



TECHNICAL BASICS

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TECHNICAL INDEX



What is an encoder?

The encoder is a device that converts the angular or linear motion of a shaft or axle into a series of electrical digital pulses.

These pulses are used to control the motion of the mechanical shaft that generated them. The encoder is composed by:

- Mechanical interface
- Code wheel (or magnetic actuator or linear scale)
- Optoelectronic receiver (or magnetic sensor)
- Electrical interface

Main technologies used in encoders to detect the signals are:

- Photoelectrical or optical scanning (rotary or linear)
- Magnetic field variations (rotary or linear)
- Potentiometer (rotary or linear)
- Magnetostrictive effect (linear)
- Energy Harvesting Effect (rotary)

Main applications of rotary and linear transducers are: machine-tools, material processing machinery, robots, motor feedback systems, measure and motion control devices.

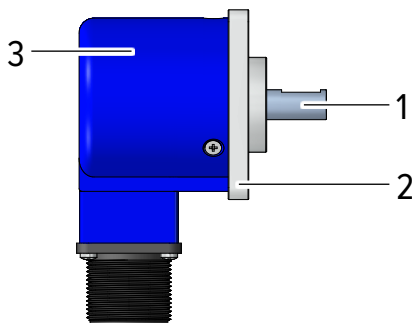
Mechanical interface

The mechanical interface consists in all those components that allow the coupling the encoder to be coupled to the machine or device of application.

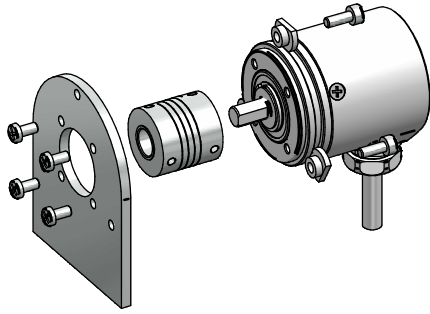
These components include:

1. An **axle**, connected to the shaft of the machine in rotation, designed in accordance to the type of fixing: **solid** or **blind/through hollow shaft**;
2. A **flange**, which fixes and adjusts the encoder to its support;
3. An **housing**, which contains and protects the disc and the electronic components.

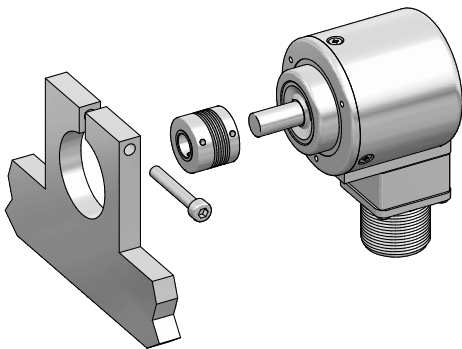
Elastic couplings can also be used to adjust the connection between the motor shaft and the encoder.



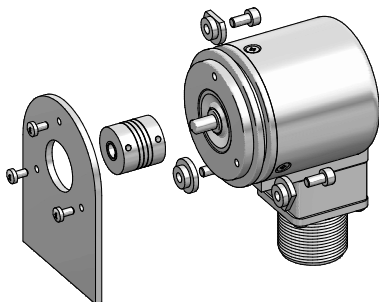
Some examples of encoders' mounting



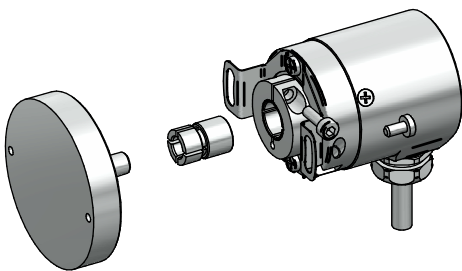
Solid shaft rotary encoder mounted by a fixing flange and the elastic coupling.



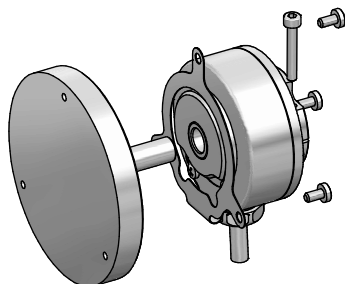
Solid shaft rotary encoder mounted by a clamping fixing.



Solid shaft rotary encoder mounted by a fixing flange (or by fixing clamps) and the elastic coupling.



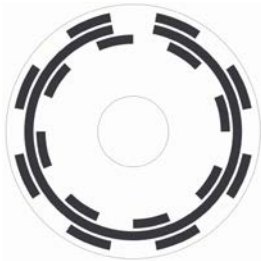
Blind hollow shaft rotary encoder mounted by a stator coupling with collar clamping shaft fixing.



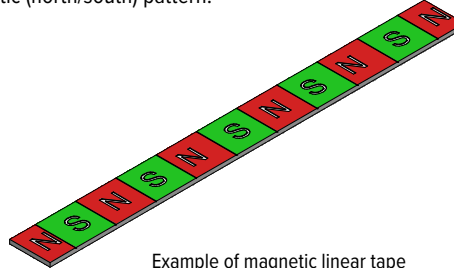
Through hollow shaft encoder with a rear collar clamping shaft fixing.

Encoder code wheel (or magnetic / linear scale)

The encoder code wheel determines the transmission code of pulses. It consists of a support made of plastic, glass or metallic material, on which a pattern of alternating clear (transparent) and opaque segments is engraved. On linear scales, this pattern is replaced by a stationary opaque strip. Magnetic sensing replaces the codewheel or linear scale with a magnetic (north/south) pattern.



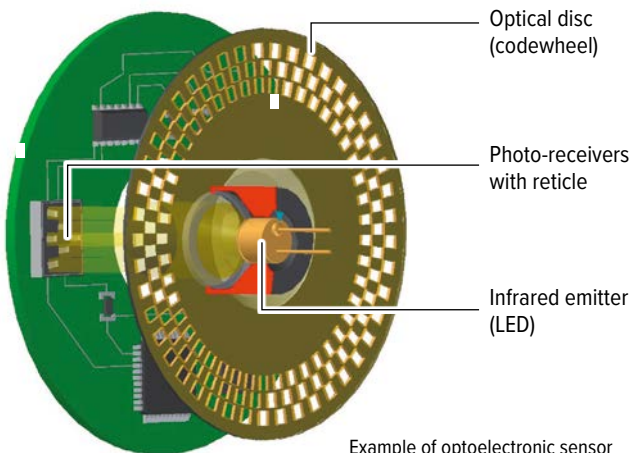
Example of a codewheel



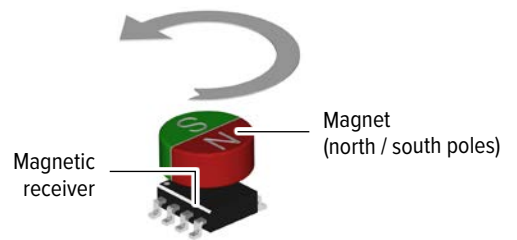
Example of magnetic linear tape

Encoder optoelectronic receiver (or magnetic sensor)

The optoelectronic receiver is made by an array of sensor (photodiodes or phototransistors) which is illuminated by an infrared light source (IR LED). Between the receiver and the LED there's the graduated codewheel. The light projects the disk image on the receivers surface which are covered by a grating called reticle having the same disk steps. The receivers trasduce the occurring light variations caused by the disk shifting and convert them into their corresponding electrical variations. In magnetic encoders system is made by a rotating actuator with a magnet and the magnetic sensor convert magnetic field variation into electrical signals.



Example of optoelectronic sensor



Example of magnetic sensor

Electrical interface

The electrical interface is how the encoder transmits data to a receiver. It uses electrical signals, which can be digital or analogue, that are sent through the encoder cable to an intelligent device, such as an interface board or PLC. The type of encoder, whether incremental or absolute, determines the electrical interface.

Interfaces on incremental encoders are:

- **NPN**
- **NPN Open collector**
- **Push pull**
- **Line driver**

Interfaces on absolute encoders are:

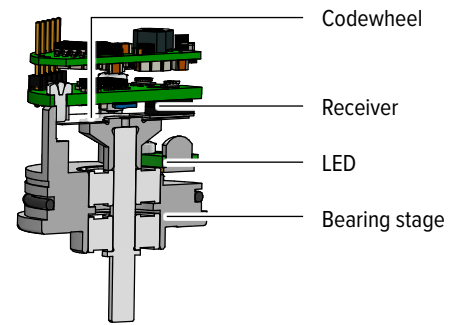
- **Analogue (voltage or current)**
- **Bit-parallel (NPN / NPN Open collector / PNP / PNP Open collector / Push pull)**
- **Serial transmission (Serial Synchronous Interface (SSI) / BiSS)**
- **Fieldbus (Canopen / Profinet / Ethercat)**

Photoelectric or optical scanning (rotary or linear)

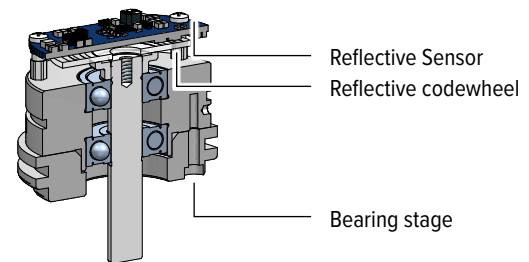
There are two ways to build an optical scanning system: transmissive or reflective. In a transmissive optical encoder, the scanning system relies on the rotation of a graduated disc or code wheel patterned with alternating opaque and clear segments. The code wheel is illuminated by an infrared light source positioned perpendicularly to the sensor.

The disc projects its image onto multiple receivers, which are masked by a grid known as a 'reticle' with the same pitch. The receivers detect changes in light that occur during the disc's rotation and convert them into corresponding electric pulses. Linear transducers operate on a similar principle, but detect motion using a linear reading system.

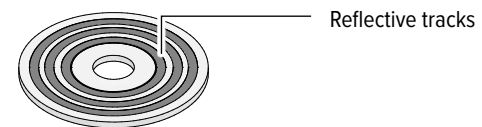
The reflective optical system is based on photoelectric scanning of a code wheel. In this technology, the light source and receiver are in the same surface mount package. The code wheel is formed by darker segments alternated with reflective ones. The light is reflected and detected by the sensor (receiver), which transforms the variations into corresponding pulses, as per the transmissive system. This type of reading allows for a reduction in device size while maintaining performance. It is an ideal solution for applications that require miniaturized encoders with high resolution.



Example of transmissive encoder



Example of reflective encoder

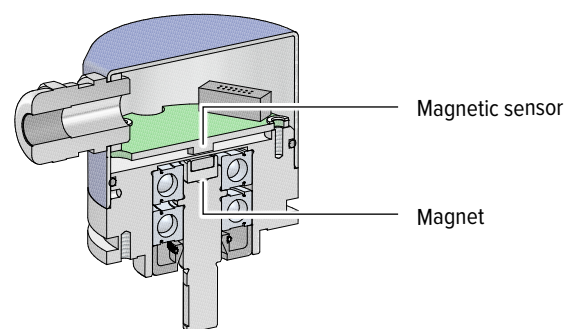


Example of multi track reflective codewheel

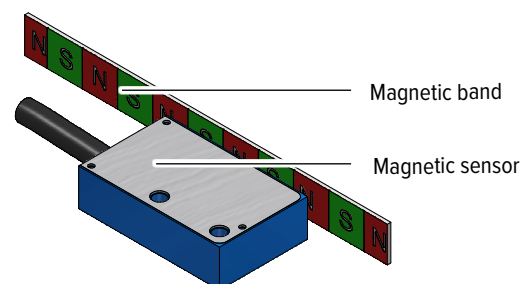
Magnetic sensing (rotary or linear)

Magnetic encoders use a signal detection system that detects changes in the magnetic flux generated by a rotating magnet (with one or more pole pairs) in front of a sensor fixed to the encoder's shaft. The sensor samples the magnetic field variation and converts it into an electric pulse, which determines the position.

There are two types of magnetic technology: on-axis and off-axis. The primary advantage of magnetic technology is its non-contact detection system, which prevents wear and makes it cost-effective due to its low maintenance and potentially infinite durability. Magnetic encoders are ideal for heavy-duty applications that require high robustness, speed, and a wide range of operating temperatures, while also ensuring excellent signal reliability.



Magnetic rotary encoder

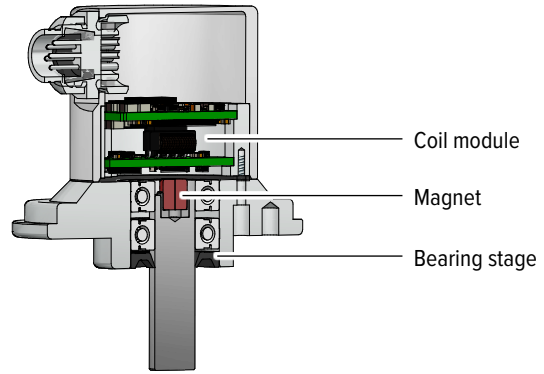


Magnetic incremental linear encoder

Energy harvesting (rotary)

Multiturn counting is enabled using energy-harvesting technology. A magnet mounted on the rotating shaft moves in tandem, and the energy-harvesting coil module cuts the moving magnet field to generate energy. This effect generates the same amount of energy independently of the rotation speed. The energy generated is sufficient to power the revolution tracking circuitry.

Therefore, miscounts are prevented even without an external power supply. This technology can replace traditional gear technology because it does not wear out (no contact technology).

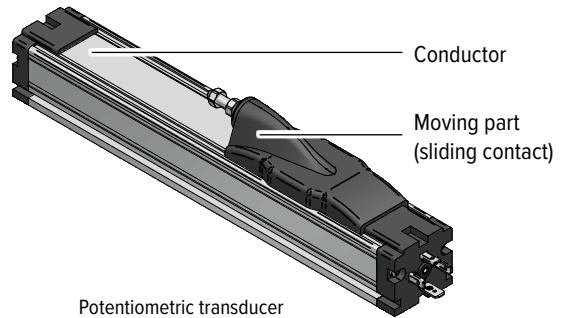


Energy Harvesting engine

Potentiometric sensing (rotary or linear)

This linear/rotary transducer consists of a wire or metal layer wound around a non-conductive support and a movable contact that shifts along the conductor. The operating principle is based on the change in resistance of an electric circuit caused by the displacement of the object whose position needs to be determined.

Potentiometers are ideal for use in machinery for processing thermo-plastics, wood, marble, iron, and steel, as well as any application that requires absolute measurement of position and motion.

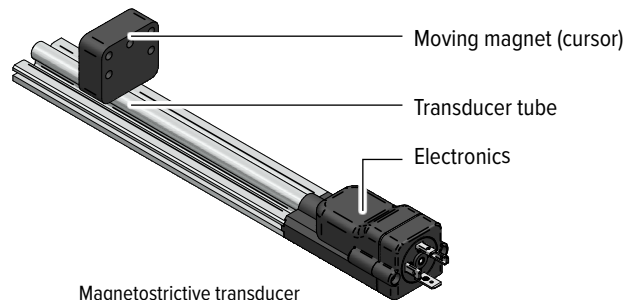


Potentiometric transducer

Magnetostrictive sensing (linear)

Magnetostrictive transducers are based on the magnetostriction principle. Certain materials expand and contract when exposed to an alternating magnetic field. The two magnetic fields are generated by the moving magnet and the current pulse inside the transducer tube. This interaction creates a strain pulse that travels inside the tube until it is detected by the electronics.

The absolute position is calculated by measuring the time of the strain pulse compared to the current pulse that generates it. This technology's key factor is the absence of any electrical contact on the slider, making the device highly resistant to wear and tear while ensuring great speed and precision.

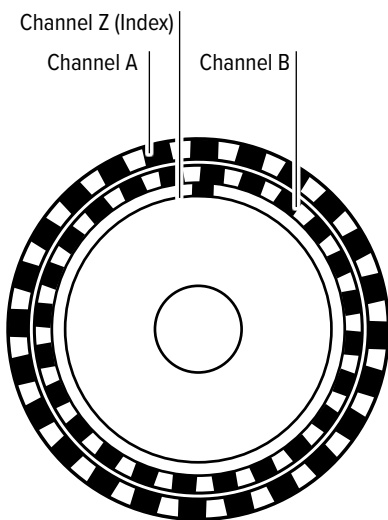


Magnetostrictive transducer

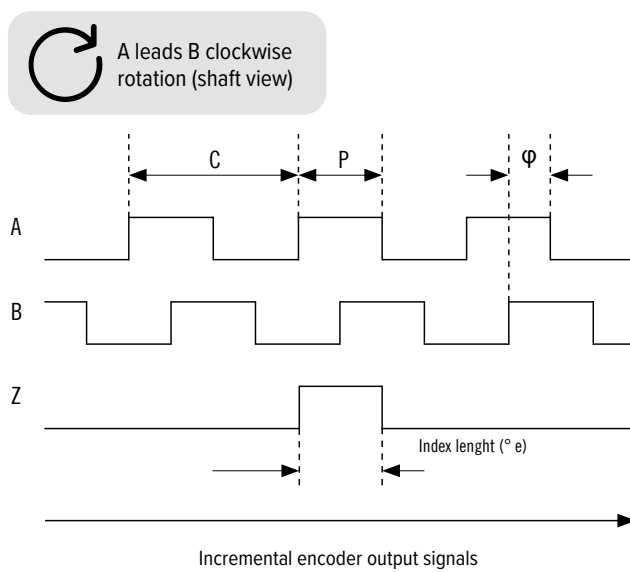
Incremental encoder

The incremental encoder is so called because it tracks changes relative to a reference point, regardless of the direction of rotation. It senses rotation, speed, and acceleration by counting output circuit pulses, but the machine's zero point must be reset at each new start. The incremental encoder typically provides two types of square waves.

Channel A provides information about the rotation speed, while channel B provides data regarding the direction of rotation based on the sequence produced by the two signals. The resolution can be increased by reading not only the rising edges but also the falling edges of A and B signals, which are out of phase by 90 degrees electrically. Using this method, an encoder with 1000 physical pulses per revolution can generate 2000 or 4000 pulses per revolution. Additionally, a Zero (Z or Index) channel is available, which provides the absolute 'zero' position of the encoder shaft and serves as a reference point.



Example of 3 channels incremental encoder codewheel



One Cycle: 360 electrical degrees (°e).

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 (P): the number of electrical degrees that an output is high during 1 cycle. This value is nominally 50 % (or $180^\circ e$).

Pulse Width Error (ΔP): the deviation, in electrical degrees, of the pulse width from its ideal value. Typical value is max $\pm 10\%$ on optical encoders or $\pm 20\%$ on magnetic encoders.

Phase (ϕ): the numbers of electrical degrees between the center of the high state of the channel A and the center of the high state of the channel B.

This value is nominally $90^\circ e$ for a quadrature output.

Phase Error ($\Delta\phi$): the deviation of the phase from its ideal value. Typical value is max $\pm 30^\circ e$ on optical encoders or $\pm 40^\circ e$ on magnetic encoders.

Index length (°e): Index is aligned on the channel A and its length can be $180^\circ e$ or $90^\circ e$ (called A&B)

Number of encoder pulses is determined from angular or linear resolution needed. For linear applications a calculation is required to convert linear movements into rotary.

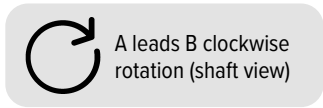
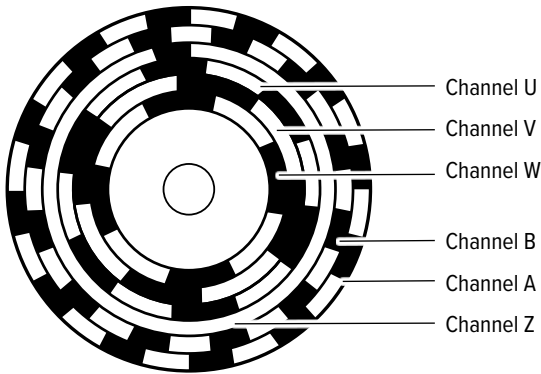
$$\text{Encoder Resolution (ppr)} = \frac{\text{Circumference}}{\text{Accuracy}}$$

Encoder max pulse frequency can be considered according to the speed and the encoder resolution.

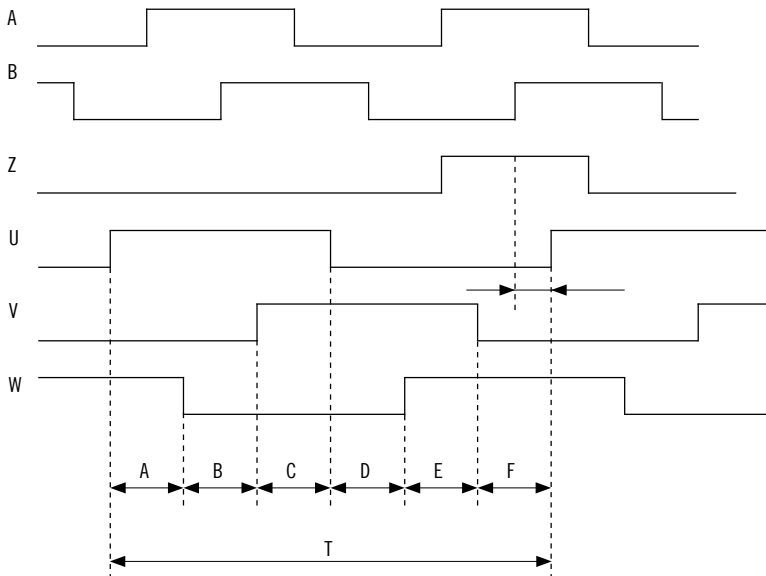
$$\text{Frequency} = \frac{\text{rpm} \times \text{resolution (ppr)}}{60}$$

There are other encoders that integrate additional electrical output signals called incremental encoders with integrated commutation signals, normally used as motor feedback. These additional signals (called U, V, W) simulate the commutation (Hall) signals, which are usually employed in brushless motors and are usually generated by integrated magnetic sensors.

In Eltra's encoders commutation signals are optically generated and are represented as 3 squared waves, shifted by 120° electrical degrees (see below table about the relation between motor poles and pulse degrees). These signals are used by the drive to generate the correct motor supply phases sequences. These commutation signals can be repeated many times within one mechanical revolution, since they depend directly on the number of poles of the motor.



Example of 6 channels commutation encoder codewheel



INCREMENTAL SIGNALS

COMMUTATION SIGNALS (HALL)

MOTOR POLES	A / B / C / D / E / F	T
4	30° ±1,5°	180°
6	20° ±1,5°	120°
8	15° ±1,5°	90°

Absolute encoder

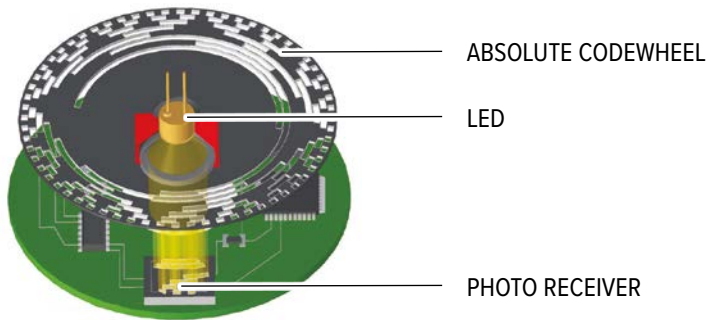
The absolute encoder provides a unique digital code for each angle position of the shaft, storing the value of the current position and, therefore, preventing the loss of the information in case of restarting the system or of a power-loss.

The absolute encoder could be of two types:

- Singleturn
- Multiturn

The singleturn absolute encoder allows a precise encoding of the angular position of the shaft, to which the encoder is coupled to, even if the power goes off. Therefore, each single degree position is converted into a specific code (Gray or binary) proportionally to the number of bit.

The multiturn absolute encoder allows a higher number of applications, representing a very interesting extension of the encoders' action field. Besides the angular tracking of the singleturn system, the multiturn stores also the counting of number of revolutions made.



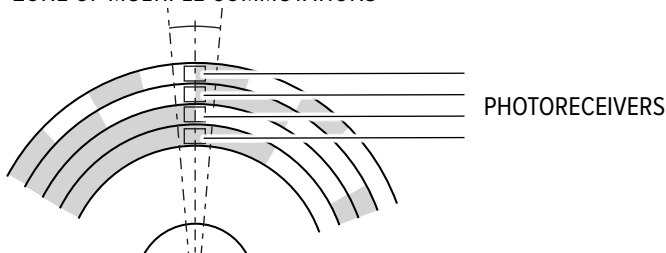
Gray or binary code

Absolute encoders maintain the absolute position value even after an interruption or loss of power. Therefore, it is essential that all position-related data is always available. Binary codes are used for this purpose. These are defined by the pattern of clear and opaque segments arranged on the disc in a transverse or longitudinal direction with respect to the direction of movement.

Binary code

The natural binary code has the disadvantage of having more binary digits change between two consecutive positions. Due to mechanical tolerances, bounces, or noise, it is possible that the commutation signals do not switch simultaneously when the state changes, resulting in intermediate situations that could cause errors in position calculation. To prevent this issue and avoid errors in the output code, an output sync signal (STROBE) is utilised.

ZONE OF MULTIPLE COMMUTATIONS



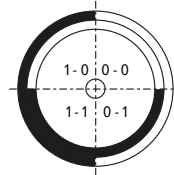
Gray code

Gray code is a binary code in which only one digit changes between consecutive steps. To avoid encoding errors caused by bit changes in contiguous positions, the code tracks are read crosswise with respect to the direction of movement.

DECIMAL	BINARY	GRAY
0	0000	0000
1	0001	0001
2	0010	0011
3	0011	0010
4	0100	0110
5	0101	0111
6	0110	0101
7	0111	0100
8	1000	1100
9	1001	1101
10	1010	1111
11	1011	1110
12	1100	1010
13	1101	1011
14	1110	1001
15	1111	1000

1-1 0-0
1-0 0-1

2 Bit optical disc with binary code



2 Bit optical disc with gray code

Gray code can be converted to binary with a simple combinatory circuit (XOR).

The gray excess code

However, if the number of defined positions is not a power of 2, even with the Gray code, more than one bit can change simultaneously between the last and the first code value. For example, in a 12 ppr absolute encoder, the code should be like the one shown in the table below. It is evident that between the positions “11” and “0”, 3 bits can simultaneously change, leading to reading errors.

The Gray excess code maintains one-bit variation specificity by aligning the 0 position with the N value.

N is a number that, when subtracted from the Gray code and converted into binary, provides the exact position value.

POSITION	GRAY
0	0000
1	0001
2	0011
3	0010
4	0110
5	0111
6	0101
7	0100
8	1100
9	1101
10	1111
11	1110
0	0000

← Error

The formula to calculate the N value is:

$$N = (2^n - IMP) / 2$$

Where : IMP is the number of PPR

2ⁿ is the power of 2 multiple immediately higher than IMP

In our example N will be:

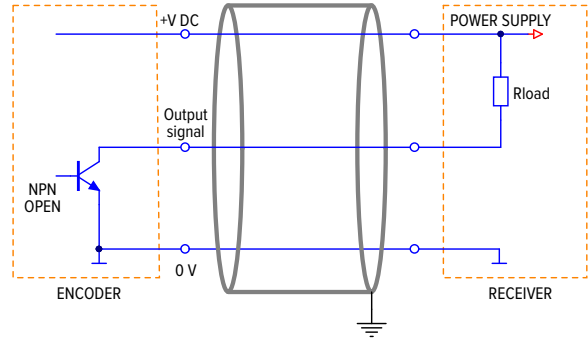
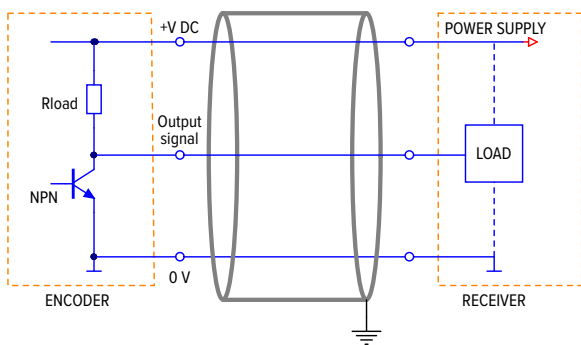
$$N = (2^4 - 12) / 2 = (16-12) / 2 = 2$$

Electrical interfaces

NPN / NPN open collector

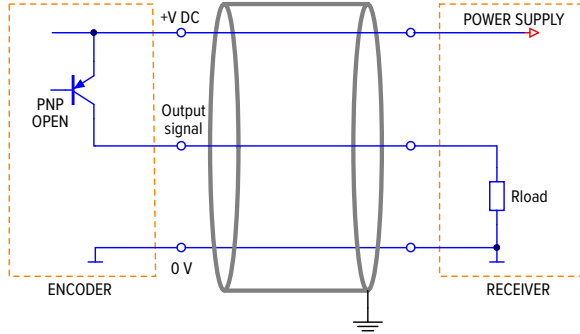
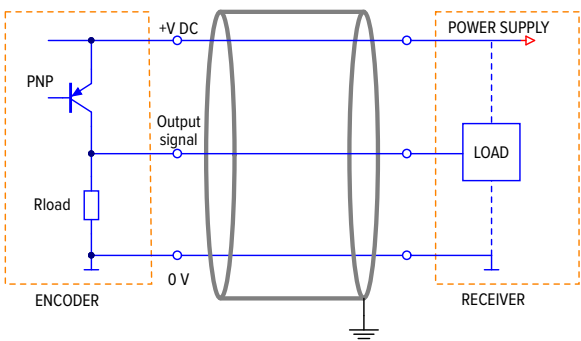
The circuit consists of an NPN transistor and a pull-up resistor, which is used to match the output voltage to the power supply when the transistor is off (also known as a 'sink output'). Output performance is limited by cable length, signal frequency, and load.

In the open collector variant, there is no pull-up resistor, allowing for signals with different voltages.



PNP / PNP open collector

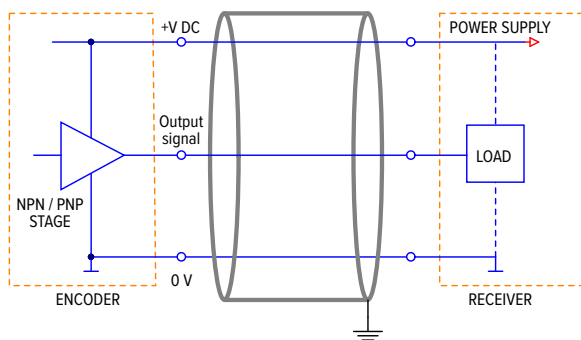
The main difference is the transistor, which is a PNP type (also known as a 'source output'). If present, the resistor is in a pull-down configuration. This configuration has the same limitations as an NPN transistor in terms of cable length, frequency, and load.



Push-Pull

In NPN or PNP electronics, frequency performance is limited by the resistor, which has a much higher impedance than a transistor. To overcome this issue, push-pull electronics use complementary transistors, reducing the impedance for commutation to positive levels and to zero.

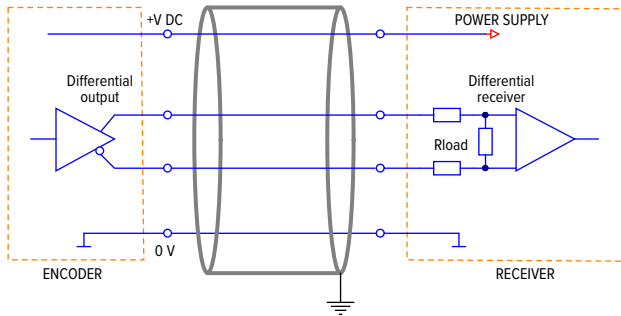
This solution increases frequency performance, allowing for longer cable connections and optimal data transmission. Saturation levels may be higher than in NPN and PNP electronics, but push-pull electronics can be used interchangeably with NPN or PNP.



Line driver

LINE DRIVER is used in environments that are particularly exposed to electrical disturbances or when the encoder is far from the receiver system. The data transmitter and receiver work on two complementary channels, limiting disturbances (cross-talk). These interferences are known as ‘common mode disturbances’ because their generation is due to a common point which is 0 V. In LINE DRIVER, transmitted and received signals are processed differentially, using the differences between complementary channels and eliminating common mode signals at the receiver.

This transmission method is available in both +5 V DC (known as RS-422) and +30 V DC models.



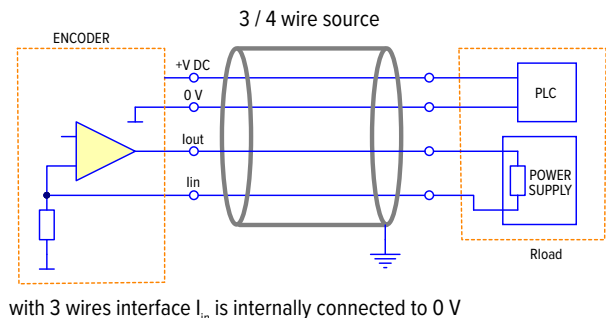
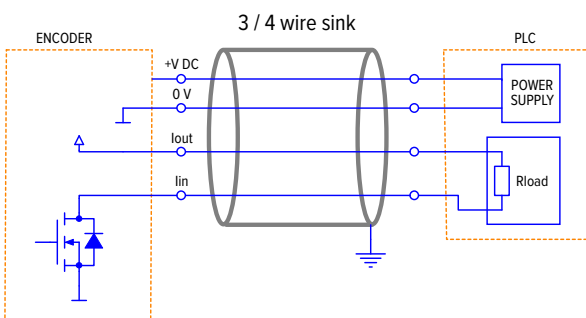
Output stage protection

An ASIC is used to protect outputs from short circuits. The solution is based on an active sensor that instantly controls the temperature of the element to be protected. It provides constant protection against repetitive and permanent short circuits, making it ideal for heavy-duty applications or harsh environments. This solution is available for LINE-DRIVER and PUSH-PULL electronics.

Analogue interface

The analogue interface provides position information through current or voltage signals and can be used as a replacement for a potentiometer. The voltage range is from 0 to 5 V or 0 to 10 V, while the current range (sink or source configuration) is from 0 to 20 mA or to 4 to 20 mA in accordance with industry-standard interfaces.

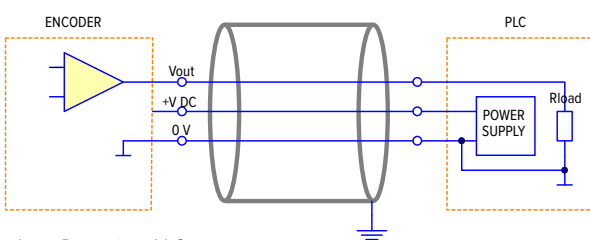
CURRENT OUTPUT



with 3 wires interface I_{out} is internally connected to +V DC
 where $R_{LOAD}^{max} = (V_{DC} - 2) / 0.02$

with 3 wires interface I_{in} is internally connected to 0 V

VOLTAGE OUTPUT



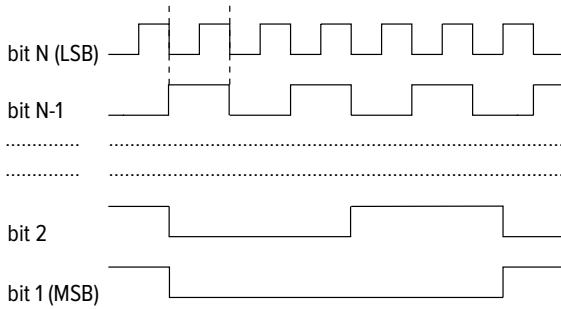
where $R_{LOAD}^{min} = 1\text{ k}\Omega$

Bit-parallel interface

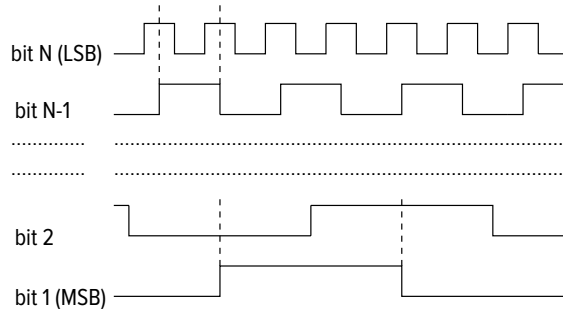
The parallel output is the standard interface for single-turn and multi-turn absolute encoders. These encoders provide position data output using a 'bit by bit' encoding, either according to Gray or binary standards, simultaneously with the device's resolution.

Parallel transmission requires a wire for each bit, resulting in increased wiring complexity for higher device resolutions.

To reduce the number of wires, other forms of data transmission such as the SSI or BiSS serial interfaces or field bus protocols like PROFIBUS, PROFINET or ETHERCAT have been implemented.



Binary bit-parallel output

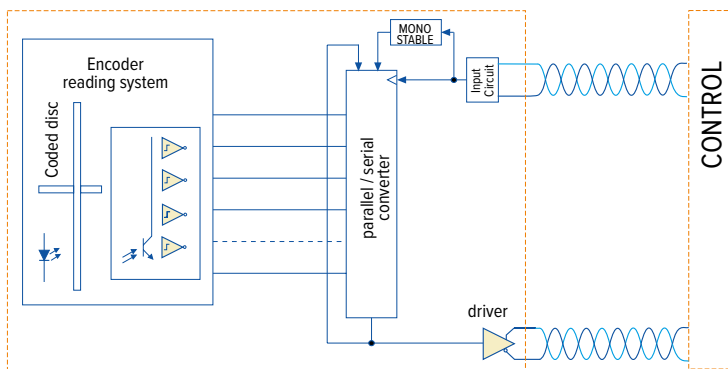


Gray bit-parallel output

SSI interface **SSI**

The automation field is constantly evolving, leading to an increased demand for precision in measurement devices, including absolute encoders.

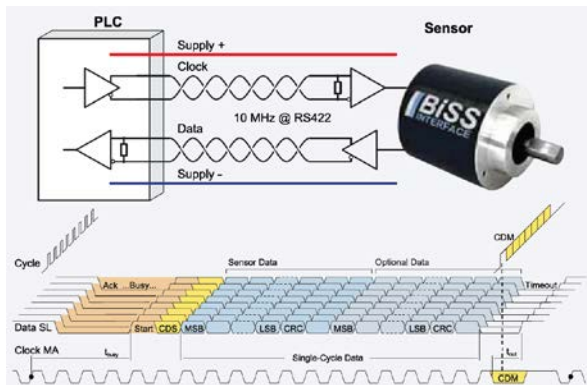
To meet this demand, absolute encoders have been designed with higher resolutions, resulting in more bits and wires. The Synchronous Serial Interface (SSI) was created to address these issues, reducing installation costs and simplifying wiring. This interface transmits digital data in serial mode using only two signals, CLOCK and DATA, regardless of the encoder's bit count.



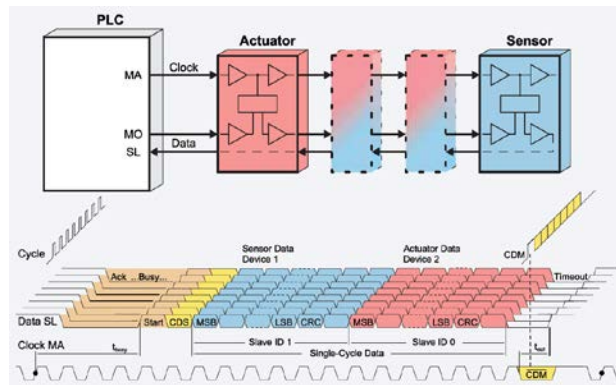
The encoder reading system obtains the position data, which is then continuously transmitted to a parallel/serial converter. The data is stored and transmitted to the output when the mono-stable circuit is activated by a clock signal transition. The CLOCK and DATA signals are transmitted differentially (RS422) to enhance immunity from interference and allow longer transmission distances.

BiSS interface BISS INTERFACE

BiSS is an open source digital interface for sensors and actuators. BiSS is hardware compatible to the industrial standard SSI (Serial Synchronous Interface) but offers additional features and options like bidirectional data communication (serial synchronous, continuous data communication) and two unidirectional lines clock and data (cyclic at high speed (up to 10 MHz), line delay compensation for high speed data transfer, request processing times for data generation at slaves, safety capable (CRC, errors, warnings) and bus capability for multiple slaves and devices in a chain. The advantage of open source protocols is that the selection of components it is not imposed so the end customer can choose the proper products related to the application, increasing the cost-efficiency. Further advantage for the end customer is the compatibility between different manufactures.

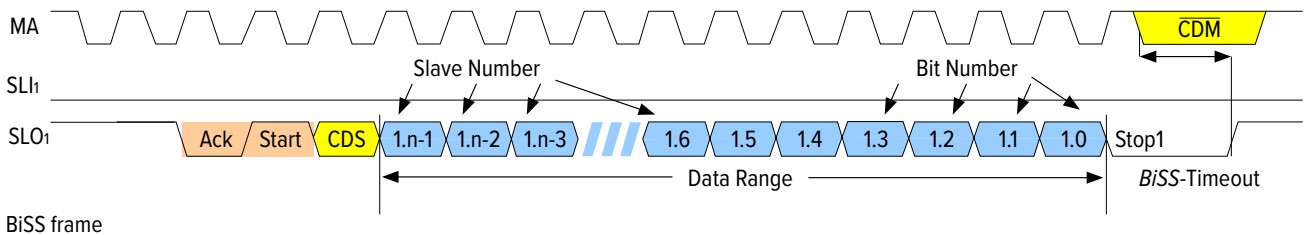


Typical BiSS encoder connection



Example of multi product BiSS connection

In point-to-point configuration, only one device with one or more slaves (sensors) is connected to the master. The master transmits the clock signal to the slave(s) via the MA line. The SL line carries the sensor data directly from the first slave back to the master. In point-to-point configuration the input SLI of the 'Last Slave' is connected to '0'. In bus configuration, all devices, which may also each include multiple slaves, are connected in a chain. Each slave therefore has two terminals (SLO and SLI) with drivers provided for high speed differential signals if applicable. The MA line supplies the clock signal from the master simultaneously to all slaves and the SLO and SLI lines connect the master and all slaves in a chain.



The BiSS frame (transmission frame) is started by the master with the clock MA, clocked and ended. Here the first rising edge at MA is used for the synchronization of all slaves. It enables the isochronous scanning of sensor data and the isochronous output of actuator data. With the 2nd rising edge from MA, all slaves set their SLO line to "0" and generate their "Ack" (Acknowledge) signal with it; it remains active (SLO = "0") until the start bit arrives at the input SLI of the respective slave. The start bit is then passed on synchronously with the clock MA from each slave delayed by one clock pulse, while the CDS bit is either passed on by the slave or is set according to the rules of the control frame. Beginning with the 2nd bit after the start bit and up to the stop bit of the BiSS frame, the data range follows, which transmits the sensor data from the slaves to the master and the actuator data from the master to the slaves. The BiSS frame ends with the BiSS timeout. In this time no further clock pulses are sent to the MA by the master. The inverse state of the MA line during the BiSS timeout is the state of the CDM (Control Data Master) bit. At the end of the data transmission, the master sets its output MO to the idle state "1". The slaves then pass on this "1" received at SLI to their output SLO as soon as they have detected the expiration of the timeout themselves. This ensures that the BiSS timeout on the line SL is only signaled to the master when all connected slaves have detected the timeout.

When the BiSS timeout expires, all slaves return to the idle state; all lines are set to the high signal level ("1") in the process.

All text and pictures copyright BiSS Association

CANopen interface CANopen®

CAN is a field bus. It operates with the CSMA/CA (Carrier Sense Multiple Access / Collision Avoidance) method. It means that collisions during bus access are avoided by a so called bitwise arbitration. The bits are coded NRZ-L (Non Return to Zero - Low).

A cyclic redundancy check (CRC) and other safety mechanisms provide a secure transmission. For synchronization a mechanism called "bit stuffing" is used. CAN is a multi-master system, i.e. several equal bus nodes can be connected without a bus master supervising the communication. In principle a CAN bus can be realized with copper wire or in fibre optic cable.

The common CAN implementation with copper wire operates with differential signals, transmitted via two wires: CANHIGH, CANLOW. Therefore CAN has a good common mode rejection ratio.

Data is transmitted with bits that can either be dominant or recessive. The dominant (0) always overwrites the recessive (1).

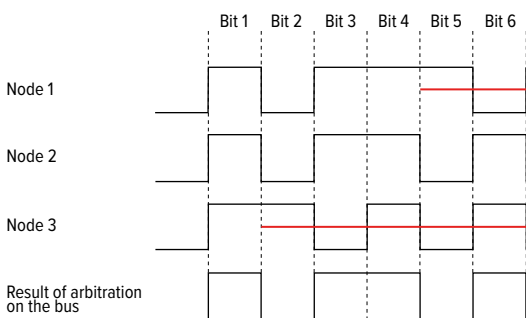
The topology of a CAN network is a line, which can be extended by stubs. The maximum length of a stub is limited to 0,5 m.

The network always has to be terminated on both ends with 120 Ohm each (between CANHIGH and CAN-LOW). Other locations or values are not allowed.

The arbitration mentioned before is used to control the bus access of the nodes by prioritization of the CAN-Identifier of the different messages.

Every node monitors the bus. If more than one node wants access on the bus, the node with the highest priority of the messages ID succeeds and the other nodes retreat until there is "silence" on the bus (see below example). Technically the first dominant bit of the ID send overwrites the corresponding recessive bit of the other IDs. In case that more than one node uses the same CAN-ID an error occurs only at a collision within the rest of the frame.

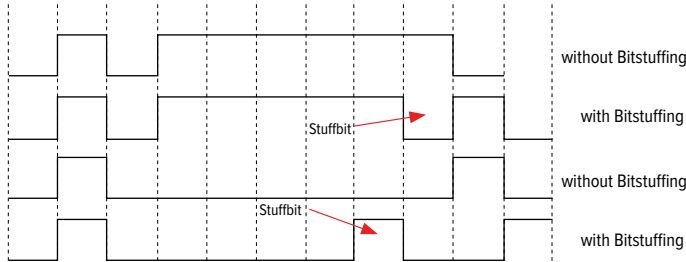
In principle a CAN-ID should only be used by a single node.



Example of arbitration

Due to the arbitration there is a ranking of the messages. The message with the lowest ID has the highest priority and therefore it has almost instant access on the bus. The exception is that an ongoing transmission will not be interrupted. So time critical messages should be assigned to the high priority CAN-IDs, but even then there is no determination in the time of transmission (non-deterministic transmission).

For the arbitration all nodes have to be synchronised. Due to the lack of a separate clock signal, the transmission of many identical bits in line would lead to the loss of synchronisation. The so called bit-stuffing is used to prevent this case. After five equal bits a complementary bit will be inserted into the transmission (the application will not notice). So the nodes can keep up resynchronising on the bit edges (see below figure).



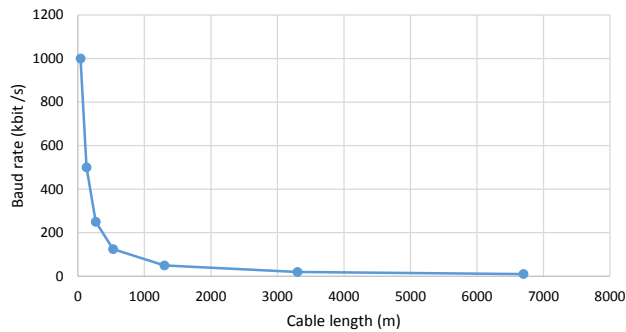
Bitstuffing

A CAN network can operate with baud rates up to 1 Mbit/s.

Due to the necessary synchronisation of the nodes, the maximum delay caused by the length of the cable has to be limited.

The limitation corresponds with the baudrate. There is a common recommendation of the maximum cable length at several baud rates:

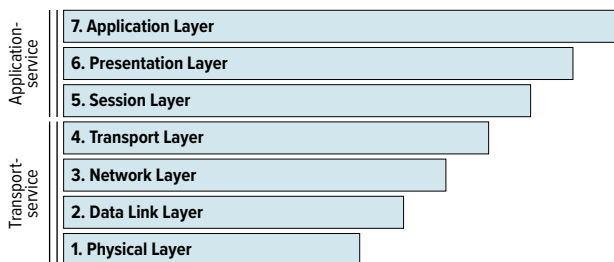
BAUD RATES (kbit /s)	CABLE LENGTH (m)
10	6700
20	3300
50	1300
125	530
250	270
500	130
1000	< 40



CAN baud rates and recommended cable length limits

CANopen

CANopen is a specified higher protocol (layer 7 protocol)



ISO-OSI model

With CANopen it is possible to transfer larger amounts of data, emergency telegrams and process data.

CANopen describes how the communication is performed. That means that parameters to configure a device are transmitted in a defined form (profile).

A CANopen profile defines objects representing the different functions of a device. These objects form a table called object dictionary.

The communication profile defines the basic services and parameters of a CANopen device (e.g. service data objects SDOs, process data objects PDOs, used CAN-IDs, etc.). The device profile defines the specific functions of a device family (e.g. encoders, i/o devices, ...).

For encoders the device profile is the encoder profile CiA 406.

PROFINET interface

The ever-shorter innovation cycles for new products makes the continuous evolution of automation technology necessary. The use of fieldbus technology has been a significant development in the past few years. It has made possible to migrate from centralized automation systems to decentralized ones. PROFIBUS, as the global market leader, has set the benchmark here for 25 years. In today's automation technology, Ethernet and information technology (IT) are increasingly calling the shots with established standards like TCP/IP and XML. Integrating information technology into automation opens up significantly better communication options among automation systems, extensive configuration and diagnostic possibilities, and network-wide service functionality.

These functions have been integral components of PROFINET from the outset. PROFINET is the innovative open standard for Industrial Ethernet.

PROFINET satisfies all requirements of automation technology; whether the application involves production automation, process automation, or drives (with or without functional safety), PROFINET is the first choice across the board. As a technology that is standard in the automotive industry, widely disseminated in machine building, and well-proven in the food and packaging and logistics industries, PROFINET has found its way into all application areas.

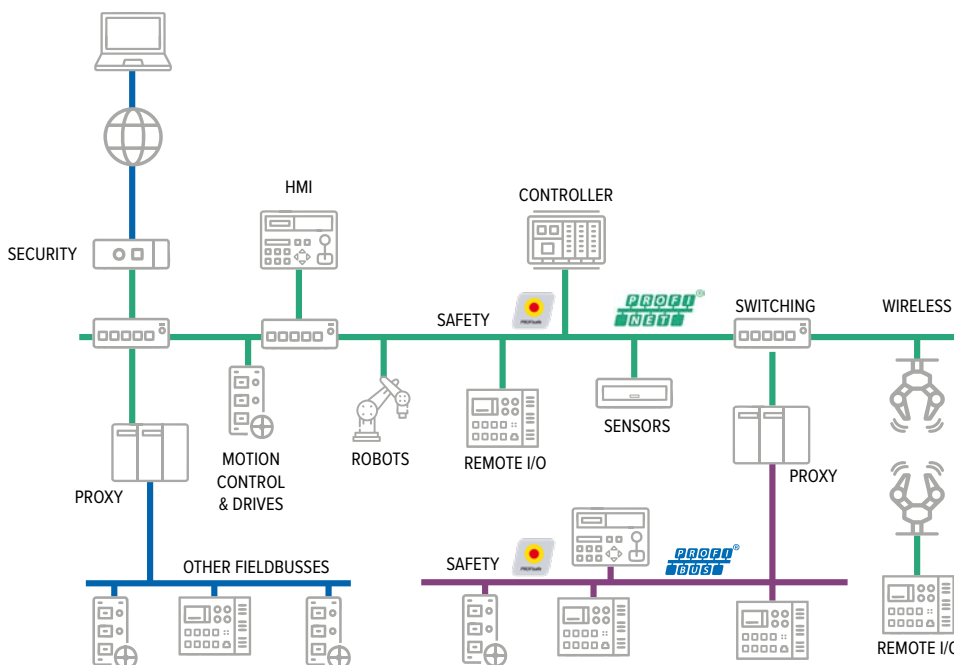
New application areas are constantly emerging, such as marine and rail applications or even day-to-day operations, for example, in a beverage shop. And now: the new PROFenergy technology profile will improve the energy balance in production processes.

PROFINET is standardized in IEC 61158 and IEC 61784.

The ongoing further development of PROFINET offers users a long-term view for the implementation of their automation tasks.

For plant and machine manufacturers, the use of PROFINET minimizes the costs for installation, engineering, and commissioning.

For plant owners, PROFINET offers ease of plant expansion and high plant availability due to autonomously running plant units and low maintenance requirements. The mandatory certification for PROFINET devices also ensures a high quality standard.



Example of plant network

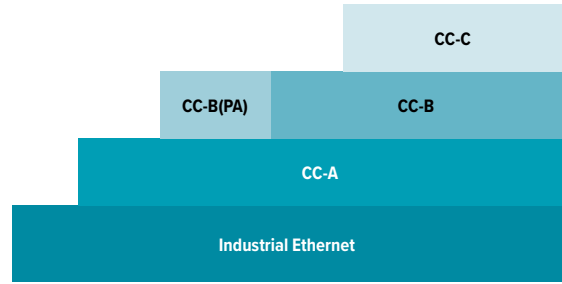
The scope of functions supported by PROFINET IO is clearly divided into conformance classes ("CC"). These provide a practical summary of the various minimum properties.

There are three conformance classes that build upon one another and are oriented to typical applications (see figure).

CC-A provides basic functions for PROFINET IO with RT communication. All IT services can be used without restriction. Typical applications are found, for example, in business automation. Wireless communication is specified for this class.

CC-B extends the concept to include network diagnostics via IT mechanisms as well as topology information. The system redundancy function important for process automation is contained in an extended version of CC-B named CC-B(PA).

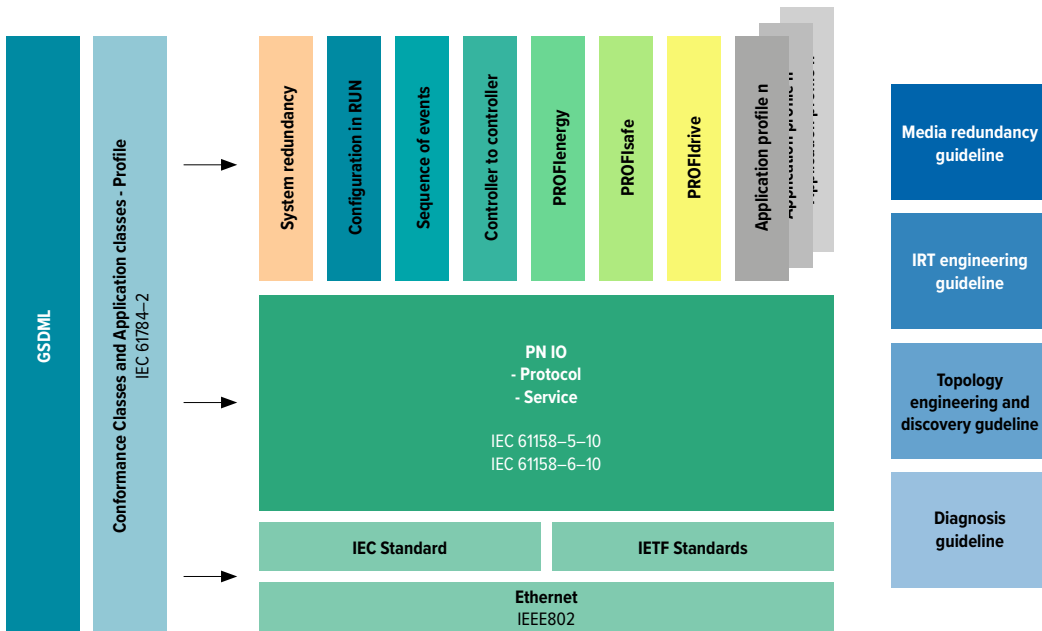
CC-C describes the basic functions for devices with hardware-supported bandwidth reservation and synchronization (IRT communication) and is thus the basis for isochronous applications.



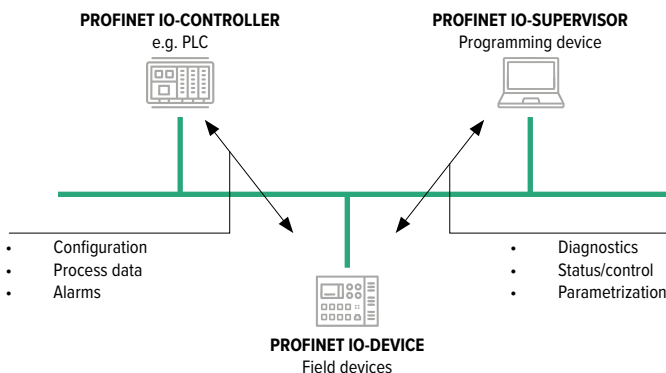
Structure of conformance classes

The conformance classes also serve as the basis for the certification and the cabling guidelines. A detailed description of the CCs can be found in the document “The PROFINET IO Conformance Classes” [7.042].

The PROFINET concept was defined in close collaboration with end users based on standard Ethernet according to IEEE 802 in IEC 61158 and IEC 61784. Figure below lists additional specifications of the functionalities in the form of different joint profiles. These form the basis for device or application-specific profiles. Instructions are created for the necessary planning, engineering, and commissioning steps. The basics for this form the guidelines for engineering PROFINET systems.



PROFINET IO follows the Provider/Consumer model for data exchange. Configuring a PROFINET IO system has the same look and feel as in PROFIBUS. The following device classes are defined for PROFINET IO (figure below):



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IO Controller: this is typically the programmable logic controller (PLC) on which the automation program runs. This is comparable to a class 1 master in PROFIBUS. The IO controller provides output data to the configured IO devices in its role as provider and is the consumer of input data of IO devices.

IO Device: an IO device is a distributed I/O field device that is connected to one or more IO controllers via PROFINET IO. It is comparable to the function of a slave in PROFIBUS. The IO device is the provider of input data and the consumer of output data.

IO Supervisor: this can be a Programming Device (PD), personal computer (PC), or human machine interface (HMI) device for commissioning or diagnostic purposes and corresponds to a class 2 master in PROFIBUS.

A plant unit contains at least one IO controller and one or more IO devices. IO supervisors are usually integrated only temporarily for commissioning or troubleshooting purposes.

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EtherCAT interface

EtherCAT is Industrial Ethernet and utilizes standard frames and the physical layer as defined in the Ethernet Standard IEEE 802.3. However, it also addresses the specific demands faced in the automation industry, where:

- there are hard real-time requirements with deterministic response times
- the system is usually made up of many nodes, each only having a small amount of cyclic process data
- hardware costs are even more important than in IT and office applications

The above requirements make using a standard Ethernet network at the field level practically impossible. If an individual Ethernet telegram is used for each node, the effective data rate sinks significantly for just a few bytes of cyclic process data: the shortest Ethernet telegram is 84 bytes long (including the Inter Frame Gap), of which 46 bytes can be used for process data. For example, if a drive sends 4 bytes of process data for the actual position and status information and receives 4 bytes of data for the target position and control information, the effective data rate for both telegrams sinks to $4/84 = 4.8\%$. Additionally, the drive usually has a reaction time that triggers the transmission of the actual values after receiving the target values. At the end, not much of the 100MBit/s transfer rate remains.

Protocol stacks, such as those used in the IT world for routing (IP) connection (TCP), require additional overhead for each node and create further delays through the stack runtimes.

EtherCAT overcomes the difficulties described in the previous section with its high performing mode of operation, in which a single frame is usually sufficient to send and receive control data to and from all nodes! The EtherCAT master sends a telegram that passes through each node. Each EtherCAT slave device reads the data addressed to it on the fly, and inserts its data in the frame as the frame is moving downstream. The frame is delayed only by hardware propagation delay times. The last node in a segment or branch detects an open port and sends the message back to the master using Ethernet technology's full duplex feature.

The telegram's maximum effective data rate increases to over 90 %, and due to the utilization of the full duplex feature, the theoretical effective data rate is even greater than 100 MBits/s.

The EtherCAT master is the only node within a segment allowed to actively send an EtherCAT frame; all other nodes merely forward frames downstream. This concept prevents unpredictable delays and guarantees real-time capabilities.

The master uses a standard Ethernet Media Access Controller (MAC) without an additional communication processor. This allows a master to be implemented on any hardware platform with an available Ethernet port, regardless of which real-time operating system or application software is used.

EtherCAT slave devices use an EtherCAT Slave Controller (ESC) to process frames on the fly and entirely in hardware, making network performance predictable and independent of the individual slave device implementation.

ETHERNET HEADER			ETHERCAT TELEGRAM					ETHERNET	
DA	SA	Type	Frame HDR	Datagram 1	Datagram 2	...	Datagram n	Pad.	FCS
(6)	(6)	(2/4)	(2)	(10+n+2)	(10+m+2)		(10+k+2)	(0...32)	(4)

EtherType 0x88A4

EtherCAT in a standard Ethernet frame (according to IEEE 802.3)

EtherCAT embeds its payload in a standard Ethernet frame. The EtherCAT frame is identified with the Identifier (0x88A4) in the EtherType field. Since the EtherCAT protocol is optimized for short cyclic process data, the use of bulky protocol stacks, such as TCP/IP or UDP/IP, can be eliminated.

To ensure Ethernet IT communication between the nodes, TCP/IP connections can optionally be tunneled through a mailbox channel without impacting real-time data transfer.

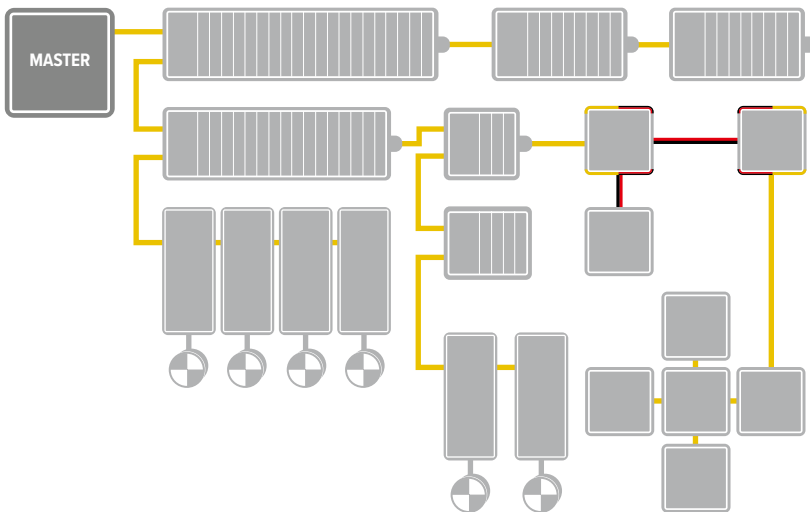
During startup, the master device configures and maps the process data on the slave devices. Different amounts of data can be exchanged with each slave, from one bit to a few bytes, or even up to kilobytes of data. The EtherCAT frame contains the frame header and one or more datagrams. The datagram header indicates what type of access the master device would like to execute:

- Read, write, or read-write
- Access to a specific slave device through direct addressing, or access to multiple slave devices through logical addressing (implicit addressing)

Logical addressing is used for the cyclical exchange of process data. Each datagram addresses a specific part of the process image in the EtherCAT segment, for which 4 GBytes of address space is available. During network startup, each slave device is assigned one or more addresses in this global address space. If multiple slave devices are assigned addresses in the same area, they can all be addressed with a single datagram. Since the datagrams completely contain all the data access related information, the master device can decide when and which data to access. For example, the master device can use short cycle times to refresh data on the drives, while using a longer cycle time to sample the I/O; a fixed process data structure is not necessary. This also relieves the master device in comparison to in conventional fieldbus systems, in which the data from each node had to be read individually, sorted with the help of the process controller, and copied into memory. With EtherCAT, the master device only needs to fill a single EtherCAT frame with new out put data, and send the frame via automatic Direct Memory Access (DMA) to the MAC controller.

When a frame with new input data is received via the MAC controller, the master device can copy the frame again via DMA into the computer's memory – all without the CPU having to actively copy any data.

Line, tree, star, or daisy-chain: EtherCAT supports almost all of topologies. EtherCAT makes a pure bus or line topology with hundreds of nodes possible without the limitations that normally arise from cascading switches or hubs.



Flexible topology: line, tree, star, or daisy-chain

When wiring the system, the combination of lines with branches or drop lines is particularly beneficial: the ports necessary to create branches are directly integrated in many I/O modules, so no additional switches or active infrastructure components are required.

The star topology, the Ethernet classic, can also naturally be utilized.

Modular machines or tool changers require network segments or individual nodes to be connected and disconnected during operation. EtherCAT Slave Controllers already include the basis for this Hot Connect feature. If a neighboring station is removed, then the port is automatically closed so the rest of the network can continue to operate without interference. Very short detection times faster than 15 microseconds guarantee a smooth changeover. EtherCAT offers a lot of flexibility regarding cable types, so each segment can use the exact type of cable that best meets its needs. Inexpensive industrial Ethernet cable can be used between two nodes up to 100m apart in 100BASE-TX mode. Furthermore, the protocol addition EtherCAT P enables the transmission of data and power via one cable.

This option enables the connection of devices such as sensors with a single line. Optical fibres (such as 100BASE-FX) can also be used, for example for a node distance greater than 100 m. The complete range of Ethernet wiring is also available for EtherCAT. Up to 65,535 devices can be connected to one EtherCAT segment, so network expansion is virtually unlimited. Because of the practically unlimited number of nodes, modular devices such as sliced I/O stations can be designed in such a way that each module is an EtherCAT node of its own. Hence, the local extension bus is eliminated; the high performance of EtherCAT reaches each module directly and without any delays, since there is no gateway in the bus coupler or head station any more.

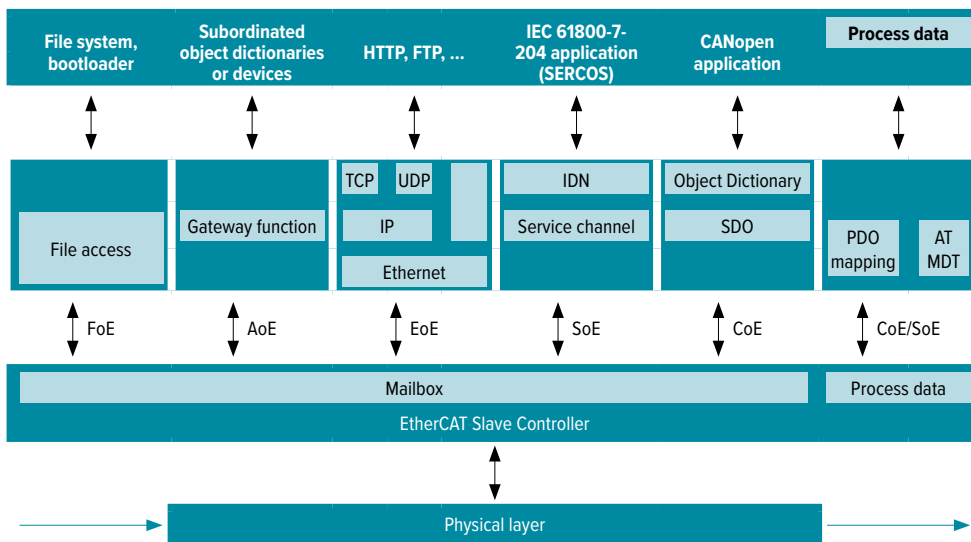
In order to configure and diagnose slave devices, it is possible to access the variables provided for the network with the help of acyclic communication. This is based on a reliable mailbox protocol with an auto-recover function for erroneous messages.

In order to support a wide variety of devices and application layers, the following EtherCAT communication profiles have been established:

- CAN application protocol over EtherCAT (CoE)
- Servo drive profile, according to IEC 61800-7-204 (SoE)
- Ethernet over EtherCAT (EoE)
- File access over EtherCAT (FoE)
- ADS over EtherCAT (AoE)

A slave device isn't required to support all communication profiles; instead, it may decide which profile is most suitable for its needs. The master device is notified which communication profiles have been implemented via the slave device description file. With the CoE protocol, EtherCAT provides the same communication mechanisms as in CANopen®-Standard EN 50325-4: Object Dictionary, Mapping of Process Data Objects (PDO) and Service Data Objects (SDO). Even the network management is similar.

This makes it possible to implement EtherCAT with minimal effort in devices that were previously outfitted with CANopen, and large portions of the CANopen Firmware are even reusable. Optionally, the legacy 8-byte PDO limitation can be waived, and it's also possible to use the enhanced bandwidth of EtherCAT to support the upload of the entire Object Dictionary. The device profiles, such as the drive profile CiA 402, can also be reused for EtherCAT.



Different communication profiles can coexist in the same system

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Output signal levels

Please refer to the table below for output levels based on the specific electrical interface.

SIGNAL LEVELS							
Output circuit	NPN	NPN Open collector	PNP	PNP Open collector	Push-pull	Line driver HTL	RS422
Ordering code	N	C	R	U	P / PC	L	S / RS
Load current	20 mA	20 mA	20 mA	20 mA	20 mA	20 mA	/
Signal levels HIGH (min) LOW (max)	+V DC - 2,5 V 0,5 V	/ 0,5 V	+V DC - 2,5 V 0,5 V	/ 0,5 V	+V DC - 2,5 V 0,5 V	+V DC - 2,5 V 0,5 V	2,5 V 0,5 V
Note		Ext. power supply max +30 V DC		Ext. power supply max +30 V DC			
Reverse polarity power supply protection	see product datasheet						
Short circuit proof outputs	see product datasheet				short circuit to 0V , +V DC or between channels ¹		

¹ when power supply correctly applied

Encoder cable length

Depending on the application, the maximum cable length may be shorter, especially where there is a high level of electrical noise.

Please carefully select the power supply core diameter. The size should be sufficient to ensure that the encoder power supply does not fall below the minimum voltage specified in the product datasheet. Always use shielded cables. For further details or information, please contact our offices directly.

INCREMENTAL ENCODERS			
Power supply (+ V DC)	Electrical interface	Frequency (kHz)	Max cable length (m)
5V	RS-422	50	300
5V	RS-422	100	200
5/30V - 5/28V - 8/24V	Line driver HTL	50	80
5/30V - 5/28V - 8/24V	Line driver HTL	100	40
5/30V - 5/28V - 8/24V	Push-pull	50	60
5/30V - 5/28V - 8/24V	Push-pull	100	30

ABSOLUTE ENCODERS			
Power supply (+ V DC)	Electrical interface	Frequency (kHz)	Max cable length (m)
8/28V - 8/30V	Push pull Bit-parallel	25	100
5V - 8/28V - 8/30V	SSI	100	300
5V - 8/28V - 8/30V	SSI	200	200
5V - 8/28V - 8/30V	SSI	400	50
5V - 8/28V - 8/30V	SSI	1000	10
12/28V	Analogue (current)	-	200

System setup: ambient temperature (20°C / +68°F), load current 20 mA , Eltra AWG 24 shielded cable.

Absolute encoders auxiliary inputs / outputs

INPUTS

UP/DOWN (U/D): when connected to a logic HIGH, the encoder output will invert the counting direction. This is equivalent to rotating the encoder shaft in the opposite direction. The Up/Down setting must be configured before powering up.

LATCH: When connected to a logic state of HIGH, the output data is frozen. In this way, while the encoder shaft is turning, the output data remains stable.

RESET: when connected to a logic state of HIGH, it sets the output position to zero. The reset must be activated only when the encoder shaft is at a standstill.

OUTPUTS

STROBE: available only with the binary code. The output data is considered valid when all data has been updated and the logic state is set to HIGH.

INPUT	STATE HIGH	STATE LOW
U / D	Inverts the code	No effect
LATCH	Blocks the code	No effect
RESET	Output reset	No effect

PRECAUTIONS AGAINST ELECTROSTATIC DISCHARGES

Ensure that the metallic case of the connector is connected to the ground through a ring fixed to the connector screw, as shown in Figure 1.

Connect the cable shield to both, the ground and the connector case, as illustrated in Figure 2.

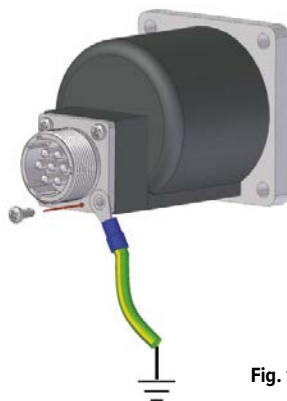


Fig. 1



Fig. 2

To enhance protection against electrostatic discharges, connect the metallic connector case to ground.

MTTFd information

Eltra-manufactured sensors are not safety devices unless explicitly stated in the product datasheet.

The MTTFd mentioned in the datasheet only pertains to the electronic and / or the electrical components of the sensor.

The MTTFd, expressed in years, is calculated using the 'Parts Count' method (as described in EN ISO 13849-1 Annex D.1). This involves adding up the failure rates of all individual components, assuming that a dangerous failure of any component (worst-case scenario) will result in a loss of sensor functionality. The individual component failure rates are based on the Siemens SN29500 (40°C ambient temperature and nominal load) standards or those provided by the component manufacturer.



Installation and precautions



The transducer must be used in accordance with its specifications. It is a precision measuring instrument and not a safety device.



Personnel responsible for mounting and commissioning the device must be qualified and carefully follow installation instructions. It is strongly recommended to avoid any mechanical or electrical modifications for safety reasons. Any modifications will void the warranty.



To ensure proper functioning, avoid subjecting the device to stress or impact.



Ensure that the mechanical coupling of the transducer is designed as specified in the technical datasheet and that the product is installed according to the instructions provided.



Additionally, check that the operating environment is free from corrosive agents (such as acids) or substances that are incompatible with the device and its IP rating.



Ensure the device is properly grounded. If necessary, provide an additional external connection.



Products with variant codes (a number or combination of numbers after ".") may have different mechanical, electrical, or connection requirements than standard products. Please refer to the additional documentation.



Installation and wiring should only be performed by trained personnel in a POWER-OFF condition.



To prevent short-circuits, insulate any unused wires at varying lengths. Do not connect unused pins on the connector.



Before switching on, verify the voltage range applicable for the device.



Place power and signal cables in a way that avoids capacitive or inductive interferences that may cause device malfunction. Also, keep the transducer cable far from power lines or any other cable with high noise levels.



The user who integrates the transducer into their appliance must comply with CE/UKCA regulations and is responsible for marking the end machine/device.



Failure to observe these usage and installation precautions may void the warranty.



Eltra disclaims any liability for damages or injuries resulting from non-compliance with these directives.



The products should be stored in their original packaging in a dust-free, dry and temperature-regulated location that is free from chemical influences or mechanical shock/vibrations.



For storage periods exceeding 12 months, rotate the encoder shaft every 12 months at low speed (e.g. by hand) to allow the bearing lubricant to distribute.

Please refer to www.eltra.it for sales conditions.