Analog Hall Sensors

Summary

Analog Hall sensors can be chosen as an option for many FAULHABER Brushless DC-Motors and can be used for both speed control (particularly at low speeds) and motion control. Analog Hall sensors are an economical, lightweight and compact alternative to encoders and are a preferred solution for many customers.

The documentation here is meant to give an overview over the properties of the signals and an overview over the necesarry steps if a motor having analog hall-sensors is to be operated at a custom controller.

Applies To

2-Pole Motors	LM-Motors	BX4 Motors	BP4 Motors	Flat Motors[1]
0620…B	LM 0830	2232…BX4 (S)	2264…BP4	1509…B
1218…B	LM 1247	2250….BX4 (S)	3274…BP4	2610…B
1226…B	LM 1483	3242…BX4		
1628…B	LM 2070	3268…BX4		
2036…B				
2057…B(HS)				
2444…B				
3056…B				
3564…B				
4490…B(S)				

Table 1 Motors that can be equipped with analog hall sensors

SpeedController[2]	MotionController V2.5	MotionController V3.0
SC 1801	MCBL 3002 S/P	MC 5004
SC 2402	MCBL 3003 P	MC 5005
SC 2804	MCBL 3006 S	MC 5010
SC 5004	MCLM 300x for LM motors	
SC 5008		

Table 2 FAULHABER MotionControllers and SpeedControllers supporting analog hall-sensors as a speed or position feedback

[1] With some limitations (for further information please see Applications Note 145: Brushless DC Flat Micro Motors with Analog Hall Sensors)

[2] The capabilities of the controller might depend on the selected execution. Please refer to the datasheet.

SpeedControlSystems	MotionControlSystems V2.5	MotionControlSystems V3.0
2232...BX4 SC 2250...BX4 SC	2232...BX4 CxD 2250...BX4 CxD	
3242...BX4 SC 3268....BX4 SC	3242...BX4 Cx 3268...BX4 Cx	MCS 3242...BX4 MCS 3268...BX4
		MCS 3274...BP4

Table 3 FAULHABER MotionControlSystems do always use analog hall-sensors as encoder. SpeedControl-Systems can optionally be equipped with analog hall-sensors

Possible combination of motors and controllers

Motor-type	Option-No A-Hall	SC	MC V2.5	MC V3.0
0620 … B	K2280	✓	✓	-
1218 … B **1226 … B**	K1855	✓	✓	✓
1628 … B … **4490 … B/BS**	K1155	✓	✓	✓
BX4	3692	✓	✓	✓
BP4	3692	✓	-	✓
BL-Flat	Z3692	✓	-	-

Table 4

Glossary

There are a few special terms in this product application note:

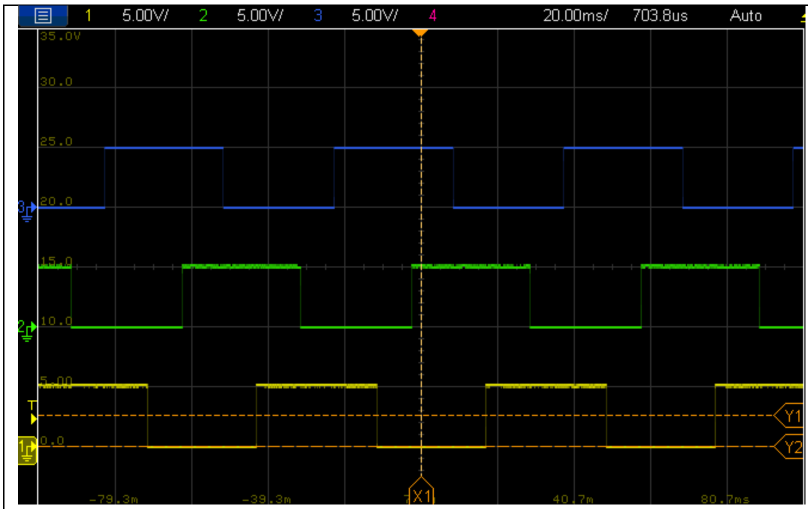
120°e	The °e denotes an electrical angle of a motor. Here we are mostly discussing the electrical view of a motor – so the angle within on electrical period of the hall-sensors or the voltages. In motors having more than one pole pair, there is a multiple of electrical periods per mechanical turn.
Motion Controller	The FAULHABER controllers used for servo-drive applications
Speed Controller	The FAULHABER controllers used for pure speed control of a motor
BX4	FAULHABER BX4 motors
BP4	FALUHABER BP4 motors
C(X)R	FAULHABER DC-motors out of either the CR or the CXR series
SR	FAULHABER DC-motors out of the SR series

Description

General Information

At FAULHABER brushless-motors two different integrated sensors systems can be found:

Three digital Hall sensors



The sensors are positioned with a 120 °e angle. This allows for simple block-commutation. The motor-speed can be calculated too.

Digital hall-sensors are mainly used for simple speed control or in combination with an additional incremental encoder.

Yellow: $Hall_A$

Green: $Hall_B$

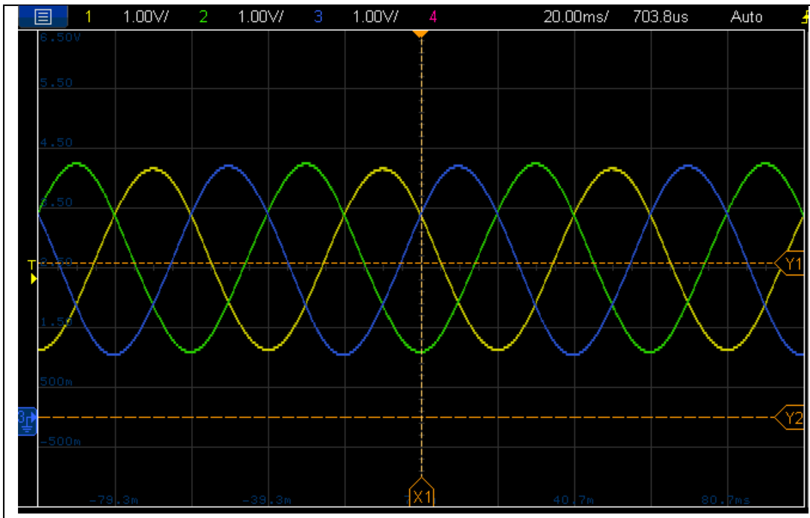
Blue: $Hall_C$

Clockwise operation

Figure 1 Digital Hall sensors

For further information on digital hall sensors, please refer to application note - 163

Three analog Hall sensors



The sensors are positioned with a 120 °e angle. Due to the linear behavior of the signals the actual angle can be interpolated.

Analog hall-sensors which are primarily used for motion control.

Yellow: $Hall_A$

Green: $Hall_B$

Blue: $Hall_C$

Clockwise operation

Figure 2 Analog Hall sensors

Electrical characteristics of the hall sensors of FAULHABER BLDC motors

BLDC motor family	2-Pole BLDC Motors		LM-Motors	BX4- Motors	BP4 - Motors	Flat - Motors
BLDC motor types	0620…B, 1218…B, 1226…B	1628…B, 2036…B, 2057…B(HS), 2444…B, 3056…B, 3564…B, 4490…B(S)	LM 0830, LM 1247, LM 1483, LM 2070	2232…BX4(S), 2250…BX4(S), 3242…BX4, 3268…BX4	2264…BP4, 3274…BP4	1509…B, 1515…B, 2610…B, 2622…B
Supply voltage range V (min. / typ. / max.)	(4.5 / 5 / 5.5)					
Current consumption mA (min./ typ. / max.)	(- / - / 33)	(- / - / 48)	(- / 21 / 27)			
Max. output current capacity / channel mA	10					
Output stage type	Push- Pull					

Table 5 Electrical characteristics of different analog Hall-sensors in FAULHABER motors

Specification of analog Hall signals and operation with FAULHABER controllers

The general electrical signals of analog hall-sensors are

	minimum	nominal	maximum
Phase-to-Phase offset	112°e	120°e	128°e
Supply voltage U_{DD}	4.8 V	5.0 V	5.3 V
Offset voltage U_{offset}	2.2 V	2.5 V	2.8 V
Peak-to-peak voltage U_{ss}	1.75 V	-	3.5 V
Maximum voltage U_{max}	3.0 V	-	4.2 V
Maximum voltage U_{max} BP4			5.0 V
Amplitude Deviation[3]	-	-	0.35 V

Table 6 Electrical specification of analog Hall-sensors in FAULHABER motors

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

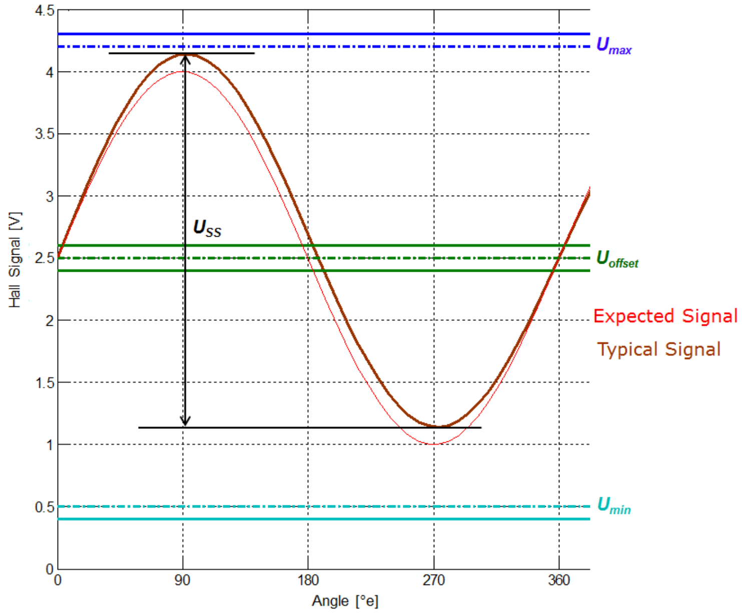


Figure 3 Example of analog Hall signal

Resolution of analog Hall in operation with FAULHABER controllers

The electrical angle is calculated out of the three sinusoidal signals by interpolation. There are different options how to do this. Only two are listed here.

Method A – Table-Look-up within ±30°e of zero-crossing

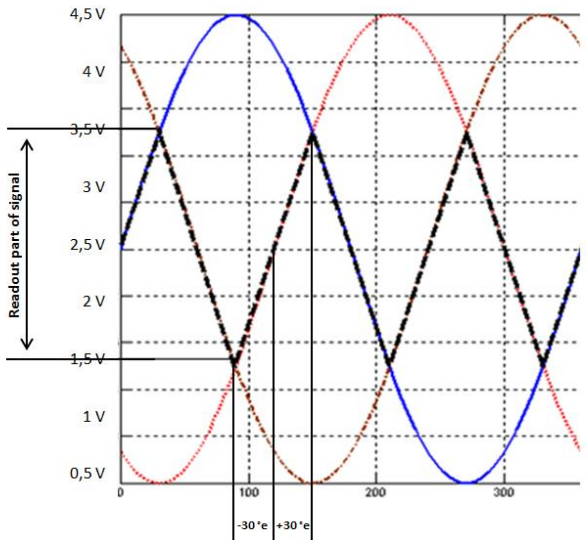


Figure 4 position interpolation using analog hall-signals within 360 °e

Using a look-up-table of the signals within the ±30°e range the angle can efficiently be calculated in three steps:

1. Identify the segment - one of the 6 segments in Figure 4
2. Look-up the interpolated angle within the segment
3. Add the segment offset to the interpolated angle

Method B - Angular transformation + ArcTan

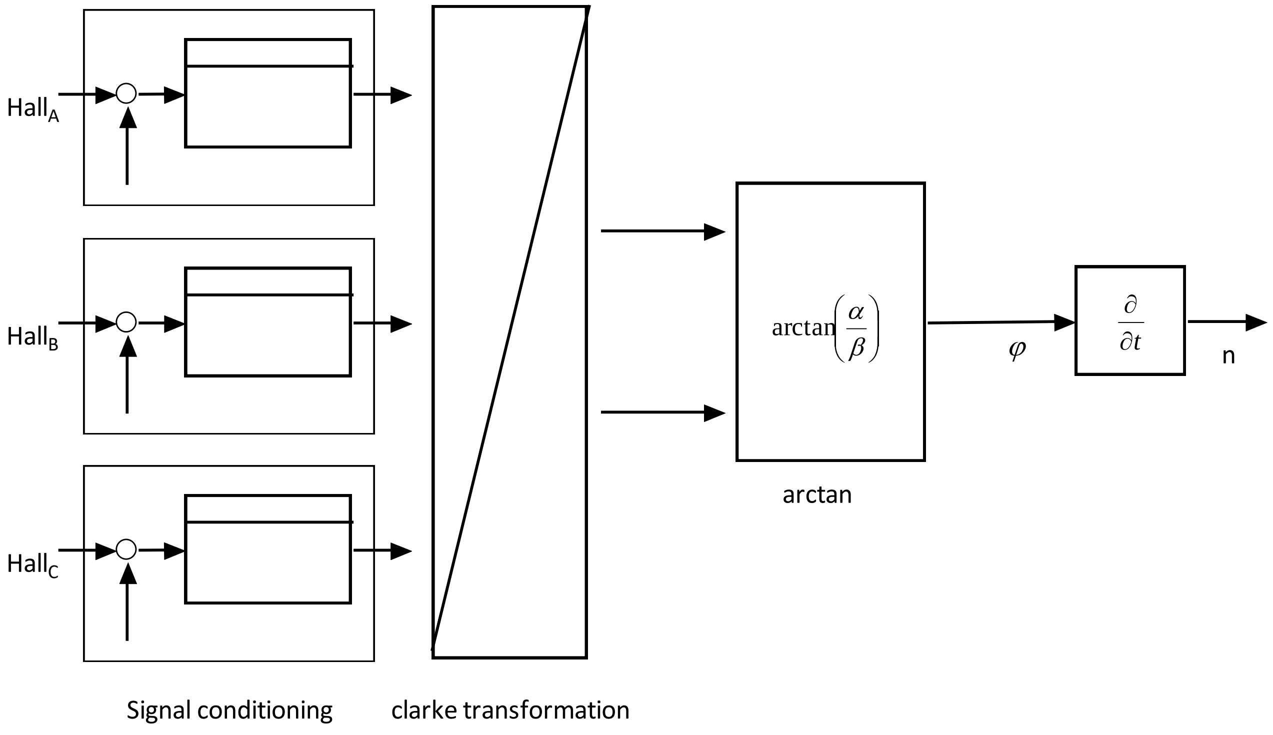


Figure 5 position calculation using a clarke-transformation and arctan

Alternatively the three signals can first be converted into two sinusoidal signals having a 90°el. offset (α,β). The actual angle is then calculated using the arctan (Figure 5).

	On many targets the arctan will again be implemented using a table-lookup. So in fact the two methods are very similar in their behavior and results.

	Figure 5 also includes the necessary signal conditioning of every hall-signal.

Necessary signal-conditioning

The three analog halls-sensors of a motor will always differ in terms of sensitivity and offset. These values might even change during operation due the changes of the motor temperature.

Due to the environment some electrical noise is to be expected too. So in a first step a reasonable low-pass filter should be added before the A/D conversion.

Inside the controller, as a part of the software offset and amplitude of the three sensor signals have to be adjusted before the three signals are fed into the angular calculation.

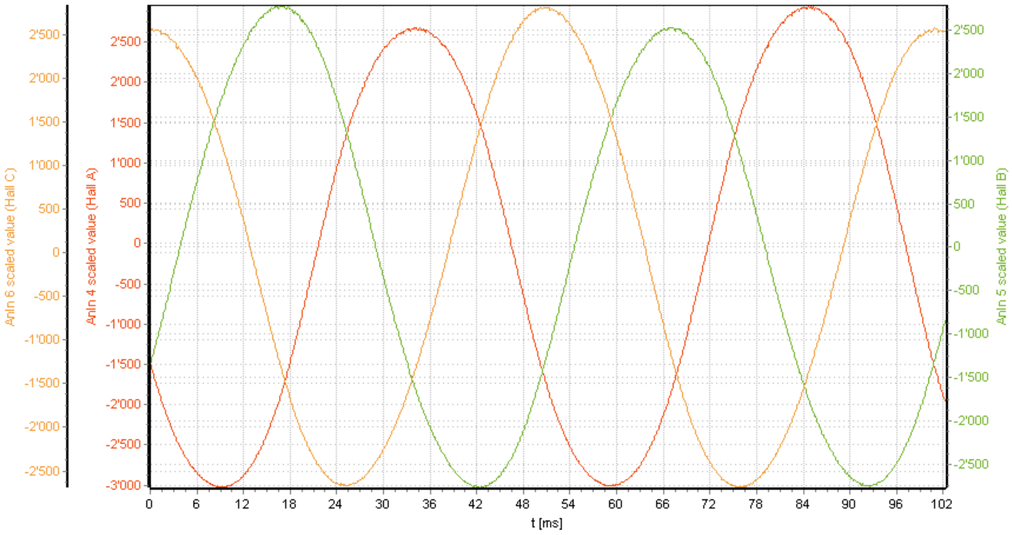


Figure 6 Signal amplitudes of a BX4/BP4 motor

In 4pole-motors the hall-signals do have different signal amplitudes in their different magnetic segments. FAULHABER MotionControllers implement a special compensation mechanism to deal with this effect.

If a non FALUHABER controller is to be used a combination of digital hall-sensors and an incremental encoder or a single-turn absolute encoder might be the recomended solution.

Resolution & Accuracy

The interpolation in Figure 4 allows a simple estimation of the angular resolution of such an encoder system[4].

Using a 12-bit A/D converter a 12-bit resolution is to be expected.

	SC	MC V2.5	MC V3.0
Resolution per turn	2048 increments	3000 increments	4096 increments

Table 7

The accuracy of the calculated angle depends on the linearity of the sensor-signals as well as on their actual relative offset.

Type	Size	Resolution	Precision	Dynamics	Typical Combination
IE2	++	… 4096 Incr	0.5°	++	SR, C(X)R, BL
IE3	+	… 4096 Incr	0.5°	++	C(X)R, BL
IER3	+	… 40000 Incr	0.1°	+++	C(X)R, BL
A-Hall (BX4)	+++	… 4096 Incr	0.8°	++	BL, LM

Table 8 Comparison of A-Hall with typical incremental encoders

In general the resolutions of analog Hall sensors are comparable to many FAULHABER encoders. The magnetic IE3-1024 with 1024 lines per revolutions for example determines 1024 x 4 = 4.096 increments per revolution.

The resolutions and the accuracy of analog Hall sensors are sufficient for most motion control applications. In demanding high precision or fast positioning applications, encoders with higher resolution and accuracy like the optical encoder IER3-10.000 with resolutions of up to 4 x 10.000 = 40.000 increments should be used.

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[4] Typically the analog hall-signals will be converted into a digital value inside some µController or DSP using an A/D-converter. The available resolution of the A/D-converter has to cover the complete signal range as given in Table , even if the used signal amplitude of a given motor is smaller. The resolution per turn can then be estimated out of the ratio of used signal range to allowed signal range multiplied with the number of interpolation segments – 6 in case of a 2-pole motor.

So if the allowed range 0V … 5V is converted into 4096 increments by a 12 bit A/D converter and a signal range of ±1V is used the maximum resolution is:

max. Resolution = (2V act. range /5 V max. range) x 4096 incr. x 6 ≈ 10'000 incr.

FALUHABER MotionControllers and MotionControlSystems use an internal signal conditioning which will result in a typical accuracy of +/-1.5° for a 2-pole motor resp. +/-0.8° for a 4-pole motor.

Dynamic performance

In simple test-setup the dynamic performance of a 3268G024 BX4 motor combined with a MC 5005 S CO has been compared. The drive was operated at 24V. A brake-chopper was used to allow for maximum deceleration.

The load was a small disc only.

Speed step

The motor was accelerated from 0 min-1 to 1000 min-1. Results are given for the rise-time and the settling-time as there is an overshoot.

Position step

The motor was moved forward by 1 turn. The result is the settling-time as there is no overshoot here.

Results

Motor & Sensor	Speed Step (0 … 1000 min-1)	Pos-Step (1 turn) no feed-formward	Pos-Step (1 turn) active feed-formward
3268 BX4 A-Hall	7 ms / 50ms	56 ms	40 ms
3268 BX4 IE3-1024	7 ms / 25ms	56 ms	37 ms
3268 BX4 IER3-10000	6ms / 10ms	45 ms	27 ms

Table 9 Dynamic performance of a BLDC-motor having different feedback systems

	Three different sensor-systems have been used: • D-Hall & IER3 10000 • D-Hall & IE3 1024 • A-Hall

Figure 7 Test-setup for the dynamic performance of different sensor-systems

Commutation sequence and phase alignment

For a FAULHABER BL-motor the commutation sequence is:

Direction	Commutation sequence
Clock-wise	Phase A – Phase C – Phase B
Counter clock-wise	Phase A – Phase B – Phase C

Table 10

Figure 8 and Figure 9 show the alignment of a single phase voltage (phase C) compared to the analog hall-sensor signals of the motor. The measurement is based on the equivalent circuit of a BL-motor in Figure 10.

For clock-wise operation the positive zero-crossing of the phase-voltage U_C (red line in Figure 8) is aligned to the maximum of hall-sensor B. the offset from $Hall_B$ to $Hall_C$ in additional 120°e.

So for a 2-pole motor there is a phase-shift of 90°e+120°e between the hall-sensor and the EMF of the phase.

	The phase-alignment of a BX4- or BP4-motor is shifted by 180°e.

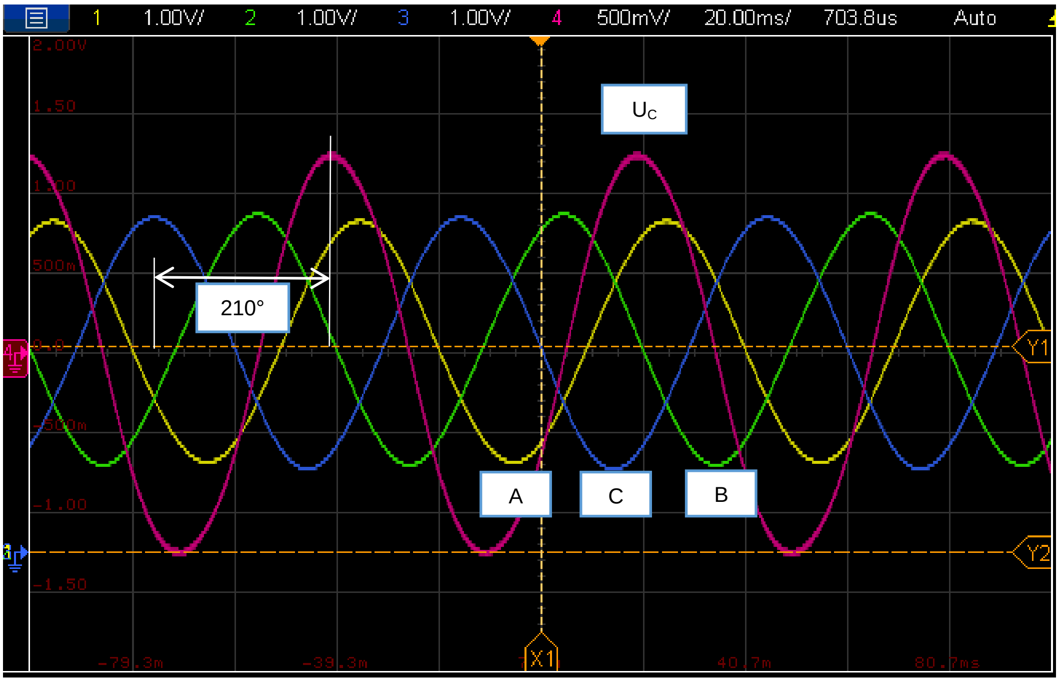

Figure 8 clock-wise operation of a FAULHABER 2-pole brushless motor

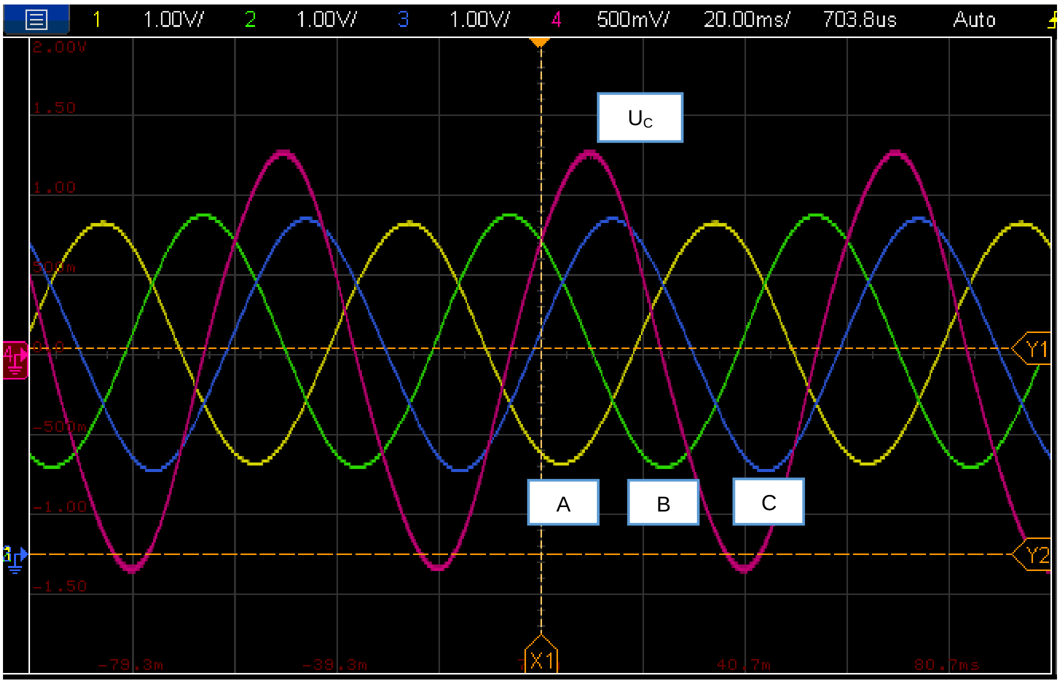

Figure 9 counter clock-wise operation of a FAULHABER brushless motor

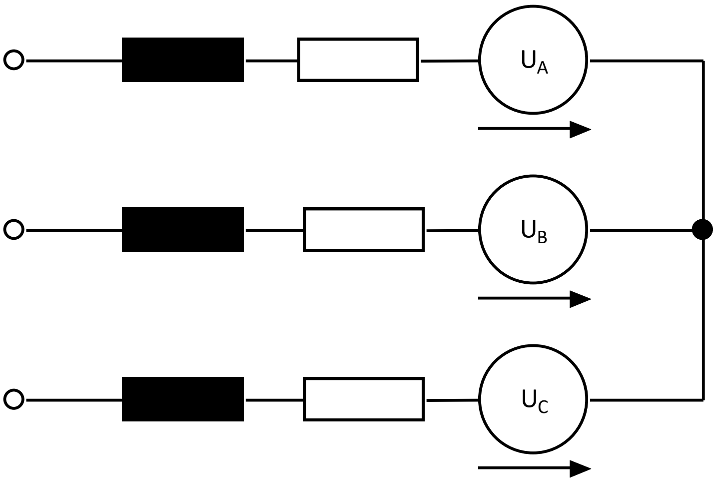

Figure 10 Equivalent cirquit of a BLDC motor

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