10-Bit 360° Programmable Magnetic Rotary Encoder

FEATURES

- Contactless high-resolution rotary position encoder over a full turn of 360 °
- Serial communication interface (SSI)
- 10-bit pulse width modulation output (PWM)
- Quadrature A/B and Index output signal
- Step/Direction and Index output signal
- 3-Phase commutation for brushless DC motors
- Ration speed up to 10000 rpm
- Serial read-out of multiple interconnected devices using daisy chain mode
- Wide temperature range:-40℃ to 125℃
- SSOP16 package

APPLICATIONS

- Industrial applications:
  - Contactless rotary position sensing
  - Robotics
  - Brushless DC motor commutation
- Automotive applications:

  Steering wheel position sensing

  Headlight position control

  Gas pedal position sensing

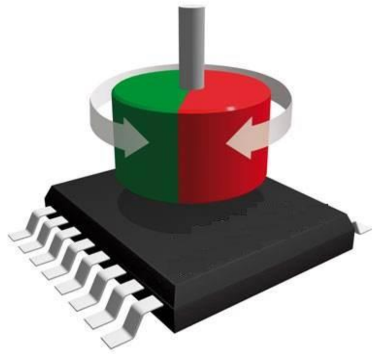
DESCRIPTION

The SC60104 10-bit angular encoder is a contactless magnetic position sensor with integrated Hall sensors for scanning a permanent magnet. The signal conditioning unit generates constant amplitude sine and cosine voltages that can be used for angle calculation. The SC60104 is a system-on-chip, combining integrated Hall elements, analog front end and digital signal processing in a single device.

The absolute angle measurement provides instant indication of the magnet's angular position with a resolution of 0.35° =1024 positions per revolution. The output digital data is available as a serial bit stream and as a PWM signal.

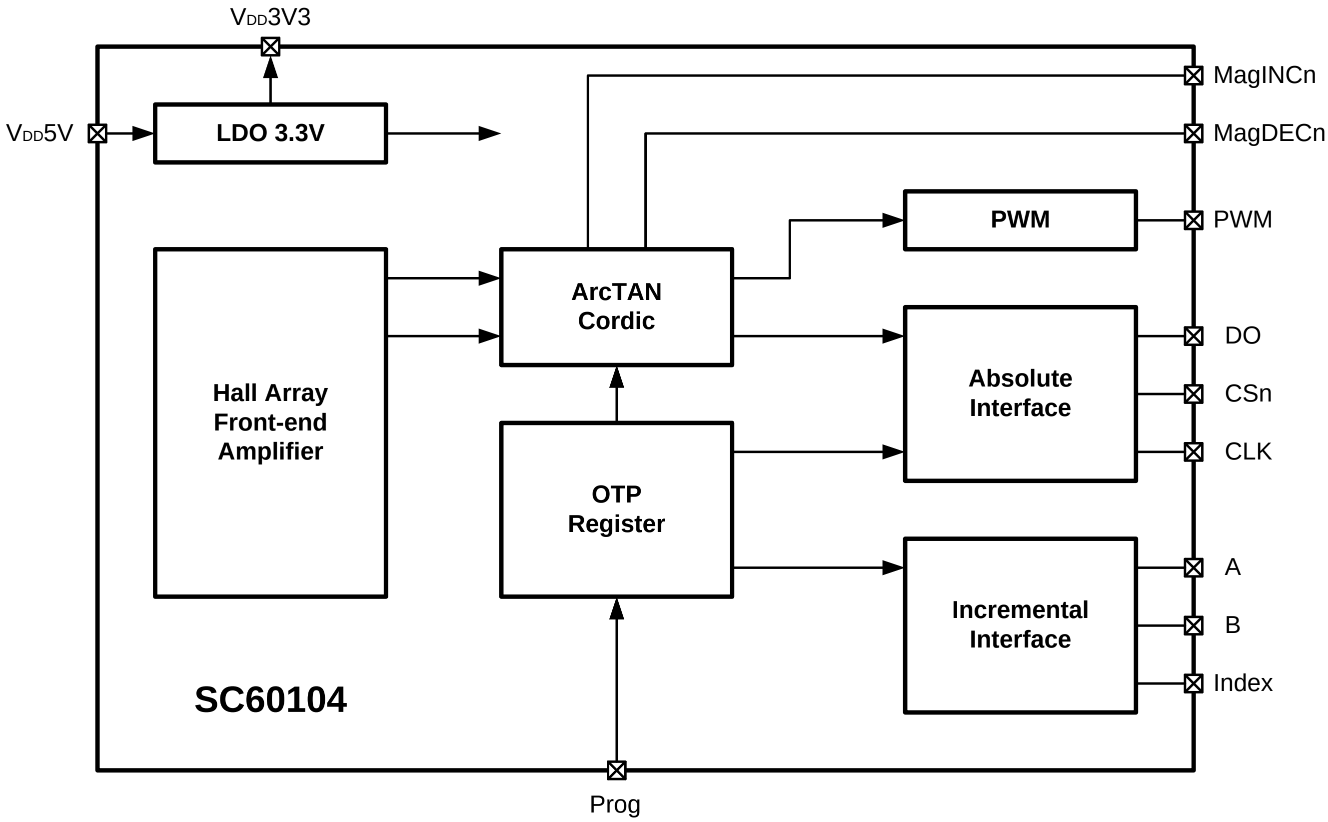
An internal voltage regulator allows the SC60104 to operate under either 3.3V or 5V power supply. An incremental output is available, making the chip suitable for replacement of various optical encoders.

The device is packaged in a 16-pin SSOP. It is lead (Pb) free, with 100% matte tin-plated lead-frame.



CONTENTS

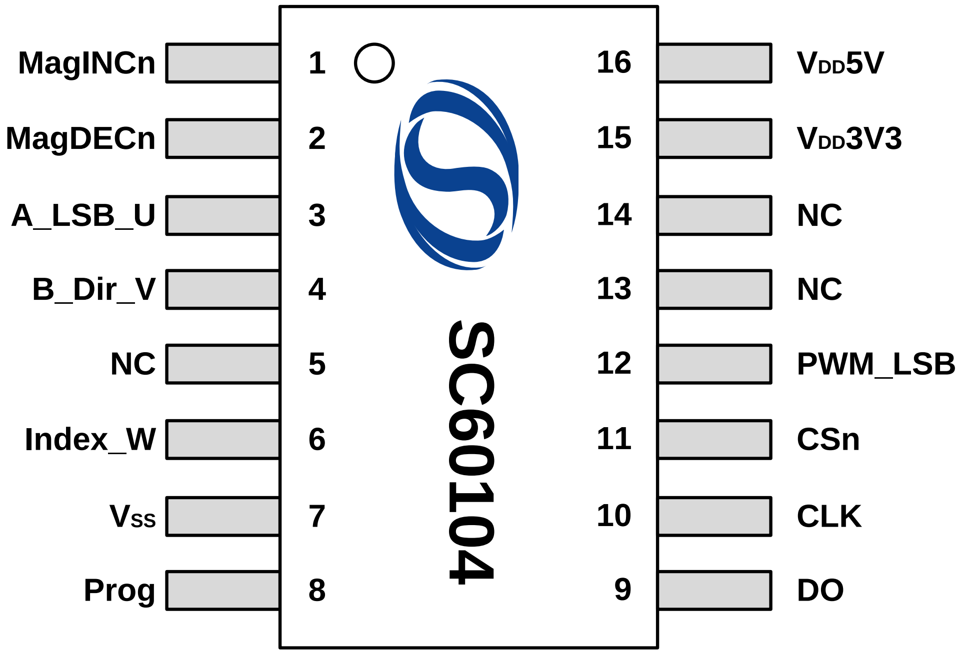
BLOCK DIAGRAM



ORDERING INFORMATION

Part Number	Packing	Mounting	Ambient, T_A	Marking
SC60104SP	1000 pcs /Reel	16-pin SSOP	-40℃ to 125℃	60104

TERMINAL CONFIGURATION



Pins 1 and 2 are the magnetic field change indicators, these outputs can be used to detect the valid magnetic field range. And those indicators can also be used for contact-less push-button functionality.

Pins 3, 4 and 6 are the incremental pulse output pins. The functionality of these pins can be configured through programmable OTP register.

Pin 8 is used to program the different incremental interface modes, the incremental resolution and the zero position into the OTP. This pin is also used as digital input to shift serial data through device in Daisy Chain Configuration.

Pin 11 selects a device and initiates serial data transfer. A logic High at CSn puts the data output pin (DO) to tri-state and terminates serial data transfer. This pin also used for Alignment Mode.

Pin 12 allows a single wire output of the 10-bit absolute position value. The value is encoded into a pulse width modulated signal with 1µS pulse width per step (1µS to 1024µS over a full turn).

Terminal		Type	Description
Name	Number		
MagINCn	1	DO_OD	Magnetic field strength increase indicators; active low
MagDECn	2	DO_OD	Magnetic field strength decrease indicators; active low
A_LSB_U	3	DO	Mode1.x: Quadrature A channel Mode2.x: Least Significant Bit Mode3.x: U signal
B_Dir_V	4	DO	Mode1.x: Quadrature B channel Mode2.x: Direction of Rotation Mode3.x: V signal
NC	5	--	No connected
Index_W	6	DO	Mode1.x: Indicates the absolute zero position Mode2.x: Indicates the absolute zero position Mode3.x: W signal
VSS	7	Ground	Ground
Prog	8	DI_PD	OTP programming input and data input for daisy chain mode
DO	9	DO_T	Data output pin of synchronous serial interface
CLK	10	DI, ST	Clock of synchronous serial interface, Schmitt-trigger input
CSn	11	DI_PU, ST	Chip select (CSn; active low)
PWM_LSB	12	DO	PWM output pin
NC	13	--	No connected
NC	14	--	No connected
V_{DD}3V3	15	Supply	3.3V-reulator output
V_{DD}5V	16	Supply	Positive supply voltage 5 V

Abbreviations for Pin Types:

DO_OD : Digital output open drain

DO : Digital output

DI_PD : Digital input pull-down

DI_PU : Digital input pull-up

DI : Digital input

DO_T : Digital output / tri-state

ST : Schmitt-trigger input

ABSOLUTE MAXIMUM RATINGS

Characteristic	Symbol	Notes	Min.	Max.	Unit
Supply DC Voltage V_{DD}	V_{DD}	--	-0.3	7	V
Supply Transient Voltage V_{DD}	V_{DDT}	Transient	--	7	V
3V3 DC Voltage	--		-0.3	5	V
3V3 Transient Voltage	--	Transient	--	5	V
Input Pins	V_{in}	--	-0.3	7	V
Input Current	I_{SCR}	No Latch-up	-100	100	mA
Operating Ambient Temperature	T_A	--	-40	150	℃
Storage Temperature	T_{STG}	--	-65	165	℃
Maximum Junction Temperature	$T_{J(max)}$	--	--	165	℃

Note: Stresses above those listed here may cause permanent damage to the device. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

ESD PROTECTION

Human Body Model (HBM) tests according to: standard JEDEC EIA/JESD22-A114

Parameter	Symbol	Limit Values		Units
		Min.	Max.	
ESD-Protection	V_{ESD}	-4	4	kV

OPERATING CHARACTERISTICS

Valid through the full operating temperature range, VDD5V=4.5V to 5.5V(5V operation),C_{bypass}=0.1µF;unless otherwise specified

characteristics	Symbol	test conditions	Min.	Typ.	Max.	Unit
operating conditions						
Ambient temperature	T_A	--	-40.0	--	125	℃
Supply Current	I_{DD}	--	--	16	21	mA
Supply Voltage at V_{DD}5V	V_{DD}5V	--	4.5	5	5.5	V
Supply Voltage at V_{DD}5V and V_{DD}3V3	V_{DD}3V3	--	3	3.3	3.6	V
CMOS Schmitt-Trigger Inputs:CLK,CSn(CSn=Internal Pull-UP)						
High level input Voltage	V_{IH}	--	0.7*VDD5V	--	--	V
Low level input Voltage	V_{IL}	--	--	--	0.3*VDD5V	V
Schmitt trigger hysteresis	V_{on}-V_{off}	--	1	--	--	V
Input leakage Current Pull-up low level input current	I_{leak}	CLK only	-1	--	1	µA
	I_{iL}	CSn only, V_{DD}5V:5.0V	30	--	-100	µA
CMOS Output Open Drain:MagINCn,MagDEcn						
Low level output Voltage	V_{OL}	--	--	--	0.4	V
Output Current	I_O	V_{DD}5V:4.5V	--	--	4	mA
		V_{DD}5V:3.0V	--	--	2	mA
Open drain leakage current	I_{OZ}	--	--	--	1	µA
CMOS Output:A,B,Index,PWM						
High level output Voltage	V_{OH}	--	V_{DD}5V-0.5	--	--	V
Low level output Voltage	V_{OL}	--	--	--	0.4	V
Output Current	I_O	V_{DD}5V:4.5V	--	--	4	mA
		V_{DD}5V:3.0V	--	--	2	mA

OPERATING CHARACTERISTICS (continued)

characteristics	Symbol	test conditions	Min.	Typ.	Max.	Unit
Tristate CMOS Output: DO						
High level output Voltage	V_{OH}	--	V_{DD}5V-0.5	--	--	V
Low level output Voltage	V_{OL}	--	--	--	0.4	V
Output Current	I_O	V_{DD}5V:4.5V	--	--	4	mA
		V_{DD}5V:3.0V	--	--	2	mA
Tri-state Leakage current	I_{OZ}		--	--	1	μA
Magnetic Input Specification						
Diameter	d_{mag}	Φ6mmX2.5mm for cylindrica Magnets	4	6	--	mm
Thickness	t_{mag}		2.5	--	--	mm
Field amplitude	B_{pk}	--	45	--	75	mT
Magnetic offfset	B_{off}	Constant magnetic stray field	--	--	±10	mT
Field non-linearity		Including offset gradient	--	--	5	%
Input frequency（rotational speed or magnet）	f_{mag_abs}	Absolute mode:600rpm	--	--	10	Hz
	f_{mag_inc}	Incremental mode:up to 30000rpm	--	--	500	Hz
Displacement radius	D_{isp}	Max,X-Y offset between defined IC package center and magnet axis	--	--	0.25	mm
		Max,X-Y offset between defined IC chip center and magnet axis	--	--	0.485	mm
Chip placement tolerance	---	Placement tolerance of chip within IC package	--	--	±0.235	mm
Electrical System Specifications						
Resolution	RES		--	--	10	bit
7 bit	LSB	Adjustable resolution only available for incremental output modes:Least significant bit,minimum step	--	2.813	--	deg
8 bit			--	1.406	--	deg
9 bit			--	0.703	--	deg
10 bit			--	0.352	--	deg

OPERATING CHARACTERISTICS (continued)

characteristics	Symbol	test conditions	Min.	Typ.	Max.	Unit
Integral non-linearity(optimum)	INL_{opt}	Maximum error with respect to the best line fit, T_{amb}=25°C	--	---	±0.9	deg
Integral non-linearity(optimum)	INL_{temp}	Maximum error with respect to the best line fit, T_{amb}=-40°C to 125°C	-	--	±1.4	deg
Integral non-linearity	INL	Best line fit=(Err_{max}-Err_{min})/2 Over displacement tolerance,Tamb=-40°C to 125°C	--	--	±2.8	deg
Differential non-linearity	DNL	10 bit,no missing codes	--	--	±0.176	deg
Transition noise	TN	RMS equivalent to 1 sigma	--	--	0.12	deg
Hysteresis	Hyst	Incremental modes only	--	0.704	--	deg
Power-on-reset threshold ON voltage;300mV typ.Hysteresis	V_{on}	DC supply voltage 3.3V	1.37	2.2	2.9	V
Power-on-reset threshold OFF voltage;300mV typ. Hysteresis	V_{off}	DC supply voltage 3.3V	1.08	1.9	2.6	V
Power-up time	t_{PwrUP}	Until offset compensation finished	--	--	50	ms
System propagation delay absolute output	t_{delay}	Includes delay of ADC and DSP	--	--	48	µs
System propagation delay absolute output		Calculation over two samples	--	--	192	µs
Synchronous Serial Interface (SSI)						
Data output activated	$t_{DOactive}$	Time between falling edge of CSn and data output activated	--	--	100	ns
First data shifted to output register	t_{CLKFE}	Time between falling edge of CSn and first falling edge of CLK	500	--	--	ns
Start of data output	$t_{CLK/2}$	Rising edge of CLK shifts out one bit at a time	500	--	--	ns
Data output valid	$t_{DOvaild}$	Time between falling edge of CSn and data output valid	357	--	413	ns

OPERATING CHARACTERISTICS (continued)

characteristics	Symbol	test conditions	Min.	Typ.	Max.	Unit
Data output tristate	$t_{DOtristate}$	After the last bit DO changes back to"tristate"	--	--	100	ns
Pulse width of CSn	t_{CSn}	CSn=high;TO initiate read-out of next angular position	500	--	--	ns
Read-out frequency	f_{CLK}	Clock frequency to read out serial data	>0	--	1	MHz
Pulse width Modulation Output						
PWM frequency	f_{PWM}	Signal period=1025us±5% at T_{amb}=25°C	0.927	0.976	1.024	KHz
		Signal period=1025us±5% at T_{amb}=-40°C to 125°C	0.878	0.976	1.074	KHz
Minimum pulse width	PW_{MIN}	Position 0d;angle 0 degree	0.9	1	1.1	µs
Maximum pulse width	PW_{MAX}	Position 1023d;angle 395.65 degree	922	1024	1126	µs
Incremental Outputs						
Incremental Outputs valid after power-up	$t_{incremental}$	Time between first falling edge of CSn after power-up and valid incremental outputs	--	--	500	ns
Incremental indication valid	t_{Dir}	Time between rising or falling edge of LSB output and valid directional indication	--	--	500	ns

FUNCTIONAL DESCRIPTION

The SC60104 is manufactured in a CMOS standard process and uses a spinning current Hall technology for sensing the magnetic field distribution across the surface of the chip

The integrated Hal l elements are placed around the center of the device and deliver a voltage representation of the magnetic field at the surface of the IC

Through Sigma-Delta Analog / Digital Conversion and DSP algorithms, the device provides accurate high-resolution angular position information. For this purpose, a Coordinate Rotation Digital Computer calculates the angle and the magnitude of the Hall array signals.

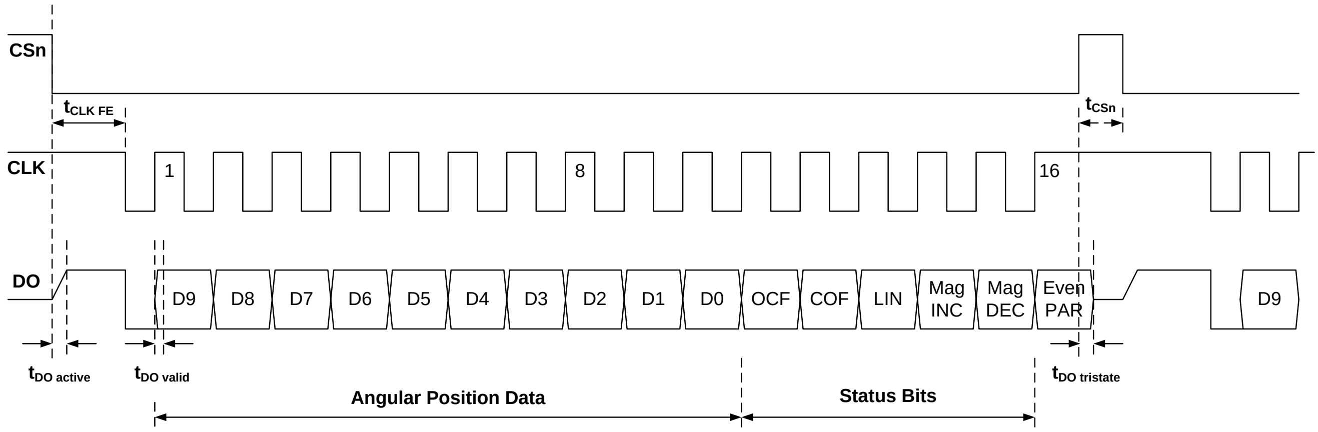
The DSP is also used to provide digital information at the outputs MagINCn and MagDECn that indicate movements of the used magnet towards or away from the device's surface.

A small low cost diametrically magnetized (two-pole) standard magnet provides the angular position information. The SC60104 senses the orientation of the magnetic field and calculates a 10-bit binary code. This code can be accessed via a SSI. In addition, an absolute angular representation is given by a PWM signal at pin 12

The device also provides incremental output signals. The various incremental output modes can be selected by programming the OTP mode register bits. The default setting is a quadrature A/B mode including the Index signal with a pulse width of 1 LSB. The Index signal is logic high at the user programmable zero position.

SSI Interface

Synchronous Serial Interface with Absolute Angular Position Data



If CSn changes to logic low, DO will change from high impedance (tri-state) to logic high and the read-out will be initiated.

- After a minimum time $t_{CLK FE}$, data is latched into the output shift register with the first falling edge of CLK
- Each subsequent rising CLK edge shifts out one bit of data
- The serial word contains 16 bits, the first 10 bits are the angular information D[9:0], the subsequent 6 bits contain system information, about the validity of data such as OCF, COF LIN, Parity and Magnetic Field status
- A subsequent measurement is initiated by a log. High pulse at CSn with a minimum duration of t_{CSn}

Data Content

- D9:D0 absolute angular position data (MSB is clocked out first)
- OCF (Offset Compensation Finished), logic high indicates the finished Offset Compensation Algorithm.
- COF (CORDIC Overflow), logic high indicates an out of range error in the CORDIC part. When this bit is set, the data at D9:D0 is invalid. The absolute output maintains the last valid angular value.
- LIN (Linearity Alarm), logic high indicates that the input field generates a critical output linearity. When this bit is set the data at D9:D0 may still be used, but can contain invalid data. This warning maybe resolved by bringing the magnet within the X-Y-Z tolerance limits.
- MagINCn (Magnitude Increase), becomes logic high, when the magnet is pushed towards the IC.
- MagDECn (Magnitude Decrease), becomes logic high, when the magnet is pushed away from the IC.

MagINCN	MagDECn	Description
0	0	No distance change; magnetic input field OK(45mT to 75mT)
0	1	Distance increase:Pull-function.This state is dynamic, it is only active while the magnet is moving away from the chip Z-axis
1	0	Distance Decrease:Pull-function.This state is dynamic, it is only active while the magnet is moving away from the chip Z-axis
1	1	Magnetic input field invalid-out of range:<45mT or >75mT

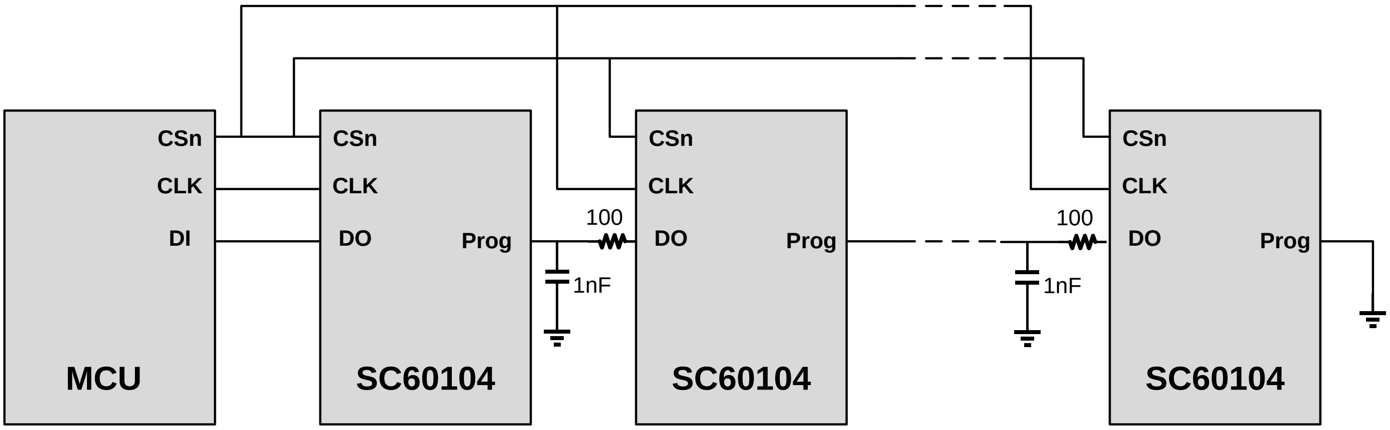
Note: Pins 1 and 2 (MagINCn, MagDECn) are open drain outputs and require external pull-up resistors. If the magnetic field is in range, both outputs are turned OFF

- Even Parity bit for transmission error detection of bits 1 to 15 (D9 to D0, OCF, COF, LIN, MagINCn, MagDECn). Data D9:D0 is valid, when the status bits have the following configurations:

OCF	COF	LIN	MagINCn	MagDECn	Parity
1	0	0	0	0	Even checksum of bits 1:15
			0	1	
			1	0	

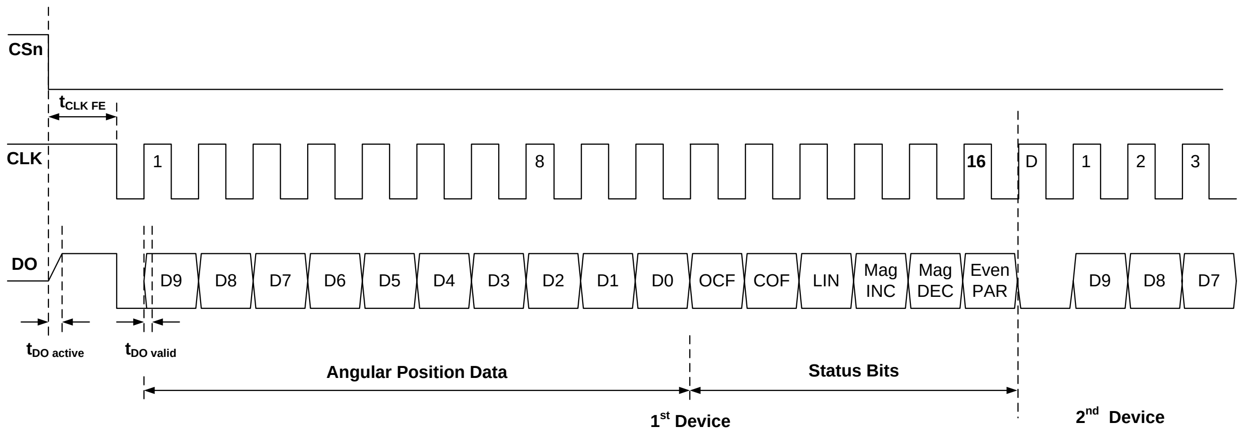
- The absolute angular position is sampled at a rate of 10 kHz (0.1mS). This allows reading of all 1024 positions per360 degrees within 0.1 seconds = 9.76 Hz (~10Hz) without skipping any position. Multiplying 10 Hz by 60, results the corresponding maximum rotational speed of 600 rpm. Readout of every second angular position allows for rotational speeds of up to 1200 rpm.
- Consequently, increasing the rotational speed reduces the number of absolute angular positions per revolution. Regardless of the rotational speed or the number of positions to be read out, the absolute angular value is always given at the highest resolution of 10 bit.
- The incremental outputs are not affected by rotational speed restrictions due to the implemented interpolator. The incremental output signals may be used for high-speed applications with rotational speeds of up to 10000 rpm without missing pulses.

Daisy Chain Mode



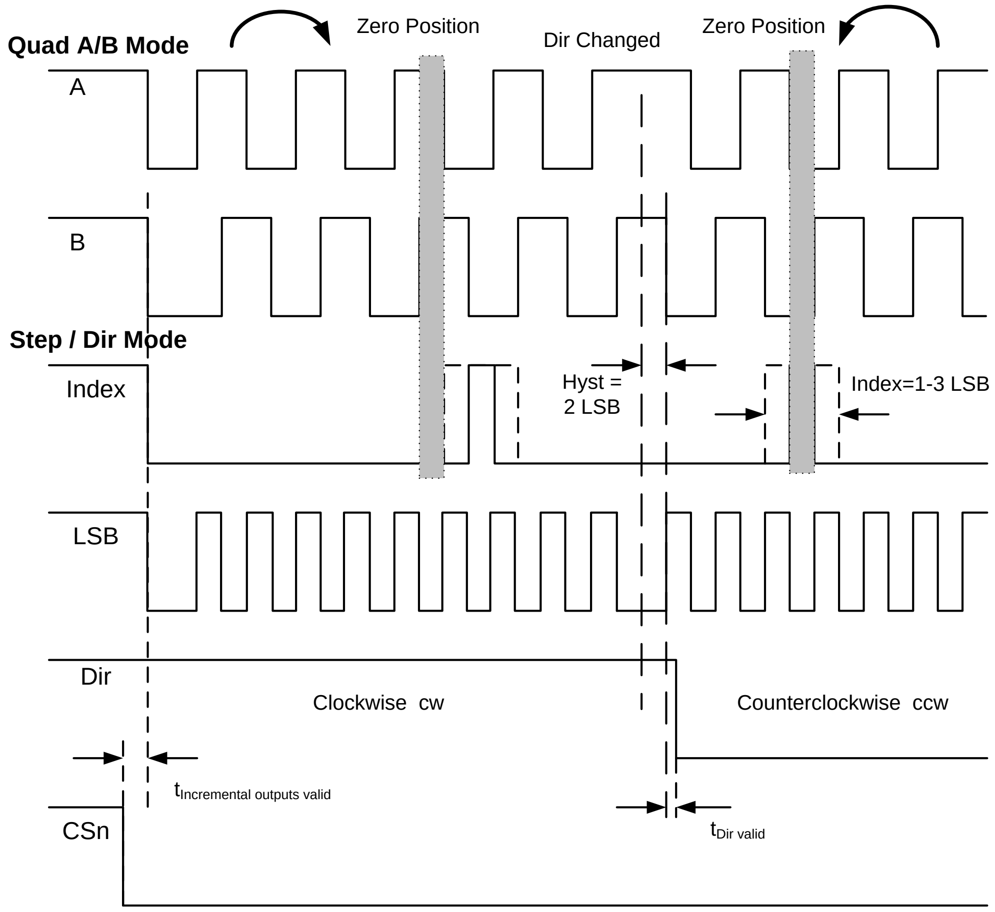
The Daisy Chain mode allows connection of several SC60104's in series, while still keeping just one digital input for data transfer. This mode is accomplished by connecting the data output (DO; pin9) to the data input (Prog; pin8) of the subsequent device. An RC filter must be implemented between each Prog pin of device N and DO pin of device N+1, to prevent the encoders to enter the alignment mode, in case of ESD discharge, long cables, or not conform signal levels or shape. The serial data of all connected devices is read from the DO pin of the first device in the chain. The Prog pin of the last device in the chain should be connected to V_{SS}.

The length of the serial bit stream increases with every connected device, it is n* (16+1) bits. The last data bit of the first device is followed by a logic low bit and the first data bit of the second device (D9), etc.…



Incremental Outputs

Three different incremental output modes are possible with quadrature A/B being the default mode. The following figure shows the two-channel quadrature as well as the step/direction incremental signal and the direction bit in clockwise and counter-clockwise direction.



Quadrature A/B Output (Quad A/B Mode)

The phase shift between channel A and B indicates the direction of the magnet movement. Channel A leads channel B at a clockwise rotation of the magnet (top view) by 90 electrical degrees. Channel B leads channel A at a counter-clockwise rotation.

LSB Output (Step/Direction Mode)

Output LSB reflects the LSB (least significant bit) of the programmed incremental resolution (OTP Register Bit Div0. Div1). Output Dir provides information about the rotational direction of the magnet which may be placed above or below the device. Dir is updated with every LSB change.

In both modes (quad A/B and step/direction) the resolution and the index output are user programmable. The index pulse indicates the zero position and is by default one angular step wide. However, it can be set to three LSBs by programming the Index-bit of the OTP register.

Incremental Output Hysteresis

To avoid flickering incremental outputs at a stationary magnet position, a hysteresis is introduced. In case of the rotational direction change, the incremental outputs have a hysteresis of 2 LSB. Regardless of the programmed incremental resolution, the hysteresis of 2 LSB always corresponds to the highest resolution of 10 bit. In absolute terms, the hysteresis is set to 0.704 degrees for all resolutions.

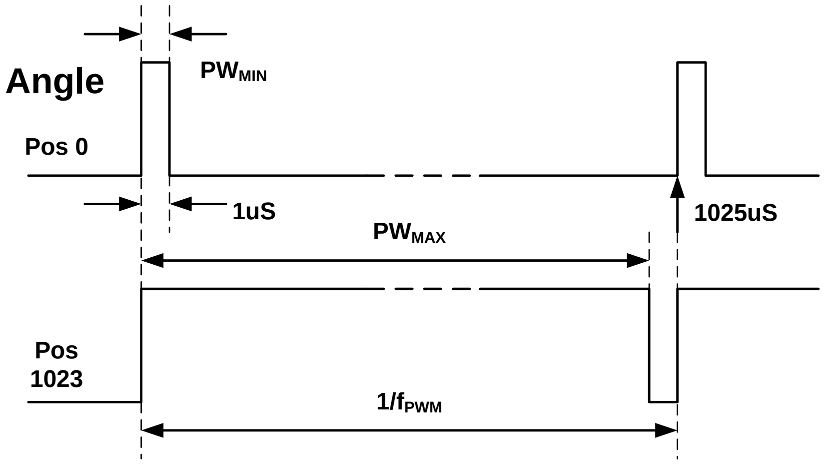
For constant rotational directions, every magnet position change is indicated at the incremental outputs. If for example the magnet turns clockwise from position “x+3” to “x+4”, the incremental output would also indicate this position accordingly. A change of the magnet’s rotational direction back to position “x+3” means, that the incremental output still remains unchanged for the duration of 2 LSB, until position “x+2” is reached. Following this direction, the incremental outputs will again be updated with every change of the magnet position.

Pulse Width Modulation Output

The SC60104 provides a pulse width modulated output (PWM), whose duty cycle is proportional to the measured angle.

$$\text{Position} = t_{on} \times 1025 / (t_{on} + t_{off}) - 1$$

The PWM frequency is internally trimmed to an accuracy of ±5% (±10% over full temperature range). This tolerance can be canceled by measuring the complete duty cycle as shown below:

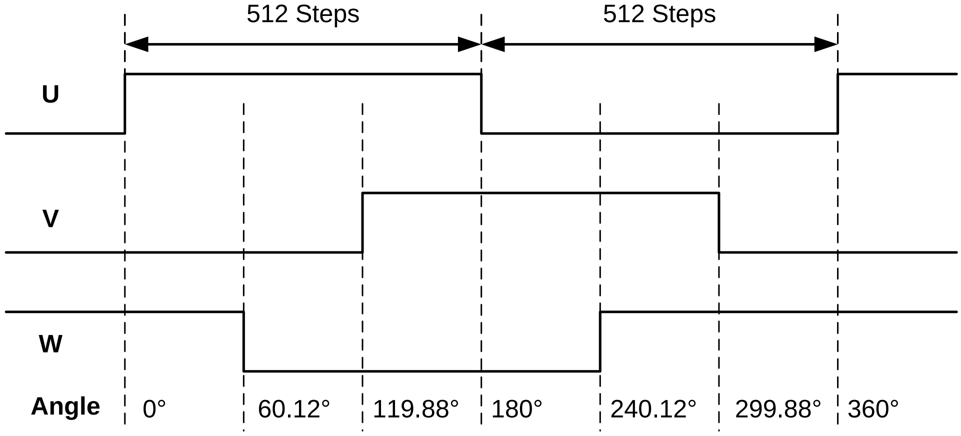


Parameter	Symbol	Typ	Unit	Note
PWM frequency	f_{PWM}	0.9756	kHz	Signal period: 1025µS
MIN pulse width	PW_{MIN}	1	µS	Position 0d
Max pulse width	PW_{MAX}	1024	µS	Position 1023d

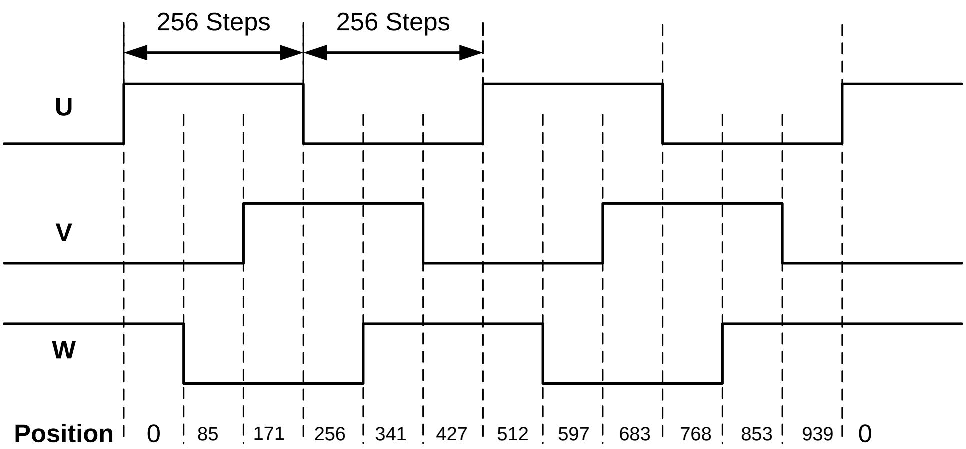
Brushless DC Motor Commutation Mode

Brushless DC motors require angular information for stator commutation. The SC60104 provides UVW commutation signals for one and two pole pair motors. In addition to the three-phase output signals, the step output at pin 12 allows high accuracy speed measurement. Two resolutions (9 or 10 bit) can be selected by programming Div0.

One-pole-pair

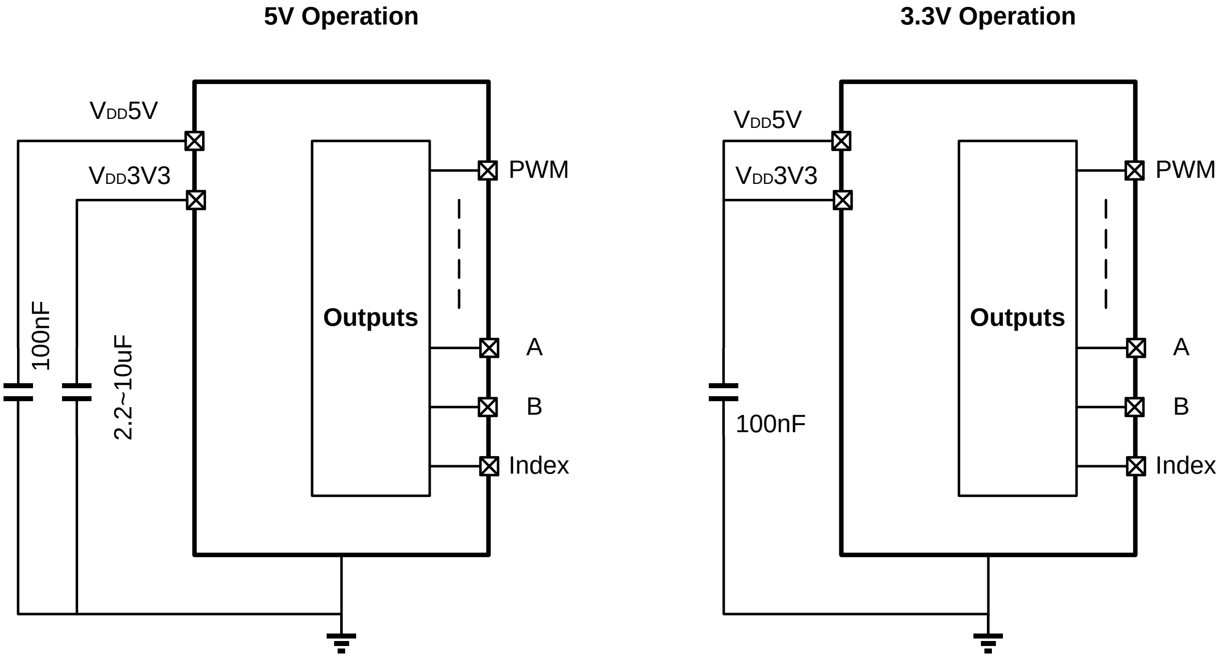


Two-pole-pair



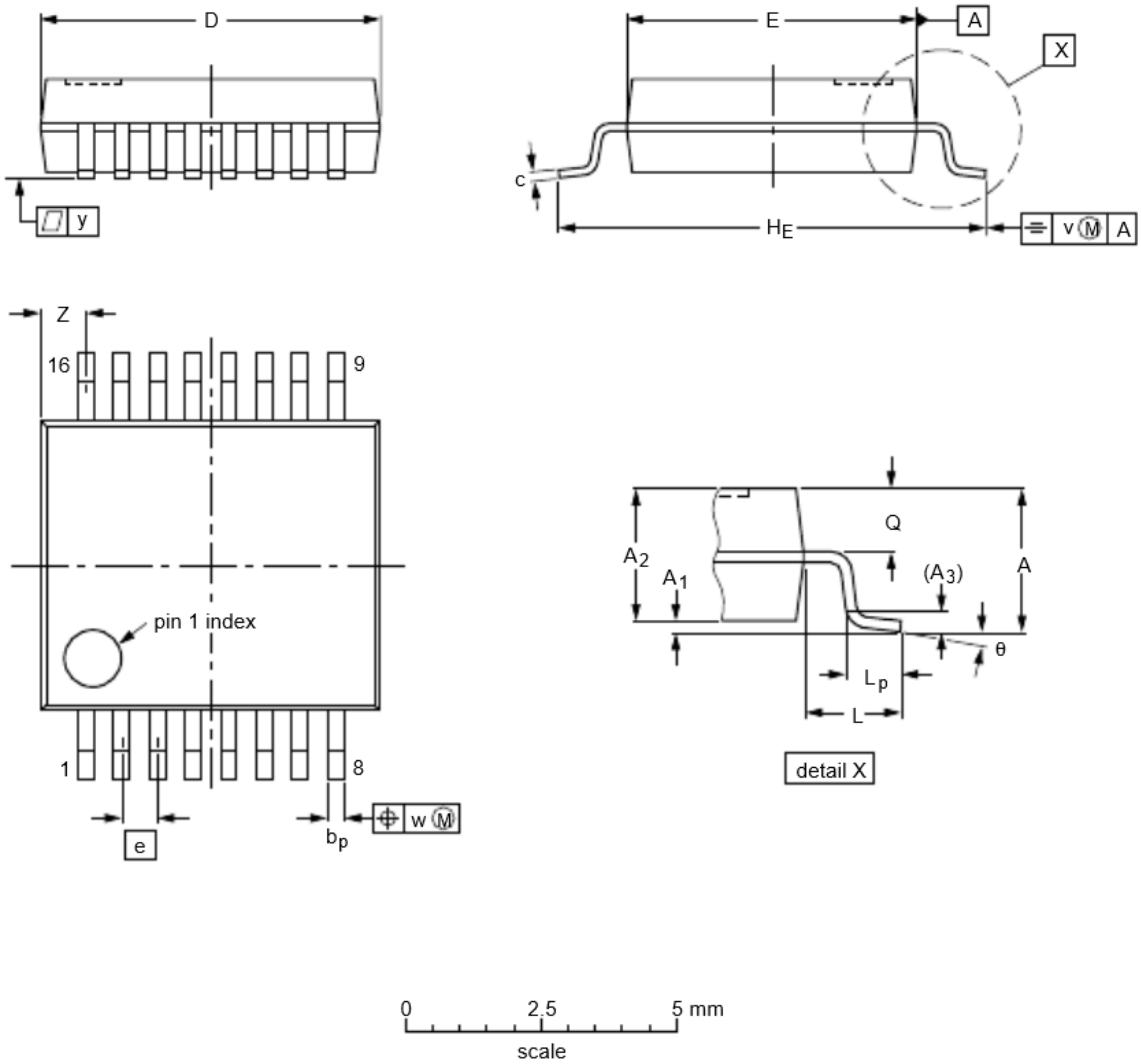
3.3V / 5V Operation

The SC60104 operates either at 3.3V ± 10% or at 5V ± 10%. This is made possible by an internal 3.3V LDO voltage regulator. The internal supply voltage is always taken from the output of the LDO, meaning that the internal blocks are always operating at 3.3V.



A buffer capacitor of 100nF is recommended in both cases close to pin $V_{DD}5V$. Note that pin $V_{DD}3V3$ must always be buffered by a capacitor. It must not be left floating, as this may cause an instable internal 3.3V supply voltage which may lead to larger than normal jitter of the measured angle.

PACKAGE INFORMATION



DIMENSIONS (mm are the original dimensions)

UNIT	A	A_1	A_2	A_3	b_p	c	D(1)	E(1)	e	H_E	L	L_P	Q	v	w	y	Z(1)	θ
mm	2	0.21	1.85	0.25	0.38	0.25	6.5	5.6	0.65	8.2	1.25	0.95	0.9	0.2	0.13	0.1	1.00	8°
		0.05	1.65		0.22	0.09	5.9	5.0		7.4		0.55	0.7				0.55	0°

Note

1. Plastic or metal protrusions of 0.25mm maximum per side are not included.

REVISION HISTORY

Date	Revision	Description
Apr 4,2019	RevA1.0	Initial release
Jul 16,2019	RevA1.1	Update typical application circuit
May 31,2020	RevA1.2	Add version history
Nov,17 2020	RevA1.3	Update format