

ZMID4200

Inductive Position Sensor IC

Description

The ZMID4200 is an inductive position sensor IC, applicable for absolute rotary or linear motion sensing in industrial, medical, and consumer applications. The ZMID4200 uses the physical principles of induction in a wire loop and eddy currents to detect the position of an electrically conducting target that is sliding or rotating above a set of coils, consisting of one transmitter coil and two receiver coils.

The three coils are typically printed as copper traces on a printed circuit board (PCB). They are arranged such that the transmitter coil induces a secondary voltage in the receiver coils that depends on the position of the metallic target above the coils.

A signal representative of the target's position over the coils is obtained by demodulating and processing the secondary voltages from the receiver coils. The target can be any kind of metal, such as aluminum, steel, or a PCB with a printed copper layer.

Three output options are available, selectable by user programming:

- 10-bit Analog output (default)
- 10-bit PWM digital output (programming option)
- 12-bit SENT digital output (programming option)

Physical Characteristics

- Operation temperature: -40 C to +150°C
- Supply voltage: 4.5V to 5.5V
- Small 14-TSSOP package

Application Usage

- Qualified for industrial, medical and consumer applications only – not qualified for usage in automotive applications

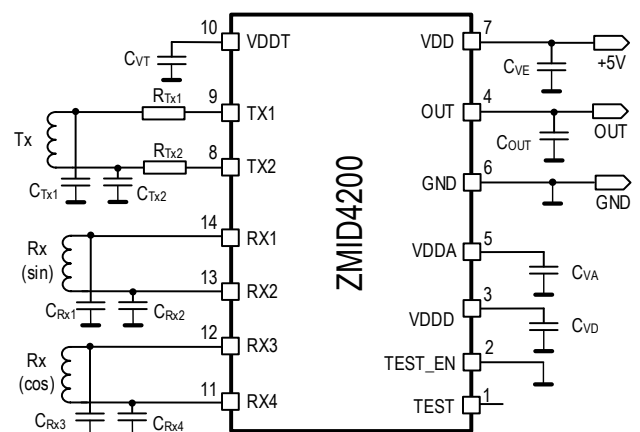
Typical Applications

- Rotary position sensors up to 360°; e.g. rotary actuators, potentiometer replacement
- Small-angle sensors or arc-motion sensors, e.g. industrial pedal or valve sensors, robotics
- Linear motion sensors, e.g. linear-actuators, position sensors, fluid-level sensors, slide potentiometer replacement

Features

- Position sensing based on inductive principle
- Cost effective; no magnet required
- Immune to magnetic stray fields; no shielding required
- Suitable for harsh environments and extreme temperatures
- Only three wires (ground, supply, output)
- Nonvolatile user memory; programming through output pin
- Single IC supports on-axis and off-axis rotation, linear motion, and arc motion sensing
- High resolution, even for small angle ranges
- High accuracy:  $\leq 0.2\%$  full scale
- 9-point user linearization
- Rotation sensing up to a full turn of 360°
- Overvoltage and reverse-polarity protection: -14V to +18V maximum, depending on product
- ESD and short-circuit protection
- Power or ground loss detection
- Programmable linearization
- Adaptive gain control supporting a wide range of coil designs and target displacement

Application Circuit Example



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## 1. Pin Assignments

The ZMID4200 is available in a 14-TSSOP RoHS package.

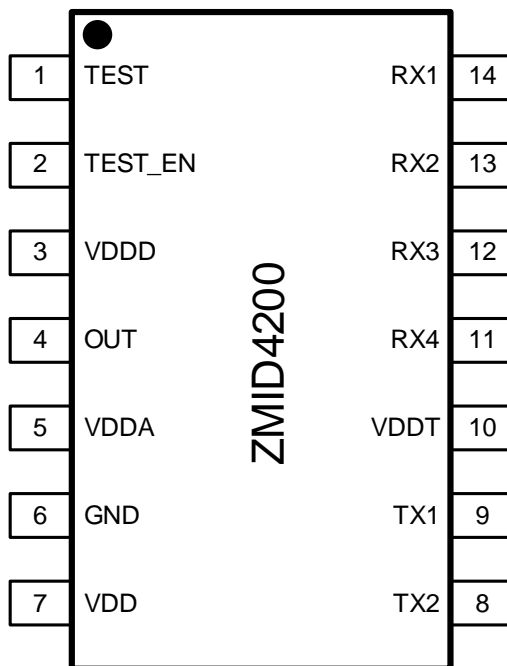


Figure 1. Pin Assignments for 14-TSSOP Package – Top View

## 2. Pin Descriptions

Table 1. Pin Descriptions

| Number | Name    | Type                                   | Description   |
|--------|---------|--|---|
| 1      | TEST    | Input/output                           | Factory test pin; must be left unconnected.   |
| 2      | TEST_EN | Input/output                           | Factory test pin. Connect to the GND pin.   |
| 3      | VDDD    | Supply                                 | Internal regulated digital supply voltage. Connect capacitor CVD = 100nF from the VDDD pin to the GND pin, no other load.   |
| 4      | OUT     | Analog output (default setting)        | When configured as analog output, refer to section 8.1, Figure 5, and Figure 6 for external connections.  |
|        |         | PWM digital output                     | When configured as PWM digital output, refer to section 8.2 and Figure 8 for external connections.  |
|        |         | SENT digital output                    | When configured as SENT output, refer to section 8.3, and Figure 12 for external connections.   |
|        |         | Digital input/output: programming only | Digital One-Wire Interface (OWI) used during programming.   |
| 5      | VDDA    | Supply                                 | Internal regulated analog supply voltage. Connect CVA = 100nF from the VDD pin to the GND pin; no other load.   |
| 6      | GND     | Ground                                 | Common ground connection.   |
| 7      | VDD     | Supply                                 | External supply voltage. Connect the VDD pin to CVE = 100nF capacitor in parallel with a 1pF to 10pF capacitor connected to the GND pin.  |
| 8      | TX2     | Analog output                          | Connect the transmitter coil to TX1 and TX2 via the series resistors RTx1 and RTx2. The resonant frequency is adjusted with capacitors C <sub>TX1</sub> and C <sub>TX2</sub> between TX1 and TX2 to GND (see the Application Circuit Example and Figure 4). C <sub>TX1</sub> and C <sub>TX2</sub> must have the same capacitance value. They can be calculated with Equation 4. |
| 9      | TX1     |  |   |
| 10     | VDDT    | Supply                                 | Internal supply voltage for transmitter amplifier. Connect to CVT = 100nF to GND.   |
| 11     | RX4     | Analog input                           | Connect receiver coil 2 between the RX4 and RX3 pins.   |
| 12     | RX3     |  |   |
| 13     | RX2     |  |   |
| 14     | RX1     | Analog input                           | Connect receiver coil 1 between the RX2 and RX1 pins.   |

### 3. Absolute Maximum Ratings

The absolute maximum ratings are stress ratings only. Stresses greater than those listed below can cause permanent damage to the device. Functional operation of the ZMID4200 at the absolute maximum ratings is not implied. Exposure to absolute maximum rating conditions could affect device reliability.

Table 2. Absolute Maximum Ratings

| Symbol                | Parameter                          | Conditions   | Minimum | Maximum | Units |
|-----------------------|------------------------------------|--|---------|---------|-------|
| V <sub>VDD</sub>      | External supply voltage            |  | -18     | 18      | V     |
| V <sub>OUT_ANA</sub>  | Analog output voltage              | For negative voltage, external current must be limited to 10mA | -14     | 14      | V     |
|                       |                                    | Without external current limitation                            | -0.3    | 14      | V     |
| V <sub>OUT_PWM</sub>  | PWM output voltage                 | For negative voltage, external current must be limited to 10mA | -14     | 18      | V     |
|                       |                                    | Without external current limitation                            | -0.3    | 18      | V     |
| V <sub>OUT_SENT</sub> | SENT output voltage                | For negative voltage, external current must be limited to 10mA | -14     | 18      | V     |
|                       |                                    | Without external current limitation                            | -0.3    | 18      | V     |
| V <sub>OSC_COIL</sub> | Oscillator coil pins: EP, EN       |  | -0.3    | 5.5     | V     |
| V <sub>RX1</sub>      | Receiver coil pin: RX1             |  | -0.3    | 3.6     | V     |
| V <sub>RX2</sub>      | Receiver coil pin: RX2             |  |         |         |       |
| V <sub>RX3</sub>      | Receiver coil pin: RX3             |  |         |         |       |
| V <sub>RX4</sub>      | Receiver coil pin: RX4             |  |         |         |       |
| V <sub>TEST_ENA</sub> | Test pin: TEST_ENA                 |  | -0.3    | 5.5     | V     |
| V <sub>TEST_D</sub>   | Test pin: TEST_D                   |  | -0.3    | 3.6     | V     |
| V <sub>VDDA</sub>     | Regulated supply voltage pin: VDDA |  | -0.3    | 3.6     | V     |
| V <sub>VDDD</sub>     | Regulated supply voltage pin: VDDD |  | -0.3    | 3.6     | V     |
| V <sub>VDDT</sub>     | Regulated supply voltage pin: VDDT |  | -0.3    | 4.2     | V     |

### 4. Operating Conditions

Conditions: VDD = 5V ±10%, TAMB = -40°C to +150°C.

Table 3. Operating Conditions

| Symbol            | Parameter                                | Conditions     | Minimum | Typical | Maximum | Units |
|-------------------|--|----------------|---------|---------|---------|-------|
| T <sub>AMB</sub>  | Ambient temperature                      |                | -40     |         | 150     | °C    |
| T <sub>J</sub>    | Junction temperature                     |                | -40     |         | 175     | °C    |
| T <sub>STOR</sub> | Storage temperature                      |                | -50     |         | 150     | °C    |
| R <sub>THJA</sub> | Thermal resistance junction to ambient   |                |         |         | 140     | °C/W  |
| V <sub>VDD</sub>  | Supply voltage                           |                | 4.5     | 5       | 5.5     | V     |
| ESD               | Electrostatic discharge, HBM 100pF/1.5kΩ | Pins GND, VDD  |         |         | ±4      | kV    |
|                   |  | Pin OUT        |         |         | ±3      | kV    |
|                   |  | All other pins |         |         | ±2      | kV    |

## 5. Electrical Characteristics

The following electrical specifications are valid for the operating conditions as specified in Table 3 ( $T_{AMB} = -40^{\circ}\text{C}$  to  $+150^{\circ}\text{C}$ ).

**Table 4. Electrical Characteristics**

| Symbol                   | Parameter                                   | Conditions   | Minimum | Typical | Maximum | Units               |
|--------------------------|---|--|---------|---------|---------|---------------------|
| $V_{VDD\_TH\_H}$         | VDD switch ON threshold                     | The device is activated when VDD increases above this threshold              |         |         | 4.4     | V                   |
| $t_{START}$              | Startup Time                                | Time between $V_{DD} > V_{VDD\_TH\_H}$ and valid output at OUT               |         | 5       | 9       | ms                  |
| $V_{VDD\_TH\_L}$         | VDD switch OFF threshold                    | The device is deactivated when VDD decreases below this threshold            | 4       |         |         | V                   |
| $V_{VDD\_OVH}$           | Over-voltage detection high                 | The device is deactivated after VDD increases above this voltage             |         |         | 7       | V                   |
| $V_{VDD\_OVL}$           | Over-voltage detection low                  | The device is activated after VDD decreases below this voltage               | 5.6     |         |         | V                   |
| $V_{VDDA}$               | Regulated analog supply output voltage      | Internally regulated, fixed  |         | 3.3     |         | V                   |
| $V_{VDDD}$               | Regulated digital supply output voltage     | Internally regulated, fixed  |         | 2.0     |         | V                   |
| $V_{VDDT}$               | Regulated coil driver supply output voltage | Internally regulated, user programmable. Nominal voltage at room temperature | 2.7     | 3.3     | 4.1     | V                   |
| $TC_{VDDT}$              | Temperature coefficient of VDDT regulator   |  |         | 4000    |         | ppm/K               |
| $I_{CC}$                 | Current consumption                         | Without coils, no load   | 5       |         | 9       | mA                  |
|                          |   | With coils, no load; depending on programmable Tx coil current               |         | 12      | 20      | mA                  |
| <b>Angle Calculation</b> |   |  |         |         |         |                     |
| $t_{REFRESH}$            | Output update rate                          | Analog output  |         |         | 10      | kHz                 |
| $RES_{CORDIC}$           | CORDIC resolution                           | Internal; over $360^{\circ}$ electrical                                      |         | 16      |         | bits                |
| <b>Performance</b>       |   |  |         |         |         |                     |
| INL                      | Accuracy <sup>[a]</sup>                     | See note [a].  |         | 0.2     |         | % FS <sup>[b]</sup> |

[a] The achievable accuracy depends on proper coil and target design. Nonlinearity errors in the calculated position might be further improved by 9-point linearization.

[b] Full scale range

**Table 5. Coil Specifications**

| Symbol             | Parameter   | Conditions                                  | Minimum        | Typical | Maximum | Units            |
|--------------------|---|---|----------------|---------|---------|------------------|
| $R_{Peq}$          | Equivalent parallel resistance of the LC resonant circuit | See Equation 1                              | 250            |         |         | $\Omega$         |
| $f_{OSC}$          | Transmitter frequency                                     | LC oscillator                               | 2.2            | 3.5     | 5.6     | MHz              |
| $V_{TX\_P}$        | Transmitter coil amplitude                                | Peak voltage, pins TX1 vs. TX2              |                |         | 7200    | mV <sub>pp</sub> |
| $R_{TX1}, R_{TX2}$ | TX Series resistor  | For reduced EMC emission                    |                | 10      |         | Ohm              |
| $C_{TX1}, C_{TX2}$ | LC oscillator capacitor                                   | Split capacitor for LC frequency adjustment | See Equation 4 |         |         | nF               |
| $V_{RX}$           | Receiver coil amplitude                                   | Input signal range                          | 50             |         | 360     | mV <sub>pp</sub> |

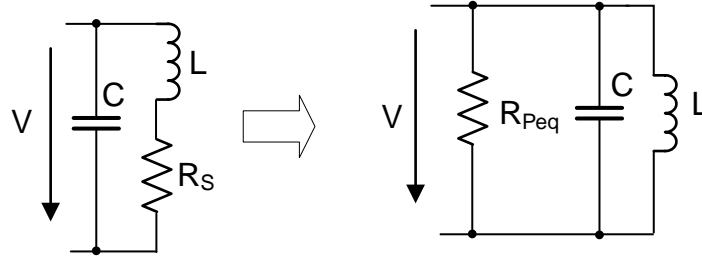


Figure 2. Parallel Resonator Circuit

The equivalent parallel resistance  $R_{Peq}$  of the LC oscillator can be calculated using Equation 1. It defines the minimum loss resistance that the oscillator can drive for safe operation.

$$R_{Peq} = \frac{1}{R_S} \times \frac{L}{C} \tag{Equation 1}$$

Where

- $R_{Peq}$  Equivalent parallel resistance of the LC oscillator.
- $R_S$  Serial resistance of the transmitter coil at the transmitter frequency.
- $L$  Coil reactance at the resonant frequency.
- $C$  Capacitance of the parallel capacitor CT.

The oscillator frequency is determined by the values of coil L and capacitors  $C_{Tx1}$  and  $C_{Tx2}$  as the following:

Oscillator frequency:

$$f_{TX} = \frac{1}{2\pi \sqrt{L \times \frac{C_{Tx1} \times C_{Tx2}}{C_{Tx1} + C_{Tx2}}}} \tag{Equation 2}$$

For  $C_{Tx1} = C_{Tx2}$  :

$$f_{TX} = \frac{1}{2\pi \sqrt{L \frac{C_{Tx1}}{2}}} \tag{Equation 3}$$

$$C_{Tx1} = C_{Tx2} = \frac{2}{L(2\pi f_{TX})^2} \tag{Equation 4}$$

Where:

- $f_{TX}$  = Oscillator frequency in MHz
- $L$  = Coil impedance in  $\mu$ Henry
- $C_{Tx1}, C_{Tx2}$  = Capacitance in  $\mu$ Farad

Table 6. Nonvolatile Memory (EEPROM)

| Parameter                       | Conditions                | Minimum | Typical | Maximum | Units            |
|---------------------------------|---------------------------|---------|---------|---------|------------------|
| Data retention                  | $T_J = 85^\circ\text{C}$  | 10      |         |         | Years            |
| Endurance; Erase / Write cycles | $T_J = 25^\circ\text{C}$  | 100 000 |         |         | Cycles           |
|                                 | $T_J = 125^\circ\text{C}$ | 10 000  |         |         |                  |
| Junction temperature            | For read cycles           | -40     |         | +175    | $^\circ\text{C}$ |
|                                 | For write cycles          | -40     |         | +125    |                  |

## 6. Circuit Description

### 6.1 Overview

The ZMID4200 ICs is an inductive position sensor for use in industrial, medical and consumer applications. It operates on the principles of induction in a wire loop and eddy currents. The sensing element is a set of coils that are directly connected to the IC. The coils consist of one transmitter coil and two receiver coils. The transmitter coil and a capacitor form a free running LC oscillator that is directly driven by the IC. It generates a magnetic field within the transmitter coil area that is picked up by the receiver coils.

The voltage generated by the receiver coils depends on the position of the target in the sense that areas shielded by the target generate a weaker secondary voltage compared to areas that are not shaded by the target.

The two receiver coils are arranged so that the secondary voltages are relatively phase shifted by electrical 90°, thereby generating a response curve (receiver coil output voltages versus position) that resembles a sine and cosine waveform over the range of target travel. By having a sine and cosine shaped response, a ratiometric measurement is possible, which greatly improves the robustness of the system because the output signal will remain stable, even if the gap between coils and target is varied.

Figure 3 shows an example of a linear motion sensor with one transmitter coil (Tx loop) and two receiver coils (Sin loop and Cos loop). The arrows in the receiver coils indicate the direction of the induced current relative to each other. The direction of the current either clockwise (cw) or counterclockwise (ccw) determines the polarity of the voltage generated in each loop (RxCos, RxSin).

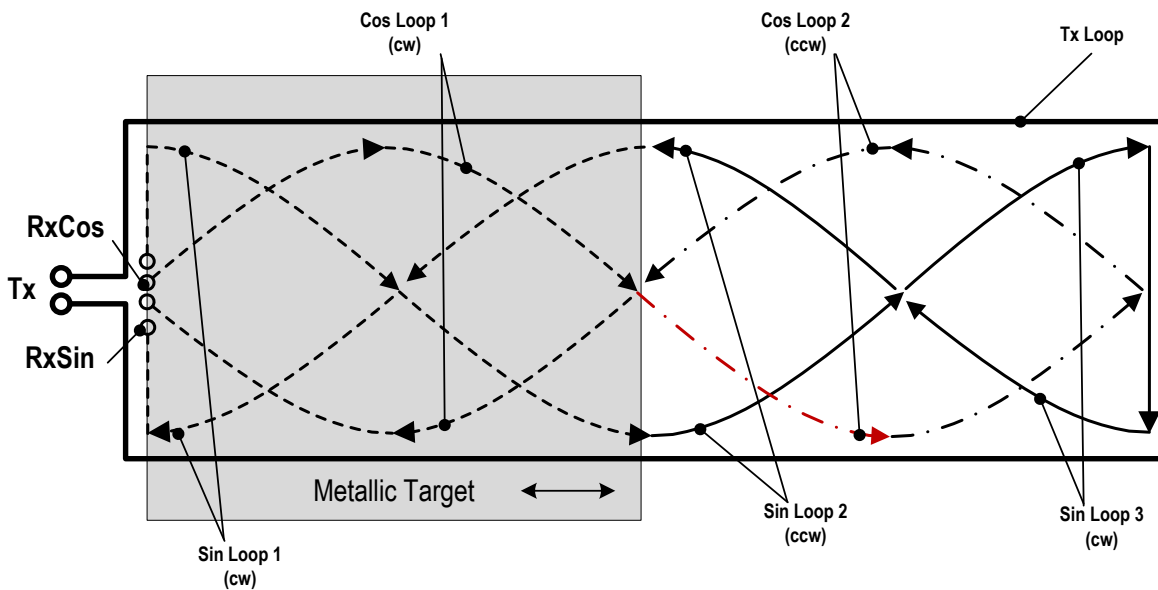
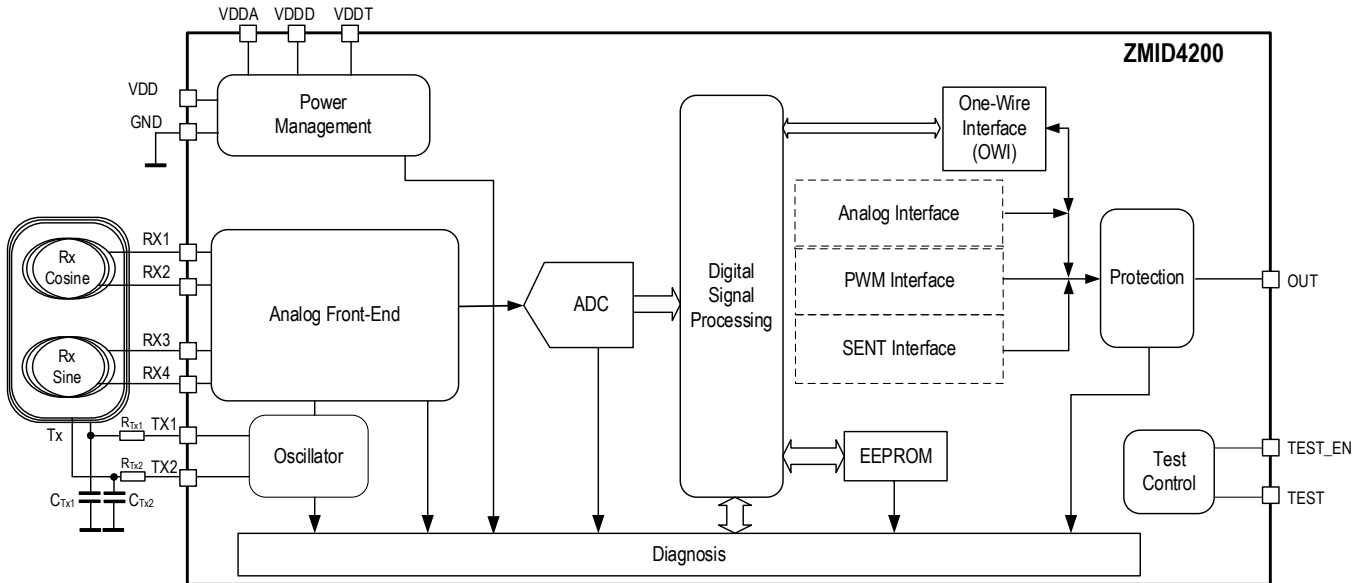


Figure 3. Coil Design for a Linear Motion Sensor



## 6.2 Block Diagram

Figure 4 shows the block diagram of the ZMID4200



**Figure 4. Block Diagram**

The main building blocks include the following:

- Power management: power-on-reset (POR) circuit, low drop-out (LDO) regulators for internal supplies.
- Oscillator: generation of the transmitter coil signal.
- Analog front-end: demodulator and gain control for the receive signals.
- Analog-to-digital converter (ADC): conversion into digital domain.
- Digital signal processing: offset correction; conversion of sine and cosine signals into angle and magnitude; angle range adjustment; and linearization.
- EEPROM: nonvolatile storage of factory and user-programmable settings.
- One-wire interface (OWI): programming of the chip through the output pin.
- Interface options:
  - Analog output
  - PWM output
  - SENT output
- Protection: overvoltage, reverse polarity, short circuit protection.
- Test control: factory testing; connect TEST\_D and TEST\_ENA pins as indicated in Table 1.

Note: For the LC tank circuit, the capacitor  $C_T$  should be placed as close as possible to the ZMID4200 pins TX1 and TX2 to minimize the loop area between pins and capacitor(s).

## 7. Protection and Diagnostics

### 7.1 I/O Protection

In order to meet high quality requirements for overvoltage and reverse-polarity protection on both the output and power supply pins, the ZMID4200 includes several protection and diagnosis features:

- Detection of broken power line, interrupted output signal, and broken ground connection on the receiving side
- Protection against short circuit of output pin to GND, output pin to VDD, and supply VDD to GND
- Overvoltage protection on supply pin VDD
- Overvoltage protection on output pin
- Reverse-polarity protection on supply pin VDD to GND
- Reverse-polarity protection on output pin to GND
- Reverse-polarity protection on output pin to VDD

### 7.2 Diagnostics

The ZMID4200 monitors a number of diagnostic features as described in following list:

- Supply voltage too low or too high
- Rx sine coil: open, short, short to ground, or short to Rx cosine coil
- Rx sine coil: amplitude error or offset error
- Rx cosine coil: open, short, short to ground, or short to Rx sine coil
- Rx cosine coil: amplitude error or offset error
- Tx coil: amplitude too low or open
- Tx coil: frequency out of range
- LC oscillator failure
- CORDIC magnitude too high or too low
- Missing target
- Internal EEPROM failure
- ADC signal processing overflow

## 8. Selection of the Output Interface

The ZMID4200 offers three different types of output interfaces on pin 4 (OUT):

1. Analog interface, see section 8.1 for details
2. PWM interface, see section 8.2 for details
3. SENT interface, see section 8.3. for details

In the default configuration at initial shipment, the output interface is set to Analog output. PWM or SENT interfaces can be configured by the user through programming (see section 9).

### 8.1 Analog Output (Default Setting)

Typical interface circuits for the ZMID4200 configured with an analog output are shown in Figure 5 and Figure 6.

Note: The pull-up or pull-down resistors are not mandatory for normal operation. However, they are recommended for proper detection of broken ground or broken supply wires at the receiving side.

Note:  $R_F$ ,  $C_F$  = optional low pass filter. Values depend on user's application.

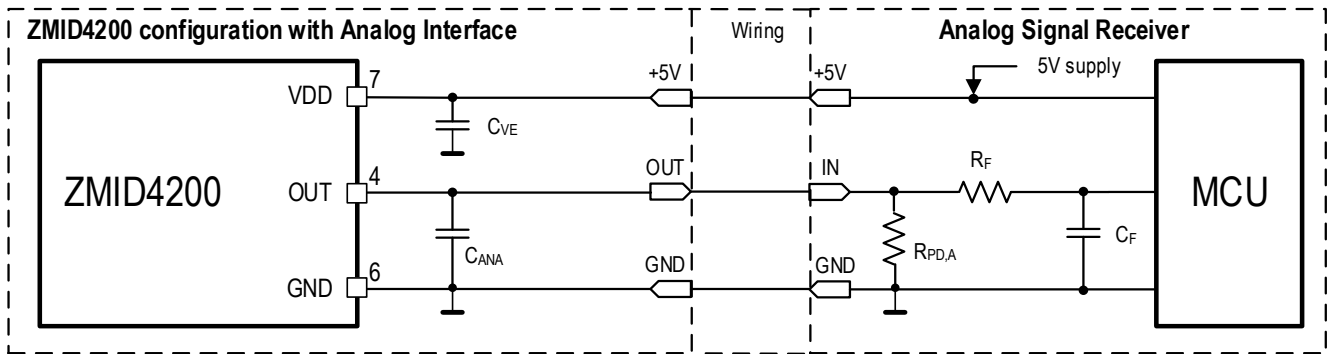


Figure 5. External Components for ZMID4200 Analog Interface with Pull-Down Resistor

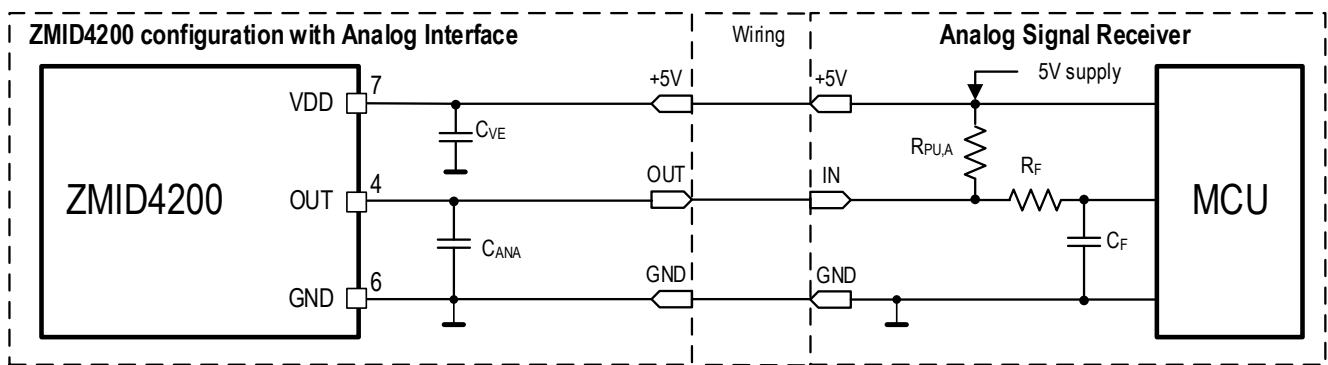


Figure 6. External Components for ZMID4200 Analog Interface with Pull-up Resistor

Table 7. Analog Output Buffer Characteristics

Note: Refer to the VDD pin description in Table 1 for the value of  $C_{VE}$ .

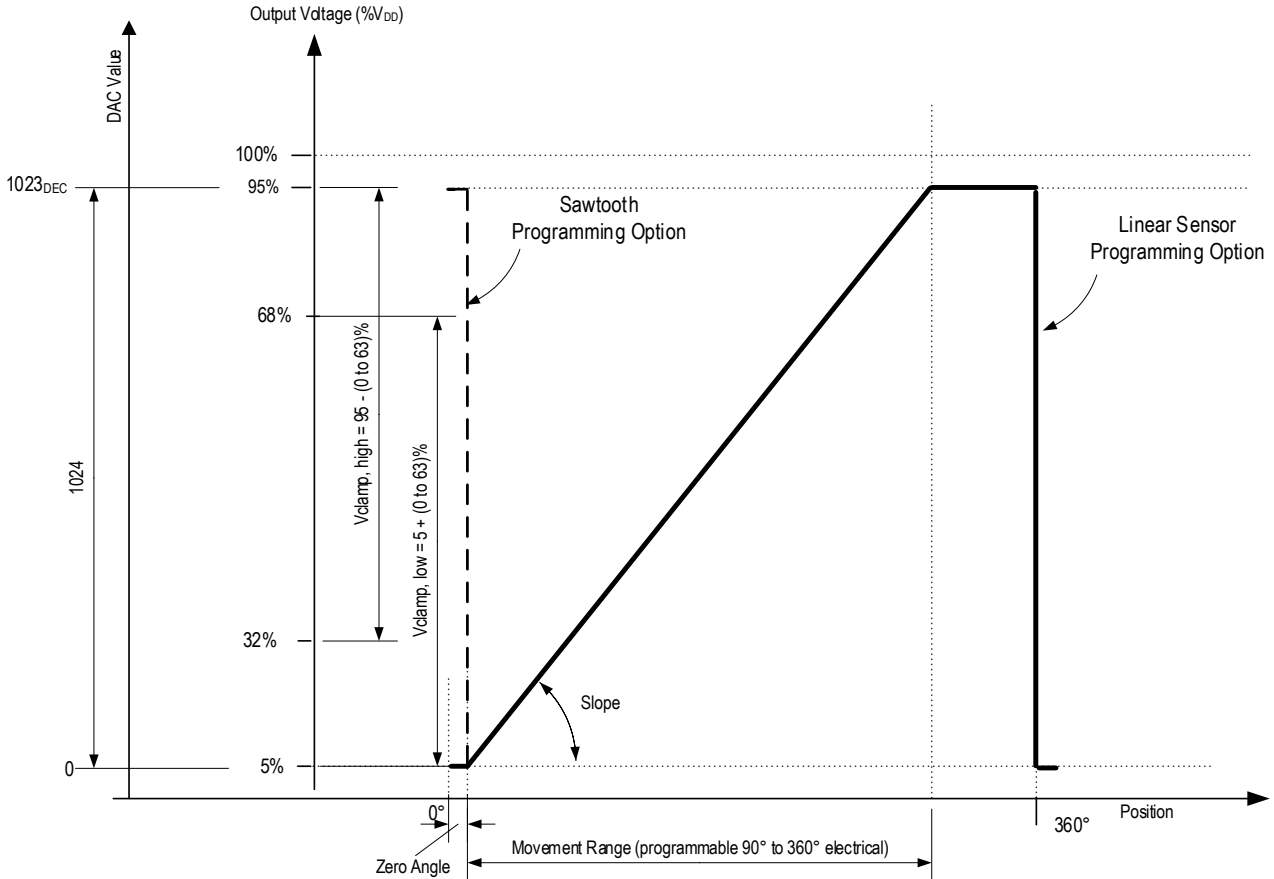
| Symbol        | Parameter                                | Conditions   | Minimum | Typical | Maximum | Units         |
|---------------|--|--|---------|---------|---------|---------------|
| Out_err       | Analog output error                      | Offset and nonlinearity error  | -6      |         | 6       | mV            |
| Step_large    | Output response, large step              | Step = 4.5V, $C_{ANA} = 10\text{nF}$ , $R_{PD,A} = 5\text{k}\Omega$ , 10% to 90% |         |         | 160     | $\mu\text{s}$ |
| $T_{UPD,ANA}$ | Analog output update rate (programmable) | Minimum oversampling rate  | 50.1    | 55.7    | 61.2    | $\mu\text{s}$ |
|               |  | Maximum oversampling rate  | 401     | 445.4   | 490     |               |
| $C_{ANA}$     | Load capacitor for analog output         | Max. 6.8nF for OWI programming   | 0.47    |         | 27      | nF            |
| $RES_{ANA}$   | Analog output resolution                 | Resolution of DAC  |         |         | 10      | bits          |
| $R_{PU,A}$    | Output pull-up resistor                  |  | 3       | 4.7     | 10      | k $\Omega$    |
| $R_{PD,A}$    | Output pull down resistor                |  | 3       | 4.7     | 10      | k $\Omega$    |
|               | Normal operating range                   | Limits are programmable  | 5       |         | 95      | %VDD          |
| Diag_high_ana | Diagnostic high for analog               |  | 96      |         |         | %VDD          |
| Diag_low_ana  | Diagnostic low for analog                |  |         |         | 4       | %VDD          |
| $V_{CL,L}$    | Clamping level, low <sup>[a]</sup>       | Programmable in 1% steps   | 5       |         | 68      | %VDD          |
| $V_{CL,H}$    | Clamping level, high <sup>[a]</sup>      | Programmable in 1% steps   | 32      |         | 95      | %VDD          |
| Current_limit | Output node short current                | Short to VDD or GND  |         |         | 50      | mA            |

[a] Low clamping level must be programmed lower than the  $V_{CL,H}$  high clamping level.

For the ZMID4200, the 100% position range is mapped to a voltage range from 250mV to 4750mV. The stepping rate of the clamping parameters is 1% so that the analog voltage stepping rate is 47.5 mV/%. The diagnostic low level is  $\leq 200\text{mV}$  and the diagnostic high level is  $\geq 4800\text{mV}$ .

Note that the minimum and maximum output positions can be mapped to the mechanical range of the application by programming the zero angle offset, slope programming (linear vs. sawtooth), and clamping level register

settings (refer to section 0 and Figure 8). For example, for a pedal sensor with ratiometric analog output, having 20° mechanical degrees of movement range and clamping levels of 5% and 95%, the output value 0.25V (5% of VDD) represents 0° mechanical degrees and the output value 4.75V (95% of VDD) represents 20° mechanical degrees. Note that the slope can be programmed to either rising (as shown in Figure 8) or falling with increasing electrical angle.



Note: An example of 5% and 95% clamping levels and a rising slope setting is illustrated.

Figure 7. Example of Analog Output Transfer Function and Programming Options

## 8.2 PWM Output (Programming Option)

The typical interface circuit for the ZMID4200 with PWM output is shown in Figure 8.

Note: R<sub>F</sub>, C<sub>F</sub> = optional low pass filter. Values depend on user's application.

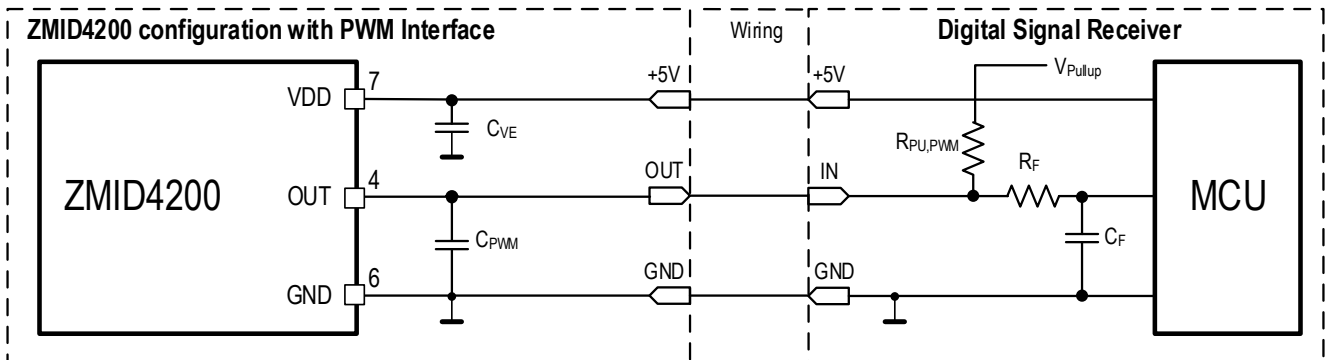


Figure 8. External Components for ZMID4200 PWM Interface with Pull-Up Resistor

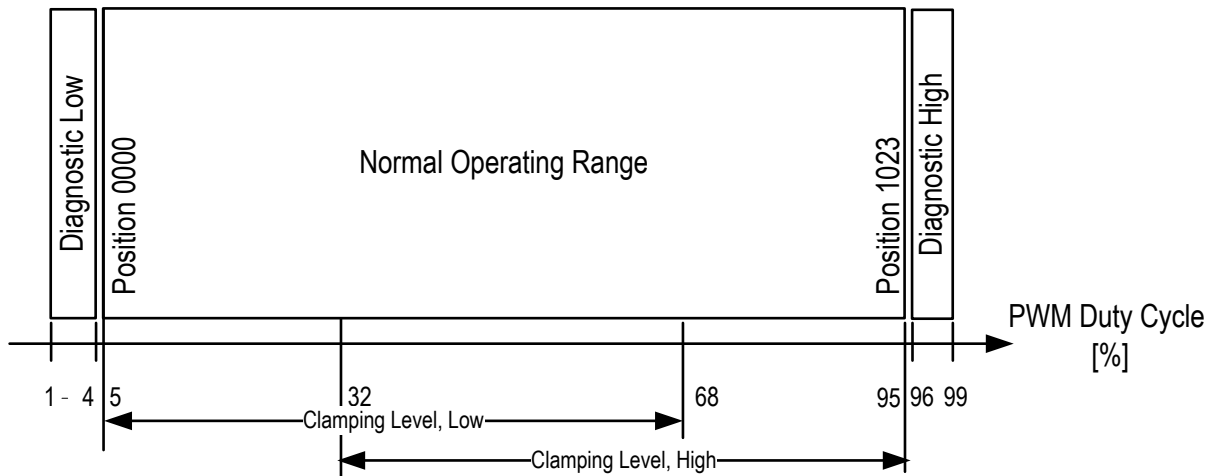
**Table 8. PWM Output Buffer Characteristics**

Note: Refer to VDD pin in Table 1 for the value of  $C_{VE}$ .

| Symbol          | Parameter                           | Conditions   | Minimum      | Typical   | Maximum      | Units        |
|-----------------|-------------------------------------|--|--------------|---|--------------|--------------|
| $f_{PWM}$       | PWM output frequency                | User programmable  | Typical - 7% | 0.125<br>0.25<br>0.50<br>0.75<br>1.00<br>1.25<br>1.50<br>2.00 | Typical + 7% | kHz          |
| $t_{PWM\_FALL}$ | PWM fall time                       | $C_{PWM}=4.7nF$ , $R_{PU,PWM}=1k\Omega$ ,<br>$V_{Pullup}=5V$ , 2 correction bits | 2.45         |   | 4.55         | $\mu s$      |
| $RES_{PWM}$     | PWM resolution                      |  |              |   | 10           | bits         |
| $V_{Pullup}$    | PWM output voltage (pull-up)        |  |              |   | 16           | V            |
| $R_{PU,PWM}$    | Pullup resistor for PWM             | $V_{Pullup}=5V$  | 1            |   | 10           | k $\Omega$   |
|                 |                                     | $V_{Pullup}=16V$   | 3            |   | 10           |              |
| $C_{PWM}$       | Load capacitor for PWM output       | Max. 6.8nF for OWI programming   | 1            | 4.7   | 20           | nF           |
|                 | Normal operating range              | Limits are programmable  | 5            |   | 95           | % duty cycle |
| Diag_high_PWM   | Diagnostic high for PWM             |  | 96           | 97.5  |              | % duty cycle |
| Diag_low_PWM    | Diagnostic low for PWM              |  |              | 2.5   | 4            | % duty cycle |
| $D_{CL\_L}$     | Clamping level, low <sup>[a]</sup>  | Programmable in 1% steps   | 5            |   | 68           | % duty cycle |
| $D_{CL\_H}$     | Clamping level, high <sup>[a]</sup> | Programmable in 1% steps   | 32           |   | 95           | % duty cycle |

[a] Low clamping level must be programmed lower than the  $D_{CL\_H}$  high clamping level.

The 100% position range is mapped to a duty cycle of 5% to 95%. A clamping step of 1% is mapped to a duty cycle change of 0.9%. The diagnostic low level is mapped to a 2.5% (typical) duty cycle; the diagnostic high level is mapped to a 97.5% (typical) duty cycle.



**Figure 9. PWM Signal Range**

The graph in Figure 10 shows examples of different PWM signals with 5%, 50%, and 95% duty cycle, representing the minimum, 50%, and maximum output values.

Note that the minimum and maximum output positions can be mapped to the mechanical range of the application by programming the zero angle offset, slope programming (linear or sawtooth), and clamping level (minimum/maximum duty cycle) register settings (see section 0 and Figure 12). For example, for a pedal sensor with PWM output, having 20° mechanical degrees of movement range and clamping levels of 5% and 95%, the

output value 0 represents 0° mechanical degrees and the output value 1023<sub>DEC</sub> represents 20° mechanical degrees. Note that the slope can be programmed to either rising (as shown in Figure 12) or falling with increasing electrical angle.

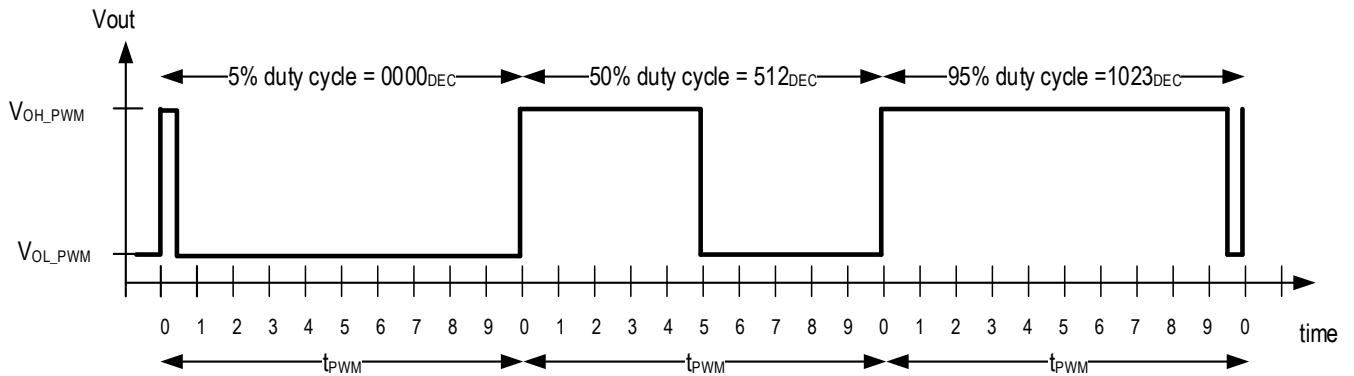
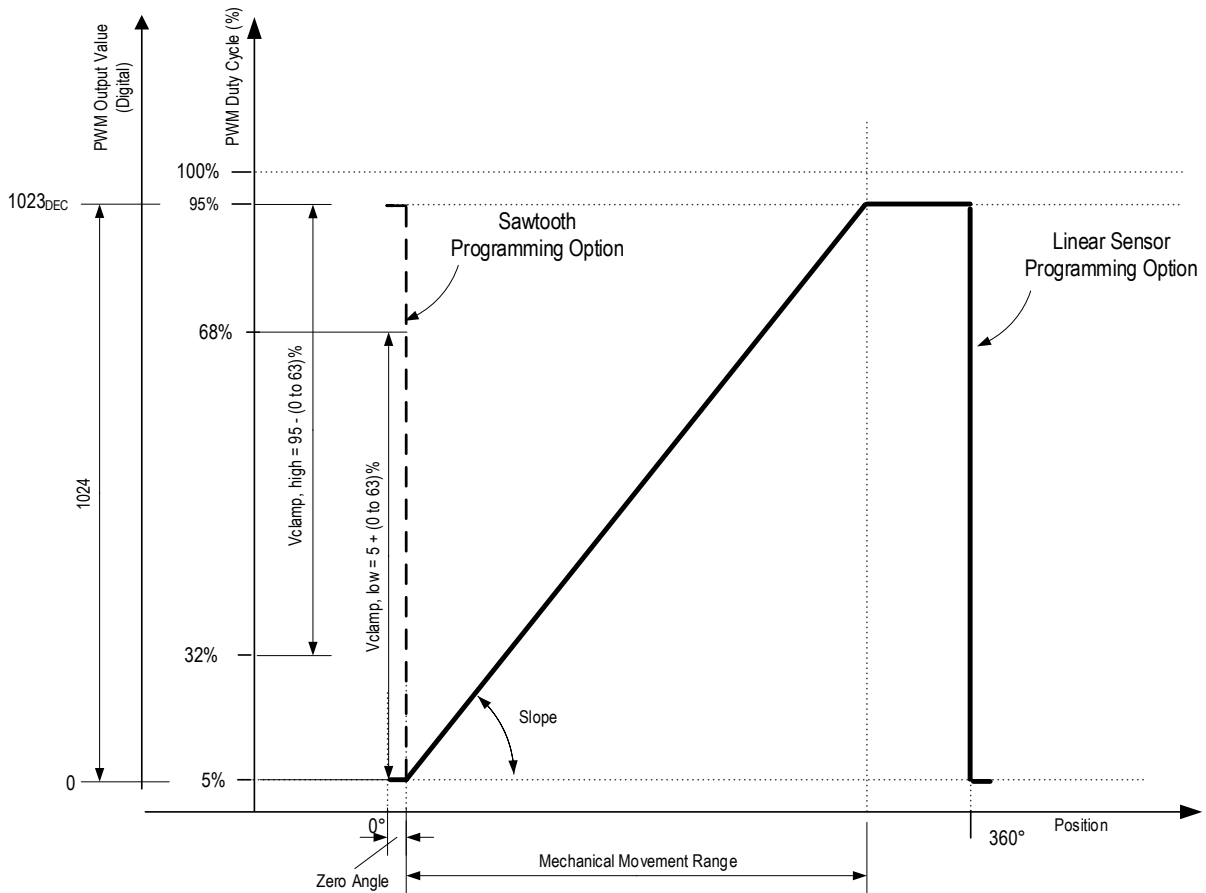


Figure 10. Example of PWM Output Signal



Note: An example of 5% and 95% clamping levels and a rising slope setting is illustrated.

Figure 11. Example of ZMID4200 PWM Output Transfer Function and Programming Options

### 8.3 SENT Output (Programming Option)

The typical interface circuit for the ZMID4200 with SENT output is shown in Figure 12.

Values for  $C_1$ ,  $C_2$  and  $R_0$  depend on user's application.

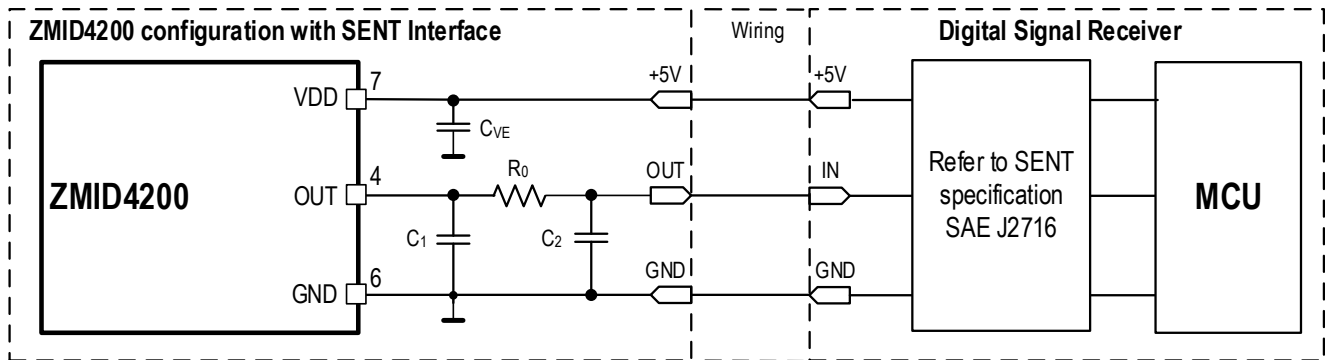


Figure 12. External Components for ZMID4200 SENT Interface

Table 9. SENT Output Buffer Characteristics

Note: Refer to VDD pin in Table 1 for the value of  $C_{VE}$ .

| Symbol             | Parameter                    | Conditions         | Minimum | Typical | Maximum | Units   |
|--------------------|------------------------------|--------------------|---------|---------|---------|---------|
| $RES_{SENT}$       | SENT output resolution       |                    |         |         | 12      | bits    |
| $t_{STABLE\_HIGH}$ | SENT HIGH stabilization time | HIGH level at 3.8V | 6       |         |         | $\mu s$ |
| $V_{OL}$           | Output LOW level             |                    |         |         | 0.5     | V       |
| $V_{OH}$           | Output HIGH level            |                    | 4.1     |         |         | V       |

#### 8.3.1. SENT Protocol

The SENT (Single Edge Nibble Transmission) protocol conforms to SAE J2716, Revision 2. In addition, SENT Pause and CRC can be programmed according to SAE J2716, Revision 3.

For transmitting a nibble with the 0 value, 12 clock ticks are required: a fixed LOW period of 5 ticks followed by a HIGH period of 7 ticks. One tick equals  $t_{TICK} = 3.0\mu s$  to  $3.67\mu s$  (see Table 10).

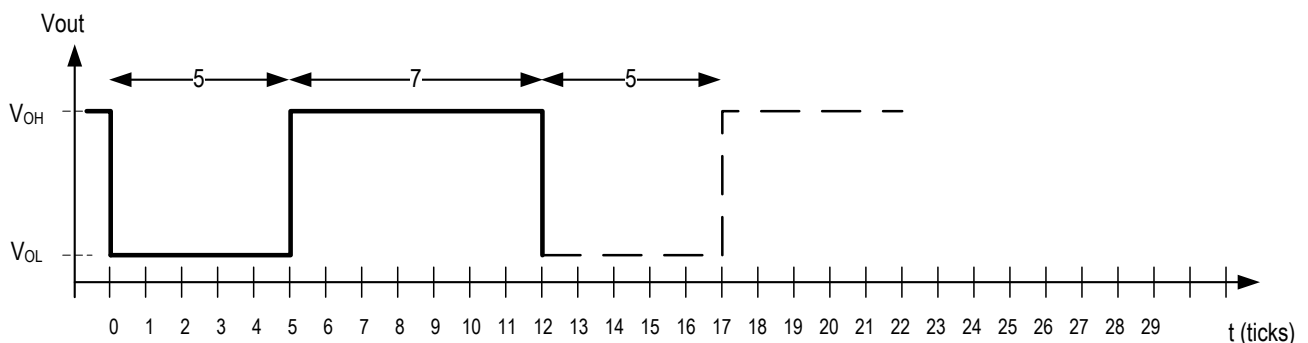


Figure 13. SENT Nibble Output for Value = 0<sub>DEC</sub>

For transmitting a nibble with the value 15<sub>DEC</sub> (1111<sub>BIN</sub>, F<sub>HEX</sub>), 27 clock ticks are required: a fixed LOW period of 5 ticks followed by a HIGH period of 22 ticks. The total time for one nibble can be calculated as with the following equation:

$$t_{NIBBLE} = t_{TICK} * (12 + x)$$

Where x = the nibble decimal value = 0 to 15.

Table 10. SENT Tick Length

| Decimal         | 0  | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10 | 11 | 12 | 13 | 14 | 15 |
|-----------------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| Hexadecimal     | 0  | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | A  | B  | C  | D  | E  | F  |
| Number of Ticks | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 |

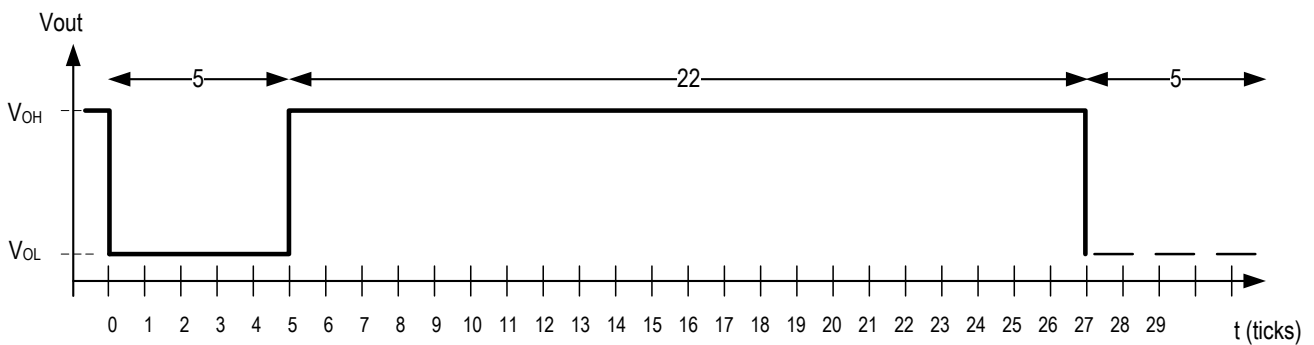


Figure 14. SENT Nibble Output for Value = 15<sub>DEC</sub>

The SENT protocol frame consists of a fixed-length synch pulse (LOW period of 5 ticks followed by a HIGH period of 51 ticks), followed by a status nibble, 6 data nibbles, and a CRC nibble. An optional pause pulse can be programmed to adjust the SENT frame to a fixed length of 270 ticks.

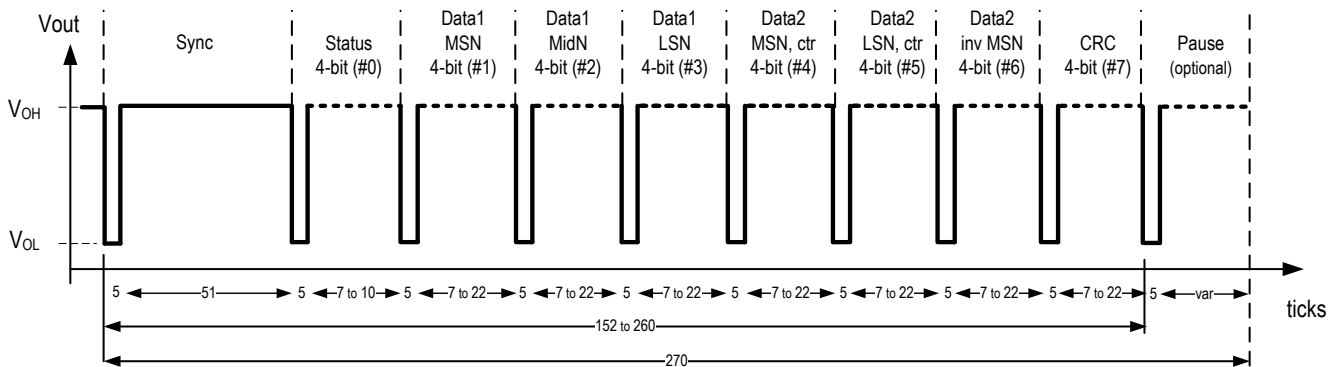


Figure 15. SENT Frame

Note that the status nibble has a maximum length of only 5 + 10 = 15 ticks since bits 2 and 3 are always zero:

Status nibble: 0000<sub>BIN</sub> = Normal operation

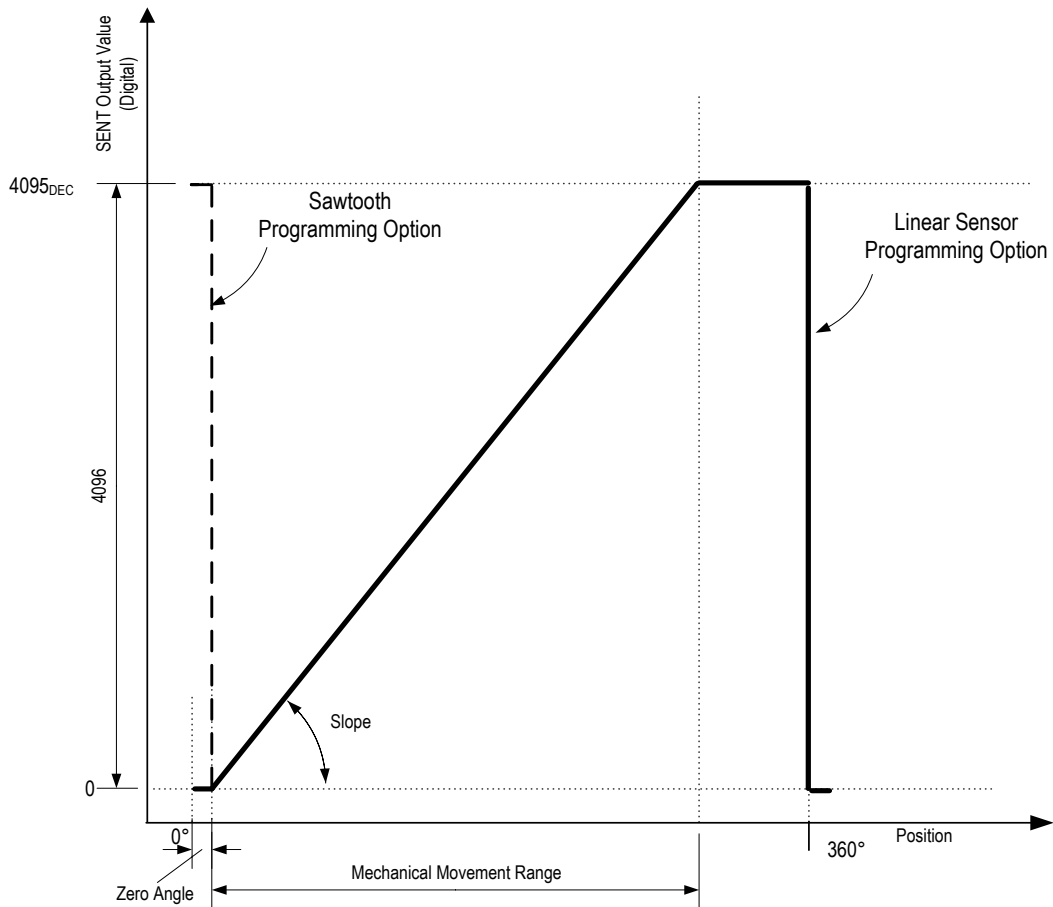
0011<sub>BIN</sub> = Diagnostic state



The SENT output frame format can be programmed in one of two options:

1. 12-bit position data + 8-bit rolling counter (“ctr” in Figure 15) + inverted copy of Data1 MSN (nibble #1 in Figure 15) + cyclic redundancy check (CRC). In this option, the SENT frame length is between 152 and 260 ticks with a variable frame length and 270 ticks with a fixed frame length.
2. 12-bit position data + “000” data + CRC. In this option, if the pause pulse is disabled, the SENT frame has the shortest possible length: less than 220 ticks.

Note that the minimum and maximum output positions can be mapped to the mechanical range of the application by programming the zero angle offset and slope register settings (see section 9 and Figure 16). For example, for a pedal sensor with SENT output having 20° mechanical degrees of movement range, the output value 0 represents 0° mechanical degrees and the output value 4095<sub>DEC</sub> represents 20° mechanical degrees. Note that the slope can be programmed to either rising (as shown in Figure 16) or falling with increasing electrical angle.



Note: An example using the rising slope setting is illustrated.

Figure 16. Example of ZMID4200 SENT Output Transfer Function and Programming Options

## 9. Programming Options

The ZMID4200 offers a variety of programming options. The IC is programmed through the output pin 4 (OUT) via a proprietary bi-directional one-wire interface (OWI). For programming, no additional wires or programming voltage is required, so the IC can be fully programmed in the field.

Additional documents related to programming are available for download on the ZMID4200 product page:

- *ZMID4200 Technical Brief OWI Interface*: one wire interface protocol description.
- *ZMID4200 Register Map*: detailed memory map.

The main programming functions are described in Table 11.

**Table 11. Programming Options Overview**

| Function                   | Programming Option  | Notes  |
|----------------------------|---|--|
| Output interface           | Analog (default), PWM or SENT   | Selection of the output interface  |
| Coil input                 | Reverse coil polarity (increasing or decreasing output relative to target movement) | Invert coils to change the direction of the output values  |
| Input amplifier            | Offset of sine and cosine channels  | Offset correction before CORDIC angle calculation  |
| Slope of transfer function | Steepness of slope, rising/falling  | Adjustment of angle range  |
| Zero position              | Zero angle  | To match mechanical zero position with electrical zero position  |
| Linearization              | 9-point linearization   | To increase accuracy and compensate for imperfections in coil design   |
| Transmitter coil           | Coil driver current and amplitude   | To optimize Tx oscillator  |
| Output mode                | Linear or sawtooth  | Single or multiple ramps   |
| Clamp low, clamp high      | Minimum, maximum output voltage   | Define normal operating range  |
|                            | Minimum, maximum PWM duty cycle   | Define normal operating range  |
| Diagnostic levels          | Output voltage in diagnostic mode   | To indicate diagnostic alarm   |
|                            | PWM duty cycle in diagnostic mode   | To indicate diagnostic alarm   |
| PWM fall time              | PWM output signal slew rate   | To optimize EMC performance  |
| PWM base frequency         | PWM frequency   | Base frequency of PWM signal   |
| SENT CRC                   | CRC according to SAE J2716, Rev.2 or Rev.3  | Implementation of CRC calculation  |
| SENT Pause                 | Optional pause setting according to SAE J2716, Revision 2 or Revision 3             | Revision 2: No pause pulse<br>Revision 3: Fixed frame length + pause   |
| SENT Frame                 | Type of data transmitted in SENT frame  | A) 12-bit position data + 8-bit rolling counter + inverted copy of first data nibble + CRC (see Figure 17).<br><br>12-bit position data + "000" data + CRC |
| Diagnostics                | CORDIC magnitude upper and lower levels   | To trigger alarm if CORDIC magnitude is out of range   |
|                            | Transmitter coil frequency alarm  | Detects out of range Tx frequency  |
|                            | Automatic gain control (AGC)  | Detects AGC out of range   |
|                            | EEPROM double error; shadow register parity error                                   | Internal memory errors   |
|                            | R1 or R2 coil open or short   | Detect defective receiver coils  |
|                            | Signal processing overflow  | Internal processing errors   |

## 10. Operation at High Rotation Speeds

The ZMID4200 is primarily designed for low-speed or static operation due to their inherent interface types (analog ramp, PWM, SENT). There is no upper speed limit for using the ZMID4200 in high speed applications; however, due to the maximum data rate at the various outputs, the resolution (on a rotary application: number of steps per revolution) will be reduced with increasing speed.

### 10.1 Data Rates, Resolution, and Rotational Speed

The maximum output data rates for the various versions are given in Table 12.

Table 12. Maximum Output Data Rate

| Type of Output | Maximum Output Rate, Updates per Second | Notes                             |
|----------------|---|-----------------------------------|
| Analog ramp    | 10000                                   | Linear analog ramp                |
| PWM            | 2000                                    | Programmable from 125Hz to 2000Hz |
| SENT           | 1235                                    | 270 ticks at 3μS                  |

With these maximum output data rates, the resolution versus rotation speed relationship is shown in the graph in Figure 12.

Examples of the number of steps per revolution at 10rpm and 1000rpm electrical speed are given in Table 13.

Table 13. Resolution at Different Rotation Speeds

| Type of Output | Steps per Revolution at 10 rpm | Steps per Revolution at 1000 rpm, el. |
|----------------|--------------------------------|---------------------------------------|
| Analog ramp    | 1024                           | 600                                   |
| PWM            | 1024                           | 120                                   |
| SENT           | 4096                           | 74                                    |

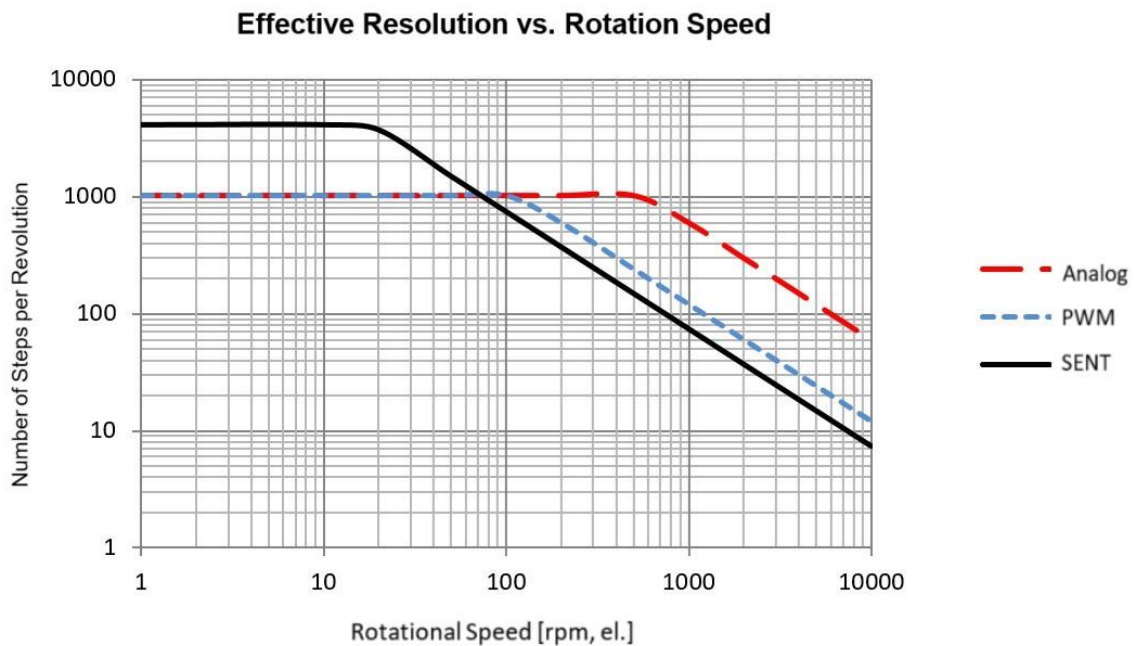


Figure 17. Relationship between Resolution and Rotational Speed

## 10.2 Electrical vs. Mechanical Speed

Rotation speed is given in electrical rpm [rpm, el], which is the number of electrical periods per minute. To calculate the mechanical rotation speed in multi-period coil designs, divide the electrical rpm by the number of periods per 360°.

For example:

- 1-periodic coil design,  $1 \times 360^\circ$  angle range per revolution: mechanical speed = electrical speed
- 2-periodic coil design,  $2 \times 180^\circ$  angle range per revolution: mechanical speed = electrical speed / 2

## 11. Interpolation, Linearity Error Correction

A post-CORDIC linearity correction is available to correct nonlinearities and to further increase the overall accuracy of the system.

The correction factors are applied by linear interpolation between 9 equidistant points over one phase (0 to 360°) with one of two options:

- Option 1: Starting at 0° with intervals of 45°
- Option 2: Same as option1 shifted by 22.5°, starting at 22.5° with intervals of 45°

**Table 14. Linearity Correction Points**

| Point    | 1     | 2     | 3      | 4      | 5      | 6      | 7      | 8      | 9              |
|----------|-------|-------|--------|--------|--------|--------|--------|--------|----------------|
| Option 1 | 0°    | 45°   | 90°    | 135°   | 180°   | 225°   | 270°   | 315°   | 360°           |
| Option 2 | 22.5° | 67.5° | 112.5° | 157.5° | 202.5° | 247.5° | 292.5° | 337.5° | 382.5° (22.5°) |

Note that in a rotating application, correction point 1 (0°) and point 9 (360°) coincide at the same angle. Therefore, in such cases, it is useful to use the same correction values for both point 1 and point 9.

In general, the correction points are applicable as follows:

Correction point 1 is used for angles  $0^\circ \leq \alpha < 45^\circ$  and optionally for  $22.5^\circ \leq \alpha < 67.5^\circ(\dots)$

Correction point 9 is used for angles  $315^\circ \leq \alpha < (360^\circ = 0^\circ)$  and optionally for  $337.5^\circ \leq \alpha < 22.5^\circ$ .

For each point, an offset can be applied. Angle values between two points are corrected by linear interpolation between the two linearization points.

## 12. Application Examples

Typical coil and target arrangements are shown in Figure 18 to

Figure 23: linear motion; arc motion; and on-axis (end of shaft) and off-axis (side shaft) rotary. Many other arrangements are also possible. In the figures, blue indicates the target and the dashed lines indicate range of travel. See Table 15 for resolution values.

Note: The coils are shown in a simplified form. Detailed guidelines on coil design and programming options are available on request from Renesas application support. Note that within each base configuration, the movement range can be further fine-trimmed by user programming.

Examples:

An angle sensor for 0 to 270° angle range would use a 360° base configuration (360°/1) and could then be trimmed to a maximum angle of 270° by user programming.

An angle sensor for 0 to 110° angle range would use a 120° configuration (360°/3) and could then be trimmed to a maximum angle of 110° by user programming.

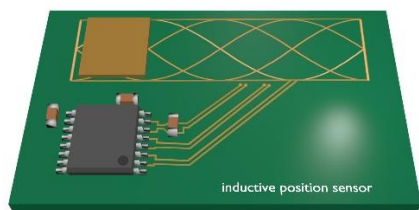


Figure 18. Example Setup: Linear Motion

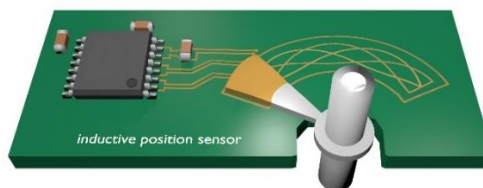


Figure 19. Example Setup: Arc Motion

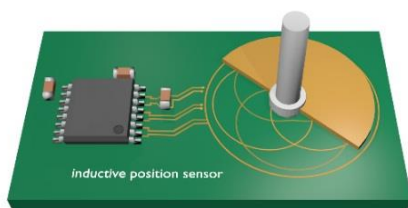


Figure 20. Example Setup: End-of-Shaft Rotation, 1 x 360°

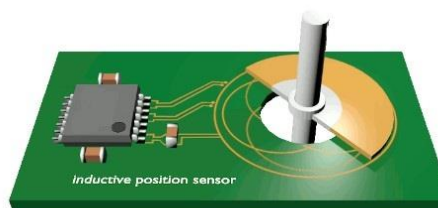


Figure 22. Example Setup: Through-Shaft Rotation, 1 x 360°

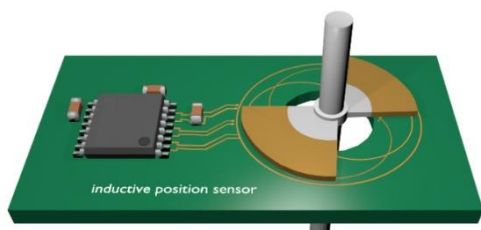


Figure 21. Example Setup: Through-Shaft Rotation, 2 x 180°

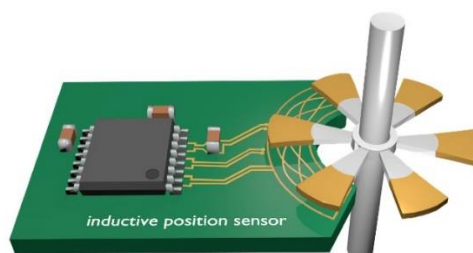


Figure 23. Example Setup: Side-Shaft Rotation, 6 x 60°

One of the key advantages of inductive position sensors is the flexibility to adapt the coil design to the needs of any given application. They can be designed for rotary, arc, or linear motion and in addition, the movement range can be adjusted. This way, the maximum resolution can be achieved, even for applications having only a small range of travel. Table 15 shows examples for calculating the effective resolution (movement range for 1 LSB or step), depending on coil design and output configuration.

Table 15. Examples of Resolution Differences Depending on Configuration

| Range of Travel for Example Application   | Resolution of Measurement                    |                                    |
|---|--|------------------------------------|
|   | Analog and PWM Output (1024 Steps per Phase) | SENT Output (4096 Steps per Phase) |
| Linear Position Sensing Range of Travel = Coil Length Minus Target Length (See the example in Figure 18)                  | (Range of Travel)/1024                       | (Range of Travel)/4096             |
| Arc Position Sensing Range of Travel = Coil Arc Angle Minus Target Angle (Width of Target) (See the example in Figure 19) | (Range of Travel)/1024                       | (Range of Travel)/4096             |
| Arc Position Sensing Range of Travel = 1 x 130°   | 130°/1024 = 0.127°                           | 130°/4096 = 0.0317°                |
| 1 x 360° (See the examples in Figure 20 and Figure 22)  | 0.35°/Step                                   | 0.088°/Step                        |
| 2 x 180° (See the example in Figure 21)   | 0.18°/Step                                   | 0.044°/Step                        |
| 6 x 60° (See the example in Figure 23)  | 0.059°/Step                                  | 0.015°/Step                        |

## 13. Electromagnetic Compatibility (EMC)

Guidelines for EMC compliant circuit designs are available in the *ZMID4200 EMC Recommendations* document on the ZMID4200 product page.

## 14. Package Outline Drawings

The package outline drawings are appended at the end of this document and are accessible from the link below. The package information is the most current data available and is subject to change without notice or revision of this document.

<https://www.renesas.com/eu/en/document/psc/14-tssop-package-outline-drawing44mm-body-065mm-pitchpgg14t1>

## 15. Marking Diagram



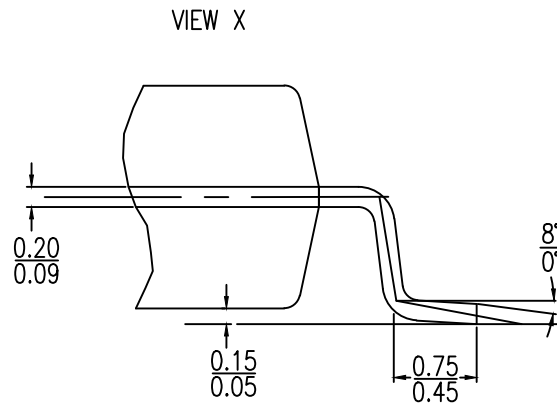
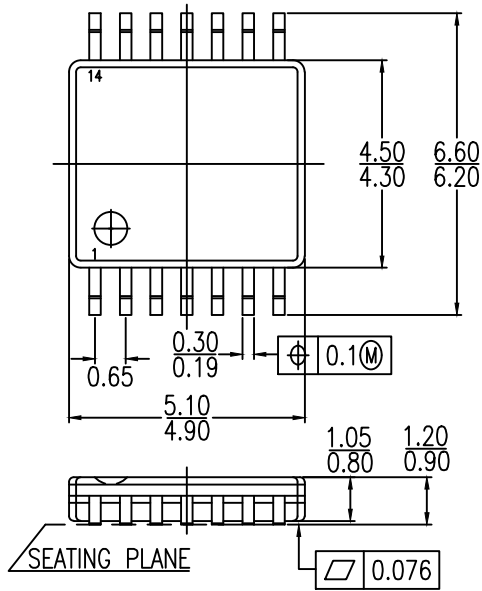
- Line 1: First four characters of part code (ZMID)
- Line 2: Next four characters of the part code (4200) followed by  
A = Design revision  
I = Industrial qualification
- Line 3: "XXXXXX" = Lot number
- Line 4: "YYWW" = Manufacturing date:  
YY = last two digits of manufacturing year  
WW = manufacturing week

## 16. Ordering Information

| Orderable Part Number | Description and Package   | MSL Rating | Carrier Type                | Temperature     |
|-----------------------|---|------------|-----------------------------|-----------------|
| ZMID4200AI1R          | 14-TSSOP, 4.4 mm × 5.0 mm   | 1          | 13" Reel, 4000 parts / reel | -40°C to +150°C |
| ZMID4200STKIT         | ZMID4200 Starter Kit including USB communication board, 3 application modules and connection cables |            |                             |                 |

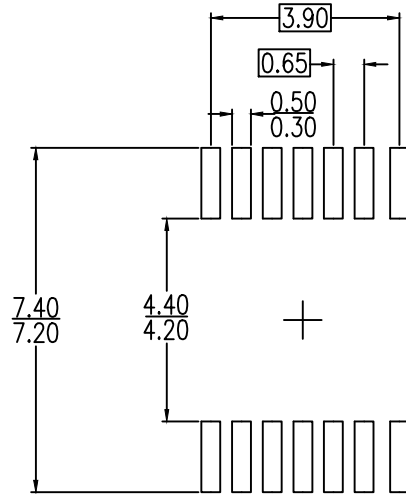
## 17. Revision History

| Revision Date | Description of Change |
|---------------|-----------------------|
| Aug. 19, 2021 | Initial release.      |



NOTE:

1. ALL DIMENSIONS ARE IN MILLIMETERS



LAND PATTERN DIMENSIONS

NOTE:

1. ALL DIMENSIONS ARE IN MILLIMETERS

| Package Revision History |         |                    |
|--------------------------|---------|--------------------|
| Date Created             | Rev No. | Description        |
| Mar, 10 2017             | Rev 01  | Added Land Pattern |
| Dec, 19 2017             | Rev 02  | New Format         |



