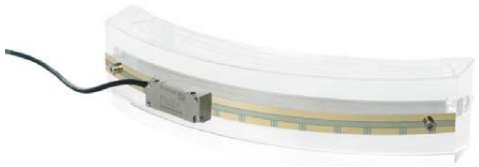

**Please note**

- No photos or videos during the presentation or the company tour
- No publishing of content without prior approval

**Bitte beachten**

- Keine Fotos oder Videos während der Präsentation oder des Firmenbesuchs
- Veröffentlichung von Inhalten nur nach Freigabe

## Angle Encoders

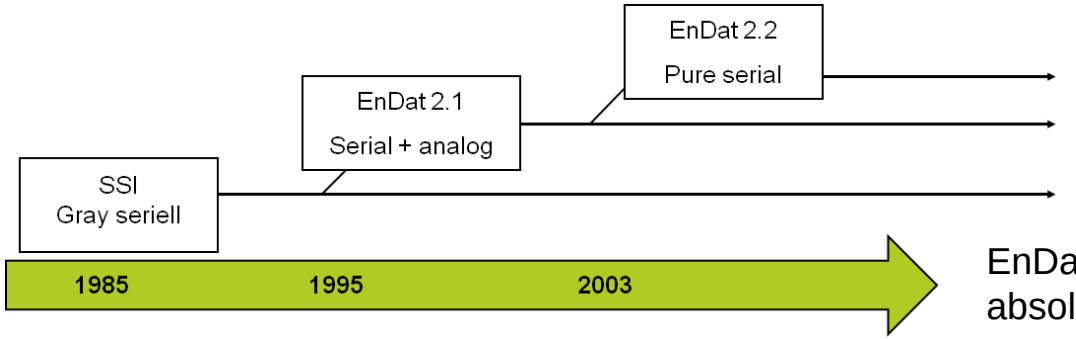



## Linear Encoders

## Rotary Encoders

# History Encoders Interfaces -Excerpt-






EnDat 2.2: uniform interface for absolute and incremental encoders

## EnDat 2.1

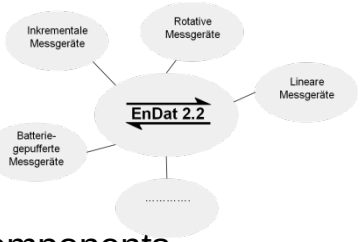
- Serial data communication (max. 2 MHz)
- Interpolation of 1 Vpp-Signals: subsequent electronic
- Alarms and Warnings
- Automatic self-configuration (Parameter, etc.)
- Electronic type-plate
- Typical Application:
  - EnDat communication based on µC
  - one-time reading of absolute position
  - control loop works based on interpolated 1 Vpp-signals

## EnDat 2.2

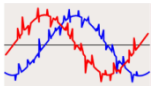
- Pure serial communication (max. 8..16 MHz)
- Uniform interface for absolute and incremental measuring systems
- Certified for safety technology
- Interpolation unit at the subsequent electronic can be eliminated
- Extended possibilities for encoder diagnostics
- Additional information (temperature, etc.)
- Simpler connectors and cables
- Extended power supply range
- Typical application:
  - EnDat communication is based on FPGA
  - Control loop works based on absolute position values

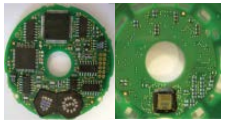
# Benefits for Control and Drive Technology

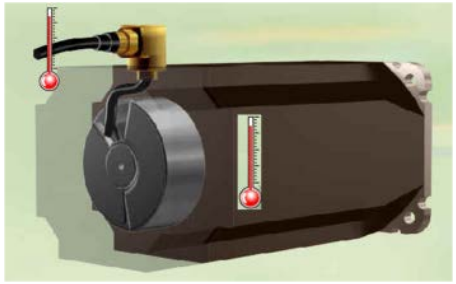


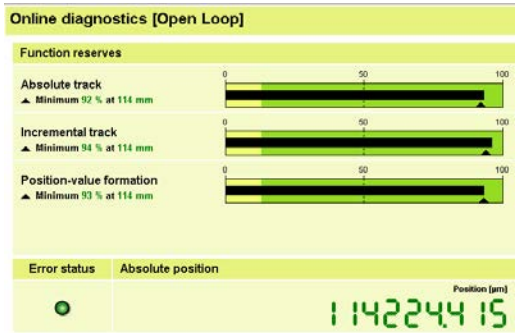


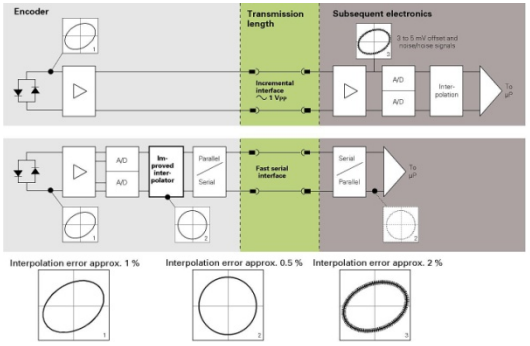

- **Uniform interface**
  for incremental and absolute encoders
- **Low system costs**
  Low-cost connectors, cables and receiver components
- **Improved quality of workpiece (contour accuracy, surface finish)**
  through optimized control loop timing and optimized interpolation strategies
- **Improved noise immunity**
  through digital signal transmission
- **High availability** through automatic self-configuration, diagnosis and reduced number of components
- **Certified for safety-oriented technology**
- **Compatible with EnDat 2.1 encoders**

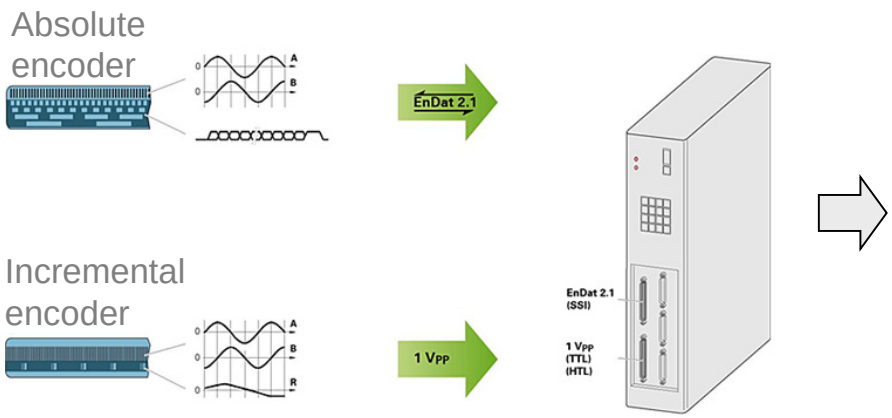


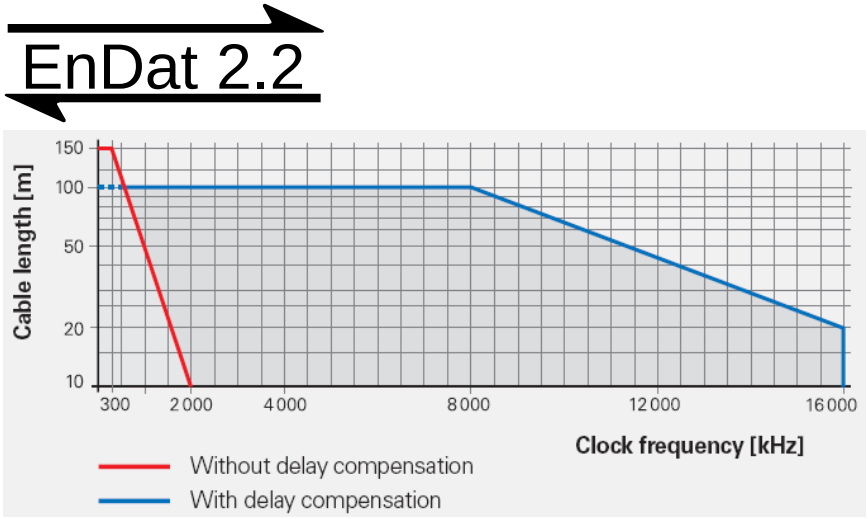









## EnDat 2.1 is a subset of EnDat 2.2

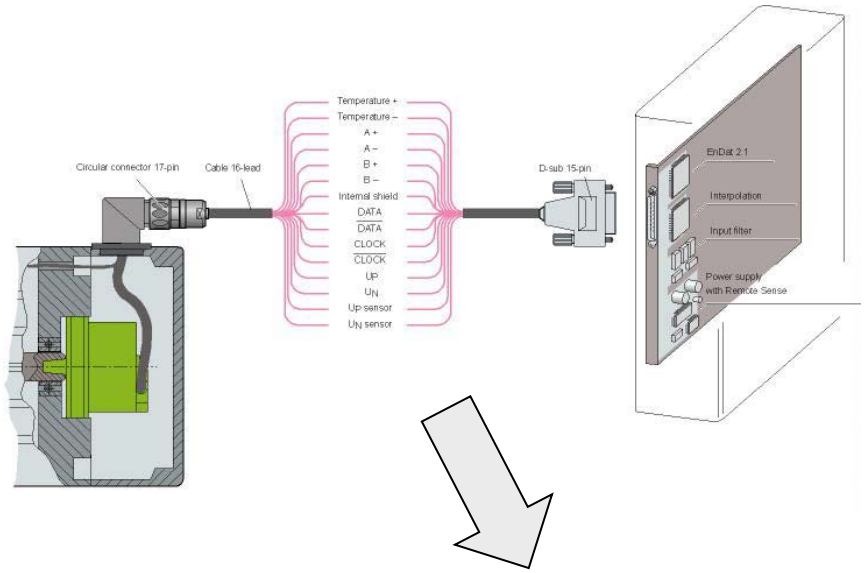
**EnDat 2.2 command set (includes EnDat 2.1 command set)**
- Position values for incremental and absolute encoders
- Additional data on the position value
  - Diagnostics, test values
  - Absolute position values after reference run of incremental encoders
  - Parameter upload/download
  - Commutation
  - Acceleration
  - Limit position signal
  - Position value 2 for safety-related applications or incremental encoders

**EnDat 2.1 command set**
- Absolute position values
- Send and receive parameters
- Reset
- Test command
- Test values

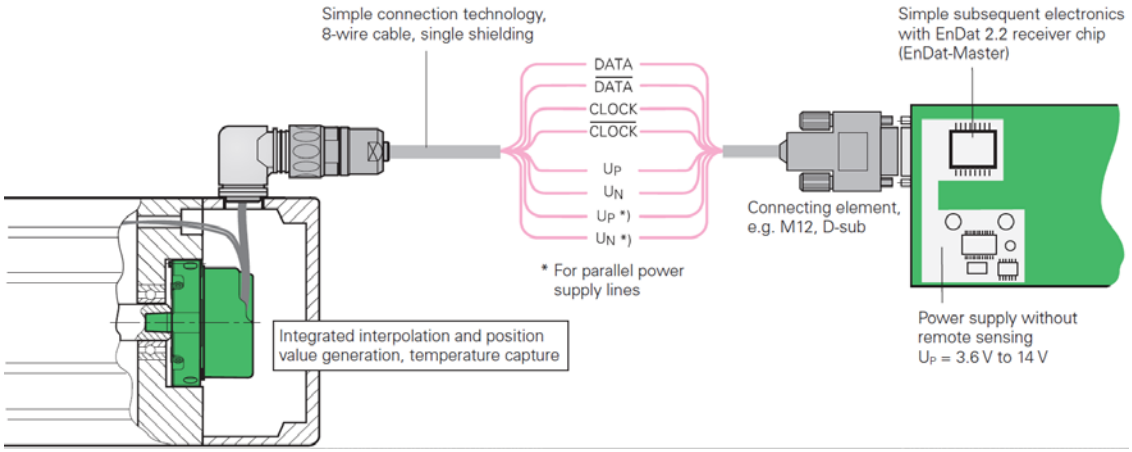
| | | | Mode bit | | | | | |
|---|---|---|---|---|---|---|---|---|
| No. | Mode command | | M2 | M1 | M0 | (M2) | (M1) | (M0) |
| 1 | Encoder send position values | EnDat 2.1 command set / EnDat 2.2 command set | 0 | 0 | 0 | 1 | 1 | 1 |
| 2 | Selection of memory area | | 0 | 0 | 1 | 1 | 1 | 0 |
| 3 | Encoder receive parameter | | 0 | 1 | 1 | 1 | 0 | 0 |
| 4 | Encoder send parameter | | 1 | 0 | 0 | 0 | 1 | 1 |
| 5 | Encoder receive reset [1] | | 1 | 0 | 1 | 0 | 1 | 0 |
| 6 | Encoder send test values | | 0 | 1 | 0 | 1 | 0 | 1 |
| 7 | Encoder receive test command | | 1 | 1 | 0 | 0 | 0 | 1 |
| 8 | Encoder send position value with additional data | EnDat 2.2 command set | 1 | 1 | 1 | 0 | 0 | 0 |
| 9 | Encoder send position value and receive selection of memory area [2] | | 0 | 0 | 1 | 0 | 0 | 1 |
| 10 | Encoder send position value and receive parameter [2] | | 0 | 1 | 1 | 0 | 1 | 1 |
| 11 | Encoder send position value and send parameter [2] | | 1 | 0 | 0 | 1 | 0 | 0 |
| 12 | Encoder send position value and receive error reset [2] | | 1 | 0 | 1 | 1 | 0 | 1 |
| 13 | Encoder send position value and receive test command [2] | | 1 | 1 | 0 | 1 | 1 | 0 |
| 14 | Encoder receive communication command [3] | | 0 | 1 | 0 | 0 | 1 | 0 |

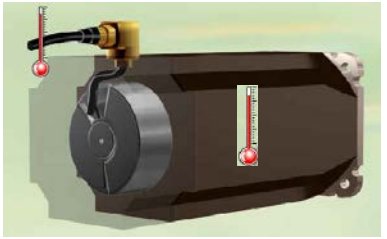
# Benefits: System Costs





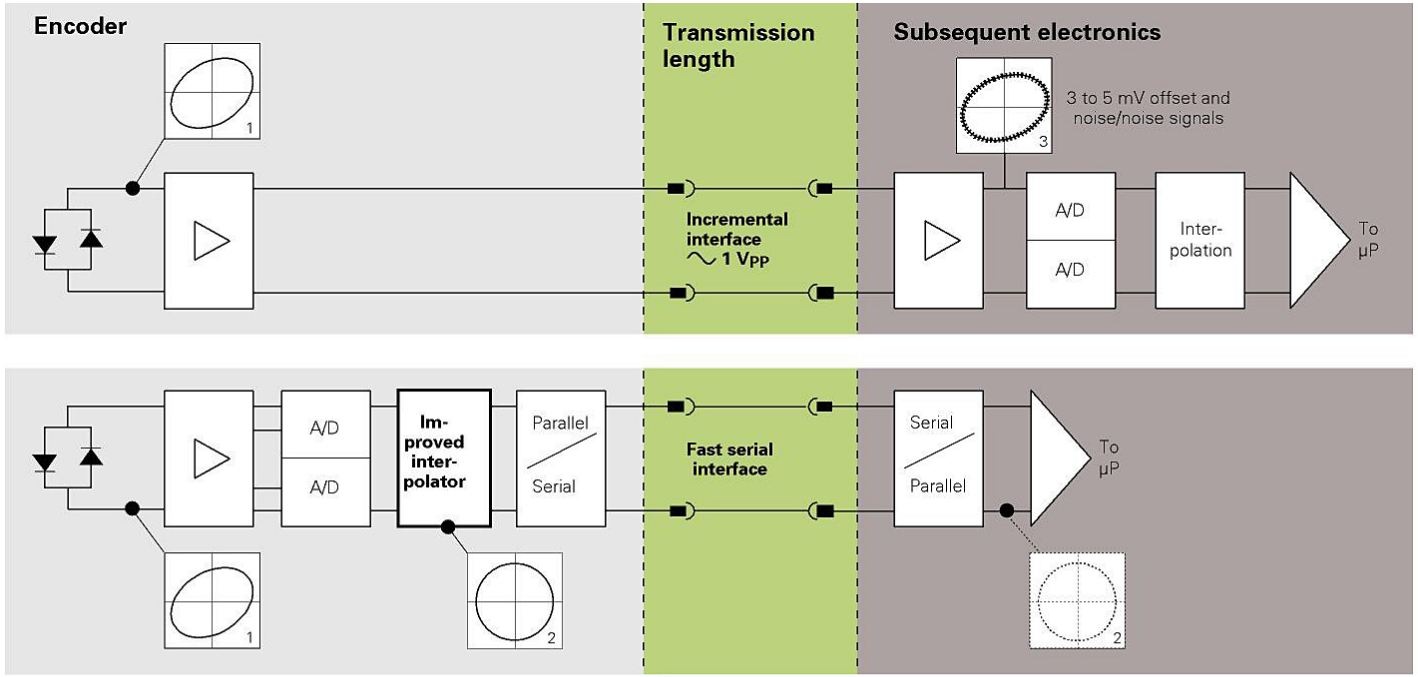

- EnDat Master Softmacro
- Power supply: 3,6 ... 5,25 or 14V
- 1 Vpp receiver and interpolation can be omitted
- Smaller Connectors (M23 → M12)
- Cable (single shielding, number of wires
- Temperature Sensors via serial protocol
- HMC 6

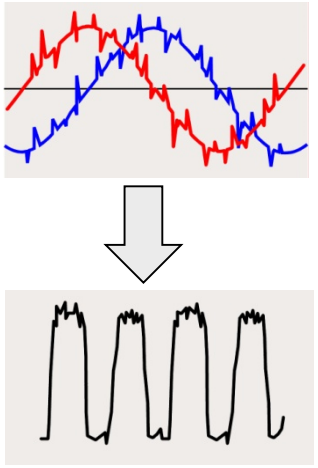


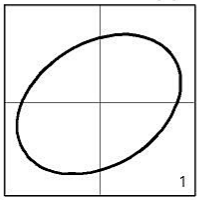
# Benefits: Improved Quality and EMC



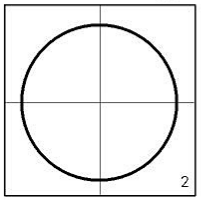


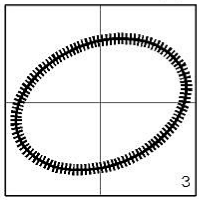
Interpolation error approx. 1 %



Interpolation error approx. 0.5 %



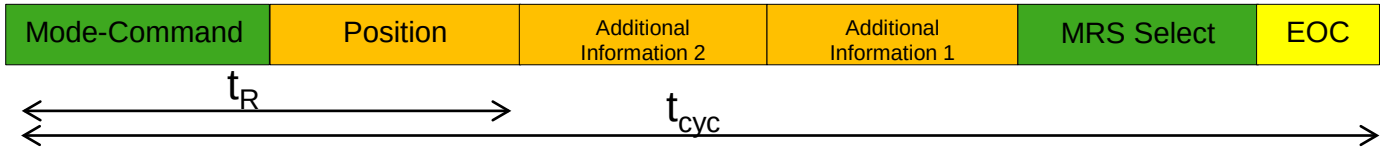
Interpolation error approx. 2 %



- **Pure digital position transfer: encoder position quality will be to 100% transferred to the control.**
- **Interpolation and compensation can be optimally fit to the scanning principle.**
- **New scanning technologies will not essentially provide 1 Vpp signals**
- **EMC: Influences on the signal shape no longer impair the position information ➔ robustness**

# Benefits: Transmission Times






- $t_R$ → Readout time (time till position is available at the EnDat Master)
- $t_{Cyc}$ → Cycle time (attainable cycle time)

→ Depending on: Encoder ($t_{CAL}$, bit-length), clock frequency and cable and requested information

**Example:**

- 37 Bit
- $t_{CAL}$ = 7 µs
- 20 m cable
- $t_R$ → Readout time
- $t_{Cyc}$ → Cycle time

| Requested Info | $f_{CLK}$ | $t_R$ | $t_{cyc}$ |
|---|---|---|---|
| Position only | 4 MHz | ~ 19 µs | ~ 24 µs |
| | 8 MHz | ~ 13 µs | ~ 18 µs |
| | 16 MHz | ~ 10 µs | ~ 15 µs |
| + one additional information | 4 MHz | | ~ 42 (31) µs |
| | 8 MHz | | ~ 28 (22) µs |
| | 16 MHz | | ~ 21 (17) µs |
| + two additional information | 4 MHz | | ~ 49 (39) µs |
| | 8 MHz | | ~ 32 (25) µs |
| | 16 MHz | | ~ 23 (18) µs |

Values in brackets: no change in selection of additional information; no „MRS Select“

# Benefits: High Availability



## Commissioning times

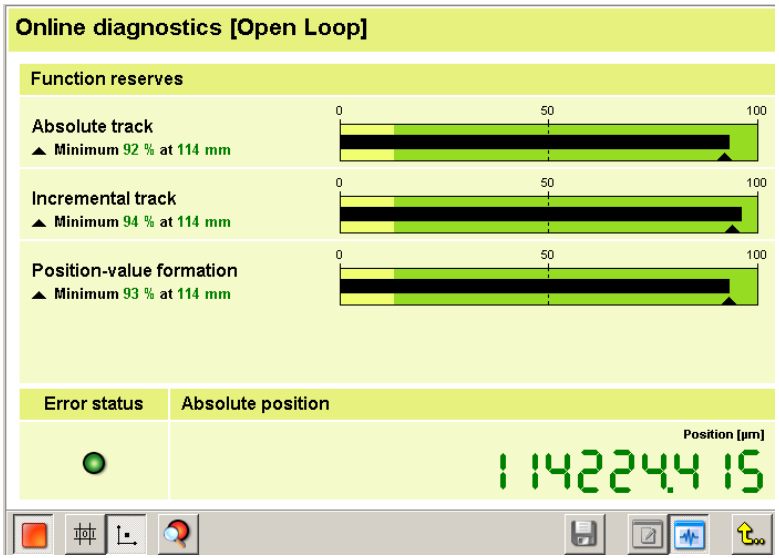
- Memory module in encoder for commissioning parameters for the control or drive (“electronic typeplate”)
- Encoder parameters for commissioning the sensors in the encoder

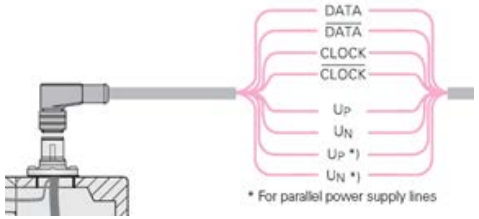
## Diagnosis

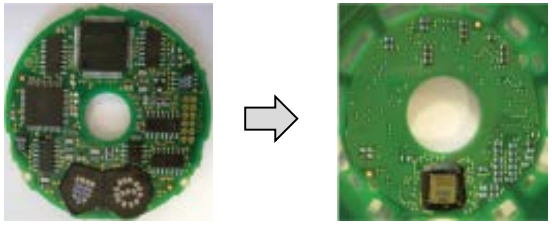
- Error bits for detection of encoder-specific malfunctions
- Warning bit for minimizing maintenance work
- Online diagnostics

## Components

- Fewer components in the system
- Simpler, and therefore more reliable, wiring of electrical components
- Increased integration density of electrical components in encoder

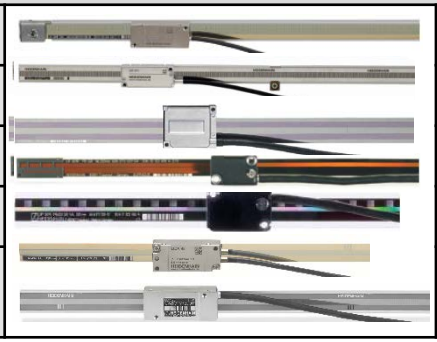


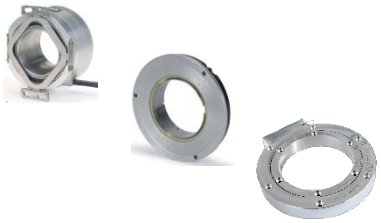
# Encoder Roadmap



| | | | EnDat 2.2 pure serial | EnDat 2.2 pure serial Functional Safety |
|---|---|---|---|---|
| **Sealed Linear Encoder** | | | | |
| LC 1xx; full-size |  | ML 140 ... 4240 mm; Accuracy ±3 µm / 5 µm | ✓ | ✓ |
| LC 4xx; small-size | | ML 70 ... 2040 mm ; Accuracy ±3 µm / 5 µm | ✓ | ✓ |
| LC 2xx; full-size | | ML 3240 ... 28040 mm; Accuracy ±5 µm | ✓ | In preparation |
| **Angle Encoder with Integral Bearing** | | | | |
| RCN 2xxx/5xxx/8xxx |  | Accuracy ±1” ... ±10”<br>Hollow shaft 20 mm ... 180 mm | ✓ | ✓ |
| RCN 6xxx | | | ✓ | ✓ |
| ECN 2xxx | | | ✓ | – |
| ROC 2xxx<br>ROC 7xxx | | Accuracy ±5”; Solid shaft Ø10 mm<br>Accuracy ±2”; Solid shaft Ø14 mm | ✓ | – |
| **Angle Encoders without Integral Bearing** | | | | |
| ECA |  | Outer diameter 104 mm ... 560 mm<br>Accuracy > ±2” | ✓ | ✓ |
| ERM | | Outer diameter 65 mm ... 453 mm<br>Accuracy > ±6,5” | ✓ (+ EIB) | – |
| **Exposed Linear Encoders** | | | | |
| LIC 4100 (absolute) |  | ML 70 ... 27040 mm; Accuracy ±15/±5/±3 µm | ✓ | ✓ |
| LIC 2100 (absolute) | | ML 120 ... 6020 mm; Accuracy ±15 µm | ✓ | – |
| LIP | | ML 20 ... 3040 mm; Accuracy ±3/±1/±0,5 µm | ✓ | – |
| LIF | | ML 70 ... 3040 mm; Accuracy ±3/±1 µm | ✓ (+ EIB) | – |
| LIDA 400<br>LIDA 200 | | ML 140 ... 30040 mm; Accuracy ±15/±5/±3 µm<br>Up to 10000 mm, Accuracy ±15 µm | ✓ | In preparation |

# Encoder Roadmap



| | | | | EnDat 2.2 pure serial | EnDat 2.2 pure serial Functional Safety |
|---|---|---|---|---|---|
| **Integrated Rotary Encoder, construction form 35 mm** | | | | | |
| Optical ST + MT |  | Singleturn 23 bit/Multiturn 12 bit | IP 40 | ✓ | ✓ |
| Inductive ST + MT | | Singleturn 19 bit/Multiturn 12 bit | IP 00 | – | ✓ |
| Inductive ST + BBMT | | Singleturn 18 bit/Multiturn 16 bit | IP 00 | ✓ | – |
| **Integrated Rotary Encoder, construction form 56 mm** | | | | | |
| Optical ST + MT |  | Singleturn 25 bit/Multiturn 12 bit | IP 40 | ✓ | ✓ |
| Inductive ST + MT | | Singleturn 19 bit/Multiturn 12 bit | IP 20 | ✓ | ✓ |
| **Integrated Rotary Encoder, construction form 87 mm** | | | | | |
| Optical ST |  | Singleturn 25 bit<br>Hollow shaft 25…50 mm | IP 64 | ✓ | – |
| Inductive ST, BBMT | | Singleturn 19 bit/Multiturn 16 bit<br>Hollow shaft 30 … 50 mm | IP 20 | ✓ | – |
| ExI 4000 ST, BBMT | | Singleturn 20 bit/Multiturn 16 bit<br>Hollow shaft 90 mm/180 mm | IP 40 | ✓ | ✓ |
| **Mounted Rotary Encoder, construction form 35 mm** | | | | | |
| Optical ST + MT |  | Singleturn 23 bit/Multiturn 12 bit<br>Hollow shaft Ø 6 mm<br>Solid shaft Ø 4 mm | IP 64 | ✓ | – |
| **Mounted Rotary Encoder, construction form 56 mm** | | | | | |
| Optical ST + MT |  | Singleturn 25 bit/Multiturn 12 bit<br>Hollow shaft Ø 8/10/12 mm<br>Solid shaft Ø 6/10 mm | IP 64 | ✓ | ✓ |

# Order Designation



| Ordering designation *) [2)] | Power supply *) | Command set | Version | Max. clock frequency [5)] |
|---|---|---|---|---|
| EnDat 01 | See specification of the encoder | See specifications of the encoder | With incremental signals | ≤ 2 MHz |
| EnDat 21 | | | Without incremental signals | |
| EnDat 02 | Expanded range: 3.6 ≥ Up ≥ 5.25 V respectively 14 V [1)] | EnDat 2.2 | With incremental signals | ≤ 2 MHz [2) 3)]<br>8 ≤ $f_{CLK}$ ≤ 16 MHz [2) 4)] |
| EnDat 22 | | | Without incremental signals | 8 ≤ $f_{CLK}$ ≤ 16 MHz [2)] |

*) Name on ID label
[1)] Exception EIB: Supply voltage 5V +/- 10%
[2)] Value can be read out via parameters
[3)] For encoders with fixed cable assembly
[4)] For encoders with pluggable cable assembly
[5)] Please observe max. permissible cable lengths

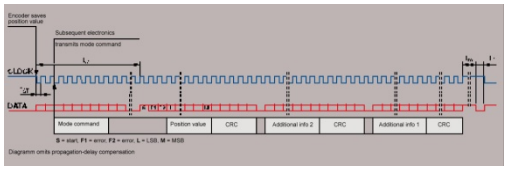
- **The order designation is indicated on the ID label!**
- **In the future, EnDat 2.1 encoders (EnDat 01 or 21) will also be available with the EnDat 2.2 command set!**
- **The clock frequency values apply to the encoder only (to be taken into account for pluggable cable assemblies)**
- **Service encoders: Pay attention to the parameters!**

# Stages of Implementation



## Implementation steps:

- **Step 1:**
  Physical layer
  (Timing, “bits and bytes”)

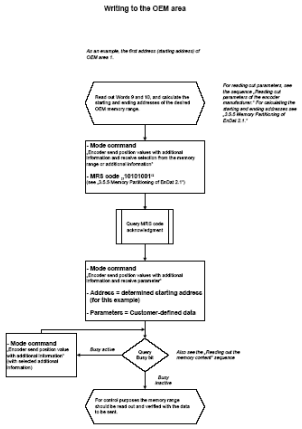



- **Step 2:**
  Communication on the basis of mode commands; handling of parameters and memory areas

| | Mode command | Mode bit | | | | | |
|---|---|---|---|---|---|---|---|
| | | M2 | M1 | M0 | (M2) | (M1) | (M0) |
| Type 2.1 | Encoder send position values | 0 | 0 | 0 | 1 | 1 | 1 |
| | Selection of memory area | 0 | 0 | 1 | 1 | 1 | 0 |
| | Encoder receive parameter | 0 | 1 | 1 | 1 | 0 | 0 |
| | Encoder send parameter | 1 | 0 | 0 | 0 | 1 | 1 |
| | Encoder receive reset ① | 1 | 0 | 1 | 0 | 1 | 0 |
| | Encoder send test values | 0 | 1 | 0 | 1 | 0 | 1 |
| | Encoder receive test command | 1 | 1 | 0 | 0 | 0 | 1 |
| Type 2.2 | Encoder send position values with additional data | 1 | 1 | 1 | 0 | 0 | 0 |
| | Encoder send position value* and receive selection of memory area | 0 | 0 | 1 | 0 | 0 | 1 |
| | Encoder send position value* and receive parameter | 0 | 1 | 1 | 0 | 1 | 1 |
| | Encoder send position value* and send parameter | 1 | 0 | 0 | 1 | 0 | 0 |
| | Encoder send position value* and receive error reset | 1 | 0 | 1 | 1 | 0 | 1 |
| | Encoder send position value* and receive test command | 1 | 1 | 0 | 1 | 1 | 0 |
| | Encoder receive communication command | 0 | 1 | 0 | 0 | 1 | 0 |

* With additional data ① Same reaction as from switching the power supply off and on

- **Step 3:**
  Realization of complex sequences, e.g. deletion of errors




- **Step 4:**
  Integration of EnDat sequences in the customer application

## HEIDENHAIN offers:

- **Step 1:**
  EnDat Master

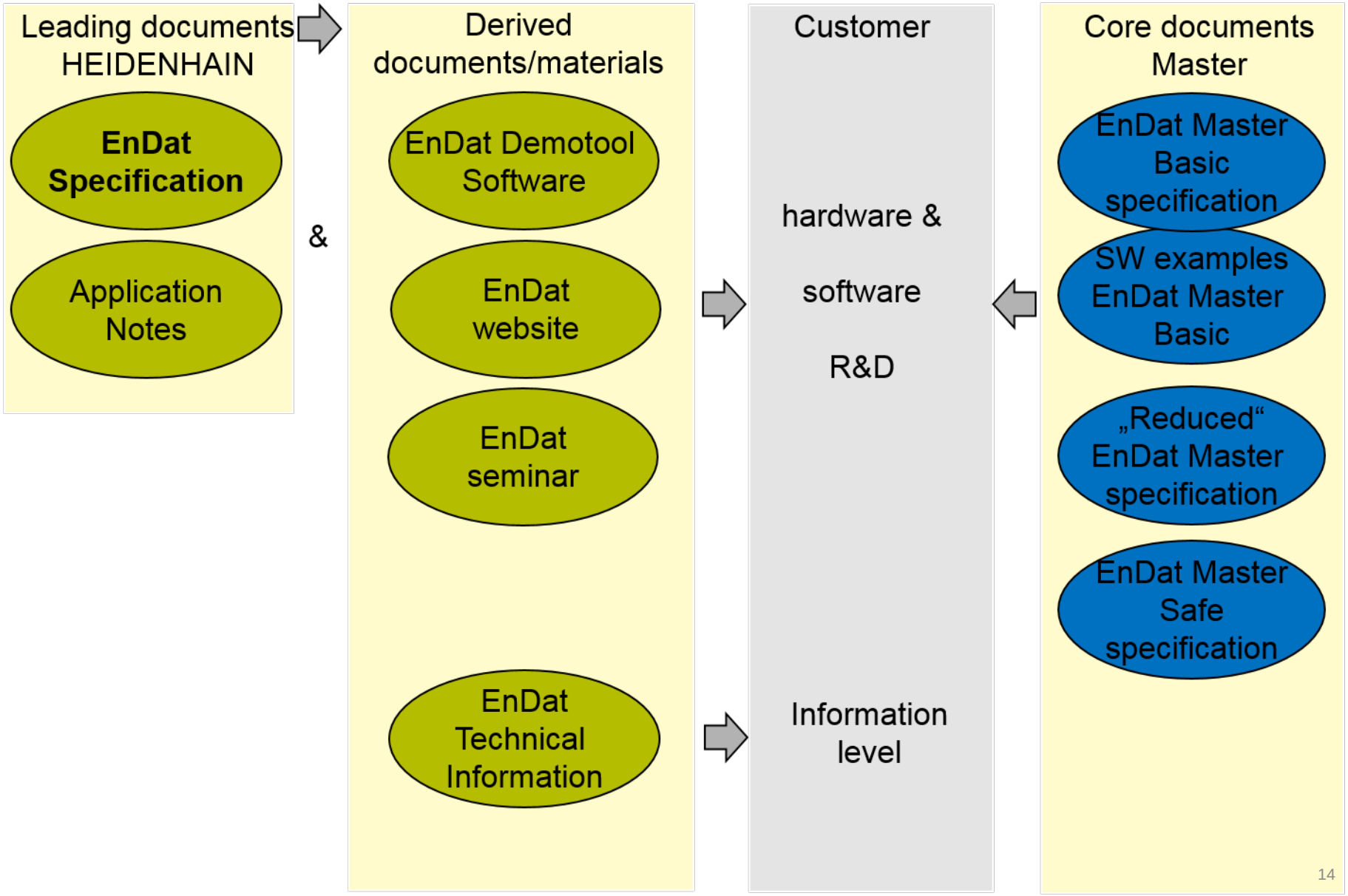
- **Step 2:**
  EnDat demo tool software or the customer’s “low-level” application software in conjunction with the EnDat Master

- **Step 3:**
  Software sequences
  (see EnDat Application Note)

- **Step 4:**
  e.g. EnDat demo program for EIB 74x

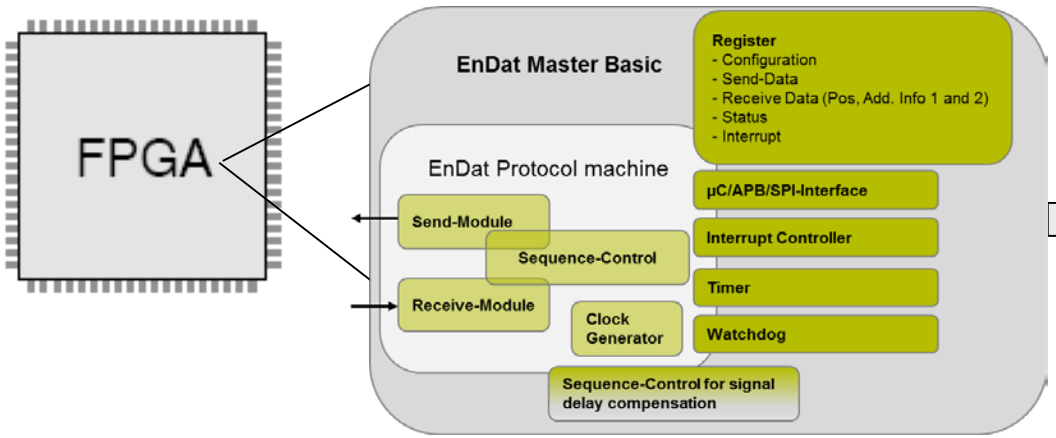
# Documentation





# EnDat Master






- EnDat Master Safe
- EnDat Master Basic
- EnDat Master Reduced
  (EnDat Master Mini see separate slide)
- EnDat Master Light

EnDat Master “light” and “reduced” contain only the EnDat protocol machine and the sequential control for compensating the run time.

| | EnDat 2.2 Master | | EnDat 2.2 Master | |
|---|---|---|---|---|
| | **“light”** | **“reduced” (base for “Mini”)** | **“Basic”** | **“Safe”** |
| **Logic elements** | Approx. 160 | Approx. 650 | > 2100 | > 6300 |
| **For use with** | All EnDat 2.2 encoders:<br>Linear, angle and rotary encoders with photoelectric, inductive and magnetic scanning<br>Only absolute encoders | Incremental and absolute encoders with battery backup | | |
| **Additional data 1 and 2** | No | Yes | | |
| **Support for functional safety** | No | See functional-safety without EnDat Master safe | | Yes (purely serial) |
| **Bus interface included** | No | | Yes | |
| **Properties** | VHDL example code (covers only part of the EnDat functions). Suitable for implementation in subsequent electronics to only a limited extent | Only pure EnDat functionality (EnDat protocol machine) integrated. Advisable, e.g. for multi-channel applications. Code was tested in an example application | Encapsulated code block (tested by HEIDENHAIN); designed for short “time-to-market” and simple operation | Master for functional-safety applications |

**EnDat 2.2 Master**

- Refer to the HEIDENHAIN website:
  http://www.heidenhain.de/de_EN/documentation/fundamentals/interfaces/endat-22/endat-master/

- Available from HEIDENHAIN are the following FPGA-based Master packages (see also previous slide)
  - EnDat Master Reduced — VHDL source code
  - EnDat Master Basic — SPI, APB and µC Interface, VHDL source code, simulation script
  - EnDat Master Safe — APB and µC Interface, VHDL source code, simulation script

- µC-based
  - Solutions with integrated EnDat Master (SoC-based)
    - Texas Instruments
    - Renesas
    - Hilscher
  - µC in general: EnDat realized by means of software
    - Example code is available but must be adapted to the respective µC

# Tools for Implementation and Testing



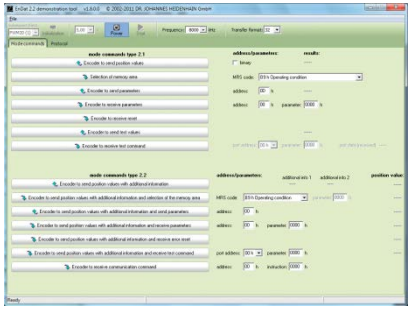
## PWM 20 or rather PWM 21

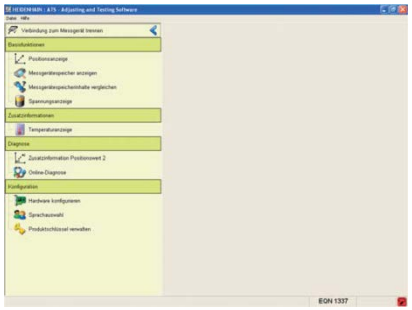

Special Hard- and Software-Version

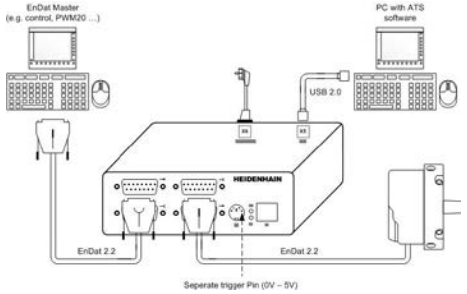
EnDat Demotool Software

ATS Software

EnDat Error injection tool








„Engineering“

„Service“

„Engineering“

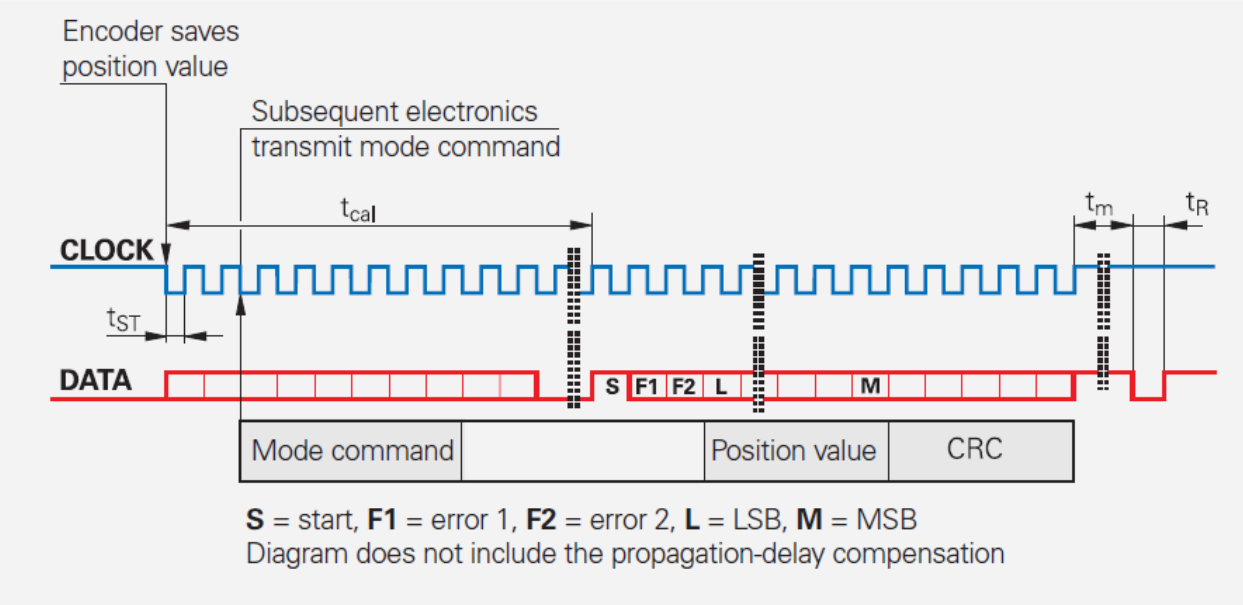
➔ **Special Agreement and Treatment**

# Basic communication



- **$t_{ST}$ (recovery time III):** Must be considered when propagation-delay compensation is used to prevent collisions on the data line.
- **$t_{CAL}$ (calculation time):** Time for forming the position value in the encoder (word 39).
- **$t_M$ (recovery time I):** Marks the end of an EnDat transmission.
- **$t_R$: (recovery time II):** Required for the encoder to reach a defined initial state.

**Position value packet without additional data**



# Mode Commands



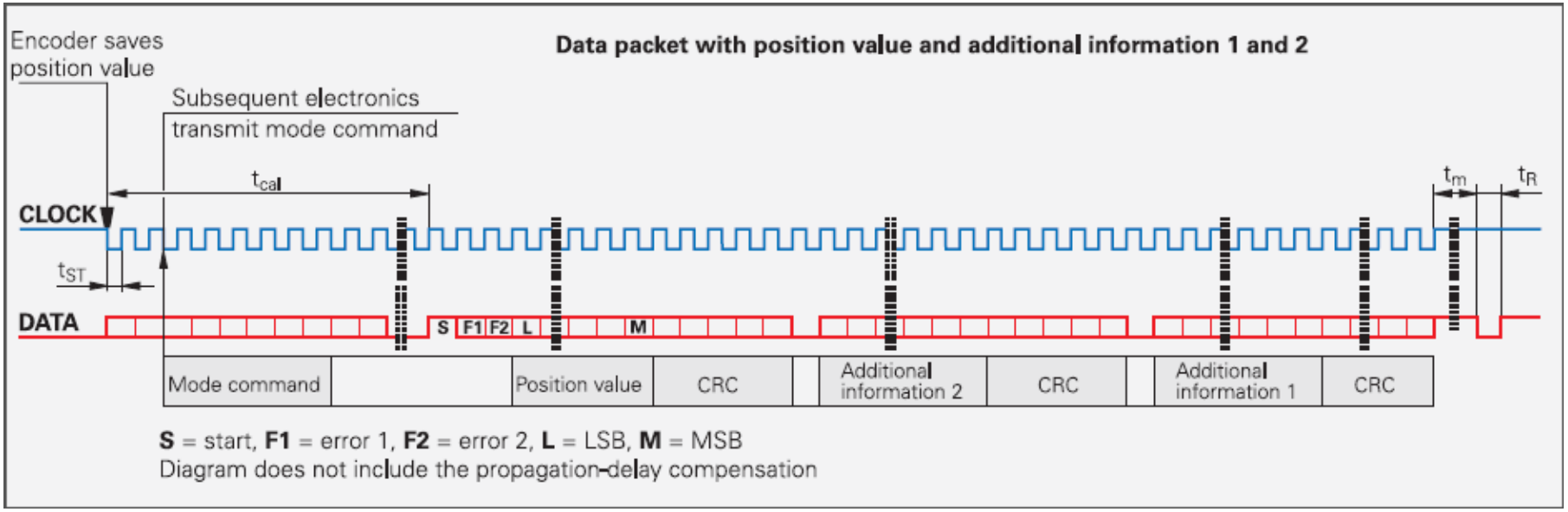
| | Mode command | Mode bit | | | | | |
|---|---|---|---|---|---|---|---|
| | | M2 | M1 | M0 | (M2) | (M1) | (M0) |
| Type 2.1 | Encoder send position values | **0** | **0** | **0** | 1 | 1 | 1 |
| | Selection of memory area | **0** | **0** | **1** | 1 | 1 | 0 |
| | Encoder receive parameter | **0** | **1** | **1** | 1 | 0 | 0 |
| | Encoder send parameter | **1** | **0** | **0** | 0 | 1 | 1 |
| | Encoder receive reset ① | **1** | **0** | **1** | 0 | 1 | 0 |
| | Encoder send test values | **0** | **1** | **0** | 1 | 0 | 1 |
| | Encoder receive test command | **1** | **1** | **0** | 0 | 0 | 1 |
| Type 2.2 | Encoder send position values with additional data | **1** | **1** | **1** | 0 | 0 | 0 |
| | Encoder send position value* and receive selection of memory area | **0** | **0** | **1** | 0 | 0 | 1 |
| | Encoder send position value* and receive parameter | **0** | **1** | **1** | 0 | 1 | 1 |
| | Encoder send position value* and send parameter | **1** | **0** | **0** | 1 | 0 | 0 |
| | Encoder send position value* and receive error reset | **1** | **0** | **1** | 1 | 0 | 1 |
| | Encoder send position value* and receive test command | **1** | **1** | **0** | 1 | 1 | 0 |
| | Encoder receive communication command | **0** | **1** | **0** | 0 | 1 | 0 |

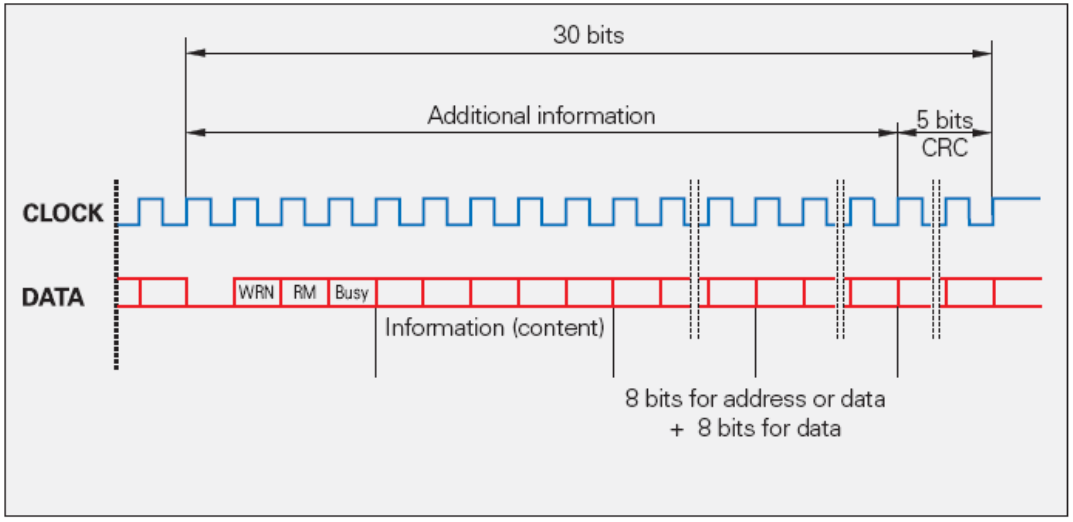
* With additional data

① Same reaction as from switching the power supply off and on

# Additional Information





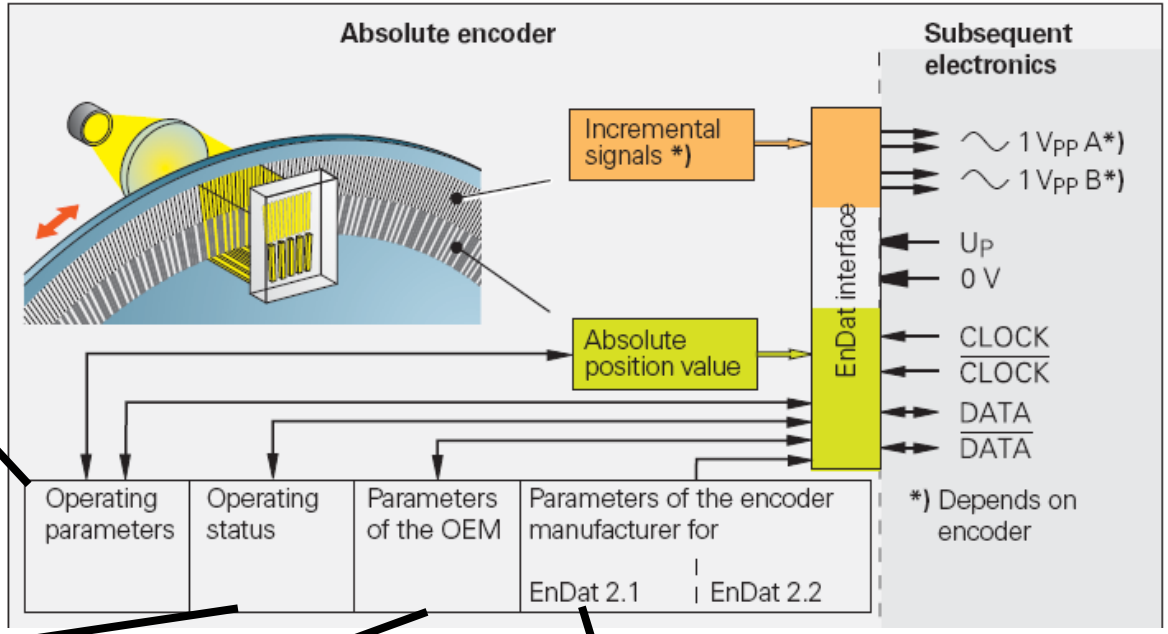

**Additional Information:**

- Diagnosis
- Sensor Information
- Position Value 2 (safety, incremental)
- Memory access in closed loop operation
- Limit signals
- ……

# Memory Areas



- Datum shift
- Configuration of diagnosis
- Bus operation (in preparation)
- I/O functionality
- Status of touch probe
- Re-referencing




- Errors
- Warnings
- Write protection
- Function initialization

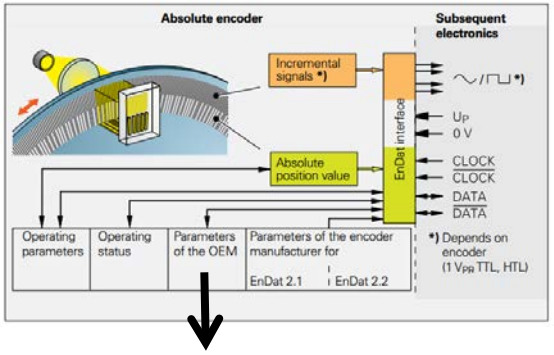
- Freely program-mable by OEM
- "Electronic ID label"

- Encoder-specific parameters for automatic self-configuration
- Supported errors, warnings, functions
- ...

# Electronic ID Label



- System-related information can be saved in the "Parameters of the OEM" area.
  - Unambiguous identification and configuration of the drive system
  - Error-prone manual parameterization is avoided
  - Shorter commissioning time
  - Support provided to the Service technician minimizes standstill times




  - Free programmable by OEM
  - „electronic type-plate“

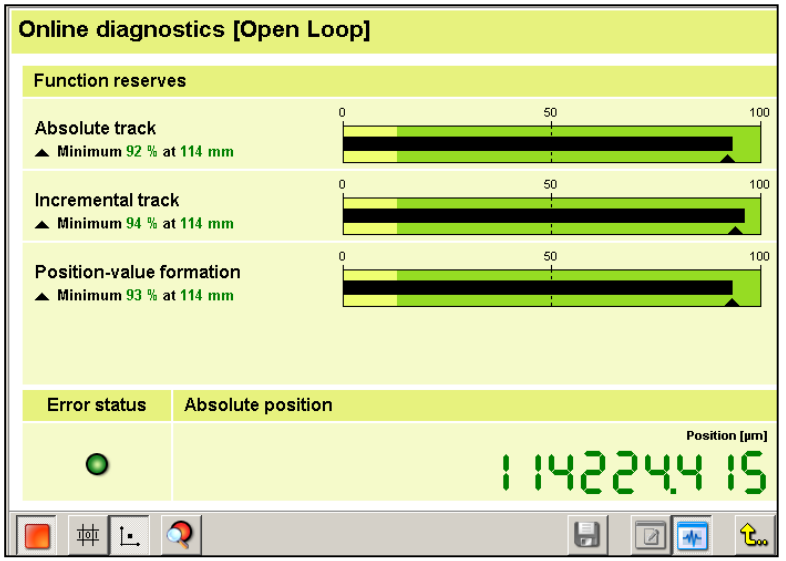
- Type of information that is typically saved
  - Information on the motor
    - Logistics: ID number, serial number, ...
    - Mechanics: Design of the brake, torques, ...
    - Electronics: Current limit values, control parameters
  - Service information
    - Further information on the system configuration, maintenance dates, ...
  - Status data
    - Status data are usually captured by the higher-level control and stored in the encoder, for example during start-up

## Commissioning data and process information

- Commissioning data for the control, the drive, and the sensors are stored by HEIDENHAIN in the encoder or can be stored by the OEM (electronic ID label).
- Mounting information is available from encoders that require mounting. For inductive rotary encoders, this includes, for example, the distance from the rotor and the stator.
- Process information can be saved in the encoder through the inverter during normal running operation (e.g., information such as speed ranges, motor currents, etc.)
  These data, in combination with diagnostics and mounting information, enable comprehensive system monitoring.

## Diagnostics

- Error messages for the recognition of encoder-specific malfunctions
- Warning messages for minimizing maintenance times
- Valuation numbers for evaluating the functional reserve of the encoder (access to the valuation numbers during normal running operation)

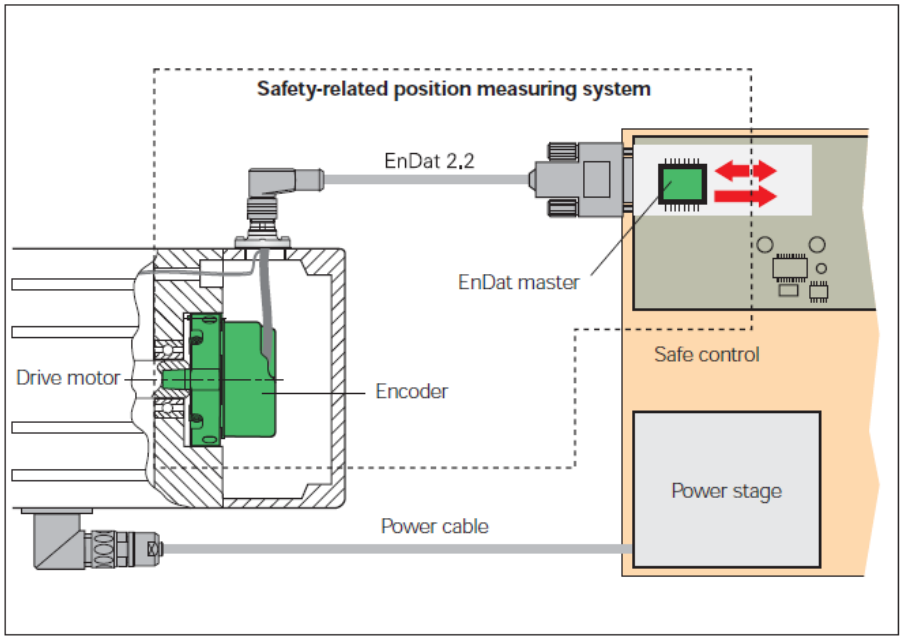


# Safety Technology



**In practice, the complete "safe drive" system consists of:**

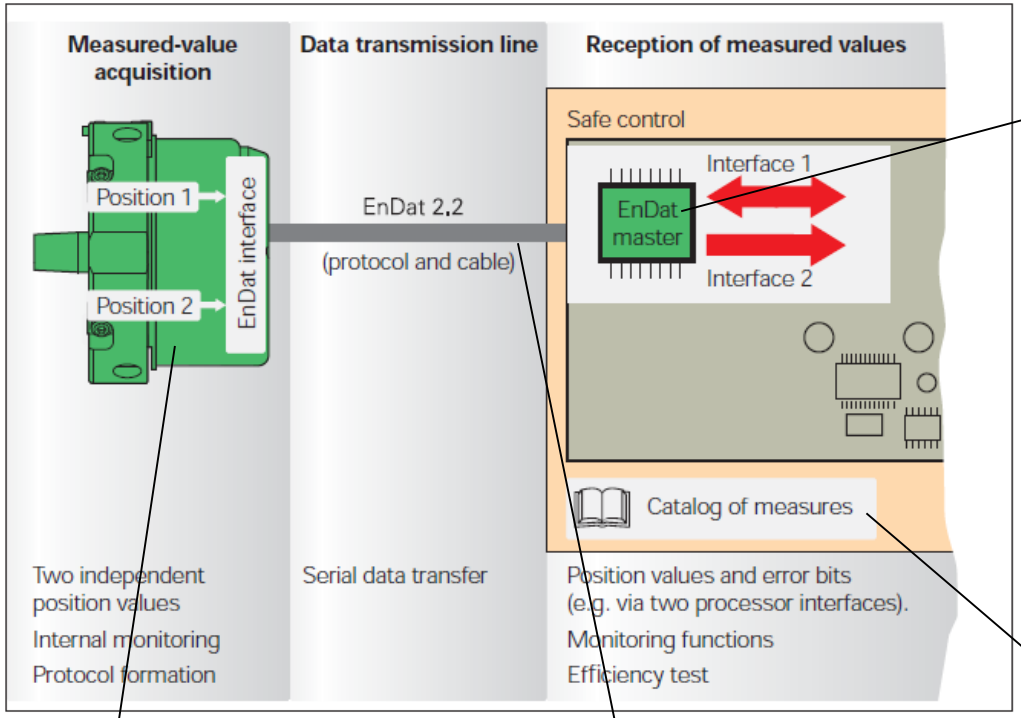
- Safety-related position measuring system
- Safety-oriented control
  - EnDat master with monitoring functions (EnDat Master Safe, see figure below) or
  - EnDat master without monitoring functions (EnDat Master Basic)
- Power stage with motor power cable and drive
- Physical connection between encoder and drive (e.g. shaft connection/coupling)





| | ECN 1325<br>Singleturn | EQN 1337<br>Multiturn |
|---|---|---|
| **Safety-related data** | Applicable as single-encoder system in the control loop for applications of the control category<br>• SIL 2 (Safety Integrated Level) as in DIN EN IEC 61508<br>• PL2 (Performance Level) as in DIN EN ISO 13849<br>• Category 3 according to EN 954-1<br>Safe in the singleturn range | |
| PFH | ≤ 1 x $10^{-8}$ Probability of failure per hour | |
| Angular error of the safe position | ≤ ± 0.7° (9 bits) | |

# Safety Technology




**EnDat Master**

- Position values and error bits via two processor interfaces
- Monitoring Functions
- Efficiency tests

**Note:**

- The EnDat master and the package of measures are independent of the encoder (rotary, linear, angular encoder)

- Two independent position values
- Internal monitoring
- Protocol generation
- Serial data transfer (EnDat22 + HEIDENHAIN cable)
- Measures for safe control

**The integration of safety functions in a technical device only works if the encoder functions with the safety-oriented application.**
**EnDat 2.2 is only one of the factors in achieving this goal.**

## Use of the EnDat Master Safe

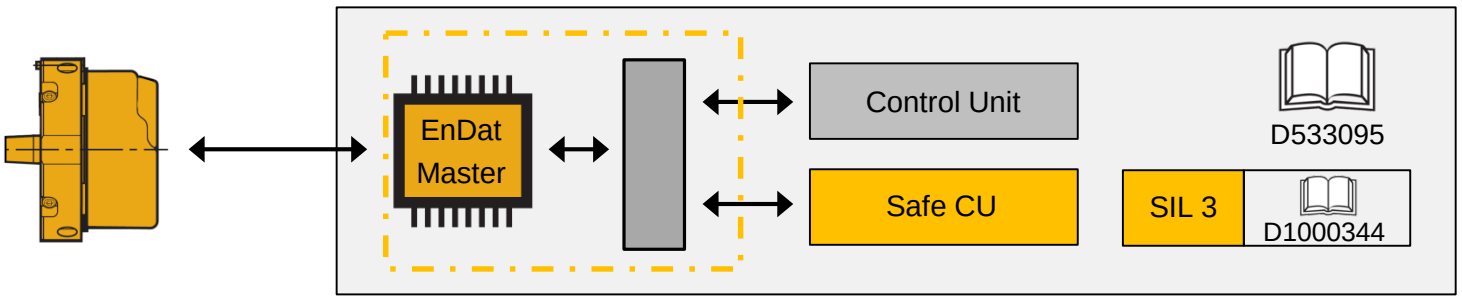
- The EnDat master performs preprocessing and verification of the safety information
- Safety functions are performed by the EnDat Master and safe control
- Up to SIL 3 is possible (but only with the EnDat Master Safe)

### Benefits:

- EnDat Master relieves the safe CU
- EnDat master buffers safety information (decoupling of the cycle times of safety and control)
- Safety functions in EnDat Master are pretested and verified

### Disadvantages:

- EnDat Master is a part of the safety chain
  → Decoupling of the pure control functions and safety function is laborious and depends on the control design and safety design.
- EnDat Master must be certified (and with it usually the FPGA)
- Size of the EnDat master



# EnDat 2.2: Functional Safety



## Use of a non-safe EnDat Master

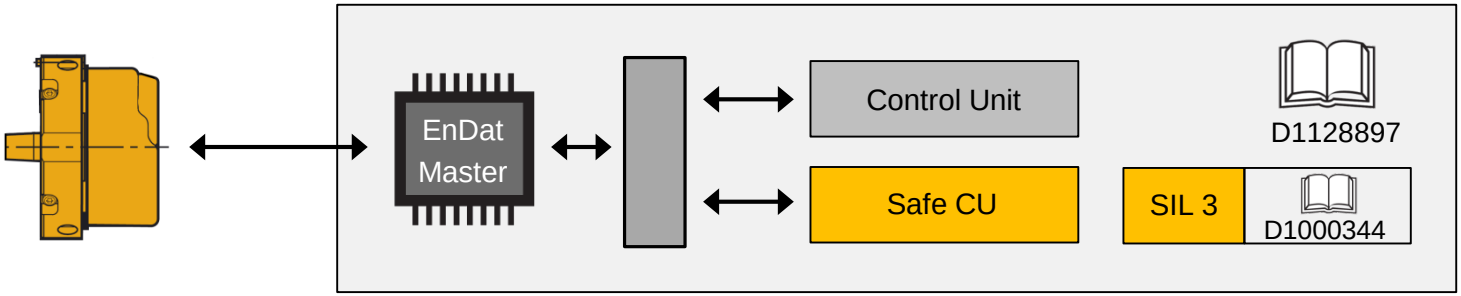
- The EnDat master transfers the complete EnDat communication for evaluation to the safe CU.
  As a supplement, a measurement of the so-called “recovery-time $t_M$” is required. This measurement is a diagnostic function, not a safety function
- The EnDat Master does not modify the data and also does not perform any safety functions
- The EnDat Master is not a part of the safety chain
- Up to SIL 3 is possible

### Benefits:

- The EnDat master is not a part of the safety chain:
  → Certification of the EnDat Master is not necessary
  → Decoupling of control functions and safety functions
- Easy integration into a wide range of safety architectures
- Size of the EnDat Master

### Disadvantages:

- The safe CU has to evaluate all data of the EnDat transmission because there is no preprocessing of the data in the EnDat master (safe CU has to process the data in the control cycle)
  → The interface with the safe CU must be designed appropriately and the safe CU must process the data quickly enough.




Safety relevant