EnDat 2.2

Bidirectional Interface for Position Encoders

Data Transfer

Position Values

Parameters

Hardware

Digital drive systems and feedback loops with position encoders for measured value acquisition require **fast data transfer** with **high transmission reliability** from the encoders. Further data, such as **drive-specific parameters, compensation tables,** etc., must also be made available. For high system reliability, the encoders must be integrated in routines for error detection and have **diagnostic capabilities.**

The EnDat interface from SUMTAK is a digital, bidirectional interface for encoders. It is capable both of transmitting position values from incremental and absolute encoders as well as transmitting or updating information stored in the encoder, or saving new information. Thanks to the serial transmission method only four signal lines are required. The data are transmitted in synchronism with the clock signal from the subsequent electronics. The type of transmission (position values, parameters, diagnoses, etc.) is selected by mode commands that the subsequent electronics send to the encoder.

Benefits of the EnDat Interface

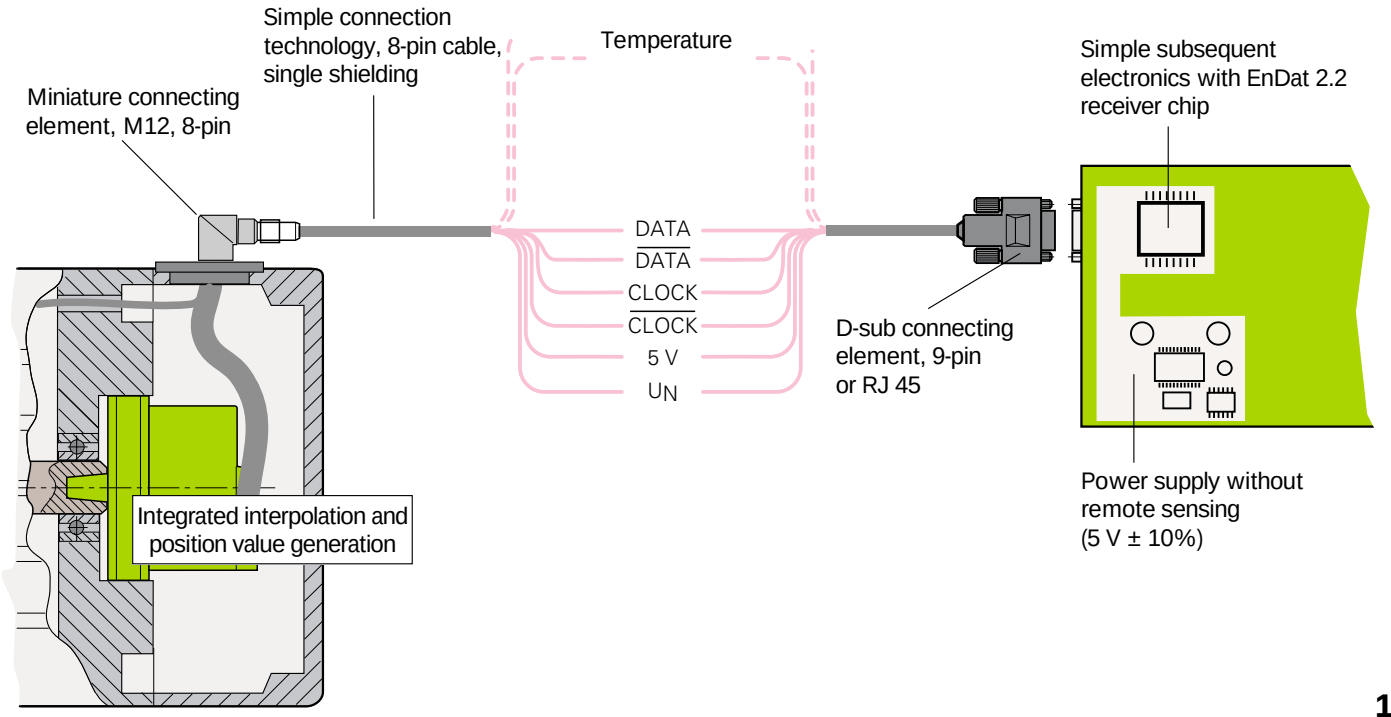
Cost optimization:
- A single interface for all absolute and incremental encoders
- Simple subsequent electronics with EnDat receiver chip and standard components
- Simpler, more economical power supply, since remote sensing is not required
- Simple connection technology: Standard connecting elements (M12 - 8-pin) single shielded standard cable and low wiring costs
- Small motor or system dimensions through compact connecting elements
- No expensive additional sensory analysis and wiring: EnDat 2.2 transmits additional information (limit switch/acceleration)
- Faster servicing for initial operation: datum shifting through offsetting by a value in the encoder

Improved quality
- Higher system accuracy through specific optimization of the encoder
- High contour accuracy, particularly for CNC machine tools: position value formation in the encoder permits shorter sampling intervals without influencing the computing time of the CNC

Higher availability
- Automatic configuration of the system axis: all necessary information can be saved in the encoder (electronic ID label)
- High system reliability through purely digital data transmission
- Diagnosis through monitoring messages and warnings that can be evaluated in the subsequent electronics
- High transmission reliability through cyclic redundancy checking

Safety techniques (in preparation)
- EnDat 2.2 was conceived for safety-oriented machine designs
- Two independent error messages
- Two independent position data for error detection
- Checksums and acknowledgments
- Forced dynamic sampling of error messages and CRC formation by subsequent electronics

Support for state-of-the-art machine designs
- Suitable for direct drive technology thanks to high resolution, short cycle times and commutation information
- Cyclic sampling every 25 µs with full "read and write" mode
- Position values available in the subsequent electronics after only approx. 10 µs



Compatibility of EnDat2.2>2.1

The extended EnDat interface version 2.2 is compatible in its communication, command set and time conditions with the previous version 2.1, but also offers significant advantages. It makes it possible, for example, to transfer additional information with the position value without sending a separate request for it. The interface protocol was expanded and the time conditions were optimized as follows:

- Increase clock frequency (CLOCK) (4 MHz, 8 MHz now being tested)
- Optimize calculating time (position value acquisition within 5 µs)
- Minimize dead time (recovery time) (1.25 to 3.75 µs)

EnDat 2.2 (includes EnDat 2.1)

- Position values for incremental and absolute encoders
- Information in addition to the position value
  - Diagnosis, test values
  - Absolute position values after referencing incremental encoders
  - Transmit and receiver parameters
  - Commutation
  - Acceleration
  - Limit position signal

EnDat 2.1

- Absolute position values
- Transmit and receive parameters
- Reset
- Test command
- Test values

Description of Function

The EnDat interface transmits position values or additional physical quantities in a temporally unambiguous sequence and serves to read out from and write to the encoder's internal memory.

1. **Position values** can be transmitted with or without additional information. The additional information types are themselves selectable by the memory area and address. Other functions such as parameter reading and writing can also be called after the memory area has been selected. Through simultaneous transmission with the position value, axes in the feedback loop can also request additional information and execute functions.
2. **Parameter reading and writing** is possible both as a separate function and in connection with the position value. Parameters can be read or written after the memory area is selected.
3. **Reset functions** serve to reset the encoder in case of malfunction. Reset is possible instead of or during position value transmission.
4. **Servicing diagnosis** makes it possible to inspect the position value even at a standstill. A test command has the encoder transmit the required test values.

Data Transmission

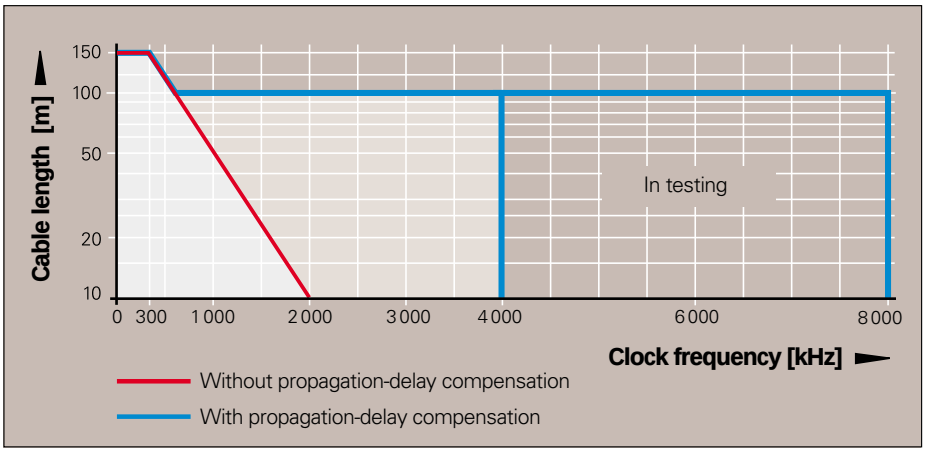
A **clock frequency (CLOCK)** is transmitted by the subsequent electronics to synchronize data transmission. When not transmitting, the clock signal is on high level.

Without propagation-delay compensation, the **clock frequency is** variable between **100 kHz** and **2 MHz.** The maximum permissible clock frequency depends on the cable length between the encoder and subsequent electronics (see diagram).

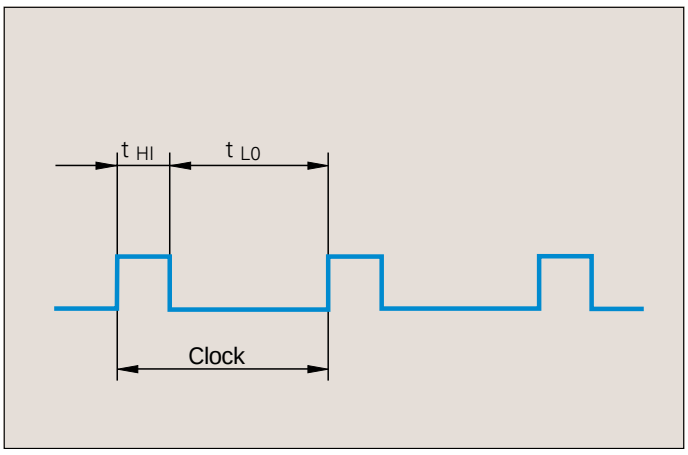
Large cable lengths and high clock frequencies increase the signal propagation time to the point that they can disturb the unambiguous assignment of data. The propagation time can be measured in a test run and then compensated. **With** such propagation-delay compensation in the subsequent electronics, clock frequencies up to **4 MHz** (8 MHz now being tested) are possible for cable lengths up to 100 m (see diagram).

The permissible clock frequencies shown in the diagrams apply for a **clock on-off ratio** of 1:1. This means that the high and low levels of the clock are equally long. For other on-off ratios, the theoretical clock frequency is calculated as $f_c = 1/2t_{min}$

Clock frequency



Clock on-off ratio

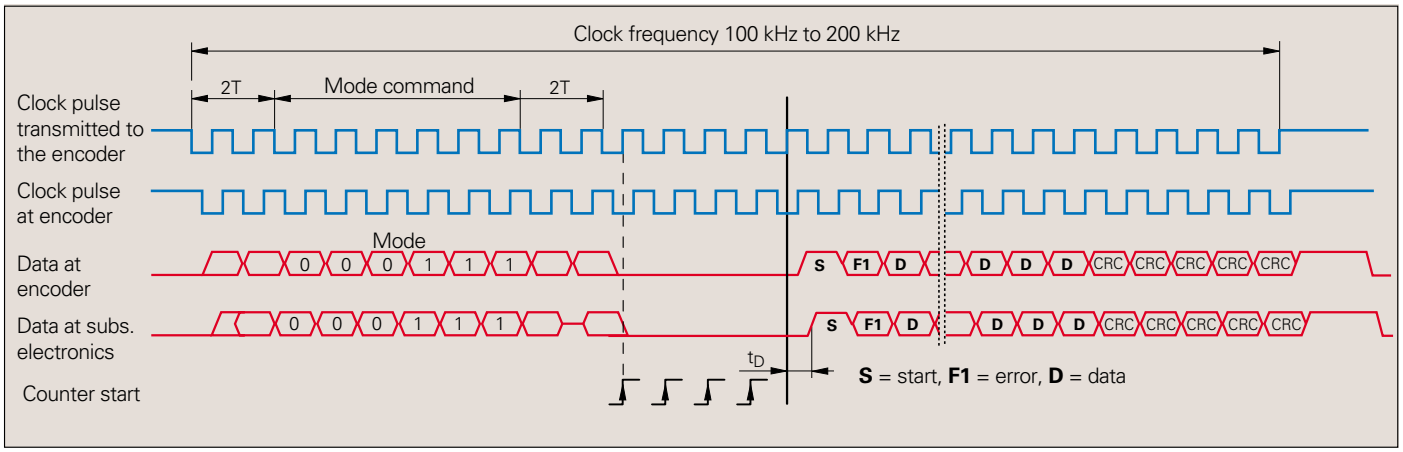


Calculating the signal propagation time

The propagation time must be ascertained after every change in the transmission line hardware, preferably automatically after every power interruption.

The subsequent electronics transmits the mode command *Encoder transmit position values without additional information* to the encoder.

After the encoder has switched to transmission, i.e. after 10 clock periods in total, a counter in the subsequent electronics starts with every rising edge.



Selecting the Transmission Type

Transmitted data can be either position values or parameters.

Position values and memory contents are transmitted serially over the data lines (DATA). The type of information to be transmitted is selected by mode commands. Mode commands define the content of the transmitted information. Every mode command consists of three bits. To ensure reliable transmission, every bit is transmitted redundantly (inverted or double). If the encoder detects an erroneous mode transmission, it transmits an error message.

				Mode Bit					
No.	**Mode Command**			**M2**	**M1**	**M0**	**(M2)**	**(M1)**	**(M0)**
1	Encoder transmit position values	EnDat 2.1	EnDat 2.2	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 transmit parameter			1	0	0	0	1	1
5	Encoder receive reset [1]			1	0	1	0	1	0
6	Encoder transmit test values			0	1	0	1	0	1
7	Encoder receive test commands			1	1	0	0	0	1
8	Encoder transmit position value with additional information			1	1	1	0	0	0
9	Encoder transmit position value and receive selection of memory area			0	0	1	0	0	1
10	Encoder transmit position value and receive parameter			0	1	1	0	1	1
11	Encoder transmit position value and transmit parameter			1	0	0	1	0	0
12	Encoder transmit position value and receive error reset			1	0	1	1	0	1
13	Encoder transmit position value and receive test command			1	1	0	1	1	0
14	Encoder receive communications command [2]			0	1	0	0	1	0

[1] Same reaction as from switching power on and off
[2] Reserved for special encoders without safety compliance

Position Values

One data packet is sent in synchronism per data transmission. The transmission cycle begins with the first falling **clock edge.** The measured values are saved and the position value calculated.

After two clock pulses (2T), the subsequent electronics transmits the **mode command** *Encoder transmit position value (with/without additional information).*

After successful calculation of the absolute position value (t_{cal}—see table), the **start bit** begins the data transmission from the encoder to the subsequent electronics. The subsequent error bits, **error 1 and error 2** (only with EnDat 2.2 commands) are group signals for all monitored functions and serve for failure monitoring. They are generated separately from each other and indicate when a malfunction of the encoder can result in incorrect position values. The exact cause of the disturbance is saved in the "operating status" memory and can be interrogated in detail.

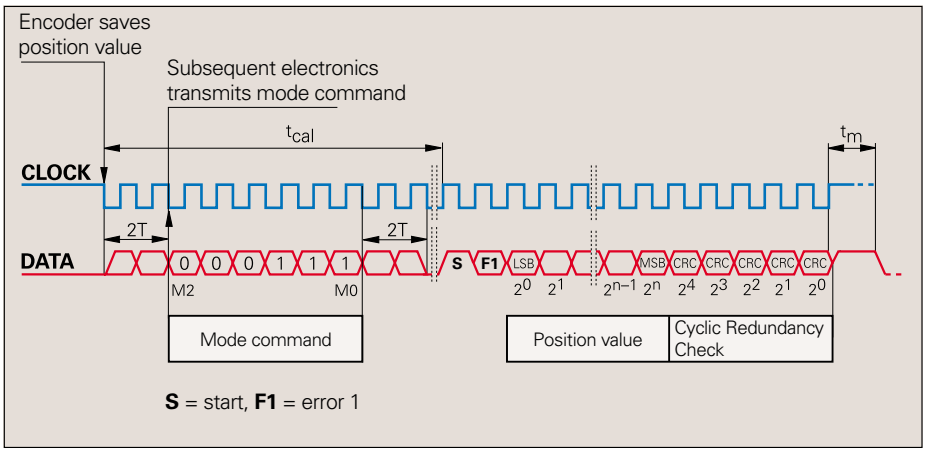
The **absolute position value** is then transmitted, beginning with the LSB. Its length depends on the encoder being used. The number of required clock pulses for transmission of a position value is saved in the parameters of the encoder manufacturer.

The data transmission of the position value is complete with **Cyclic Redundancy Check** (CRC).

This is followed in EnDat 2.2 by the **additional information** 1 and 2, each also concluded with a CRC. The content of the additional information is defined by the selection of the memory area and is transmitted in the next request cycle for additional information. This is then transmitted with every request until a new selection of another memory area changes the content.

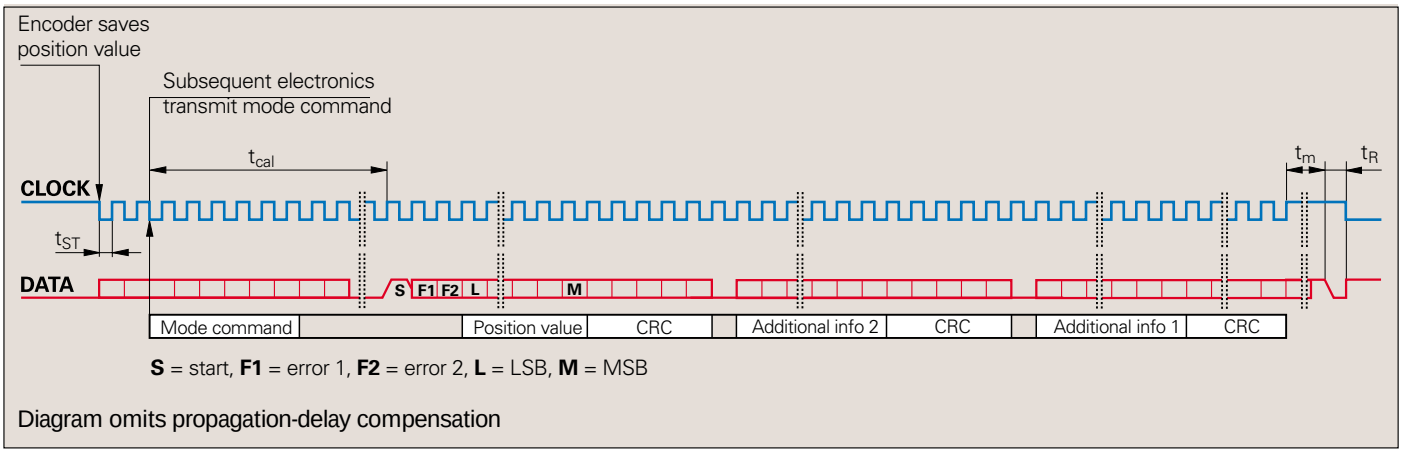
With the end of the data word, the clock must be placed on high level. After 10 to 30 µs or 1.25 to 3.75 µs (with EnDat 2.2, the assignable Recovery Time t_m) the data line falls back to low. Then a new data transmission can be initiated by starting the clock.

Position value packet without additional information (e.g. EnDat 2.1)



		Without propagation time compensation	With propagation time compensation
Clock frequency	f_c	100 kHz ... 2 MHz	100 kHz ... 4 MHz (8 MHz now being tested)
Processing time			
Position value	t_{cal}	For EnDat 2.2 encoders, typically: ≤ 5 µs	
Parameter	t_{ac}	Max. 12 ms	
Recovery Time	t_m	*EnDat 2.1:* 10 to 30 µs *EnDat 2.2:* 10 to 30 µs or 1.25 to 3.75 µs (fc ≥ 1 MHz) (adjustable by parameter)	
	t_R	Max. 500 ns	
	t_{ST}	–	2 to 10 µs
Data delay time	t_D	(0.2 + 0.01 x cable length) µs	
Pulse width	t_{HI}	0.2 to 10 µs	Maximum on-off ratio fluctuation 10%
	t_{LO}	0.2 to 50 ms	

Position value data package with two additional data (EnDat 2.2)



Content of the Data Packet

Error messages 1 and 2

The EnDat interface makes extensive monitoring of an encoder possible without an additional line. An error message becomes active if there is a malfunction in the encoder that could cause incorrect position values. At the same time, the cause of error is saved in the encoder. Errors include:

- Failed light source
- Signal amplitude too low
- Position value incorrect
- Supply voltage too high/low
- Excessive power consumption

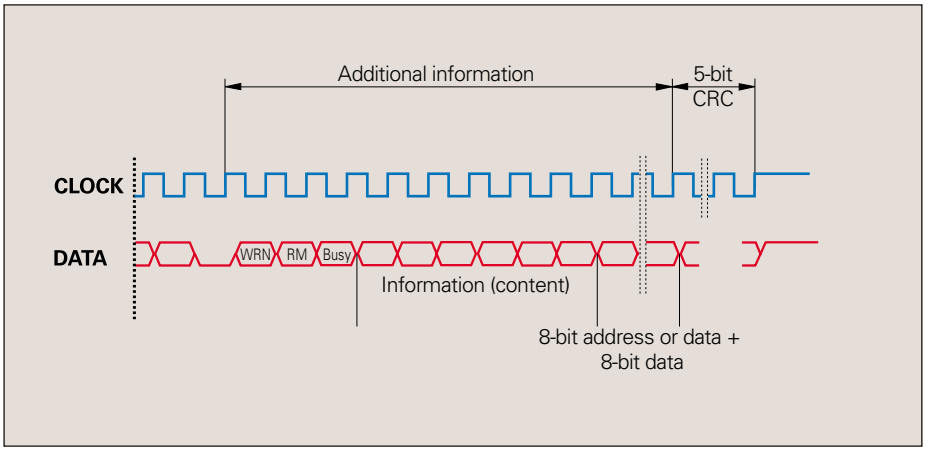
For safety reasons, a second, independently acquired error message must be generated. It is transmitted with the inverted value as error message 2.

Position value

The position value is transmitted as a complete data word whose length depends on the encoder resolution. Transmission begins with the LSB (LSB first).

Additional information

One or two additional data can be appended to the position value, depending on the type of transmission (selection by MRS code). The additional data are each 30 bits in length, with a low level as first bit. Each additional datum is concluded with a CRC that is formed from the respective additional datum without the first bit or CRC. The types of additional information supported by the respective encoder are saved in its parameters. The additional information contains status information, addresses and data.



Status Data

WRN—warnings

This collective bit for warnings indicates whether certain tolerance limits of the encoder have been reached or exceeded, for example rotational speed or light source control reserve, without necessarily indicating an incorrect position value. This function makes it possible to issue preventive warnings in order to minimize idle time. The cause of the warning can be read from the encoder memory.
The alarms and warnings supported by the respective encoder are saved in the "parameters of the encoder manufacturer" memory area.

RM—reference marks

The RM bit (Reference Mark) indicates, whether the reference run has been completed. In incremental systems, this is required in order to establish the absolute reference to the machine reference system. The absolute position value can then be read from the additional information 1. In absolute encoders the RM bit is always on high.

Busy—parameter request

With the low level, the busy bit indicates that a parameter request (read/write) is possible. If a request is being processed (high level), the encoder memory cannot be accessed.

Content of the additional information

The content of the additional information is defined by the mode command for selection of a memory area. This content, updated with each clock pulse, is transmitted until there is a new request. The following contents are possible:

Additional Information 1

- **Diagnosis**
  Cyclic information on encoder function and additional diagnostic values.
- **Position value**
  Incremental encoders transmit the position value as relative position information (counter starts from zero at switch-on). The absolute position value becomes available as soon as the reference mark has been traversed to establish the absolute reference (RM bit is high).
  Absolute encoders always transmit the absolute position value.
- **Memory parameters**
  Parameters saved in the encoder can be also transmitted along with the position values. The request is defined by a memory range selection, then the parameter is transmitted with the associated address.
- **Memory Range Selection code (MRS)—acknowledgment**
  Acknowledgment of the requested memory area selection.
- **Test values**
  Test values serve for inspection purposes, in service diagnosis, for example.
- **Temperature**
  Transmission of temperature in encoders with integrated evaluation of temperature sensors.

Additional Information 2

- **Commutation**
  Some incremental encoders provide "rough" position information for commutation in electric motors.
- **Acceleration**
  If the encoder has additional sensor systems for acceleration, it can transmit the results.
- **Limit position signals**
  Limit position signals and homing information.

MRS Code for Selection of Additional Information

	I7	I6	I5	I4	I3	I2	I1	I0	
Additional info 1	0	1	0	0	0	0	0	0	Transmit additional information 1 without data content (NOP)
	0	1	0	0	0	0	0	1	Transmit diagnosis
	0	1	0	0	0	0	1	0	Transmit position values 2 word 1 LSB
	0	1	0	0	0	0	1	1	Transmit position values 2 word 2
	0	1	0	0	0	1	0	0	Transmit position values 2 word 3 MSB
	0	1	0	0	0	1	0	1	Acknowledge memory content LSB
	0	1	0	0	0	1	1	0	Acknowledge memory content MSB
	0	1	0	0	0	1	1	1	Acknowledge MRS code
	0	1	0	0	1	0	0	0	Acknowledge test command
	0	1	0	0	1	0	0	1	Transmit test values word 1 LSB
	0	1	0	0	1	0	1	0	Transmit test values word 2
	0	1	0	0	1	0	1	1	Transmit test values word 3 MSB
	0	1	0	0	1	1	0	0	Transmit temperature 1
	0	1	0	0	1	1	0	1	Transmit temperature 2
	0	1	0	0	1	1	1	0	At present not assigned
	0	1	0	0	1	1	1	1	Transmit no more additional information 1
Additional info 2	0	1	0	1	0	0	0	0	Transmit additional information 2 without data content (NOP)
	0	1	0	1	0	0	0	1	Transmit commutation
	0	1	0	1	0	0	1	0	Transmit acceleration
	0	1	0	1	0	0	1	1	Transmit commutation and acceleration
	0	1	0	1	0	1	0	0	Transmit limit position signal
	0	1	0	1	0	1	0	1	Transmit limit position signal and acceleration
	.	.	.	.	.	.	.	.	At present not assigned
	.	.	.	.	.	.	.	.	
	.	.	.	.	.	.	.	.	
	0	1	0	1	1	1	1	1	Transmit no more additional information 2

Parameters

The encoder provides several memory areas that can be read from by the subsequent electronics. Some of the memory areas can be written to by the encoder manufacturer, the OEM, or even the end user. Certain memory areas can be write-protected.

The parameters, which in most cases are set by the OEM, largely define the function of the encoder and the EnDat interface. When the encoder is exchanged, it is therefore essential that its parameter settings are correct. Attempts to configure machines without including OEM data can result in malfunctions. If there is any doubt as to the correct parameter settings, the OEM should be consulted.

Encoder Memory Areas

Parameters of the encoder manufacturer
This write-protected memory area contains all information specific to the encoder, such as encoder type (linear, angular, singleturn/ multiturn, etc.), signal periods, number of position values per revolution, transmission format of absolute position values, direction of rotation, maximum permissible speed, accuracy at shaft speeds, support from warnings and alarms, part number, and serial number. This information forms the basis for automatic configuration.

A separate memory area contains the parameters typical for EnDat 2.2: Status of additional information, temperature, acceleration, support of diagnostic and error messages, etc.

Parameters of the OEM
In this freely definable memory area, the OEM can store his information, e.g. the "electronic ID label" of the motor in which the encoder is integrated, indicating the motor model, maximum current rating, etc.

Operating parameters
This area is available to the customer for a datum shift, the configuration of diagnosis, and instructions. It can be protected against overwriting.

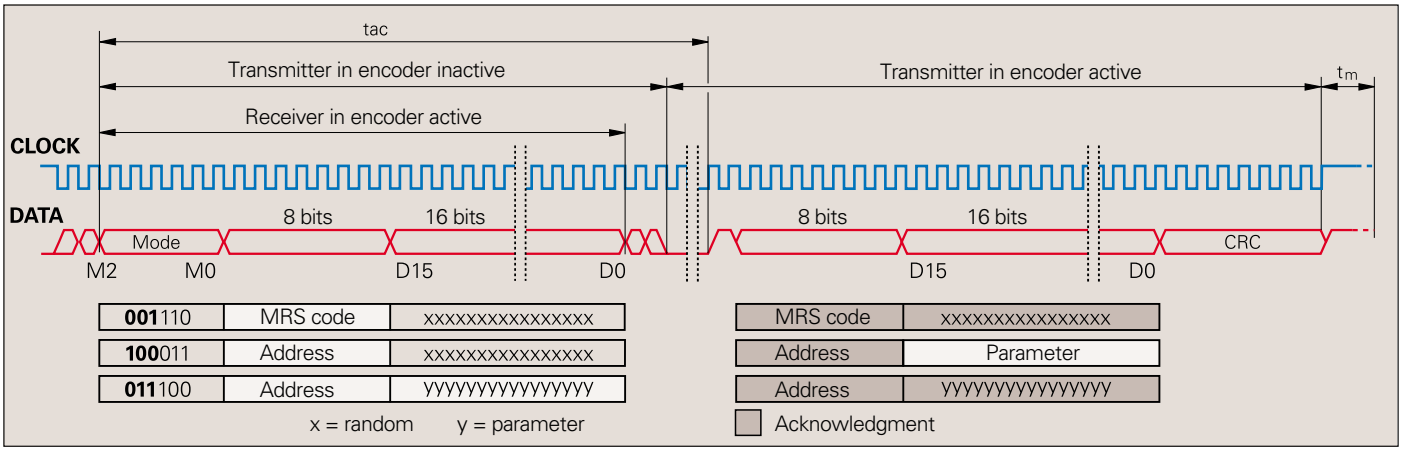
Operating status
This memory area provides detailed alarms or warnings for diagnostic purposes. Here it is also possible to activate write protection for the *OEM parameter and operating parameter* memory areas and interrogate their status.

Once write protection is activated, it cannot be removed.

Control cycles for transfer of parameters (EnDat 2.1 mode command 001110)
Before parameter transfer, the memory area is specified with the mode command *select memory area* and a subsequent memory-range-select code (MRS). The possible memory areas are stored in the parameters of the encoder manufacturer. Due to internal access times to the individual memory areas, the time t_{ac} may reach 12 ms.

Reading parameters from the encoder (EnDat 2.1 mode command 100011)
After selecting the memory area, the subsequent electronics transmit a complete communications protocol beginning with the mode command *Encoder transmit parameters,* followed by an 8-bit address and 16 bits with random content. The encoder answers with the repetition of the address and 16 bits with the contents of the parameter. The transmission cycle is concluded with a CRC check.

Writing parameters to the encoder (EnDat 2.1 mode command 011100)
After selecting the memory area, the subsequent electronics transmit a complete communications protocol beginning with the mode command *Encoder receive parameters,* followed by an 8-bit address and a 16-bit parameter value. The encoder answers by repeating the address and the contents of the parameter. The CRC check concludes the cycle.



Safety Techniques

Safety-oriented controls are the planned application for encoders with EnDat 2.2 interface. The position paper DKE-AK 226.03 (draft 04.06.98) describes the requirements of safety-oriented functions of electric drive systems in machines, particularly in Item 7.2.4 on rotary encoders with serial interface for position and velocity monitoring. The EnDat 2.2 interface supports the following safety-relevant functions:

- **Two independent error messages**
  The error messages are generated independently from each other and are transmitted at different active levels.
- **Two independent position values for error detection**
  In addition to the position value, the additional information includes a separately evaluated position value to be used for comparison in the subsequent electronics.
- **Checksums and acknowledgments**
  A checksum of all parameters is available in the memory. This checksum must agree with the sum calculated in the subsequent electronics. When parameters are transmitted to the encoder the data content is returned as acknowledgment. The data contents are then compared to monitor the communication.
- **Inversion or repetition of mode commands**
  The mode commands consist of 3 bits that are transmitted redundantly either inverted or repeated. The consistency is monitored in the encoder and acknowledged with an error response.
- **Independent individual CRC generation for position values and additional information**
  Separate CRC values are generated for the individual data packets of a transmission (position value, additional information 1 and 2).
- **Quick-response data acquisition and transmission**
  Short cycle times of less than 30 µs for data acquisition including transmission make the necessary comparisons and monitoring of transmission functions possible.
- **Forced dynamic sampling of error messages**
  Through the mode commands for requesting test values, the significance of the error messages are inverted and their generation is therefore monitored.
- **Force dynamic sampling of CRC monitoring in the subsequent electronics**
  The CRC generation in the receiver chip (EnDat master) of the subsequent electronics must be ensured through a targeted execution of bit sequences with known result.
- **Multiple transmission of the position value during start-up**
  To avoid errors during initialization, the position value must be transmitted repeatedly during start-up and compared.
- **Following error monitoring in the subsequent electronics**
  As a general additional check of the moving axes, the servo lag must be monitored in the subsequent electronics.

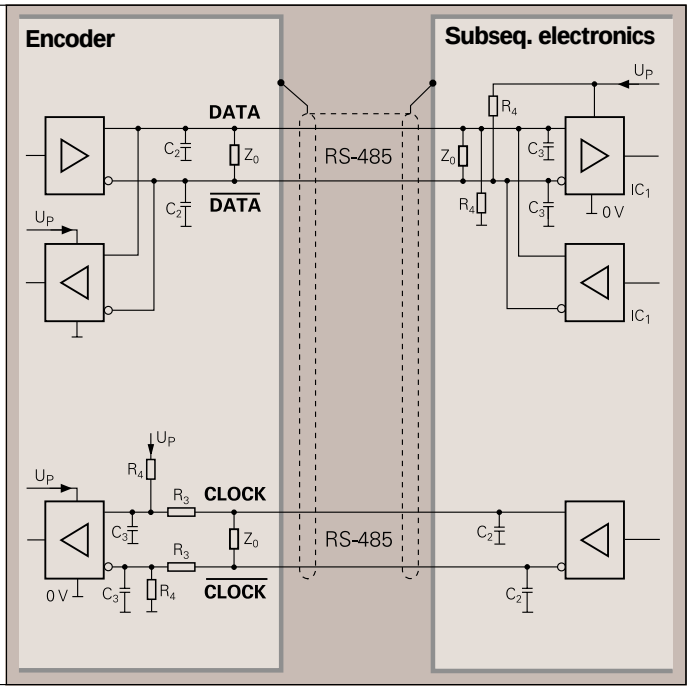
Hardware

Data (measured values or parameters) can be transferred bidirectionally between position encoders and subsequent electronics over transceiver components in accordance with RS-485 (differential signals) in synchronism with the clock signal produced by the subsequent electronics.

Code signals

IC_1 = RS 485
Differential line
receiver and driver

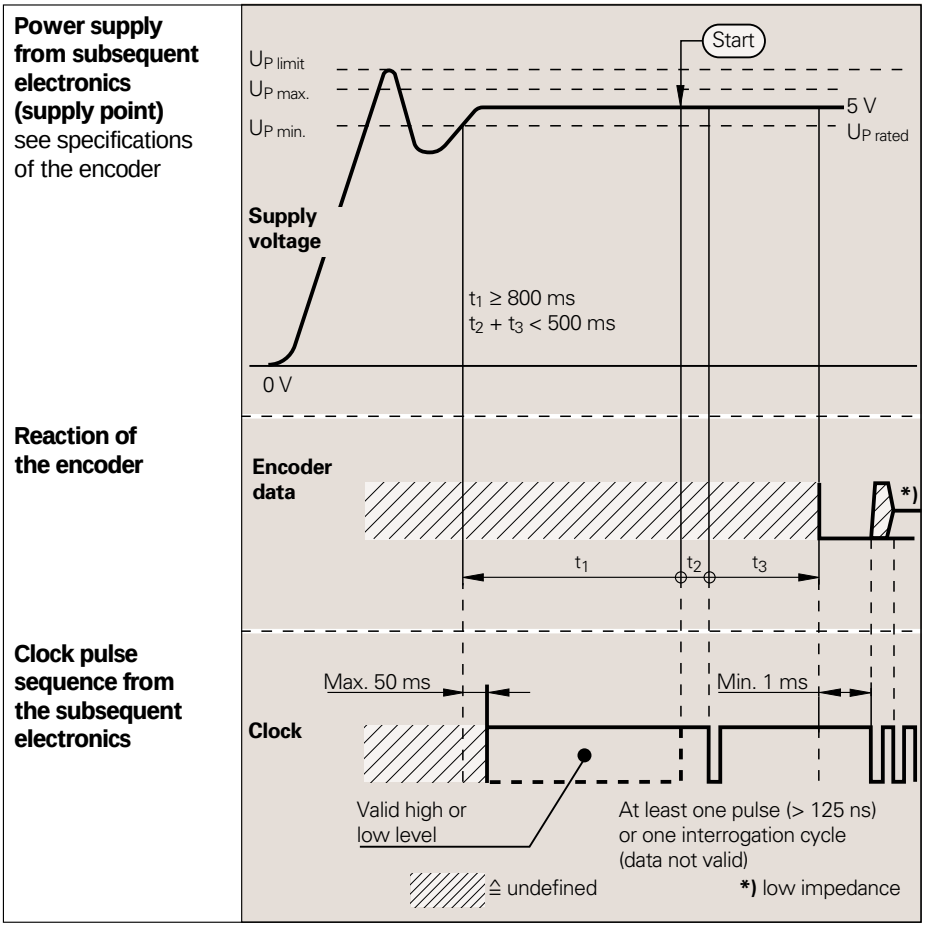
C_2 = 330 pF
C_3 = 100 pF
R_3 = 100 Ω
R_4 = 1 kΩ
Z_0 = 120 Ω



Power supply
The encoders must be powered by stabilized dc voltage. Voltage between 4.5 and 5.5 V must be available at the supply point (subsequent electronics). The encoders are designed so that the resulting voltage after attenuation through cable length, cable cross section and current consumption can be processed without correction (applies only for cable assemblies from SUMTAK).

Ripple limits are:
- High-frequency interference U_{PP} < 250 mV with dU/dt > 5 V/µs
- Low-frequency fundamental ripple U_{PP} < 100 mV

Starting behavior at the encoder
The integrated electronics require an initialization time of approx. 1 s. To attain a defined run-up time, the illustrated switch-on routine should be taken into account.



Appendix 1 : Parameters of the machine manufacturer for EnDat 2.1

Word	Content	Unit for Rotary encoder	MRS code C7	C6	C5	C4	C3	C2	C1	C0	Address HEX
4	Mask 0										04
5	Mask 1										05
6	Mask 2										06
7	Mask 3										07
8	Version of EnDat interface										08
9	Memory allocation for parameters of the OEM										09
10			1	0	1	0	0	0	0	1	0A
11	Memory allocation for compensation										0B
12											0C
13	Number of clock pulses for transmission of the position value (transmission format)										0D
14	Encoder model										0E
15	Signal period or signal periods per revolution for incremental output signals	–									0F
16											00
17	Distinguishable revolutions (only for multiturn encoders)	–									01
18	(Nominal) increment of reference marks	Signal periods									02
19	Position of the first reference mark										03
20	Measuring step or measuring steps per revolution for serial data transmission										04
21											05
22	Datum shift of the machine tool builder	Signal periods									06
23			1	0	1	0	0	0	1	1	07
24	Part number (Id. Nr.)	–									08
25											09
26											0A
27	Serial number	–									0B
28											0C
29											0D
30	Direction of rotation or traverse	–									0E
31	Status of the service diagnosis	–									0F
32	Maximum mechanically permissible linear or rotational velocity	min-1									00
33	Linear or rotational velocity-dependent accuracy, range I	LSB [1)]									01
34	Linear or rotational velocity-dependent accuracy, range II	LSB [1)]									02
35	Support of error messages 1	–									03
36	Support of warnings	–									04
37	EnDat command set	–									05
38	Measuring length (only linear encoders)	–									06
39	Maximum computing time	–	1	0	1	0	0	1	0	1	07
40	Encoder manufacturer-specific data	–									08
41		–									09
42		–									0A
43											0B
44		–									0C
45											0D
46											0E
47	CHECKSUM										0F

[1)] The higher-order byte contains a divisor with respect to the maximum permissible linear or rotational velocity up to which this accuracy applies.

Appendix 2 : Parameters of the encoder manufacturer for EnDat 2.2

Word	Content	Unit for Rotary encoder	MRS code C7	C6	C5	C4	C3	C2	C1	C0	Address HEX
0	Status of additional information 1	–									00
1	Status of additional information 2	–									01
2	Status of additional functions	–									02
3	Acceleration	$1/s^2$									03
4	Temperature	K									04
5	Diagnostic status	–									05
6	Support of error message 2	–									06
7	Dynamic sampling status	–									07
8	Dynamic sampling status	–									08
9	Measuring step or measuring step per revolution for position value 2										09
10											0A
11	Offset between position value and position value 2										0B
12			1	0	1	1	1	1	0	1	0C
13	Accuracy of the position value 2, range I depending on linear velocity or shaft speed	LSB [1)]									0D
14	Accuracy of the position value 2, range II depending on linear velocity or shaft speed	LSB [1)]									0E
15	Number of distinguishable revolutions for position value 2	–									0F
16	Direction of rotation of position value 2	–									10
17	Encoder designation	–									11
18											12
19											13
20											14
63	CHECKSUM										3F

[1)] The higher-valued byte contains the divisor with respect to the maximum permissible linear or rotational velocity up to which this accuracy is valid.

The types of additional information, additional functions, diagnostic values, and specifications that the respective encoder supports are saved in the assigned status words of these memory areas. Before interrogation of the additional information, SUMTAK recommends reading them out (typical for every initialization of encoders). In addition, the supported types of additional information and additional functions are listed in the specifications of the encoders.