SIN-COS interface and temperature sensor

Summary

The electrical interface option SIN-COS is based on linear Hall sensors that provide sine and cosine signals. This type of interface is suitable for commutation purposes as well as for position-control or speed-control applications.

The dimensions and connection type are same as the standard BX4 drives with the analog or digital interface. This interface type therefore ideal for the application where the compact design with minimum wiring effort are required.

The interface option can be combined with the 3rd generation of motion controllers MC3. Even designing own application specific control system based on an analog-to-digital conversion becomes easy due to the superior signal quality.

The SIN-COS Hall sensor based interface described in this application note is the single-ended, with typical peak-to-peak amplitude of 2.5V. As BX4 is the two pole-pair design therefore provides two signal periods per mechanical revolution. The detailed electrical signal characteristics are described in the table 2 and 3. Here it is important to note that, the SIN-COS interface based on analog Hall sensor principle, and therefore it is different from the standard industry based sine-cosine interface with 1V peak-peak amplitude.

In addition to SIN-COS interface, the drive also has an integrated temperature sensor output to get thermal status of the drive. Further details are given below in the section – temperature sensor.

Applies To

BX4 Motor-type	Option-No SIN-COS	Compatible controllers
2232…BX4	5327	MC3001
2250…BX4		MC 3602/03/06
3242..BX4		MC5004
3268..BX4		MC5005
		MC5010

Table 1 : BX4 drives which are equipped with SIN-COS interface and temperature sensor

Description

General Information

The FAULHABER BX4 brushless-motors with SIN-COS interface use the magnetic field of the rotor magnets for sensing purpose, therefore have very compact design.
For the 2 pole-pair BX4 drive, two sine and cosine periods per one mechanical rotation are available. The 90°e (or 45°m) phase shift between sine and cosine allows determination of the accurate angle .

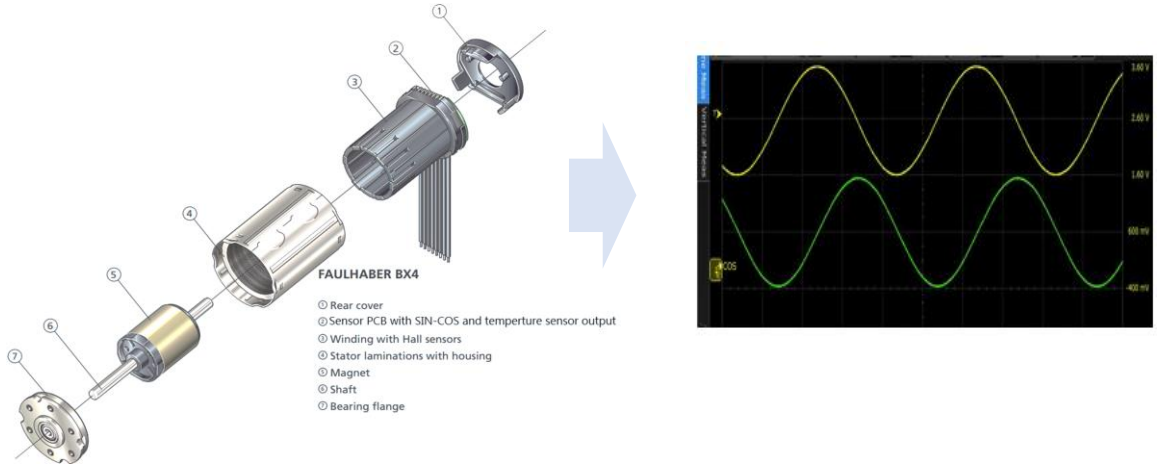


Figure 1 : Principle of sine-cosine signals for BX4 drives

Electrical characteristics of the Hall sensors

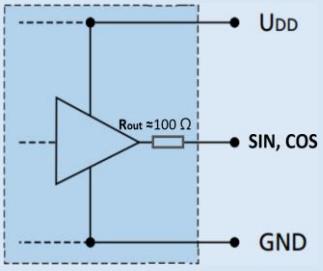
BLDC motor family	BX4-Motors
Motor types	2232…BX4, 2250…BX4, 3242..BX4, 3268..BX4
Sensor supply voltage U_{DD} (min. / typ. / max.) V	(4.5 / 5 / 5.5)
Total current consumption I_{DD} (min./ typ. / max.) mA	(- / 20 … 28 / 36)
Output stage type	Push-Pull
Max. output current capacity/channel mA	

Table 2 : Electrical characteristics of Hall-sensors used for SIN-COS interface

Specification : Sine and cosine signals

The electrical signal characteristics are specified in the table 2:

Parameter	minimum	nominal	maximum
Phase-to-Phase offset	82°e	90°e	98°e
Offset voltage U_{offset}	2.20V	2.5 V	2.8 V
Peak-to-peak voltage U_{ss}	1.7V	-	3.5 V
Maximum voltage U_{max}	3.0V	-	4.2 V
Amplitude Deviation $U_{max-diff}$[1]	0V		0.09 V
Position error[2]	-	1°m	-
Repeatability[3]	-	0.2°m	-

Table 3 : Output signal specification range for the measuring parameters

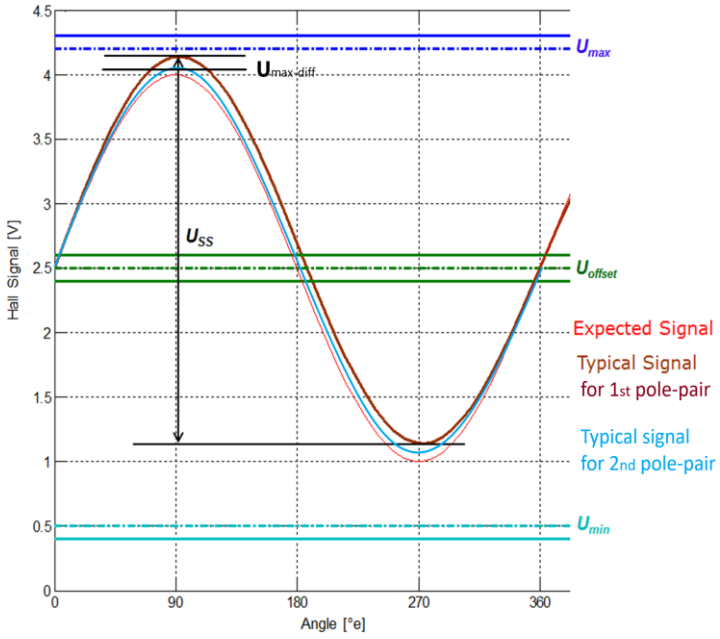


Figure 2 : Definitions of analog sine/cosine signal parameters

[1] Amplitude deviation describes the different maximum signal levels in different magnetic pole-pairs of brushless motors having 2 pole-pairs.

[2] For the definition of the Position error, please refer Appnote - 147

[3] For the repeatability of the Position error, please refer Appnote - 147

Commutation sequence and phase alignment

The commutation sequence for the FAULHABER BLDC motors is as in the table 4 below:

Direction of rotation	Commutation sequence
Clockwise (CW)	Phase C – Phase B – Phase A
Counter-clockwise (CCW)	Phase C – Phase A – Phase B

Table 4 : FAULHABER BLDC motor the commutation sequence

For the angle calculations, the signal offset voltage of 2.5V have to be subtracted from the Hall sensor output voltage signal, so that the angle at the zero crossing of the SIN and COS signals can be considered.
Figure 3 and 4 shows the relationship between phase voltages and Hall sensor voltages for the 2250 BX4 drive, in particular the phase relation of the generated phase voltage V_{CA} with respect to the COS signal of the drive. For the clockwise operation of the 2250BX4 drive, the zero crossing of the phase voltage V_{CA} is shifted typically +2.5°m from the zero-crossing of the COS signal. For the counter-clockwise direction of operation, the angle is typically -2.5°m.

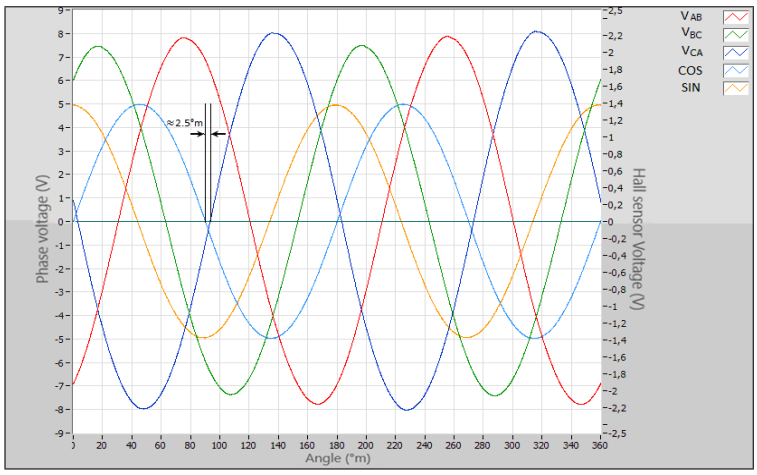


Figure 3 : Signal profile of 2250 BX4 drive with the clockwise operation

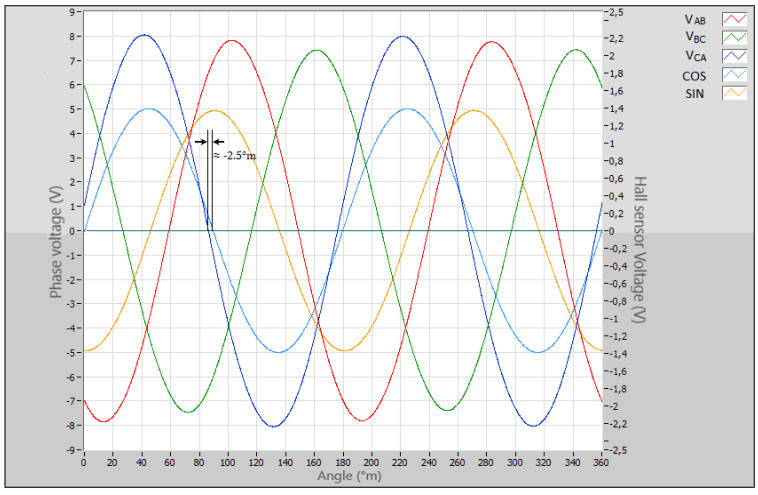


Figure 4 : Signal profile of 2250 BX4 drive with the counter-clockwise operation

The relationship of COS signal to the phase voltage V_{CA} for the BX4 drives is as in table 5 below:

Drive	Average commutation angle between COS signal and phase voltage V_{CA} with clockwise rotation	Tolerance Range
2250 BX4	5°e or 2.5°m	±10°e or ± 5°m
2232 BX4	18°e or 9°m	±10°e or ±5°m
3268 BX4	To be defined	To be defined
3242 BX4	To be defined	To be defined

Please contact MCSupport for further information

Table 5 : Commutation angle and its tolerance variation for the BX4 drives

Calculation of rotor angle and speed

To determine the electrical angle of the system, the sine (α) and cosine (β) output signals are fed into an arctan calculation, with the sine signal being alpha and the cosine signal being beta. For speed calculation a further deviation is required. Please consider that due to 2-pole pairs, there are 2 signal periods per motor revolution.

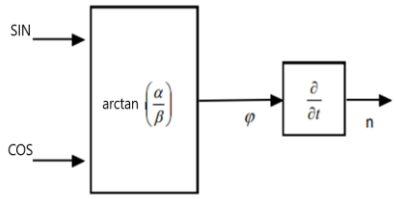
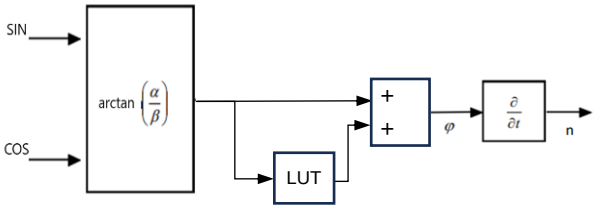


Figure 5 : Block diagram for position and speed calculation

Inside the controller, as a part of the software offset and amplitude of the two sensor signals have to be adjusted before the signals are fed into the angular calculation. The amplitude of the two sensor signals must be scaled to the range [-1, +1].

Correction of rotor angle position for 32XX BX4

For the 32XX BX4 motor, a position correction table should be used. Correction values are added in the form of a Lookup Table (LUT) (table at the end) depending on the current electrical angle.



Temperature sensor

Temperature monitoring is one of the most effective ways to protect a motor from overheating.
FAULHABER motors with a SIN-COS interface equipped with an integrated temperature sensor placed very close to the motor winding. As the motor winding being the hot-spot of the motor, the surface mounted Negative Temperature Coefficient (NTC) sensor is used to sense the temperature.
The NTC temperature sensor is a type of resistor that shows the behavior of decrease in the resistance as the temperature increases.

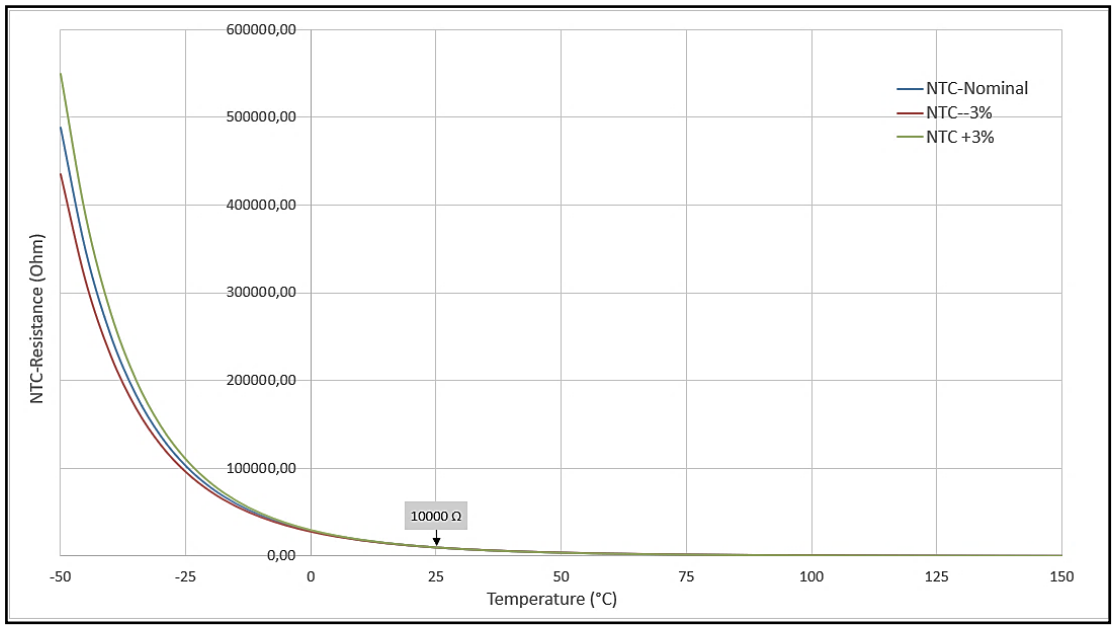


Figure 6 : Graphical characteristic of NTC resistance over internal motor temperature

The relationship between NTC-resistor and temperature is a non-linear function. The figure-6 shows the example of the drive with their NTC-characteristics measured with tolerance band of +/-3%.
Mathematical representation of the relation between NTC-resistance and temperature is as follows:

$$T_{NTC} = \frac{T_1}{\frac{T_1}{B} . ln\left[\frac{R_{NTC}}{R_1}\right] + 1} \quad \Rightarrow \quad T_{NTC} = \frac{298.15}{\frac{298.15}{4110} . ln\left[\frac{R_{NTC}}{10000}\right] + 1}$$

Where:
T_{NTC} is the temperature to be calculated in Kelvin
T_1 is the first temperature point in Kelvin (at room temperature 25°C, it is = 298.15K)
R_1 is the resistance at T1 temperature in Ohms (at room temperature 25°C, it is = 10kΩ with tolerance ±3%)
R_{NTC} is the resistance of NTC sensor at T_{NTC} temperature in Ohms
B is the constant that depends up on type of ceramic material. Its value for temperature range (-40 to 125°C) is 4110 with tolerance ±3%.

In practice, the schematic of Hall sensor and NTC-resistor is represented in the figure 7, where the NTC-resistor connected to V_{DD} through the 10kΩ series resistor. Therefore, the voltage drop across the NTC-

resistor is measured and the resistance value R2 at operating temperature T(R) is calculated based on the following formula:

$$R_{NTC} = \frac{V_{NTC} \cdot R_{series}}{V_{DD} - V_{NTC}} \quad \Rightarrow \quad R_{NTC} = \frac{V_{NTC} \cdot 10000}{5 - V_{NTC}}$$

Where :

V_{NTC} is the voltage drop measured at NTC against GND.

R_{series} is the fixed resistance of 10kΩ placed in series with NTC resistor.

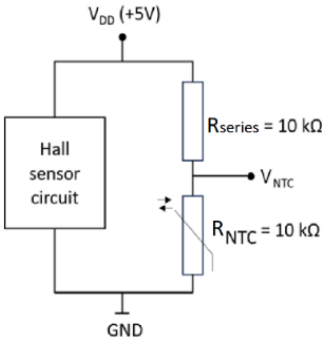


Figure 7 : Schematic related to the NTC sensor

Remarks - The calculations are based on the condition that the schematic part of Rseries and NTC-Resistor is in the unloaded condition. Small variation is expected in the loaded condition.

The practical measurements of voltage across NTC-resistor over operating temperature of the drive during the qualification are represented in the graphical form below.

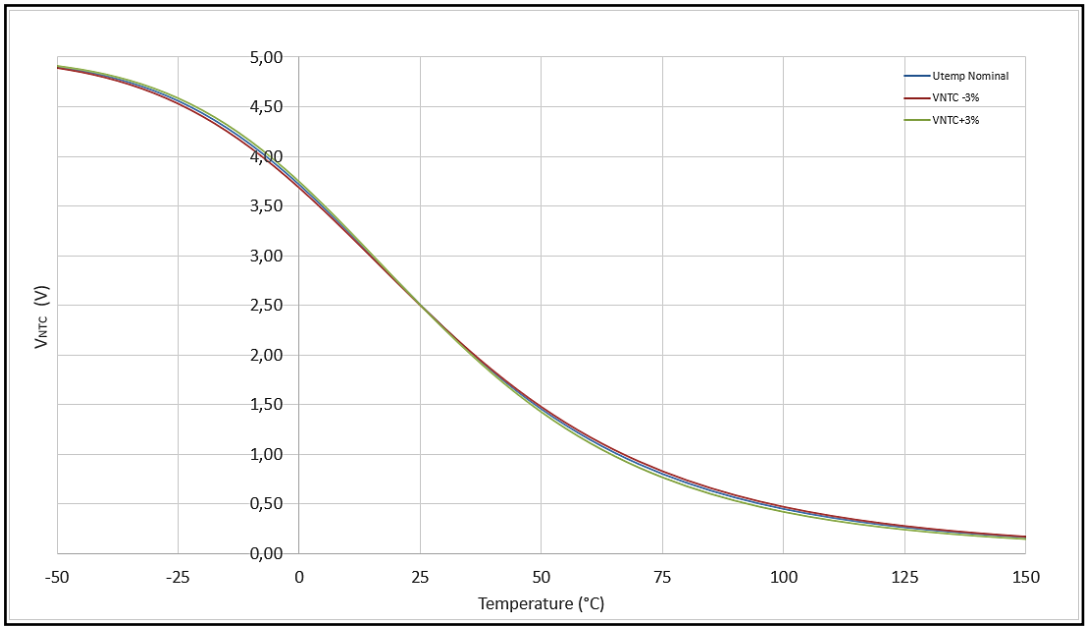
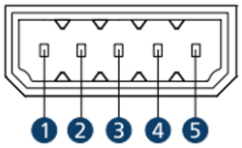


Figure 8 : NTC-Voltage characteristic over temperature

Connection diagram with Motion controller

The SIN-COS interface including the NTC-sensor output can be connected directly to the FAULHABER motion controller - generation MC3 with the use of 5-pin connector M2.



Pin Number	Designation	Description
1	V_{DD}	Power supply for sensors
2	GND	Ground connection
3	COS	Cosine output signal
4	SIN	Sine output signal
5	NTC	Temperature sensor output signal

Table 6 : Pin-assignment of sensor connection M2 of FAULHABER-MC3

For configuration of the sin/cos sensor interface use Motion Manager's wizard "Select motor" (Motion Manager 6) or "Setup drive system" (Motion Manager 7) and select the sensor system "analog hall sensors" with 2 channels (sin/cos) as in figure below:

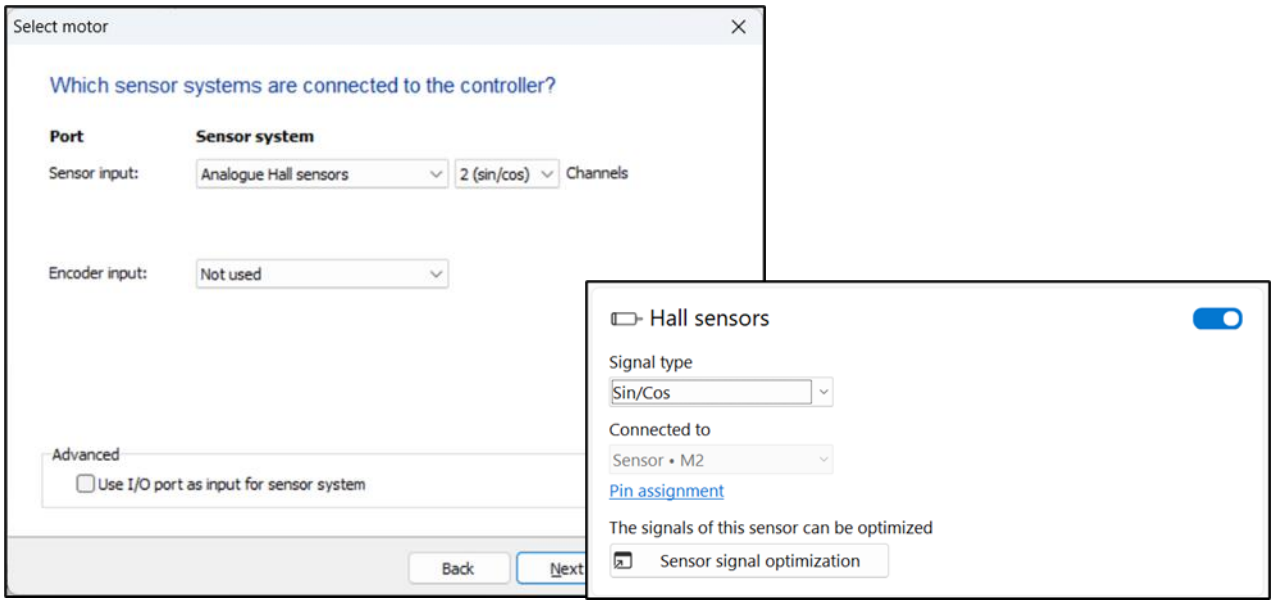


Figure 9 : Configuration – motor with sin-cos interface with MC3

The 2250 BX4 drive require the offset-angle correction typically 5°m (1821 x 0.00549°el=10°el) and can be programmed within the object browser as below in figure 10.
For 2232, 3242 and 3268 BX4 drive no offset angle programming is required.

Objekt	Index	Subindex	Parameter	Aktueller Wert	Neuer Wert	Einheit
Motor and application data for motor control	2329	08	Phase angle offset	1821		x0.00549 °(elec.)

Figure 10 : Offset angle programming for 2250 BX4 drive

Lookup Table (for 32XX BX4 position correction)

	electrical angle in rad	position correction in rad
1	-3,1170E+00	2,0565E-02
2	-3,0680E+00	1,5102E-02
3	-3,0189E+00	9,5380E-03
4	-2,9698E+00	4,3266E-03
5	-2,9207E+00	-1,8979E-04
6	-2,8716E+00	-4,1716E-03
7	-2,8225E+00	-7,2604E-03
8	-2,7734E+00	-9,4588E-03
9	-2,7243E+00	-1,0768E-02
10	-2,6753E+00	-1,1147E-02
11	-2,6262E+00	-1,0464E-02
12	-2,5771E+00	-9,4076E-03
13	-2,5280E+00	-7,1394E-03
14	-2,4789E+00	-4,5315E-03
15	-2,4298E+00	-1,5583E-03
16	-2,3807E+00	1,8114E-03
17	-2,3317E+00	5,0792E-03
18	-2,2826E+00	8,0953E-03
19	-2,2335E+00	1,1087E-02
20	-2,1844E+00	1,3720E-02
21	-2,1353E+00	1,5342E-02
22	-2,0862E+00	1,6523E-02
23	-2,0371E+00	1,6695E-02
24	-1,9880E+00	1,5979E-02
25	-1,9390E+00	1,4758E-02
26	-1,8899E+00	1,2255E-02
27	-1,8408E+00	9,0767E-03
28	-1,7917E+00	5,2244E-03
29	-1,7426E+00	5,7290E-04
30	-1,6935E+00	-4,1675E-03
31	-1,6444E+00	-9,1243E-03
32	-1,5953E+00	-1,4455E-02
33	-1,5463E+00	-1,9290E-02
34	-1,4972E+00	-2,3605E-02
35	-1,4481E+00	-2,7469E-02
36	-1,3990E+00	-3,0584E-02
37	-1,3499E+00	-3,2689E-02
38	-1,3008E+00	-3,4003E-02
39	-1,2517E+00	-3,3996E-02
40	-1,2026E+00	-3,3040E-02
41	-1,1536E+00	-3,1108E-02

42	-1,1045E+00	-2,7966E-02
43	-1,0554E+00	-2,3864E-02
44	-1,0063E+00	-1,9134E-02
45	-9,5720E-01	-1,3802E-02
46	-9,0812E-01	-7,8051E-03
47	-8,5903E-01	-1,5062E-03
48	-8,0994E-01	4,8827E-03
49	-7,6085E-01	1,1261E-02
50	-7,1177E-01	1,7526E-02
51	-6,6268E-01	2,3259E-02
52	-6,1359E-01	2,8556E-02
53	-5,6450E-01	3,2998E-02
54	-5,1542E-01	3,6508E-02
55	-4,6633E-01	3,9106E-02
56	-4,1724E-01	4,0495E-02
57	-3,6816E-01	4,0892E-02
58	-3,1907E-01	3,9890E-02
59	-2,6998E-01	3,7906E-02
60	-2,2089E-01	3,4791E-02
61	-1,7181E-01	3,0609E-02
62	-1,2272E-01	2,5654E-02
63	-7,3631E-02	2,0193E-02
64	-2,4544E-02	1,4215E-02
65	2,4544E-02	8,1934E-03
66	7,3631E-02	2,0528E-03
67	1,2272E-01	-3,8613E-03
68	1,7181E-01	-9,1628E-03
69	2,2089E-01	-1,3983E-02
70	2,6998E-01	-1,7771E-02
71	3,1907E-01	-2,0521E-02
72	3,6816E-01	-2,2517E-02
73	4,1724E-01	-2,3492E-02
74	4,6633E-01	-2,3338E-02
75	5,1542E-01	-2,2316E-02
76	5,6450E-01	-2,0558E-02
77	6,1359E-01	-1,8086E-02
78	6,6268E-01	-1,4918E-02
79	7,1177E-01	-1,1482E-02
80	7,6085E-01	-7,8527E-03
81	8,0994E-01	-4,2485E-03
82	8,5903E-01	-7,6215E-04
83	9,0812E-01	2,5073E-03
84	9,5720E-01	5,1494E-03
85	1,0063E+00	7,1255E-03

86	1,0554E+00	8,3626E-03
87	1,1045E+00	8,8314E-03
88	1,1536E+00	8,1337E-03
89	1,2026E+00	6,7007E-03
90	1,2517E+00	4,3474E-03
91	1,3008E+00	1,0320E-03
92	1,3499E+00	-3,0416E-03
93	1,3990E+00	-7,6201E-03
94	1,4481E+00	-1,2806E-02
95	1,4972E+00	-1,8184E-02
96	1,5463E+00	-2,3409E-02
97	1,5953E+00	-2,8653E-02
98	1,6444E+00	-3,3438E-02
99	1,6935E+00	-3,7359E-02
100	1,7426E+00	-4,0686E-02
101	1,7917E+00	-4,2968E-02
102	1,8408E+00	-4,4296E-02
103	1,8899E+00	-4,4485E-02
104	1,9390E+00	-4,3088E-02
105	1,9880E+00	-4,0971E-02
106	2,0371E+00	-3,7662E-02
107	2,0862E+00	-3,3242E-02
108	2,1353E+00	-2,7920E-02
109	2,1844E+00	-2,1802E-02
110	2,2335E+00	-1,5338E-02
111	2,2826E+00	-8,2437E-03
112	2,3317E+00	-1,0640E-03
113	2,3807E+00	6,3454E-03
114	2,4298E+00	1,3414E-02
115	2,4789E+00	2,0371E-02
116	2,5280E+00	2,6863E-02
117	2,5771E+00	3,2451E-02
118	2,6262E+00	3,7168E-02
119	2,6753E+00	4,1136E-02
120	2,7243E+00	4,3872E-02
121	2,7734E+00	4,5514E-02
122	2,8225E+00	4,5872E-02
123	2,8716E+00	4,5105E-02
124	2,9207E+00	4,3129E-02
125	2,9698E+00	3,9931E-02
126	3,0189E+00	3,6134E-02
127	3,0680E+00	3,1585E-02
128	3,1170E+00	2,6267E-02

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