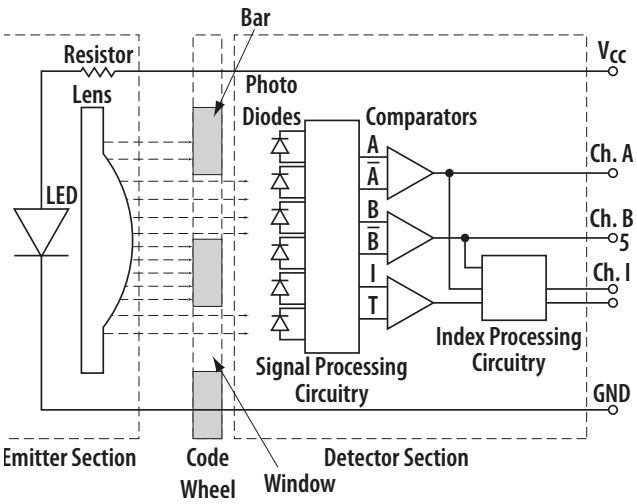
Another component of a magnetic encoder is the magnetic sensor and associated signal conditioning electronics. The encoder module is typically mounted directly on the end bell of a motor. It operates on a non-contact basis; without the need for moving parts such as seals and bearings. Because of this, mechanical wear is not a consideration.

## 2.2 Basic Encoder Operations

### 2.2.1 Operations of a Transmissive Encoder

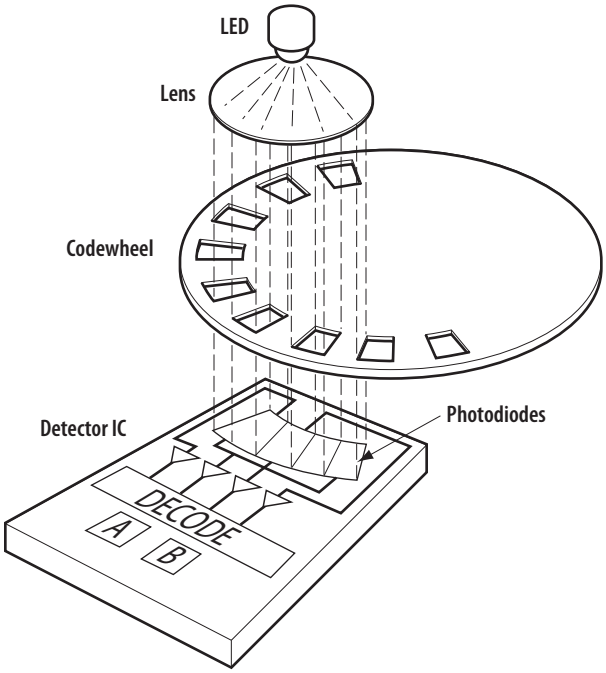
A transmissive encoder consists of an emitter, detector, codewheel or codestrip. The emitter and detector are located on the opposite sides of the codewheel or codestrip. (See Diagram 1)

**Diagram 1. Diagram of a transmissive encoder**




When light from the light source, is projected onto the moving codewheel or codestrip, the bars act as a "gate" that enables and then prevents the light penetration at intervals. This sequential action creates moving shadows that fall on the photodiodes located on the detector. The photodiodes then generates output or signal (See Diagram 2).

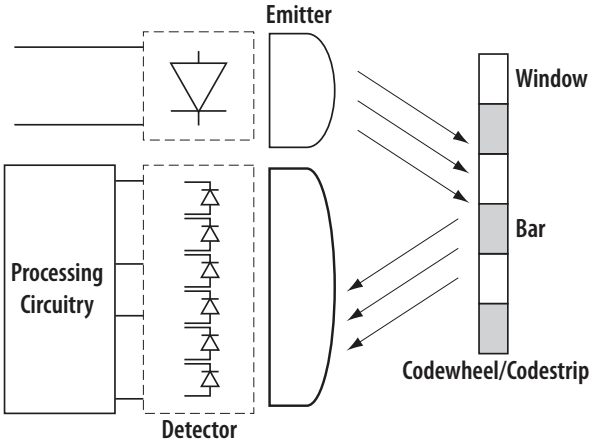
**Diagram 2. Light on the photodiode**




### 2.2.2 Operations of a Reflective Encoder

The basic elements of reflective encoders are similar to the transmissive encoder. In a reflective encoder, the emitter and detector are located on the same side of the codewheel or codestrip (See Diagram 3).

**Diagram 3. Reflective encoder process**




When light from the light source is projected onto the moving codewheel or codestrip, the bars act to reflect or not reflect the light, at intervals. This repeated action creates moving shadows that fall on the photodiodes located on the detector. The photodiodes then generates output or signal.

It is important to note that the reflective technology is currently confined to Avago's incremental optical encoders, specifically the AEDR series in modular form and housed HEDR and HRPG (Rotary Pulse Generator) series.

### 2.2.3 Operations of a Magnetic Encoder

Magnetic encoders are a viable alternative to optical types because they are inherently rugged and operate reliably under shock and vibration, at high temperature, and in contaminated and humid areas. Hall effect and magneto resistive (MR) devices are two sensors commonly used for these conditions. Motor speed and position accuracy dictate which of the two is better suited for an application.

Avago's magnetic encoder is based on the Hall sensing technology. A diametrically magnetized magnet rotates off-axis over a single or multiple pairs of linear Hall sensor arrays. Magnetic flux variations are detected by the Hall sensors and converted to analog sinusoidal voltage, where there will be one sine wave per revolution. (The Hall sensing principle allows for compact and miniature encoders with small dimensions and high resolutions). After signal processing and digitization, the absolute information is available as a serial communication data output. Thanks to the built-in compensation electronics, the magnetic encoder is very robust against temperature change as well as axial and radial shaft displacements.

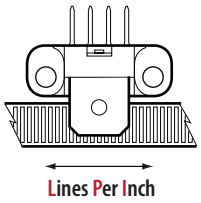
### 2.3 Units of measure

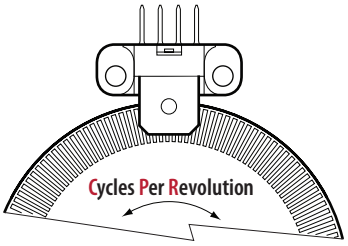
| | | |
|---|---|---|
| CPR | Cycles per Revolution | Defines the number of electrical cycles that an encoder provides in a single revolution. CPR = 2π x LPmm x Rop |
| LPI | Lines per Inch | Defines the number of window-bar pairs in a length of 1inch |
| LPmm | Lines per mm | Defines the number of window-bar pairs in a length of 1mm. Note that LPmm=LPI/25.4 |
| Rop | Optical Radius | The distance from the center of the codewheel to the middle of the data track |
| °e | Electrical Degree | Defines the electrical angle of an encoder signal. 1 cycle is equal to 360 °e |
| ° | Mechanical Degree | Mechanical angle. One revolution is equal to 360° |
| ′ | Arc Minute | Mechanical angle. 1° = 60′ |
| ″ | Arc Second | Mechanical angle. 1° = 60′ = 3600″ |
| Bit | Binary Digit | Defines the smallest resolution, usually used for absolute encoder |
| Rev. | Revolution | Define the full complete rotation of a shaft or codewheel. 1 Revolution = 360° |
| f | Frequency | Encoder count frequency. Expressed in Hertz (Hz). f = CPR x RPM/60 |
| RPM | Revolution per Minute | Angular speed that is commonly used to define motor turning speed |
| RPS | Revolution per Second | 1RPS = 60RPM |
| °C | Degree Celcius | Defines the temperature |

### 3.0 Main Characteristics

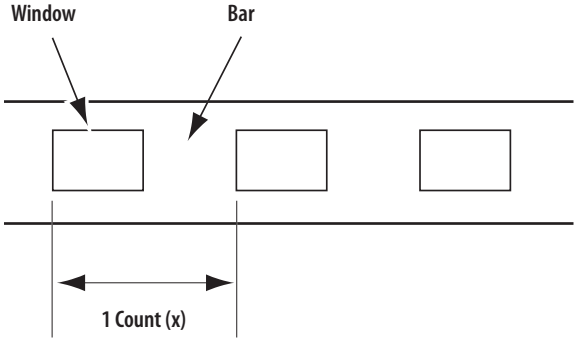
Typically there are many characteristics that designers look at before deciding which encoder will best suit their applications. Most engineers base their selection primarily on six main characteristics: resolutions, operating temperature, output signals, shaft sizes, motor speed and motor diameter.

### 3.1 Resolutions




Encoder resolution defines the smallest measurement unit that the encoder signal can provide. For a linear application, the resolution is typically defined by the pitch length (one pair of window and bar) or the count density.

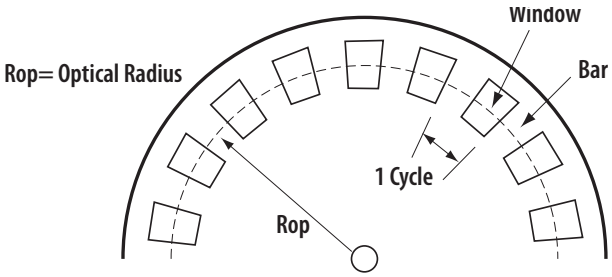



$$\text{Count Density} = \frac{\text{Number of Window and Bar Pairs}}{\text{Length}} = \frac{1}{x}$$

$$\text{LPmm} = \frac{1}{x(\text{mm})} \qquad \text{LPI} = \frac{1}{x(\text{in})}$$

Where x = pitch length (length of 1 pair of window and bar)

The pitch length is specified in millimeters or inches. The count density is referred to as the Lines per mm (LPmm) or Lines per inch (LPI).




Cycle = Mechanical rotation that corresponds to 1 pair of Window and Bar

CPR = Number of window and bar pairs per single revolution

$$\text{Count Density} = \frac{\text{Number of window and bar pairs}}{\text{Arc Length}} = \frac{\text{CPR}}{2\Pi\,\text{Rop}}$$

$$\text{LPmm} = \frac{\text{CPR}}{2\Pi\text{Rop}(mm)} \qquad \text{LPI} = \frac{\text{CPR}}{2\Pi\text{Rop}(in)}$$

For rotary encoder applications, the resolution is most commonly defined by the CPR of the encoder. Due to the quadrature relationship of an incremental output, the final resolution of the encoders can be quadrupled by decoding each rising and falling edge of the two channel encoder signals.

For example, a 1000 CPR encoder can provide an effective 4000 quadrature counts after the 4X decode at the customer interface.

### 3.2 Operating Temperature

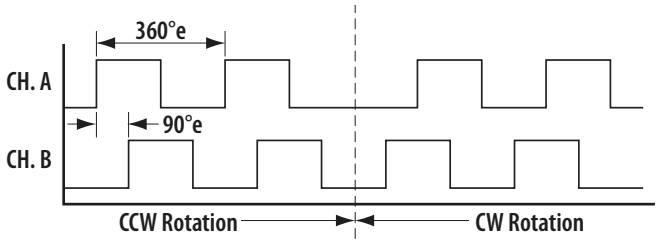
Operating temperature defines the working range that an encoder is designed for. Within the temperature range, the encoder is expected to perform as specified in the datasheet performance reliably.

Encoders are designed with components and materials that can withstand the temperature range specified. Rigorous tests and qualification is carried out to ensure a product's quality and reliability.

Operating temperatures are important to encoder applications, as the environment the encoder is working in varies from one application to another. For encoders meant for direct integration into a motor, the motor coil can be close to the encoder and temperatures of up to 100°C or higher may be expected.

### 3.3 Output Signals

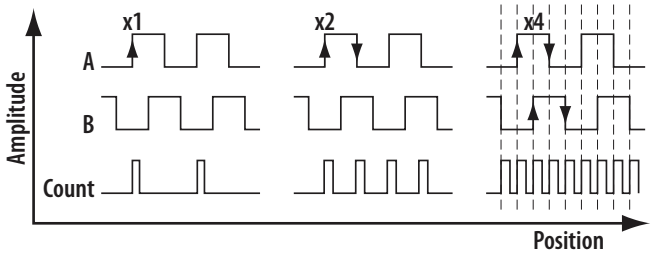
Digital signal is commonly used due to its direct interface with modern control electronics. Analog signals provide flexibility with potentially very high feedback rate to system designers. A single channel encoder only provides positional and speed info but cannot differentiate the direction of motion. A 2-channel encoder provides the directional information. A 3-channel encoder (with index) provides absolute information, typically once per revolution.




For an incremental encoder, the 2-channel output signals are in quadrature, i.e. the two periodical signals are identical but offset by 90°e. The quadrature signals provide the information on direction of rotation. In one direction, Channel A leads Channel B. In the counter direction Channel B leads Channel A.

The incremental encoder is typically decoded to provide counts information, and a decoder and counter are required. The decoding and count functions can be easily implemented by a microcontroller or accepted directly by most motor controllers.

The quadrature incremental signals are typically decoded to obtain up to four times the base CPR. Quadrature decoding counts both the rising and falling edges of Channel A and B.




The absolute encoder does not require a counter or decoder. The positional information is provided directly. The absolute encoder signal is output as a serial output.

### 3.4 Shaft Sizes

Shaft size refers to the motor shaft diameter that the encoder is mounted to. Shaft sizes are important, as the diameter will influence how big or small the shaft is that it can be fitted to. Typically a large motor will also have a larger shaft size, and vice versa. A small diameter encoder will only cater to a limited range of shaft sizes in order to maintain the overall diameter.

### 3.5 Motor Speed

Motor speed is often referred to as the RPM or revolutions per minute. The RPM rating defines the typical and maximum speed that a motor is designed to spin, with or without load.

Motor speed will determine the encoder frequency that is needed. A high CPR encoder will need a high frequency rating in order to maintain the same RPM.

The motor RPM is increasingly important in providing high dynamic and fast response to various applications, such as high speed pick and place machines. An encoder needs to have the frequency response to keep up with the motor RPM.

The mathematical relationship between encoder CPR count frequency and motor RPM is defined by the following formula:

f = RPM x CPR/60

Where:

CPR = Encoder counts Per Revolution
RPM = Motor Speed (Revolution Per Minute)
f = Encoder Count Frequency (hertz)

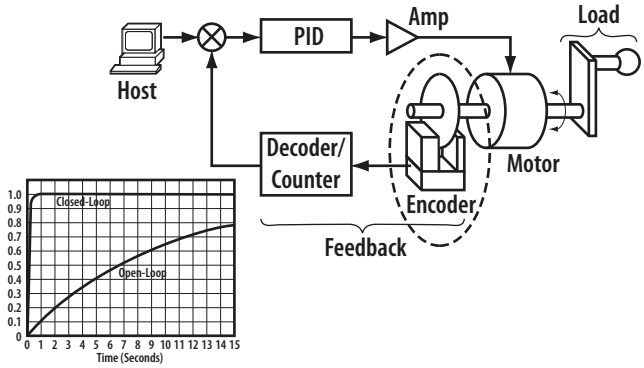
### 3.6 Motor Diameter

The diameter of the motor will determine the type of encoder that can be used. A small diameter motor will require a similar size encoder so that the overall diameter is within the same fit and form.

For miniature motors, the challenge is to have a high resolution encoder which can fit the same small diameter, and still perform at the same level.

Motor sizes will influence the force/torque that the motor can deliver and the space it requires.

## 4.0 Electrical Motor System




An electric motor converts electrical energy into mechanical energy. The reverse task of converting mechanical energy into electrical energy is accomplished by a generator or dynamo. Traction motors used on locomotives often perform both tasks if the locomotive is equipped with dynamic brakes.

Electric motors are found in household appliances such as fans, exhaust fans, fridges, washing machines, pool pumps and fan-forced ovens. They are also widely used in industrial automation and applications such as robotic arms, conveyor and automated assembly lines, and pick and place machines.

Most electric motors work by electromagnetism. Motors based on other electromechanical phenomena, such as electrostatic forces and the piezoelectric effect, also exist. The fundamental principle upon which electromagnetic motors are based is that there is a mechanical force on any current-carrying wire contained within a magnetic field. The force is described by the Lorentz force law and is perpendicular to both the wire and the magnetic field.

Most magnetic motors are rotary, but linear motors also exist. In a rotary motor, the rotating part (usually on the inside) is called the rotor, and the stationary part is called the stator. The rotor rotates because the wires and magnetic field are arranged so that a torque is developed about the rotor's axis. The motor contains electromagnets that are wound on a frame. Though this frame is often called the armature, the term is often erroneously applied. Correctly, the armature is that part of the motor across which the input voltage is supplied. Depending upon the design of the machine, either the rotor or the stator can serve as the armature.

### 4.1 Open and Closed Loop System

An open system does not have a feedback system to the controller to change its input. A closed loop system provides a feedback loop to the controller where the output is constantly monitored and the input varies as the output changes.

### 4.2 Types of Electrical Motors

There are many types of electrical motors in the market today. These motors can be categorized into six types:

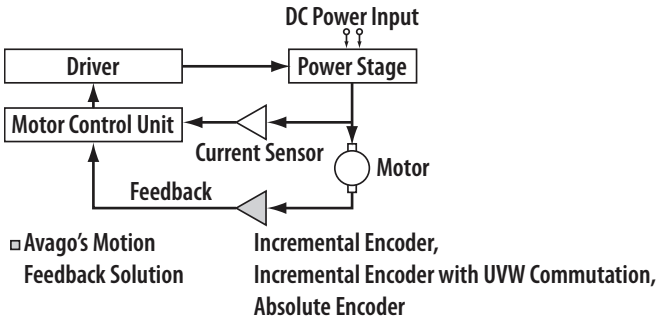
- Brushless Direct Current (BLDC) Motors
- Direct Current (DC) Motors
- Universal Motors
- Alternating Current (AC) Motors
- Stepper Motors
- Piezo motors

For the purpose of this design guide we focus our attention on the BLDC motor system. The other types of motors will be included into this design guide in the near future.

#### 4.2.1 Brushless DC Motors

Avago Technologies offers a broad range of products that provide a complete system solution for the brushless DC motor. The diagram below shows a simple block diagram of the brushless DC motor system.

**Diagram 4. Brushless DC Motor System with Encoder**




The brushless DC motor (BLDC) is a synchronous electrical motor that looks very similar to a DC motor. The only difference between a brushed motor and a BLDC is its commutator system. The commutator system of a BLDC is replaced with an intelligent electronic controller which can have the same power distribution as that found in the brushed motor.

The brush noise of a BLDC is eliminated as there is no brush used in the system. It is more durable and robust in comparison to the conventional brushed DC motor.

## 5.0 Encoder Selection Options

The selection tables in this section provide design engineers with various ways in which to begin their encoder selection. Engineers may opt to choose an encoder based on resolutions, operating temperatures, output signals, shaft sizes, and motor speed or motor diameter.

Once the appropriate attributes have been identified, look-up the ordering information by matching the part numbers of the product to our MCPD Selection Guide.

The MCPD Selection Guide further enables engineers to choose the most appropriate package in terms of mounting options, resolutions, number of channels, diameter size, pole pairs, quantity, etc.

Note: For customization or requirements beyond those provided in this guide, visit www.avagotech.com/motioncontrol.

## 5.1 Encoders for BLDC Motor System: By Resolution

Avago offers a wide range of encoder resolutions to meet the needs of different types of applications, from critical industrial applications to consumer products. The resolution range is categorized under three categories: high, medium and low resolution.

#### 5.1.1 High resolution incremental encoders

Encoders in this category can achieve a resolution above 2048 CPR. These encoders assist design engineers in obtaining peak performance through faster servo response and a better dynamic performance. Typical applications requiring this resolution range include pick and place machines, chip shooter, high-end servo motor and drives.

Although high in resolution, Avago's encoders are low in cost. The miniature design enables easy design-in applications where space is limited. Design engineers have the option of choosing between a modular unit (encoder alone) or an integrated solution, complete with customized housing that meets specific requirements.

#### 5.1.2 Medium resolution incremental encoders

Encoders in the medium range category can achieve a maximum of 2048 CPR, dependent on the type of encoders selected. The medium range encoders are widely used in the industrial automation industry and are recognized for providing design engineers with a simple and reliable feedback solution. The optical encoder provides precise position sensing capabilities. Typical applications requiring this range of encoders includes standard servo motor and drives, as well as other factory and industrial automation systems.

Avago offers one of the widest ranges of resolution options which are competitively priced to meet the different needs of applications. These encoders are designed to enable easier assembly. Design engineers have the option of choosing between modules (encoder alone) or integrated solutions; complete with customized housing to meet specific requirements.

#### 5.1.3 Low resolution incremental encoders

Encoders in the low resolution category cater to applications requiring resolution of 512 CPR and below. These encoders are recognized for providing design engineers with a simple, yet highly reliable feedback device. The enhanced performance ensures a more controlled movement and better accuracy. Typical applications requiring this resolution range include low-cost servo motors, sewing machines and various consumer and office automation applications.

Avago's encoders are competitively priced to meet the different needs of applications. These encoders are designed for an easy assembly process. Design engineers have the options of choosing between modular units (encoder alone) or integrated solutions complete with customized housing that meets specific requirements.

#### 5.1.4 Absolute single-turn encoders

Avago's single-turn optical encoders provide unique position information for each shaft location. This location is independent from all other locations.

In an absolute encoder, there are several tracks with common centers, and single light sources. As the light

passes through the slots on the moving tracks, it creates shadows at intervals. Where a shadow is detected, a low state (0) is created. When the light successfully penetrates the slot a high state (1) is created. The position of the shaft is detected by reading the pattern of 1's and 0's. For higher resolution single-turn encoders, incremental tracks are added. These tracks enable the interpolation of signals.

Avago's single-turn optical encoders provide high accuracy read-out for applications which require precise positional information. In addition, its use of the SSI non-proprietary serial communication protocol means that encoders can match most applications' output requirements. These absolute single-turn encoders come in a 13 and 16-bit resolution package to cater to the needs of a range of applications in the factory and industrial automation industry such as robotic arms, valve controls, test and measurement equipments etc.

In addition to the absolute single-turn optical encoders, Avago also offers the options for absolute single-turn magnetic encoders. This magnetic encoder solution is offered in resolutions of 10 and 12-bits. The encoders are highly robust and are able to tolerate operating temperatures up to 125°C, making it ideal for industrial applications.

#### 5.1.5 Absolute multi-turn encoders

Multi-turn encoders permit multiple turn counts. Multiple turns are achieved by placing the multiple gear-head module to the primary high resolution disk.

**5.1 Selection Table: Encoders by Resolution**

| Incremental | Part Number | Resolution | Max RPM | Operating Temperature | Output Type | No. of Channels | Motor Diameter | Shaft Sizes |
|---|---|---|---|---|---|---|---|---|
| High Resolution Range (>2048CPR) | HEDR-5xxx series | 1200-3600CPR | < 5300 | -40 - 100C | Digital | 3 -Channel | 42 | 2 to 8mm |
| | HEDC-5xxx | 50-1024CPR | >12000 | -40 - 100C | Digital | 2 & 3-Channel | 42 | 2 to 8mm |
| | AEDB/T-9340 | 1000 - 2500CPR | 4500 | -10°C - 85°C / -40°C - 115°C | Digital | 3 & 6-Channel | 42 | 3 to 12mm |
| Medium Resolution (up to 2048CPR) | HEDS-90xx/91xx/92xx | 50 - 2048CPR | >12000 | -40°C - 100°C | Digital | 2 & 3-Channel | 48 | See Note 2 |
| | HEDS-97xx | 96 - 2048CPR/ up to 480LPI | >12000 | -40°C - 85°C | Digital | 2-Channel | 40 | See Note 2 |
| | HEDL-90xx/91xx | 1000 - 2000CPR | >12000 | -40°C - 100°C | Digital | 2 & 3-Channel | 48 | See Note 2 |
| | HEDB-9xxx | 96 - 1024CPR | >12000 | -40°C - 100°C | Digital | 2 & 3-Channel | 48 | 2 to 8mm |
| | HEDx-55/56xx | 50 - 1024CPR | >12000 | -40°C - 70°C/ -40°C - 100°C | Digital | 2 & 3-Channel | 42 | 2 to 8mm |
| | AEDR-8400 | 700 - 870CPR/254 & 318LPI | < 3000 | -20°C - 85°C | Digital | 2-Channel | ≥10 | See Note 2 |
| | AEDR-850x | 294-304LPI | 55kHz | -20°C - 85°C | Digital | 3-Channel | ≥ 10 | See Note 2 |
| | AEAT-6600-T16 | 8, 16, 32, 64, 128, 256, 512, 1024 CPR | 7000 | -40°C - 125°C | Digital | 3-Channel | ≥ 10 | Not applicable |
| Low Resolution (512 CPR or less) | AEDB/T-9140 | 100 - 500CPR | >12000 | -10°C - 85°C / -40°C - 115°C | Digital | 3-Channel | 31 | 3 to 12mm |
| | HEDT-90xx/91xx | 100 - 512CPR | 12000 | -40°C - 125°C | Digital | 2 & 3-Channel | 48 | See Note 2 |
| | AEDx-8xxx | 500 CPR | <30000 | –40°C to 100°C | Digital | 2- & 3-Channel | 20 | 2-5mm |
| | AEDR-8300 | 100 - 580CPR/ 36 - 212LPI | 9000 | -20°C - 85°C | Digital | 1 & 2-Channel | ≥10 | See Note 2 |
| | AEDR-8320 | 490CPR/ 180LPI | 2450 | -10°C - 70°C | Analog | 2-Channel | ≥10 | See Note 2 |
| | HEDR-542x | 200CPR | 4800 | -10°C - 85°C | Digital | 2-Channel | 23 | 2 to 5mm |
| **Absolute** | **Part Number** | **Resolutions** | **Max RPM** | **Operating Temperature** | **Output Signal** | **Motor Diameter** | **Shaft Sizes** | |
| Single Turn | AEAT-60xx | 10 & 12-bit | 12000 | -40 to 125 °C | SSI | 23 | 6mm | |
| | AEAT-6600-T16 | 10, 12, 14, 16 bits | 7000 | -40°C - 125°C | SSI, PWM | ≥ 10 | Not applicable | |
| | AEAT-7000 | 13 bits | 12000 | -40°C - 100°C | SSI | 56 | 8mm | |
| | AEAT-9000/AEAT-9035 | 17 bits | 12000 | -40°C - 115°C | SSI | 40mm-60mm | 6-12mm | |
| Multi-Turn | AEAT-84AD | 12-bit & 14-bit | 12000 | -40°C - 125°C | SSI | 56 | Pinion, module 0.3, 14 teeth | |

Note:
1. CPR to LPI Conversion. CPR range is typical value for a 1-inch outer diameter (OD) codewheel.
2. Shaft size. Typically 2 – 8mm for 1-inch OD codewheel. Larger shaft sizes possible if used with a larger OD codewheel.
3. Maximum RPM value is based on response frequency limitation of the encoder signal. Mechanical limit may be higher.
4. Motor Diameter is suggested minimum OD of a motor that the encoder series can fit into.
5. AEAT-60xx – magnetic encoder

Avago's multi-turn absolute encoders are recognized for their reliability and consistency in providing highly accurate absolute information for multiple revolutions. These encoders have a true mechanical system which eliminates the need of a battery back-up in the event of power failures or sudden stoppage. The absolute multi-turn encoders come in a choice of 12 and 14-bits for applications in a wide range of industries. They are commonly used in industries requiring linear positioning, such as the X&Y Positioning Tables found in medical institutions and hospitals.

## 5.2 Encoders for BLDC Motor System: By Operating Temperature

In choosing encoders for specific applications, one of the main criteria to consider is the temperature conditions where the encoder will be exposed. In many industrial motor systems, the operating temperature can rise to extreme levels. Using a low temperature encoder is not suitable in such an environment. Avago offers encoders with a wide range of temperature options to suit the need for different operating conditions.

#### 5.2.1 Extended temperature range

Encoders in the extended temperature category are specifically designed to tolerate operating temperatures up to 140ºC, depending on the type of encoders selected. They provide an integrated feedback solution within the motor-housing and reduce system space requirements. Applications include servo motors and certain industrial automation systems.

Avago's range of extended temperature encoders provide highly reliable solutions that meet or exceed the standards of performance demanded by industries. In addition, the price competitiveness and features enable overall cost savings.

#### 5.2.2 Standard temperature range

Encoders classified under the standard temperature category can tolerate operating temperatures up to 85ºC, depending on the encoders selected. Encoders here meet the standard automation requirements in most industrial automation applications.  Applications include factory automation systems, semiconductor equipments, office automation and consumer applications.

Design engineers have the option of choosing between modular units (encoder alone) or integrated solutions complete with customized housing that meet specific requirements.

### 5.2 Selection Table: Encoders by Operating Temperature

| Incremental | Part Number | Operating Temperature | Max RPM | Resolution | Output Type | No. of Channels | Motor Diameter | Shaft Sizes |
|---|---|---|---|---|---|---|---|---|
| Extended Temperature Range | HEDT-904x/914x | -40ºC - 140ºC | 12000 | 512 CPR | Digital | 3-Channel | 48 | See Note 2 |
| | HEDR-5xxx series | -40ºC - 100ºC | <5300 | 1200-3600CPR | Digital | 3-Channel | 42 | 2 to 8mm |
| | HEDC-5xxx | -40ºC - 100ºC | > 12000 | 50-1024CPR | Digital | 2 & 3-Channel | 42 | 2 to 8mm |
| | HEDT-900x/910x | -40ºC - 125ºC | >12000 | 100 - 512CPR | Digital | 2-Channel | 48 | See Note 2 |
| | AEDT-9340 | –10ºC to 85ºC / –40ºC to 115ºC | 4500 | 1000-2500CPR | Digital | 6-Channel | 42 | 3-12mm |
| | AEDT-9140 | –10ºC to 85ºC / –40ºC to 115ºC | >12000 | 100-1000CPR | Digital | 3-Channel | 31 | 3-12mm |
| | AEDx-8xxx | –40ºC to 100ºC | <30000 | 500 CPR | Digital | 2 & 3-Channel | 20 | 2-5mm |
| | HEDB-9xxx | -40ºC - 100ºC | >12000 | 96 - 1024CPR | Digital | 2 & 3-Channel | 48 | 2 to 8mm |
| | HEDS/M-55/56xx | -40ºC - 100ºC | >12000 | 96 - 1024CPR | Digital | 2 & 3-Channel | 42 | 2 to 8mm |
| | AEAT-6600-T16 | -40ºC - 125ºC | 7000 | 8, 16, 32, 64, 128, 256, 512, 1024 CPR | Digital | 3-Channel | ≥ 10 | Not applicable |
| | HEDS-90xx/91xx/92xx | -40ºC - 100ºC | >12000 | 50 - 2048CPR | Digital | 2 & 3-Channel | 48 | See Note 2 |
| | HEDL-55/56xx | 0ºC - 100ºC | >12000 | 100 - 512CPR | Digital | 2 & 3-Channel | 42 | 2 to 8mm |
| | HEDL-90xx/91xx | 0ºC - 100ºC | >12000 | 308 - 1024CPR | Digital | 2 & 3-Channel | 48 | See Note 2 |
| Standard Temperature Range | HEDS-971x | -40ºC - 85ºC | >12000 | 200 - 360LPI | Analog | 2-Channel | 40 | See Note 2 |
| | HEDS-97xx/973x/974x/978x | -40ºC - 85ºC | >12000 | 96 - 2048CPR | Digital | 2-Channel | 40 | See Note 2 |
| | AEDR-830x/831x | -20ºC - 85ºC | 9000 | 100 - 580CPR/ 36 - 212LPI | Digital | 1 & 2-Channel | ≥10 | See Note 2 |
| | AEDR-8400 | -20ºC - 85ºC | < 3000 | 700 - 870CPR/254 & 318LPI | Digital | 2-Channel | ≥10 | See Note 2 |
| | HEDR-542x | -10ºC - 85ºC | 4800 | 200CPR | Digital | 2-Channel | 23 | 2 to 5mm |
| | AEDB-9140 | -10ºC - 85ºC | >12000 | 100 - 500CPR | Digital | 3-Channel | 31 | 3 to 8mm |
| | AEDR-8320 | -10ºC - 70ºC | 2450 | 490CPR/ 180LPI | Analog | 2-Channel | ≥10 | See Note 2 |
| | AEDR-850x | -20ºC - 85ºC | 55kHz | 304LPI | Digital | 3-Channel | ≥ 10 | See Note 2 |
| | HEDL-55/560x | 0ºC - 70ºC | 6000 | 1000 - 1024CPR | Digital | 2-Channel | 42 | 2 to 8mm |
| **Absolute** | **Part Number** | **Temperature** | **Max RPM** | **Resolution** | **Output Type** | **Output Signal** | **Motor Diameter** | **Shaft Sizes** |
| Extended Temperature Range | AEAT-84AD | -40ºC - 125ºC | 12000 | 12-bit & 14-bit | Multi-Turn | SSI | 56 | Pinion, module 0.3, 14 teeth 6 |
| | AEAT-60xx | -40ºC - 125ºC | 12000 | 10-bit & 12-bit | Single-Turn | SSI | 23 | |
| | AEAT-7000 | -40ºC - 100ºC | 12000 | 13 bits | Single-turn | SSI | 56 | 8mm |
| | AEAT-6600-T16 | -40ºC - 125ºC | 7000 | 10, 12, 14, 16 bits | Single-turn | SSI, PWM | ≥ 10 | Not applicable |
| | AEAT-9000 | -40ºC - 115ºC | 12000 | 17 bits | Single-turn | SSI | 40-60 mm | 6-12mm |

Note:
1. CPR to LPI Conversion. CPR range is typical value for a 1-inch outer diameter (OD) codewheel.
2. Shaft size. Typically 2 – 8mm for 1-inch OD codewheel. Larger shaft sizes possible if used with a larger OD codewheel.
3. Maximum RPM value is based on response frequency limitation of the encoder signal. Mechanical limit may be higher.
4. Motor Diameter is suggested minimum OD of a motor that the encoder series can fit into.
5. AEAT-60xx – magnetic encoder

## 5.3 Encoders for BLDC Motor System: By Output Signal

Applications are generally designed to receive and transmit three different forms of output signal: analog, digital or synchronous serial interface (SSI). Analog output signals appear as a quasi-sinusoidal wave (unprocessed) while digital output signals resemble square waves (processed).

### 5.3.1 Digital signal output incremental encoders

Encoders that provide digital output are typically required in applications such as servo motor and drives, industrial automation, factory automation, semiconductor equipments, office automation applications and consumer products.

Avago's digital encoder is designed to suit commonly available output requirements. It comes in options of transistor-transistor logic (TTL) or RS422 standard line drivers. TTL is considered a commonly available output and is compatible with TTL logic levels, normally requiring

**5.3 Selection Table: Encoders by Output Signal**

| Incremental | Part Number | Output Type | No. of Channels | Operating Temperature | Max RPM | Resolution | Motor Diameter | Shaft Sizes |
|---|---|---|---|---|---|---|---|---|
| Digital | AEAT-6600-T16 | Digital | 3-Channel (ABI or UVW) | -40°C - 125°C | 7000 | 8, 16, 32, 64, 128, 256, 512, 1024 CPR | ≥ 10 | Not applicable |
| | AEDB/T-9340 | Digital | 6-Channel | -10°C - 85°C / -40°C - 115°C | 4500 | 1000 - 2500CPR | 42 | 3 to 12mm |
| | AEDB/T-9140 | Digital | 3-Channel | -10°C - 85°C / -40°C - 115°C | >12000 | 100 - 500CPR | 31 | 3 to 12mm |
| | AEDx-8xxx | Digital | 2- & 3-Channel | –40°C to 100°C | <30000 | 500 CPR | 20 | 2-5mm |
| | HEDT-904x/914x | Digital | 3-Channel | -40°C - 140°C | 12000 | 512 CPR | 48 | See Note 2 |
| | HEDL-904x/914x | Digital | 3-Channel | 0°C - 100°C | >12000 | 400 - 1000CPR | 48 | See Note 2 |
| | HEDB/S-904x/914x | Digital | 3-Channel | -40°C - 100°C | >12000 | 50 - 2048CPR | 48 | See Note 2 |
| | HEDL-55/564x | Digital | 3-Channel | 0°C - 100°C | >12000 | 100 - 512CPR | 42 | 2 to 8mm |
| | HEDL-55/560x | Digital | 2-Channel | 0°C - 70°C/ 0°C - 100°C | >12000 | 100 - 1024CPR | 42 | 2 to 8mm |
| | HEDM/S-55/560x | Digital | 2-Channel | -40°C - 100°C/ -40°C - 70°C | >12000 | 96 - 1024CPR | 42 | 2 to 8mm |
| | HEDR-5xxx series | Digital | 3-Channel | -40°C - 100°C | >5300 | 1200-3600CPR | 42 | 2 to 8mm |
| | HEDC-5xxx | Digital | 2- & 3-Channel | -40°C - 100°C | >12000 | 50-1024CPR | 42 | 2 to 8mm |
| | HEDB-900x/910x | Digital | 2-Channel | -40°C - 100°C | >12000 | 96 - 1024CPR | 48 | 2 to 8mm |
| | HEDS-90xx/91xx/92xx | Digital | 2-Channel | -40°C - 100°C | >12000 | 50 - 2048CPR | 48 | See Note 2 |
| | HEDL-900x | Digital | 2-Channel | 0°C - 100°C | 3000 | 2048CPR | 48 | See Note 2 |
| | HEDT-900x/910x | Digital | 2-Channel | -40°C - 125°C | >12000 | 100 - 512CPR | 48 | See Note 2 |
| | HEDS-97xx/973x/974x/978x | Digital | 2-Channel | -40°C - 85°C | >12000 | 96 - 2048CPR | 40 | See Note 2 |
| | HEDR-542x | Digital | 2-Channel | -10°C - 85°C | 4800 | 200CPR | 23 | 2 to 5mm |
| | AEDR-850x | Digital | 3-Channel | -20°C - 85°C | 55kHz | 304LPI | ≥ 10 | See Note 2 |
| | AEDR-8400 | Digital | 2-Channel | -20°C - 85°C | < 3000 | 700 - 870CPR/254 & 318LPI | ≥10 | See Note 2 |
| | AEDR-830x | Digital | 2-Channel | -20°C - 85°C | 9000 | 100 - 580CPR/ 36 - 212LPI | ≥10 | See Note 2 |
| | AEDR-831x | Digital | 1-Channel | -20°C - 85°C | 9000 | 100 - 580CPR/ 36 - 212LPI | ≥10 | See Note 2 |
| Analog | HEDS-971x | Analog | 2-Channel | -40°C - 85°C | >12000 | 200 - 360LPI | 40 | See Note 2 |
| | AEDR-8320 | Analog | 2-Channel | -10°C - 70°C | 2450 | 490CPR/ 180LPI | ≥10 | See Note 2 |

Note:
1. CPR to LPI Conversion. CPR range is typical value for a 1-inch outer diameter (OD) codewheel.
2. Shaft size. Typically 2 – 8mm for 1-inch OD codewheel. Larger shaft sizes possible if used with a larger OD codewheel.
3. Maximum RPM value is based on response frequency limitation of the encoder signal. Mechanical limit may be higher.
4. Motor Diameter is suggested minimum OD of a motor that the encoder series can fit into.
5. AEAT-60xx – magnetic encoder

a 5 volt supply. Line drivers are low output impedance devices, designed to drive signals over longer distances, and are normally used with a matched receiver.

#### 5.3.2 Analog signal output incremental encoders

Encoders that provide analog output are typically required by high-end motors such as the high resolution servo motors. Analog signal output encoders have the ability to achieve higher resolution through external interpolation electronics.

#### 5.3.3 SSI signal output absolute encoders

Avago's absolute encoders are designed with a non-proprietary SSI standard output. This standard communication protocol enables the encoder to be interfaced, directly or through simple interface boards, with most signal processing circuitries to provide design-in flexibility and easy integration into existing motor controllers.

### 5.4 Encoders for BLDC Motor System: By Shaft Size

Motor shaft sizes differ from one application to another. Shaft sizes of motors typically are linearly proportional to the motor frame size or diameter. The shaft size requirement of an encoder or its codewheel is typically

**5.4 Selection Table: Encoders by Shaft Sizes**

| Incremental | Part Number | Shaft Sizes | Motor Diameter | Resolution | Max RPM | Operating Temperature | Output Type | No of Channels |
|---|---|---|---|---|---|---|---|---|
| Large | AEDB/T-9340 | 3 to 12mm | 42 | 1000 - 2500CPR | 4500 | -10°C - 85°C / -40°C - 115°C | 3 & 6-Channel | Digital |
| | HEDT-90xx/91xx | See Note 2 | 48 | 100 - 512CPR | 12000 | -40°C - 125°C | 2 & 3-Channel | Digital |
| | HEDL-90xx/91xx | See Note 2 | 48 | 1000 - 2000CPR | >12000 | -40°C - 100°C | 2 & 3-Channel | Digital |
| | HEDS-90xx/91xx/92xx | See Note 2 | 48 | 50 - 2048CPR | >12000 | -40°C - 100°C | 2 & 3-Channel | Digital |
| | HEDT-90xx/91xx | See Note 2 | 48 | 100 - 512CPR | 12000 | -40°C - 125°C | 2 & 3-Channel | Digital |
| Medium | HEDS-97xx | See Note 2 | 40 | 96 - 2048CPR/ up to 480LPI | >12000 | -40°C - 85°C | 2-Channel | Digital |
| | HEDR-5xxx series | 2 to 8mm | 42 | 1200-3600CPR | >5300 | -40°C - 100°C | 3-Channel | Digital |
| | HEDC-5xxx | 2 to 8mm | 42 | 50-1024CPR | >12000 | -40°C - 100°C | 2 & 3-Channel | Digital |
| | AEDB/T-9140 | 3 to 12mm | 31 | 100 - 500CPR | >12000 | -10°C - 85°C / -40°C - 115°C | 3-Channel | Digital |
| | HEDB-9xxx | 2 to 8mm | 48 | 96 - 1024CPR | >12000 | -40°C - 100°C | 2 & 3-Channel | Digital |
| | HEDx-55/56xx | 2 to 8mm | 42 | 50 - 1024CPR | >12000 | -40°C - 70°C/ -40°C - 100°C | 2 & 3-Channel | Digital |
| Small | AEDx-8xxx | 2-5mm | 20 | 500 CPR | <30000 | –40°C to 100°C | 2- & 3-Channel | Digital |
| | HEDR-542x | 2 to 5mm | 23 | 200CPR | 4800 | -10°C - 85°C | 2-Channel | Digital |
| | AEDR-8300 | See Note 2 | ≥10 | 100 - 580CPR/ 36 - 212LPI | 9000 | -20°C - 85°C | 1 & 2-Channel | Digital |
| | AEDR-8320 | See Note 2 | ≥10 | 490CPR/ 180LPI | 2450 | -10°C - 70°C | 2-Channel | Analog |
| | AEDR-8400 | See Note 2 | ≥10 | 700 - 870CPR/254 & 318LPI | < 3000 | -20°C - 85°C | 2-Channel | Digital |
| | AEDR-850x | See Note 2 | ≥ 10 | 304LPI | 55kHz | -20°C - 85°C | Digital | 3-Channel |
| | AEAT-6600-T16 | Not applicable | ≥ 10 | 8, 16, 32, 64, 128, 256, 512, 1024 CPR | 7000 | -40°C - 125°C | Digital | 3-Channel |
| **Absolute** | **Part Number** | **Shaft Sizes** | **Motor Diameter** | **Resolution** | **Max RPM** | **Operating Temperature** | **Output Signal** | |
| Single Turn | AEAT-60xx | 6mm | 23 | 10 & 12-bit | 12000 | -40°C - 125 °C | SSI | |
| | AEAT-7000 | 8mm | 56 | 13 bits | 12000 | -40°C - 100°C | SSI | |
| | AEAT-6600-T16 | Not applicable | ≥ 10 | 10, 12, 14, 16 bits | 7000 | -40°C - 125°C | SSI, PWM | |
| | AEAT-9000/AEAT-9035 | 8mm | 40 to 60mm | 17 bits | 12000 | -40°C - 115°C | SSI | |
| Multi-Turn | AEAT-84AD | Pinion, module 0.3, 14 teeth | 60 | 12 & 14-bit | 12000 | -40°C - 125°C | SSI | |

Note:
1. CPR to LPI Conversion. CPR range is typical value for a 1-inch outer diameter (OD) codewheel.
2. Shaft size. Typically 2 – 8mm for 1-inch OD codewheel. Larger shaft sizes possible if used with a larger OD codewheel.
3. Maximum RPM value is based on response frequency limitation of the encoder signal. Mechanical limit may be higher.
4. Motor Diameter is suggested minimum OD of a motor that the encoder series can fit into.
5. AEAT-60xx – magnetic encoder

dependent of the motor selected for the particular application. Avago Technologies offers encoder systems which match a wide range of motor shaft sizes.

#### 5.4.1 Large shaft size

Encoders in the large shaft size category are suitable for shaft sizes from 10mm or above, depending on the type of encoder selected. Some of the encoders listed here can easily fit larger shaft sizes through the use of a larger OD codewheel.

#### 5.4.2 Medium shaft size

Encoders in the medium shaft size category are suitable for shaft sizes up to 8mm, depending on the type of encoder selected. Some of the encoders listed here can accommodate larger shaft sizes by using a larger size codewheel.

#### 5.4.3 Small shaft sizes

Encoders in the small shaft sizes category are suitable for shaft sizes of 6mm and below. These encoders typically have small form factors and used in space limited applications. Some of the encoders listed here can accommodate larger shaft sizes by using a larger codewheel.

### 5.5 Encoders for BL DC Motor System: By Motor Speed

Generally, an incremental encoder will have a maximum electrical signal frequency at which it will operate. The maximum rotational speed is determined by this frequency. If the maximum speed is exceeded, the output will become unreliable and inaccuracies will occur. Usage of a high speed encoder for an application which only requires much lower speed will not be cost effective.

Avago offers a wide range of rotation speeds to meet the various types of speed requirements typically found in applications. The encoders are classified into three categories: below 3,000 revolutions per minute (rpm), 3,000 rpm to 6,000 rpm and those from 6,000 rpm to 12,000 rpm.

It is important to note that the mechanical limit for the encoders may be much higher than the electrical limit, which typically is 12000 rpm or higher.

#### 5.5.1 3,000 rpm and below

These solutions are specifically designed in compact form for an easier design-in to most applications, while maintaining a low cost structure to assist customers. Typical applications requiring low speed encoders include office automation and consumer products.

#### 5.5.2 3,000 rpm to 6,000 rpm

Avago's encoders ensure reliability and performance, meeting or exceeding standard operating requirements for feedback systems. It provides good price to performance ratio and ensures an easy assembly process.

Typical applications that require these rotational speeds include servo motor and drives, and various other applications in the industrial and factory automation process.

#### 5.5.3 6,000 rpm to 12,000 rpm

Avago's encoders ensure reliability and provide faster servo response time with an improved dynamic performance. The encoders are designed to cater to a variety of different shaft and motor sizes, complete with a wide range of resolutions and abilities to cater to compact packaging requirements.

**5.5 Selection Table: Encoders by Motor Speed**

| | Size | | |
|---|---|---|---|
| **Speed** | **< 20** | **20 to 40** | **40 to 60** |
| < 3000 | AEDR-8400<br>AEDR-850x<br>AEDR-83xx | AEDR-8400<br>AEDR-83xx<br>HEDS-97xx /90xx<br>HEDR-54xx<br>AEDB-9140 | AEDR-8400<br>AEDR-83xx<br>HEDS-97xx /90xx<br>AEDB-9340<br>HEDS-974xx<br>HEDx-55xx /56xx<br>HEDB-9000<br>HEDx-90 /91xx |
| 3000-6000 | AEDR-83xx | AEDR-83xx<br>HEDS-97xx /90xx<br>HEDR-54xx<br>AEDB/T-9140 | AEDR-83xx<br>HEDS-97xx /90xx<br>AEDB/T-9340 |
| 6000-12000 | AEDx-8xxx<br>AEAT-6600-T16 | AEDB-9140 | HEDx-55xx /56xx<br>HEDB-9000<br>HEDx-90 /91xx<br>AEAT-7000<br>AEAT-9000 |

### 5.6 Encoders for BLDC Motor System: By Motor Diameter

Electrical motors are used in a diverse range of applications stretching from industrial usage, medical equipments office automation to consumer products. Taking this into consideration, the motor system itself is offered in a variety of sizes depending on the usage, capacity , etc.

Here, Avago's encoders are developed to meet different motor diameter sizes. The encoders are suitable for motors that measure from 10mm to 56mm in diameter, or larger.

### 6.0 Ordering Information

Kindly refer to Avago Technologies's Motion Sensing and Control Products Selection Guide, publication number AV00-0099EN (11th September 2012) for ordering information on our full range of products.

**5.6 Selection Table: Encoder Compatibility To Motor Diameter**

| | Part Number | Motor Diameter | Resolution | Max RPM | Operating Temperature | Output Type | No of Channels | Shaft Sizes |
|---|---|---|---|---|---|---|---|---|
| Incremental | AEAT-6600-T16 | ≥ 10 | 8, 16, 32, 64, 128, 256, 512, 1024 CPR | 7000 | -40°C - 125°C | Digital | 3-Channel | Not applicable |
| | AEDR-8300 | ≥10 | 100 - 580CPR/ 36 - 212LPI | 9000 | -20°C - 85°C | Digital | 1 & 2-Channel | See Note 2 |
| | AEDR-8320 | ≥10 | 490CPR/ 180LPI | 2450 | -10°C - 70°C | Analog | 2-Channel | See Note 2 |
| | AEDR-8400 | ≥10 | 700CPR/ 254LPI | < 3000 | -20°C - 85°C | Digital | 2-Channel | See Note 2 |
| | AEDR-850x | ≥ 10 | 294-304LPI | 55kHz | -20°C - 85°C | Digital | 3-Channel | See Note 2 |
| | AEDx-8xxx | 20 | 500 CPR | <30000 | –40°C to 100°C | Digital | 2- & 3-Channel | 2-5mm |
| | HEDR-542x | 23 | 200CPR | 4800 | -10°C - 85°C | Digital | 2-Channel | 2 to 5mm |
| | AEDB/T-9140 | 31 | 100 - 500CPR | >12000 | -10°C - 85°C | Digital | 3-Channel | 3 to 8mm |
| | HEDS-97xx | 40 | 96 - 2048CPR/ up to 480LPI | >12000 | -40°C - 85°C | Digital | 2-Channel | See Note 2 |
| | AEDB/T-9340 | 42 | 1000 - 2500CPR | 4500 | -10°C - 85°C | Digital | 6-Channel | 3 to 10mm |
| | HEDx-55/56xx | 42 | 50 - 1024CPR | >12000 | -40°C - 70°C/ - 40°C - 100°C | Digital | 2 & 3-Channel | 2 to 8mm |
| | HEDT-90xx/91xx | 48 | 100 - 512CPR | 12000 | -40°C - 125°C | Digital | 2 & 3-Channel | See Note 2 |
| | HEDB-9xxx | 48 | 96 - 1024CPR | >12000 | -40°C - 100°C | Digital | 2 & 3-Channel | 2 to 8mm |
| | HEDL-90xx/91xx | 48 | 1000 - 2000CPR | >12000 | -40°C - 100°C | Digital | 2 & 3-Channel | See Note 2 |
| | HEDS-90xx/91xx/92xx | 48 | 50 - 2048CPR | >12000 | -40°C - 100°C | Digital | 2 & 3-Channel | See Note 2 |
| **Absolute** | **Part Number** | **Motor Diameter** | **Resolution** | **Max RPM** | **Operating Temperature** | | **Output Signal** | **Shaft Sizes** |
| Single Turn | AEAT-60xx | 23 | 10 & 12-bit | 12000 | -40°C to 125°C | | SSI | 6mm |
| | AEAT-7000 | 60 | 13 bits | 12000 | -40°C - 100°C | | SSI | 8mm |
| | AEAT-6600-T16 | ≥ 10 | 10, 12, 14, 16 bits | 7000 | -40°C - 125°C | | SSI, PWM | Not applicable |
| | AEAT-9000/AEAT9035 | 40 to 60 | 17 bits | 12000 | -40°C - 115°C | | SSI | 6 to 12mm |
| Multi-Turn | AEAT-84AD | 60 | 12-bit & 14-bit | 12000 | -40°C - 125°C | | SSI | Pinion, module 0.3, 14 teeth |

Note:
1. CPR to LPI Conversion. CPR range is typical value for a 1-inch outer diameter (OD) codewheel.
2. Shaft size. Typically 2 – 8mm for 1-inch OD codewheel. Larger shaft sizes possible if used with a larger OD codewheel.
3. Maximum RPM value is based on response frequency limitation of the encoder signal. Mechanical limit may be higher.
4. Motor Diameter is suggested minimum OD of a motor that the encoder series can fit into.
5. AEAT-60xx – magnetic encoder

# Your Imagination. Our Innovation

From the smartphone that keeps you in touch, to the fiber optic network that keeps a $10-billion corporation connected, we get our information these days through an ever-increasing array of sophisticated device technologies. And behind it all, are semiconductors that sense, illuminate, and connect the signals in order to process that digital data.

Avago Technologies is a leading supplier in III-V compound and silicon semiconductors providing an extensive range of analog, mixed signal and optoelectronics components that are backed by over 5,000 patents to approximately 40,000 end customers.

Our heritage of technical innovation dates back 45 years, and includes over 1,000 talented design and product engineers. We believe in strong customer service support and intense collaboration to create leading-edge proprietary technologies to solve customers' technical bottlenecks. In that way - Our innovation helps bring your imagination to market.

## Avago products serve three diverse end markets

**Wireless Communications** serving the smartphone/handset and Base Station infrastructure markets with over 250 patents and leading-edge products that include:

- Power Amplifiers
- Front End Modules
- Film Bulk Acoustic Resonator (FBAR) Filters
- GPS/GLONASS LNAs
- Optical Finger Navigation
- LED Backlighting, Screen Illumination
- Ambient Light and Proximity Sensors

**Wired Infrastructure** for switches/routers, data centers, supercomputers and storage/ servers with over 200 patents in parallel optics alone and products that include:

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- 20Gb SerDes ASICs in 40nm
- Storage Fibre Channel Transceivers
- QSFP/SFP Sonet Transceivers

**Industrial and Automotive Electronics** for alternative energy power generation, electronic sign and signals, automated manufacturing, automotive lighting, GPS/ GLONASS navigation, motor inverter system, battery charging and management, infotainment systems and vehicle safety systems with products that include:

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- Isolation and Digital Optocouplers
- Motion Control Optical & Magnetic Encoders
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