

## High Speed 12-Bit Magnetic Rotary Encoder IC

### 1. Features

- Contactless 12-bit resolution rotational encoder
- Programmable resolution, pole-pairs and zero position
- 12-bit absolute outputs
  - SPI interface
  - PWM interface
- Incremental outputs
  - A/B/Z interface(Up to 1024 wires)
  - U/V/W interface(1~16 pairs of pole)
  - A+/B+/Z+ and A-/B-/Z- differential output
- Sincosine difference
- Sincosine amplitude: 2V(Vpp)
- Angle linearity error  $< \pm 0.35^\circ$
- Maximum tracking speed: 20K rpm
- Wide temperature range: -40°C to 125°C
- Package available.
  - SSOP16(SS)
  - SOP8(DC)

### 2. Applications

- Contactless rotary position sensing
- Brushless DC motor commutation
- Robotics
- Angular encoder
- Rotational speed control

### 3. Description

SC6022X is a contactless high-speed, high-precision magnetic encoder chip. Hall induction point matrix is built into the center of the chip, which generates sine and cosine position signals by sensing a pair of pole magnets above. The analog to digital conversion circuit inside the chip samples the amplified sine and cosine signals, and the DSP circuit performs Angle calculation, and finally outputs various position signals. SC6022X has a resolution of 12 bits, and each circle can generate 4096 incremental Angle signals. The position of zero signals can be programmed through SPI interface, and the maximum support is 20K rpm.

SC60220/1/4 uses 16-pin SSOP package, matte tin plating, halogen-free green material, to meet the environmental requirements. SC60228 uses 8-pin SOP8 package, matte tin plating, halogen-free green material, to meet the environmental requirements.

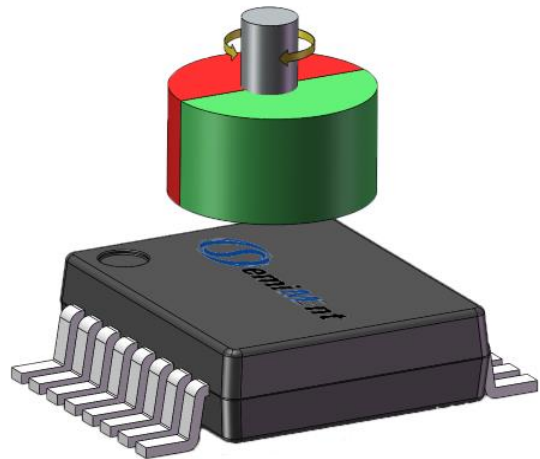


Fig.1 Schematic diagram of the work

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## 4. Terminal Configuration

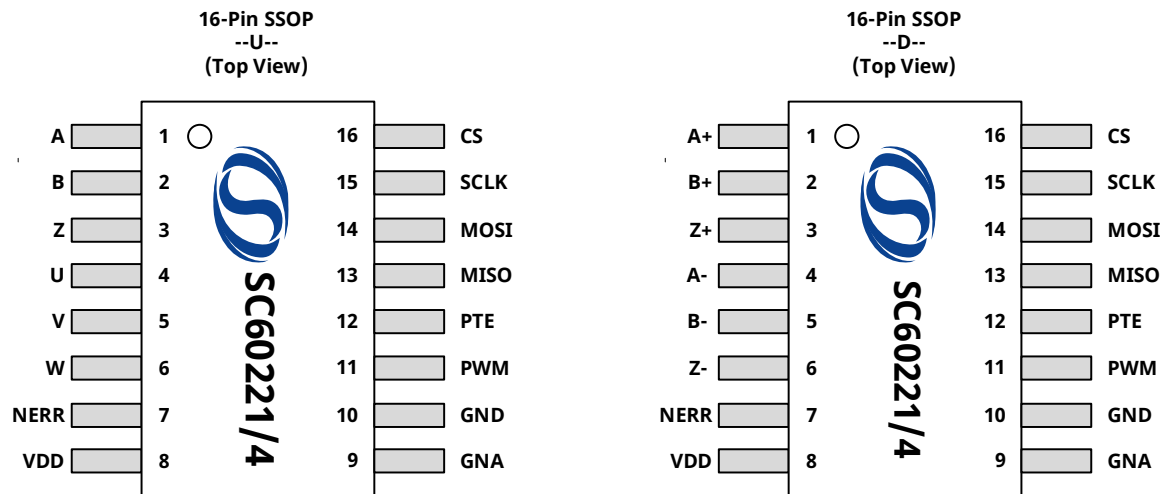


Fig.2 SC60221/4 Terminal Configuration

| No. | Pin Name    |             | I/O    | Type    | Description                       |
|-----|-------------|-------------|--------|---------|-----------------------------------|
|     | SC60221/4-U | SC60221/4-D |        |         |                                   |
| 1   | A           | A+          | Output | Digital | A phase Pulse Signal              |
| 2   | B           | B+          | Output | Digital | B phase Pulse Signal              |
| 3   | Z           | Z+          | Output | Digital | C phase Pulse Signal              |
| 4   | U           | A-          | Output | Digital | U/A- phase Pulse Signal           |
| 5   | V           | B-          | Output | Digital | V/B- phase Pulse Signal           |
| 6   | W           | Z-          | Output | Digital | W/Z- phase Pulse Signal           |
| 7   | NERR        | NERR        | Output | Digital | Error output (active low)         |
| 8   | VDD         | VDD         | -      | Power   | Power Supply PIN                  |
| 9   | GNA         | GNA         | -      | GND     | Analog Ground PIN                 |
| 10  | GND         | GND         | -      | GND     | Digital Ground PIN                |
| 11  | PWM         | PWM         | Output | Digital | PWM Pulse Output PIN              |
| 12  | PTE         | PTE         | Input  | Digital | EEPROM Programming Protection PIN |
| 13  | MISO        | MISO        | Output | Digital | SPI Output Data Signal            |
| 14  | MOSI        | MOSI        | Input  | Digital | SPI Input Data Signal             |
| 15  | SCLK        | SCLK        | Input  | Digital | SPI Clock Signal                  |
| 16  | CS          | CS          | Input  | Digital | SPI Chip Select Signal            |

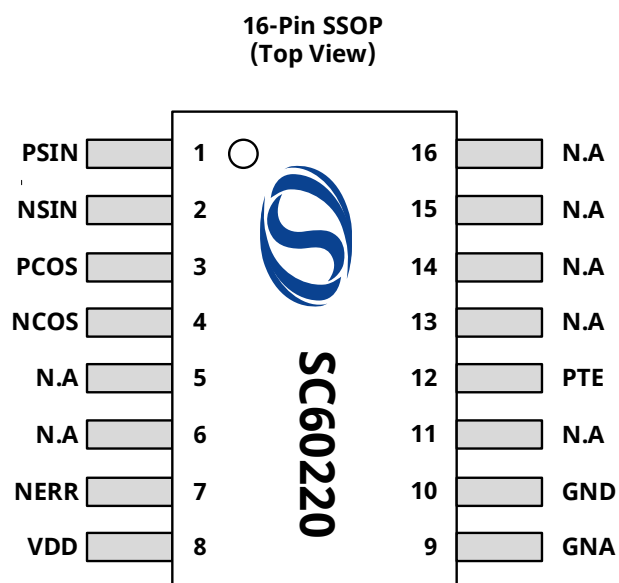


Fig.3 SC60220 Terminal Configuration

| No. | Pin Name | I/O    | Type    | Description                       |
|-----|----------|--------|---------|-----------------------------------|
| 1   | PSIN     | Output | Digital | SIN(+)                            |
| 2   | NSIN     | Output | Digital | SIN(-)                            |
| 3   | PCOS     | Output | Digital | COS(+)                            |
| 4   | NCOS     | Output | Digital | COS(-)                            |
| 5   | N.A.     | -      | -       | Not connected                     |
| 6   | N.A.     | -      | -       | Not connected                     |
| 7   | NERR     | -      | Digital | Error output (active low)         |
| 8   | VDD      | -      | Power   | Power                             |
| 9   | GNA      | -      | GND     | Analog Ground PIN                 |
| 10  | GND      | -      | GND     | Digital Ground PIN                |
| 11  | N.A.     | -      | -       | Not connected                     |
| 12  | PTE      | Input  | Digital | EEPROM Programming Protection PIN |
| 13  | N.A.     | -      | -       | Not connected                     |
| 14  | N.A.     | -      | -       | Not connected                     |
| 15  | N.A.     | -      | -       | Not connected                     |
| 16  | N.A.     | -      | -       | Not connected                     |

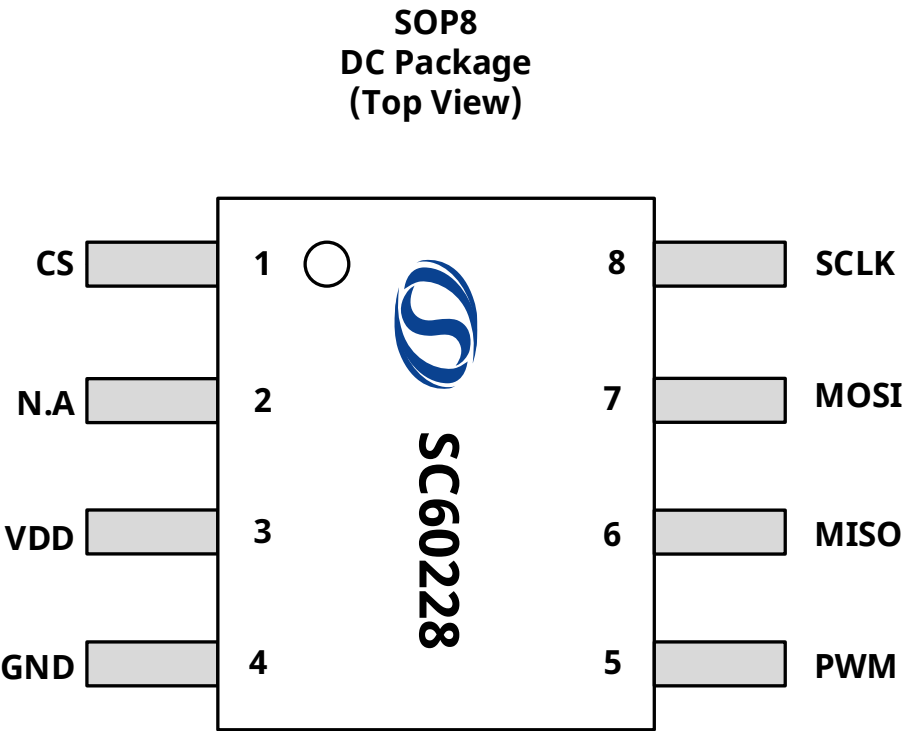


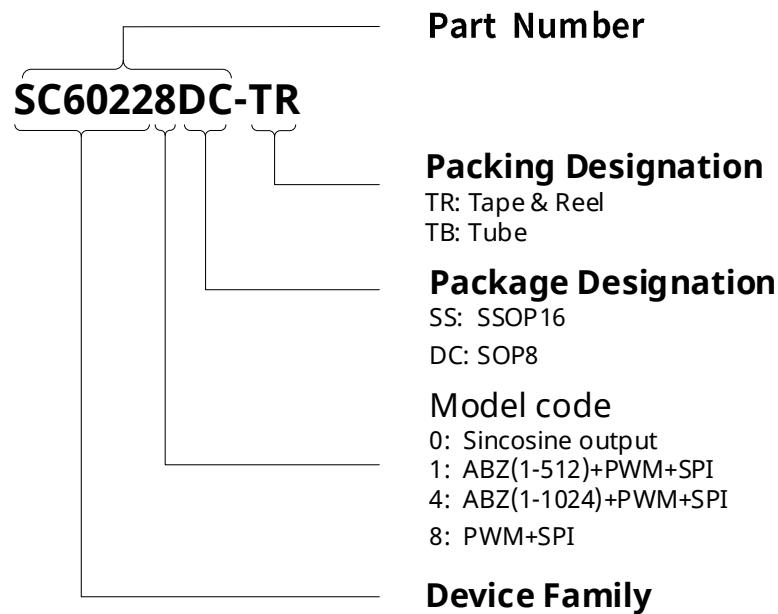
Fig.4 SC60228 Terminal Configuration

| No. | Pin Name | I/O    | Type    | Description            |
|-----|----------|--------|---------|------------------------|
| 1   | CS       | Input  | Digital | SPI Chip Select Signal |
| 2   | N.A      | -      | -       | Not connected          |
| 3   | VDD      | -      | Power   | Power                  |
| 4   | VSS      | -      | GND     | GND                    |
| 5   | PWM      | Output | Digital | PWM Pulse Output PIN   |
| 6   | MISO     | Output | Digital | SPI Output Data Signal |
| 7   | MOSI     | Input  | Digital | SPI Input Data Signal  |
| 8   | SCLK     | Input  | Digital | SPI Clock Signal       |

## 5. Ordering Information

| Ordering Information | Mark  | Ambient(°C) | Package | Pack | Amount        |
|----------------------|-------|-------------|---------|------|---------------|
| SC60220SS-TB         | 60220 | -40-125     | SSOP16  | Tube | 80 Pcs/Tube   |
| SC60221SS-TB         | 60221 | -40-125     | SSOP16  | Tube | 80 Pcs/Tube   |
| SC60224SS-TB         | 60224 | -40-125     | SSOP16  | Tube | 80 Pcs/Tube   |
| SC60228DC-TR         | 60228 | -40-125     | SOP8    | Reel | 4000 Pcs/Reel |

### Ordering Information Format



**Note:**

The specific parameters of the chip must be clearly noted when placing the order, such as examples: SC60224-U-P4-1024-244

SC60224: Part Number;

U: Not differential;

P4: 4 Polar UVW;

1024: 1024 pulse;

244: PWM frequency 244Hz.

## 6. Absolute Maximum Ratings

| Symbol       | Parameter                                                    | Test Conditions | Min. | Max. | Unit  |
|--------------|--------------------------------------------------------------|-----------------|------|------|-------|
| $V_{(i)}$    | Voltage at VDD, A, B, Z, U, V, W, MOSI, MISO, SCLK, CS, NERR |                 | -0.3 | 6    | V     |
| $I_{(i)}$    | Current in VDD                                               |                 | -10  | 20   | mA    |
| $I_{(i)}$    | Current in A, B, Z, U, V, W, MISO, NERR                      |                 | -100 | 100  | mA    |
| $I_{(i)}$    | Current in SCLK, CS, MOSI, PTE                               |                 | -10  | 10   | mA    |
|              | EEPROM Write Cycles                                          |                 | -    | 100  | cycle |
| $T_A$        | Operating ambient temperature                                |                 | -40  | 125  | °C    |
| $T_{STG}$    | Storage temperature                                          |                 | -65  | 165  | °C    |
| $T_{J(max)}$ | Operating junction temperature                               |                 | -    | 165  | °C    |

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.

## 7. ESD Protection

| Symbol    | Parameter | Test Conditions     | Min. | Max. | Unit |
|-----------|-----------|---------------------|------|------|------|
| $V_{ESD}$ | HBM       | ANSI/ESDA/JEDEC-001 | -4   | 4    | kV   |
|           | CDM       | ANSI/ESDA/JEDEC-002 | -750 | 750  | V    |

## 8. Operating Characteristics

valid through the full operate temperature range,  $V_{DD}=5V$ ,  $C_{BY}=0.1\mu F$ , unless otherwise specified

| Symbol                            | Parameter                                  | Test Conditions                                                         | Min. | Typ. | Max. | Unit       |
|-----------------------------------|--------------------------------------------|-------------------------------------------------------------------------|------|------|------|------------|
| <b>Electrical Characteristics</b> |                                            |                                                                         |      |      |      |            |
| $V_{DD}$                          | Supply Voltage                             |                                                                         | 3.0  | 5.0  | 5.5  | V          |
| $I_{DD}$                          | Supply Current                             | No load, $f_{mag}=0$ rpm                                                | 10   | 16   | 22   | mA         |
| $V_{bg}$                          | Bandgap Reference                          |                                                                         | 1.18 | 1.25 | 1.32 | V          |
| $V_{ref}$                         | Reference voltage                          |                                                                         | 45   | 50   | 55   | % $V_{DD}$ |
| $V_{th(on)}$                      | Turn-on Threshold                          | Increasing voltage                                                      | 2.6  | 2.75 | 2.9  | V          |
| $V_{th(off)}$                     | Turn-off Threshold                         | Decreasing voltage                                                      | 2.4  | 2.6  | 2.8  | V          |
| $V_{th(Hys)}$                     | Hysteresis                                 |                                                                         | 0.15 | -    | -    | V          |
| $V_{R(offset)}$                   | Reference Voltage Offset                   |                                                                         | 470  | 500  | 530  | mV         |
| <b>Clock Generation</b>           |                                            |                                                                         |      |      |      |            |
| $f_{sys}$                         | System Clock                               | Bias current adjusted                                                   | 0.8  | 1    | 1.2  | MHz        |
| $f_{sdc}$                         | AD Converter Frequency                     | Bias current adjusted                                                   | 13   | 16   | 19   | MHz        |
| <b>Sine/Digital Converter</b>     |                                            |                                                                         |      |      |      |            |
| $RES_{sdc}$                       | Sine/Digital Converter Resolution          |                                                                         | -    | 12   | -    | bit        |
| $INL_{opt}$                       | Integral non-linearity                     | $V_{DD}=5V$ , Temp=25°C, Din=1.0mm                                      | -0.5 | -    | 0.5  | Deg        |
| $INL_{temp}$                      | Integral non-linearity                     | Maximum error with respect to the best line fit, $T_{amb}=-40$ to 125°C | -0.9 | -    | 0.9  | Deg        |
| $AA_{(rel)}$                      | Relative Angular Accuracy                  | With reference to an output period at A, B                              | -20  | 0    | +20  | %          |
| TD                                | Angle Output Delay Time                    | at ABZ hysteresis = "1LSB"                                              | -    | 18.0 | 45.0 | $\mu s$    |
| <b>Signal Level Control</b>       |                                            |                                                                         |      |      |      |            |
| $V_{pp}$                          | Differential Peak-to-Peak Output Amplitude |                                                                         | 3.2  | 4.0  | 4.8  | V          |
| $t_{(on)}$                        | Controller Setting Time                    | to $\pm 10\%$ of final amplitude                                        | -    | -    | 300  | $\mu s$    |
| $Vt_{(lo)}$                       | Min. Amplitude error                       |                                                                         | 1.0  | -    | 2.8  | V          |
| $Vt_{(hi)}$                       | Max. Amplitude error                       |                                                                         | 4.8  | -    | 5.8  | V          |
| <b>PWM Output</b>                 |                                            |                                                                         |      |      |      |            |
| $F_{(pwm)}$                       | PWM frequency(default)                     | $V_{DD}=5V$ , Temp=25°C                                                 | 927  | 976  | 1024 | Hz         |
| $F_{(pwm)}$                       | PWM frequency(optional)                    | $V_{DD}=5V$ , Temp=25°C                                                 | 232  | 244  | 256  | Hz         |



## Operating Characteristics (Continued)

valid through the full operate temperature range,  $V_{DD}=5V$ ,  $C_{BYPASS}=0.1\mu F$ , unless otherwise specified

| Symbol                                            | Parameter                                                     | Test Conditions                                | Min.  | Typ. | Max. | Unit    |
|---------------------------------------------------|---------------------------------------------------------------|------------------------------------------------|-------|------|------|---------|
| <b>Magnetic Input Specification</b>               |                                                               |                                                |       |      |      |         |
| $d_{mag}$                                         | Diameter                                                      | $\phi 6mm \times 2.5mm$ for cylindrica Magnets | 4.0   | 6.0  | 10.0 | mm      |
| $t_{mag}$                                         | Thickness                                                     |                                                | -     | 2.5  | -    | mm      |
| $D_{in}$                                          | Installation Distance                                         | Recommended magnets                            | -     | 1.0  | 2.0  | mm      |
| $H_{ext}$                                         | Field Amplitude                                               | At chip surface                                | 25    | -    | 125  | mT      |
| $f_{(mag)}$                                       | Rotation Frequency                                            |                                                | -     | -    | 333  | Hz      |
| rpm                                               | Rotating Speed of Magnet                                      |                                                | -     | -    | 20   | Krpm    |
| $x_{dis}$                                         | Lateral Displacement of Magnet Axis to Center of Hall Sensors |                                                | -     | -    | 0.2  | mm      |
| $x_{pac}$                                         | Displacement Chip Center to Package Center                    |                                                | -0.15 | -    | 0.15 | mm      |
| $\varphi_{pac}$                                   | Angular Alignment of Chip vs. Package                         |                                                | -3    | -    | 3    | Deg     |
| $h_{pac}$                                         | Displacement of Chip Surface to Package Surface               |                                                | -     | 0.4  | -    | mm      |
| <b>Digital Inputs: CS,SCLK,MOSI</b>               |                                                               |                                                |       |      |      |         |
| $V_{t(hi)}$                                       | Threshold Voltage hi                                          |                                                | -     | -    | 2    | V       |
| $V_{t(lo)}$                                       | Threshold Voltage lo                                          |                                                | 0.8   | -    | -    | V       |
| $I_{pd()}$                                        | Pull-down Current MOSI                                        | $V()=1 V \dots V_{PD}$                         | 6     | 38   | 60   | $\mu A$ |
| $I_{pu()}$                                        | Pull-up Current Source at CS,SCLK                             | $V()=0 \dots V_{PD} - 1 V$                     | -80   | -140 | -200 | $\mu A$ |
| <b>Digital Inputs: PTE</b>                        |                                                               |                                                |       |      |      |         |
| $I_{pd()}$                                        | Drop-down current PTE                                         | $V()=1 V \dots V_{PD}$                         | 1     | 4    | 10   | $\mu A$ |
| PTEon                                             | Open the threshold                                            |                                                | -     | 1.7  | -    | V       |
| PTEoff                                            | Close the threshold                                           |                                                | -     | 1.3  | -    | V       |
| <b>Digital OUTPUTS: A,B,Z,U,V,W,PWM,MISO,NERR</b> |                                                               |                                                |       |      |      |         |
| $V_{S()hi}$                                       | Saturation Voltage hi                                         | $I()_{hi}=-4 mA$ , with reference to VDD       | -     | -    | 200  | mV      |
| $V_{S()lo}$                                       | Saturation Voltage lo                                         | $I()_{lo}=4 mA$ , with reference to GND        | -     | -    | 200  | mV      |
| $I_{short()hi}$                                   | Short-Circuit Current hi                                      | $V()_{hi}=GND$                                 | 10    | -    | 20   | mA      |
| $I_{short()lo}$                                   | Short-Circuit Current lo                                      | $V()_{lo}=V_{DD}$                              | 5     | -    | 15   | mA      |
| $t_{Rise}$                                        | Rise-Time lo to hi                                            | $R_L=100\Omega$ to GND                         | 5     | -    | 30   | ns      |
| $t_{Fall}$                                        | Fall-Time high to lo                                          | $R_L=100\Omega$ to VDD                         | 5     | -    | 30   | ns      |

## 9. Block Diagram

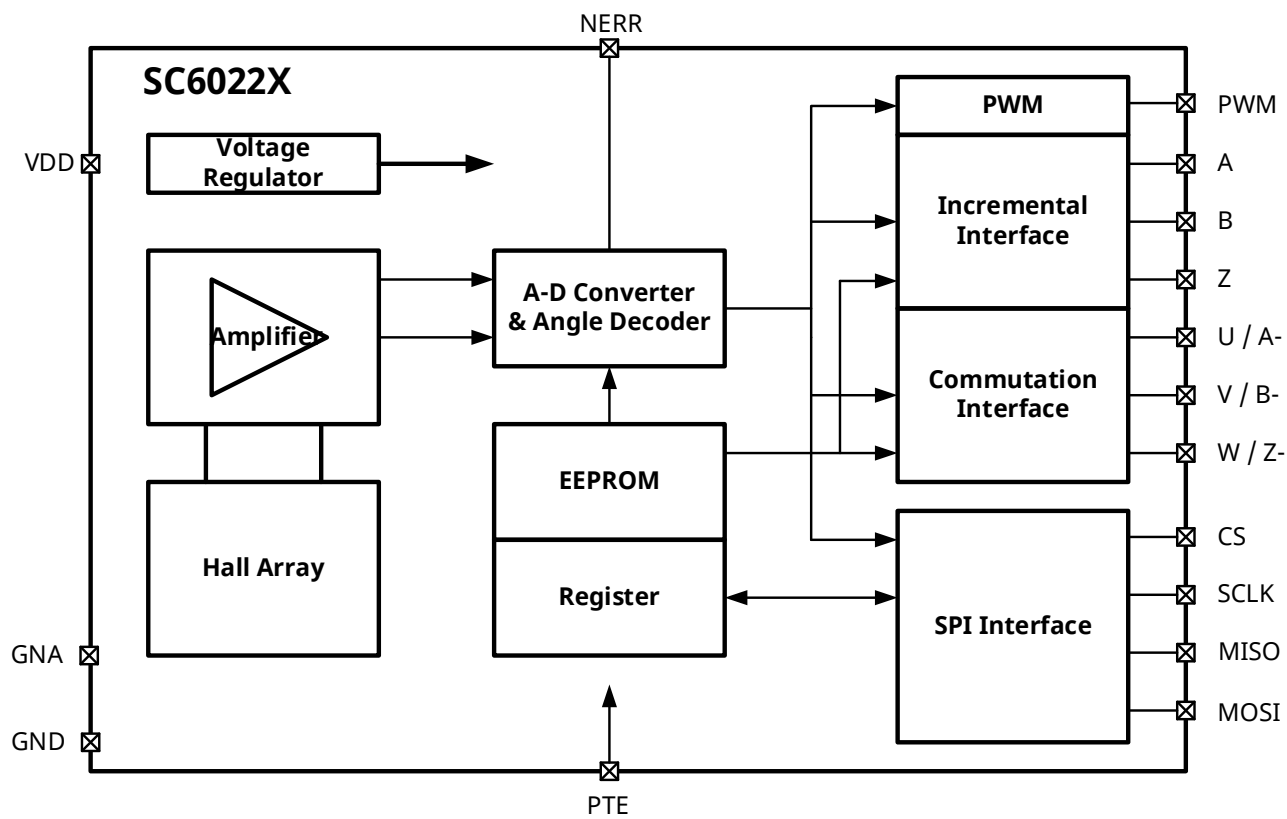


Fig.5 Block Diagram

## 10. Function Description

### 10.1. Position of the Hall Sensors

The Hall sensors are placed in the center of the package at a 90° angle to one another and arranged in a circle.

The zero-angle position of the magnet is reached when the value of  $V_{PCOS}-V_{NCOS}$  is at a maximum. This is the case when the South Pole of the magnet is exactly above the PCOS sensor and the North Pole is above sensor NCOS. When the magnet is rotated counterclockwise, the angle is increasing, as shown in the Fig.6.

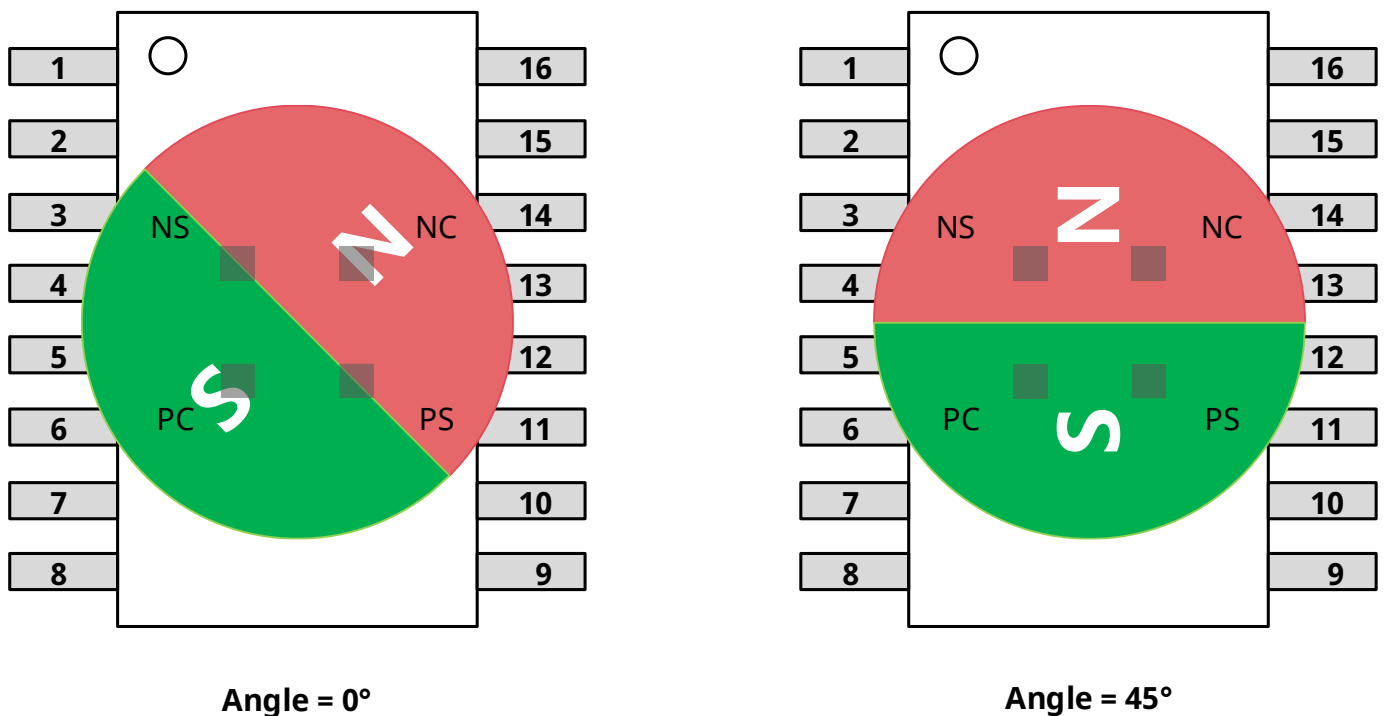


Fig.6 Schematic diagram of angular position

## 10.2. SPI Interface

### Serial Peripheral Interface Timing Diagram with Absolute Angular Position Data

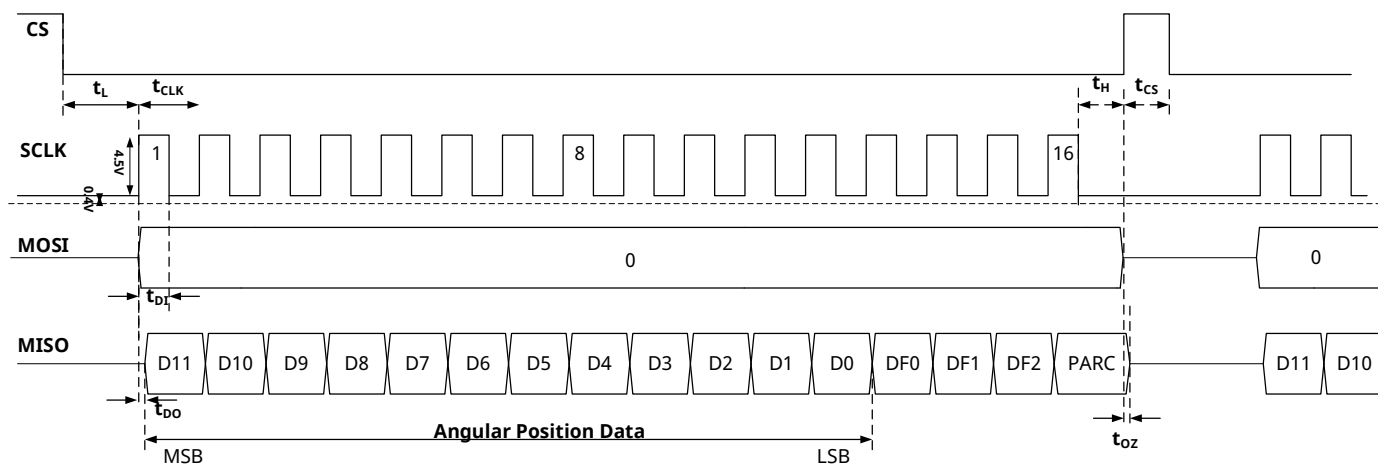


Fig.7 SPI timing diagram

### SPI Timing Definition

| Parameter | Description                                                  | Min.        | Max. | Unit |
|-----------|--------------------------------------------------------------|-------------|------|------|
| $t_L$     | Time between CS falling edge and SCLK rising edge            | 250         | -    | ns   |
| $t_{CLK}$ | Serial clk period                                            | 100         | -    | ns   |
| $t_H$     | Time between last falling edge of SCLK and rising edge of CS | $t_{CLK}/2$ | -    | ns   |
| $t_{CS}$  | High time of CS between two transmissions                    | 250         | -    | ns   |
| $t_{DO}$  | SCLK edge to data output valid                               | -           | 50   | ns   |
| $t_{DI}$  | Data input valid to falling clock edge                       | 20          | -    | ns   |
| $t_{OZ}$  | Release bus time after CS rising edge                        | -           | 10   | ns   |

### SPI Read Data Frame

| Bit  | Name | Description                                                    |
|------|------|----------------------------------------------------------------|
| 15   | PARC | Parity bit (odd) calculated on the lower 15 bits of data frame |
| 14   | DF2  | Data fixed; logic High                                         |
| 13   | DF1  | Data fixed; logic High                                         |
| 12   | ERR  | Becomes logic High, when the fault occurs                      |
| 11:0 | DATA | Absolute angular position data (MSB is clocked out first)      |

### 10.3. Incremental Outputs

The SC60221/4 provides the ABZ incremental output via A, B, Z pin. These outputs are encoded from the angle output data. When the magnet is rotating in counter-clockwise at default settings, the B-phase leads the A-phase.

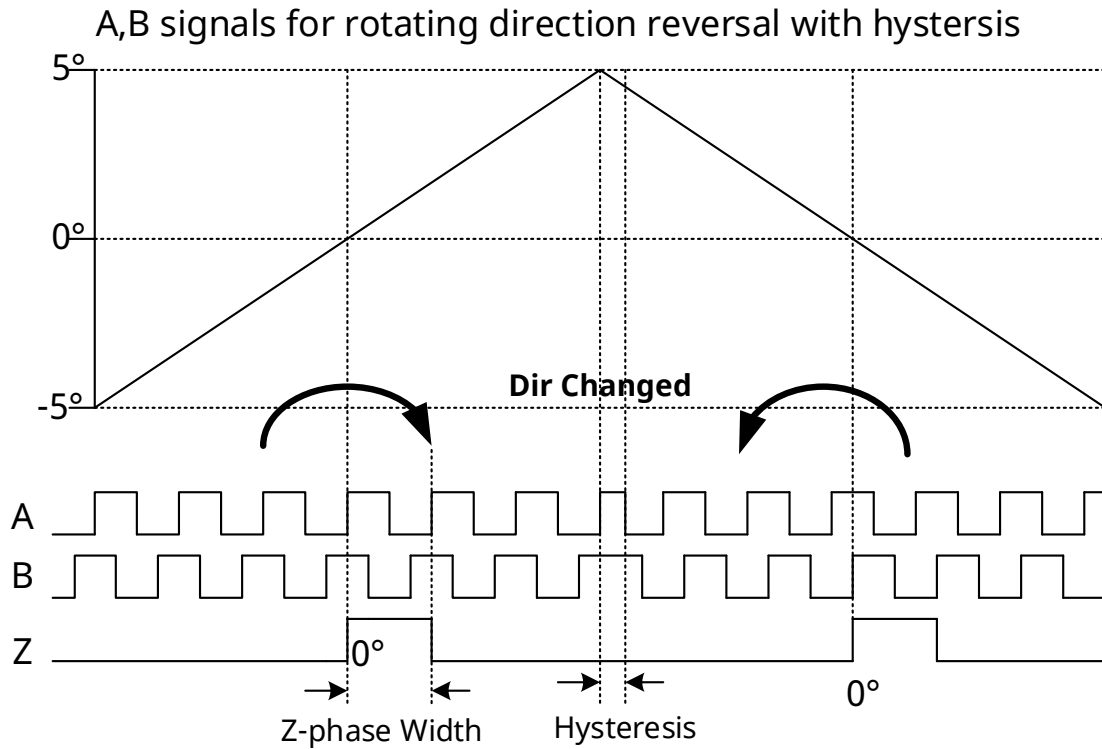


Fig.8 Pulse waveform diagram

The Z-phase width is programmable between 1LSB, 2LSB, 4LSB (default) and 8LSB.

The Z-signal position is programmable.

The ABZ Hysteresis is programmable between 0LSB, 2LSB, 4LSB (default) and 8LSB.

| ABZ Resolution Setting |         |                  |                       |
|------------------------|---------|------------------|-----------------------|
| No.                    | Type    | Pulses per Round | Counts per Revolution |
| 1                      | Binary  | 1024             | 4096                  |
| 2                      |         | 512              | 2048                  |
| 3                      |         | 256              | 1024                  |
| 4                      |         | 128              | 512                   |
| 5                      |         | 64               | 256                   |
| 6                      | Decimal | 1000             | 4000                  |
| 7                      |         | 800              | 3200                  |
| 8                      |         | 600              | 2400                  |
| 9                      |         | 500              | 2000                  |
| 10                     |         | 400              | 1600                  |
| 11                     |         | 360              | 1440                  |
| 12                     |         | 300              | 1200                  |
| 13                     |         | 200              | 800                   |
| 14                     |         | 100              | 400                   |
| 15                     |         | 50               | 200                   |

## 10.4. UVW Commutation Mode

The SC60221/4 provides UVW commutation output necessary for detecting the magnetic pole of the DC brushless motor via U, V, and W pin. The phase of each output is shifted by electric angle phase  $120^\circ$ . The output resolution is programmable from 1 to 16 pole pairs.

### One-pole-pair

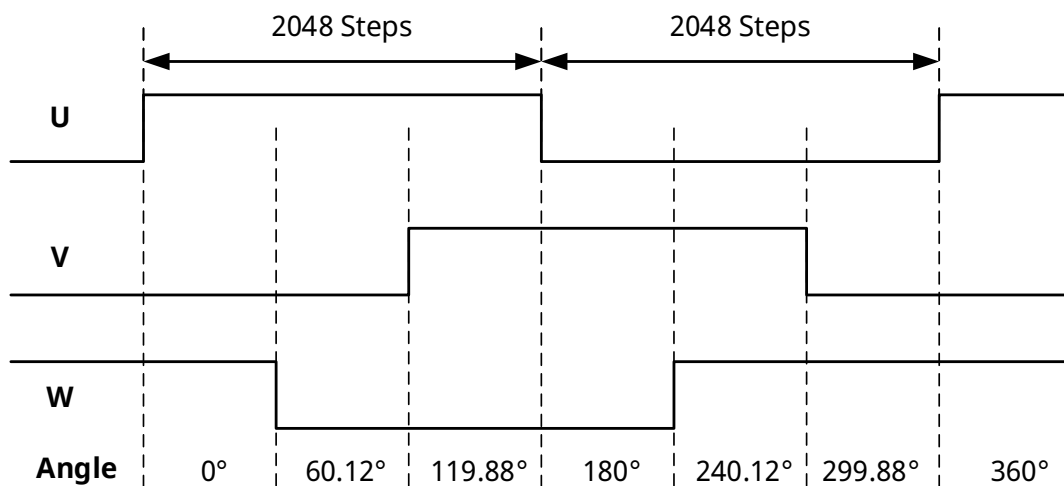


Fig.9 1 pair of polar UVW waveforms

### Two-pole-pair

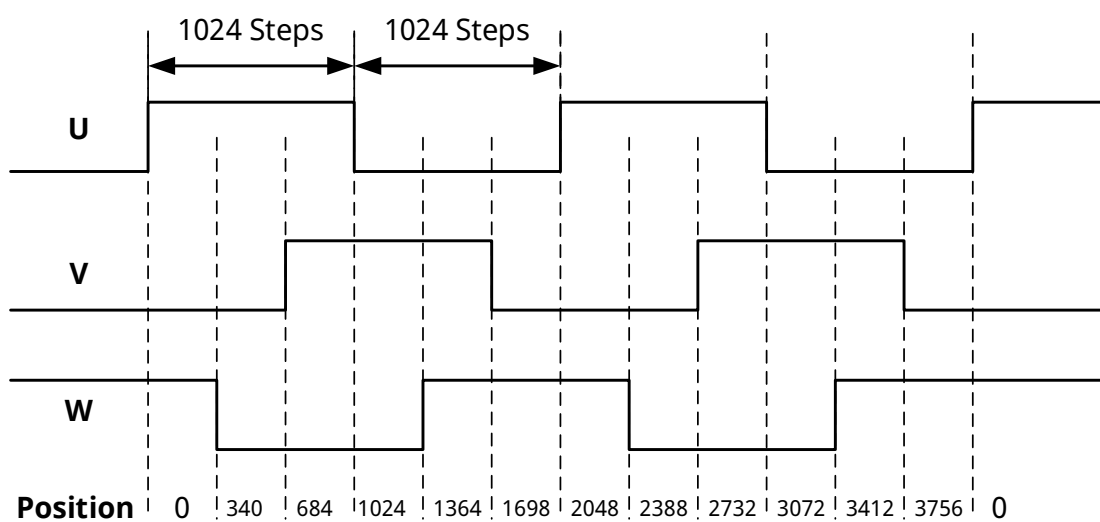


Fig.10 2 pair of polar UVW waveforms

## 10.5. Pulse Width Modulation Output

The SC60221/4/8 provides a pulse width modulated output (PWM), whose duty cycle is proportional to the measured angle.

$$\text{Position} = t_{\text{on}} \times 4098 / (t_{\text{on}} + t_{\text{off}}) - 1$$

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

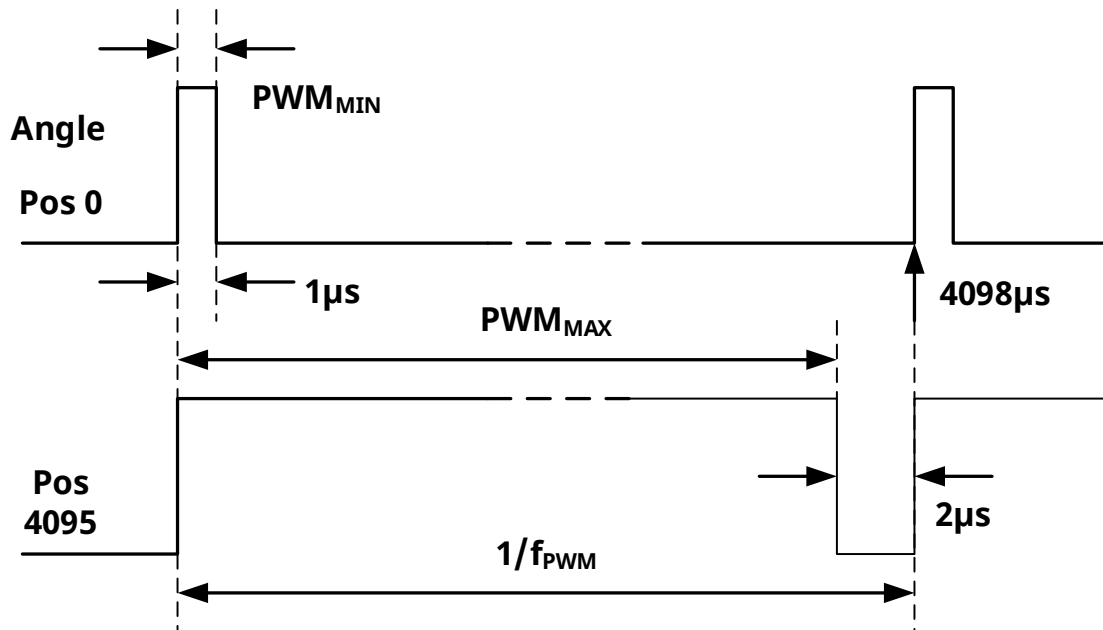


Fig.11 Schematic diagram of waveform with PWM frequency of 244Hz

### PWM default frequency(976Hz)

| Parameter       | Symbol            | Typ. | Unit | Note                             |
|-----------------|-------------------|------|------|----------------------------------|
| PWM frequency   | $f_{\text{PWM}}$  | 976  | kHz  | Signal period: 4098              |
| MIN pulse width | $PW_{\text{MIN}}$ | 0.25 | us   | Position 0d; Angle 0 deg         |
| Max pulse width | $PW_{\text{MAX}}$ | 1024 | us   | Position 4095d; Angle 359.91 deg |

### PWM optional frequency(244Hz)

| Parameter       | Symbol            | Typ. | Unit | Note                             |
|-----------------|-------------------|------|------|----------------------------------|
| PWM frequency   | $f_{\text{PWM}}$  | 244  | kHz  | Signal period: 4098              |
| MIN pulse width | $PW_{\text{MIN}}$ | 1    | us   | Position 0d; Angle 0 deg         |
| Max pulse width | $PW_{\text{MAX}}$ | 4096 | us   | Position 4095d; Angle 359.91 deg |



## 11. Typical Application

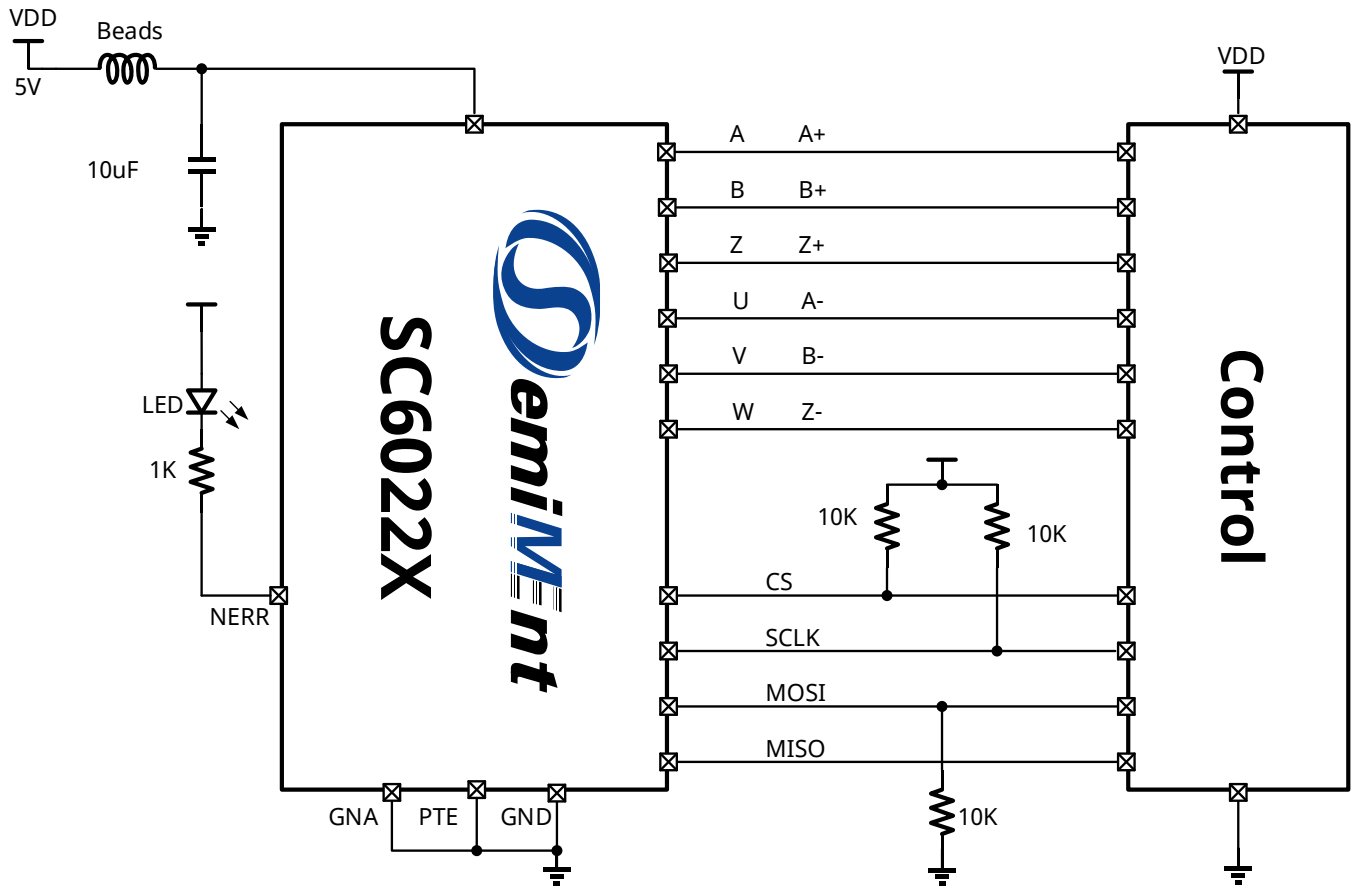
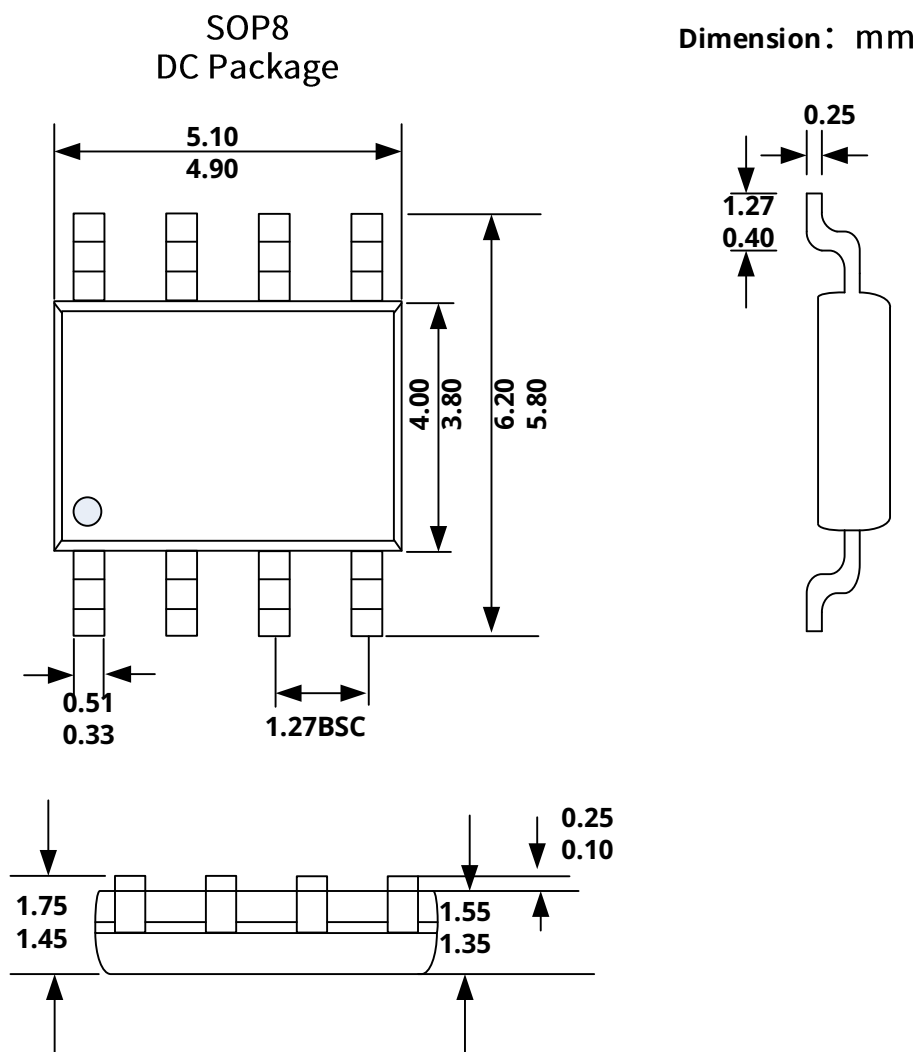


Fig.12 Typical Application

**Note:**

- (1) Add SMD inductor (magnetic bead) and 10uF decoupling capacitor to power end of magnetic encoder chip.
- (2) CS and SCLK end plus 10K pull-up resistor, MOSI plus 10K pull-down resistor.
- (3) Since SPI communication is a board-level communication protocol, it is recommended that the length of the connection line should not exceed 30cm if communication is required via wire connection.
- (4) If ABZUVW is connected to the controller end, please use RS422 differential communication chip 26C31 for differential signal transmission in long line communication.

## 12. Package Information DC



**Notes:**

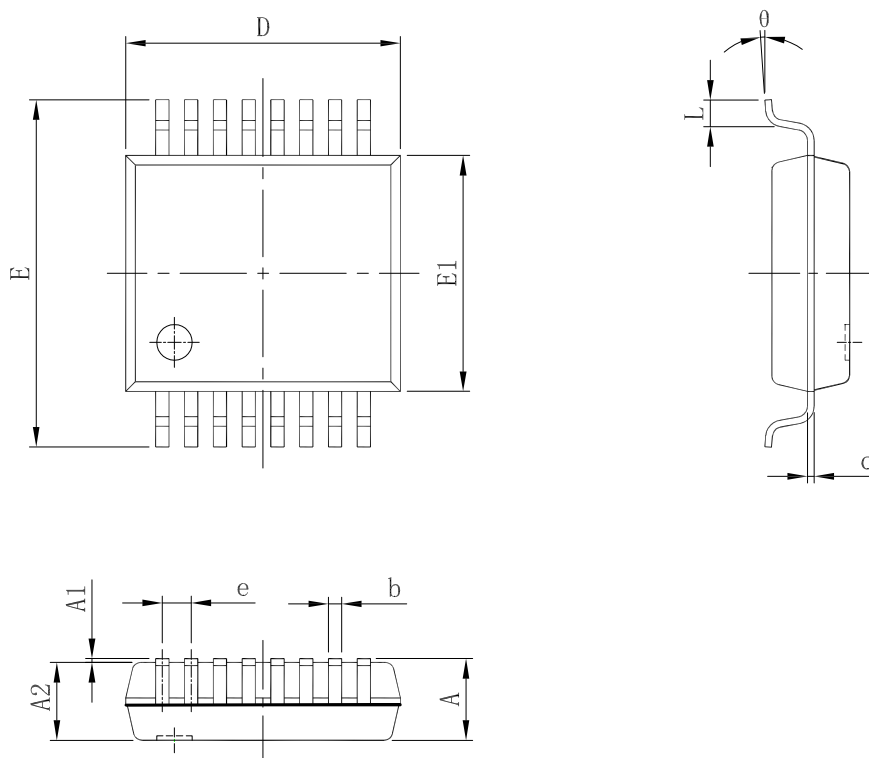
(1) Exact body and lead configuration at vendor's option within limits shown.

(2) Height does not include mold gate flash.

Where no tolerance is specified, dimension is nominal.

Fig.13 SOP8 Package Dimension Drawing

### 13. Package Information SS



| Symbol | Dimensions In Millimeters |       | Dimensions In Inches |       |
|--------|---------------------------|-------|----------------------|-------|
|        | Min.                      | Max.  | Min.                 | Max.  |
| A      | —                         | 2.000 | —                    | 0.079 |
| A1     | 0.050                     | —     | 0.002                | —     |
| A2     | 1.650                     | 1.850 | 0.065                | 0.073 |
| b      | 0.220                     | 0.380 | 0.009                | 0.015 |
| c      | 0.090                     | 0.250 | 0.004                | 0.010 |
| D      | 5.900                     | 6.500 | 0.232                | 0.256 |
| E      | 7.400                     | 8.200 | 0.291                | 0.323 |
| E1     | 5.000                     | 5.600 | 0.197                | 0.220 |
| e      | 0.650(BSC)                |       | 0.026(BSC)           |       |
| L      | 0.550                     | 0.950 | 0.022                | 0.037 |
| θ      | 0°                        | 8°    | 0°                   | 8°    |

Fig.14 SSOP16 Package Dimension Drawing

## 14. Revision History

| Revision | Date       | Description                        |
|----------|------------|------------------------------------|
| Rev.E0.1 | 2019-04-05 | Initial release                    |
| Rev.A1.0 | 2019-07-16 | Update typical application circuit |
| Rev.A1.1 | 2020-05-31 | Add version history                |
| Rev.A1.2 | 2025-02-17 | Modify the order information       |