Description

The ZMID5201, ZMID5202, and ZMID5203 ICs are a family of inductive position sensors, used for absolute rotary and linear motion sensing in automotive, industrial, medical, and consumer applications.

The ZMID520x 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.

The ZMID5201/-02-/03 ICs are fully qualified to the automotive standard AEC-Q 100, grade 0 from -40°C up to 150°C ambient temperature.

Three versions with different output interfaces are available:

- ZMID5201: Analog output
- ZMID5202: PWM digital output
- ZMID5203: SENT digital output

Available Support

- Evaluation Kit
- Documentation

Physical Characteristics

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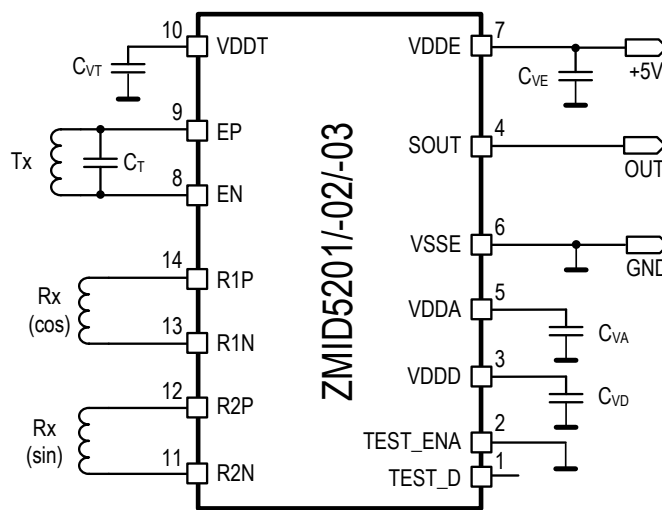- Supply voltage: 4.5V to 5.5V
- Small 14-TSSOP package

Typical Applications

- Rotary position sensors up to 360°; e.g. steering angle sensors, potentiometer replacement
- Small-angle sensors or arc-motion sensors; e.g. pedal, vehicle level, or valve sensors
- Linear motion sensors; e.g. linear-actuator position sensors, fluid-level sensors

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: ≤ 0.2% full scale
- 9-point user linearization
- Rotation sensing up to a full turn of 360º
- Overvoltage and reverse-polarity protection: -14V to +18V maximum, depending on product
- ESD and short-circuit protection
- Power or ground loss detection
- Facilitates redundant design requirements
- Programmable non-linearity correction
- Adaptive gain control supporting a wide range of coil designs and target displacement
- Suitable for implementation in safety-related systems compliant to ISO26262 up to ASIL-B

Application Circuit

Contents

List of Figures

List of Tables

1. Pin Assignments

The ZMID5201/-02/-03 ICs are available in a 14-TSSOP RoHS package.

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

1	TEST_D		R1P	14
2	TEST_ENA		R1N	13
3	VDDD		R2P	12
4	SOUT	ZMID5201/-02/-03	R2N	11
5	VDDA		VDDT	10
6	VSSE		EP	9
7	VDDE		EN	8
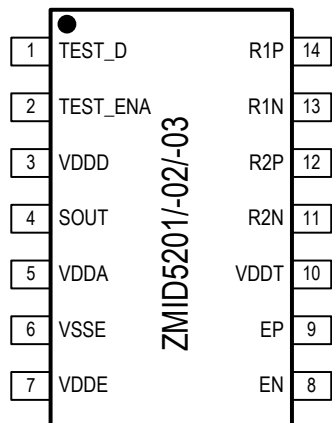
2. Pin Descriptions

Table 1.   Pin Descriptions

Number	Name	Type	Description
1	TEST_D	Input/output	Factory test pin; must be left unconnected.
2	TEST_ENA	Input/output	Factory test pin. Connect to the VSSE pin.
3	VDDD	Supply	Internal regulated digital supply voltage. Connect capacitor C_{VD} = 100nF from the VDDD pin to the VSSE pin, no other load.
4	SOUT	Analog output: ZMID5201 only	Analog output (also referred to as AOUT for the ZMID5201). Refer to section 9, Figure 5, and Figure 6 for external connections.
		PWM digital output: ZMID5202 only	PWM digital output (also referred to as PWM OUT for the ZMID5202). Refer to section 10 and Figure 11 for external connections.
		SENT digital output: ZMID5203 only	SENT output (also referred to as SENT OUT for the ZMID5203). Refer to section 11, Figure 12, Figure 13, and Figure 14 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 C_{VA} = 100nF from the VDDA pin to the VSSE pin; no other load.
6	VSSE	Ground	Common ground connection.
7	VDDE	Supply	External supply voltage. Connect the VDDE pin to C_{VE} = 100nF capacitor in parallel with a 1pF to 10pF capacitor connected to the VSSE pin.
8	EN	Analog output	Connect the transmitter coil between EP and EN. Resonant frequency is adjusted with a parallel capacitor C_T between EP and EN (see application diagram on page 1) or capacitors C_{T1} from EN to VSSE and C_{T2} from EP to VSSE (see block diagram on page 2).
9	EP		

Number	Name	Type	Description
10	VDDT	Supply	Internal supply voltage for transmitter amplifier. Connect to C_{VT} = 100nF to VSSE.
11	R2N	Analog input	Connect receiver coil 2 between the R2N and R2P pins.
12	R2P		
13	R1N	Analog input	Connect receiver coil 1 between the R1N and R1P pins.
14	R1P		

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 ZMID5201/-02/-03 at 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_{VDDE}	External supply voltage		-18	18	V
V_{OUT_ANA}	ZMID5201 analog output voltage on the AOUT pin [a]	For negative voltage, external current must be limited to 10mA	-14	14	V
		Without external current limitation	-0.3	14	V
V_{OUT_PWM}	ZMID5202 PWM output voltage on the PWM OUT pin [a]	For negative voltage, external current must be limited to 10mA	-14	18	V
		Without external current limitation	-0.3	18	V
V_{OUT_SENT}	ZMID5203 SENT output voltage on the SENT OUT pin [a]	For negative voltage, external current must be limited to 10mA	-14	18	V
		Without external current limitation	-0.3	18	V
V_{OSC_COIL}	Oscillator coil pins: EP, EN		-0.3	5.5	V
V_{R1P}	Receiver coil pin: R1P		-0.3	3.6	V
V_{R1N}	Receiver coil pin: R1N				
V_{R2P}	Receiver coil pin: R2P				
V_{R2N}	Receiver coil pin: R2N				
V_{TEST_ENA}	Test pin: TEST_ENA		-0.3	5.5	V
V_{TEST_D}	Test pin: TEST_D		-0.3	3.6	V
V_{VDDA}	Regulated supply voltage pin: VDDA		-0.3	3.6	V
V_{VDDD}	Regulated supply voltage pin: VDDD				
V_{VDDT}	Regulated supply voltage pin: VDDT				

[a]   The SOUT pin is referred to as the AOUT pin for the ZMID5201; PWM OUT for the ZMID5202; and SENT OUT for the ZMID5203.

May 24, 2017

4. Operating Conditions

Conditions: VDDE = 5V ±10%, T$_A$ = -40°C to +150°C.

Table 3.   Operating Conditions

Symbol	Parameter	Conditions	Minimum	Typical	Maximum	Units
T$_A$	Ambient temperature		-40		150	°C
T$_J$	Junction temperature		-40		175	°C
T$_{STOR}$	Storage temperature		-50		150	°C
R$_{THJA}$	Thermal resistance junction to ambient				140	°C/W
V$_{VDDE}$	Supply voltage		4.5	5	5.5	V
ESD	Electrostatic discharge, HBM 100pF / 1.5kΩ	Pins VSS, VCC	±4			kV
		Pin SOUT[a]	±3			kV
		All other pins	±2			kV

[a]   The SOUT pin is referred to as the AOUT pin for the ZMID5201; PWM OUT for the ZMID5202; and SENT OUT for the ZMID5203.

5. Electrical Characteristics

The following electrical specifications are valid for the operating conditions as specified in Table 3: (T$_A$ = -40°C to 150°C).

Table 4.   ZMID5201/-02/-03 Electrical Characteristics

Symbol	Parameter	Conditions	Minimum	Typical	Maximum	Units
V$_{VDDE\_TH\_H}$	VDDE switch ON threshold	The device is activated when VDDE increases above this threshold			4.4	V
t$_{START}$	Startup Time	Time between VDDE > V$_{VDDE\_TH\_H}$ and valid output at SOUT		5	9	ms
V$_{VDDE\_TH\_L}$	VDDE switch OFF threshold	The device is deactivated when VDDE decreases below this threshold	4			V
V$_{VDDE\_HYST}$	VDDE hysteresis		0.1			V
V$_{VDDE\_OVH}$	Over-voltage detection high	The device is deactivated after VDDE increases above this voltage			7	V
V$_{VDDE\_OVL}$	Over-voltage detection low	The device is activated after VDDE decreases below this voltage	5.6			V
V$_{VDDT}$	Regulated coil driver supply output voltage	Internally regulated, programmable	2.4		3.6	V
I$_{CC}$	Current consumption	Without coils. no load	5		9	mA
		With coils, no load; depending on programmable Tx coil current		12	20	mA

Symbol	Parameter	Conditions	Minimum	Typical	Maximum	Units
Angle Calculation						
t_{SAMPLE}	Data acquisition time		45	50	55	µs
$t_{REFRESH}$	Output update rate	Analog output			10	kHz
RES_{CORDIC}	CORDIC resolution	Internal; over 360° electrical		16		bits
Performance						
INL	Accuracy[a]	See note.[a]		0.2		% FS

[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.

Table 5. Coil Specifications

| Symbol	Parameter	Conditions	Minimum	Typical	Maximum	Units
L	Excitation coil inductance	For Tx coil as shown in block diagram in Figure 3	1.5		30	µH
Q	Quality factor	For Tx coil as shown in block diagram in Figure 3 $Q = \omega L/R$, f = 2.2MHz	10			
f_{OSC}	Excitation frequency	LC oscillator	2.2	3.5	5.6	MHz
V_{TX_P}	Excitation coil amplitude	Peak voltage, pins EP vs. EN			7200	mV_{pp}
V_{RX}	Receive coil amplitude	Input signal full range	50		360	mV_{pp}

6. Circuit Description

6.1 Overview

The ZMID5201/-02/-03 ICs are inductive position sensors for use in automotive, industrial, medical and consumer applications. They operate on the principle 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 transmit coil and two receive coils. The transmit coil and a capacitor form an LC oscillator that is directly driven by the IC. It generates a magnetic field within the transmit 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 receive coils are arranged so that the secondary voltages are relatively phase shifted by electrical 90°, thereby generating a response curve (receive 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 2 shows an example of a linear motion sensor with one transmit coil (Tx loop) and two receive coils (Sin loop and Cos loop). The arrows in the receive 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).
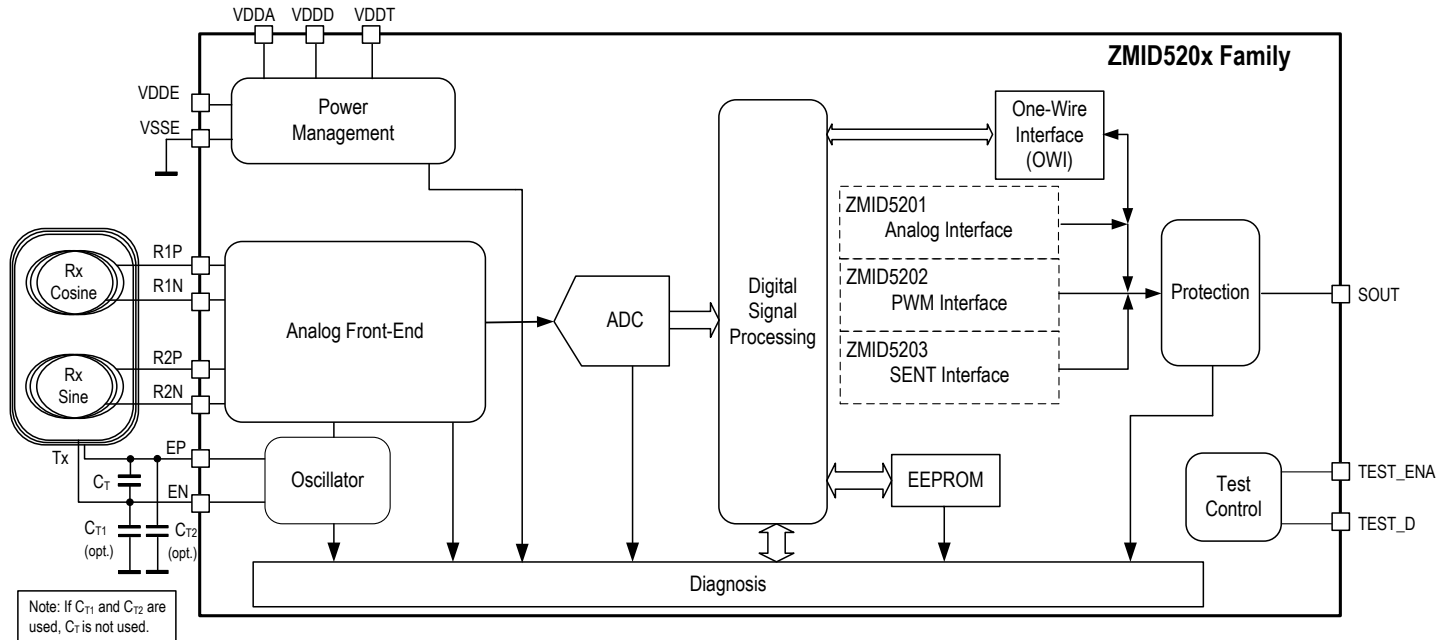
Figure 2. Coil Design for a Linear Motion Sensor
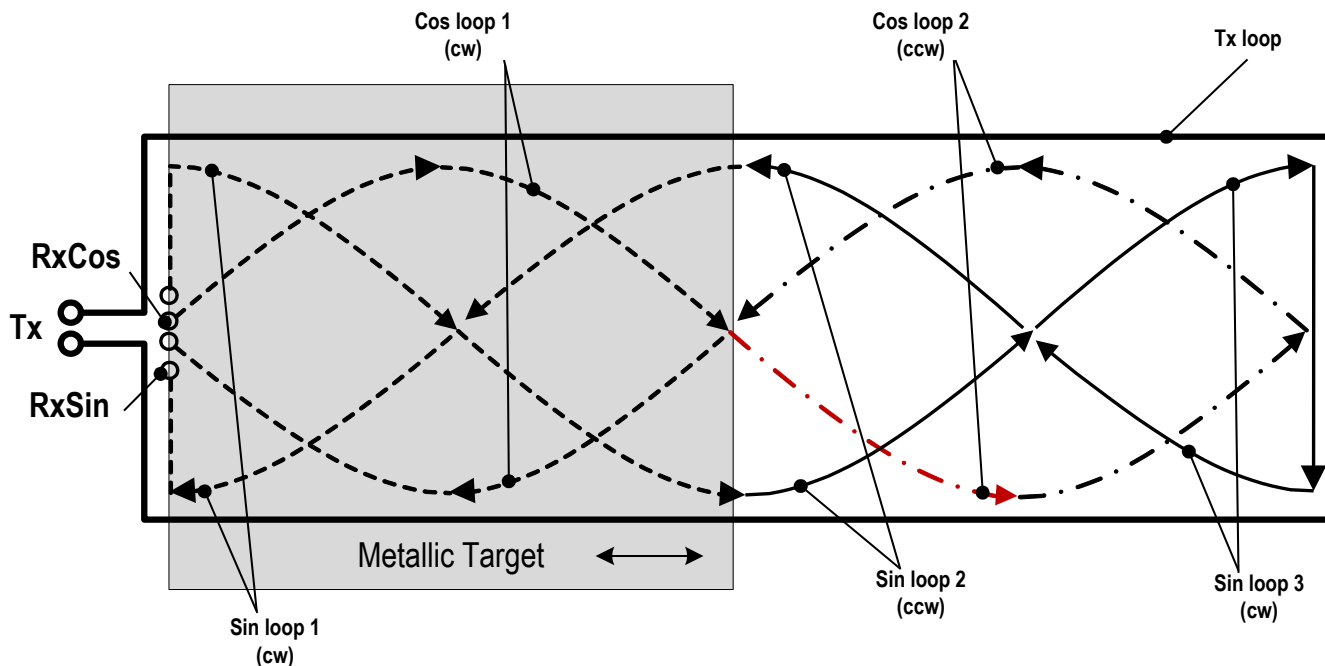
6.2   Block Diagram

Figure 3 shows the block diagram of the ZMID5201/-02/-03.

Figure 3.   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 transmit 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, linearization, etc.
- 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 for ZMID5201
  — PWM output for ZMID5202
  — SENT output for ZMID5203
- Protection: overvoltage, reverse polarity , short circuit protection
- Test control: factory testing; connect TEST_D and TEST_ENA pins as indicated in Table 1.

7. Redundant Connection

In applications requiring extended safety, a redundant set-up is required. The ZMID5201/-02/-03 ICs also support this requirement by either having two identical but physically separated sensors or by interleaving the 2×2 receiving coils and using one shared transmitter coil.

In Figure 4, two sensors share one common transmitter coil (Tx). Both sensors must share the same ground connection (GND) but could have separate positive supply connections (VDD_1, VDD_2). This setup is particularly useful for designs having limited coil space.

In normal operation, both chips drive the transmitter coil (Tx) and calculate the target's position through the receiving coil signals. If one chip fails to drive the transmitter coil, for example due to loss of supply, the host system can detect the failed part (loss of signal) while the second chip continues to drive the coil and maintains correct operation.

Figure 4.   Application Diagram, Dual Redundant Sensor with Shared Transmit Coil
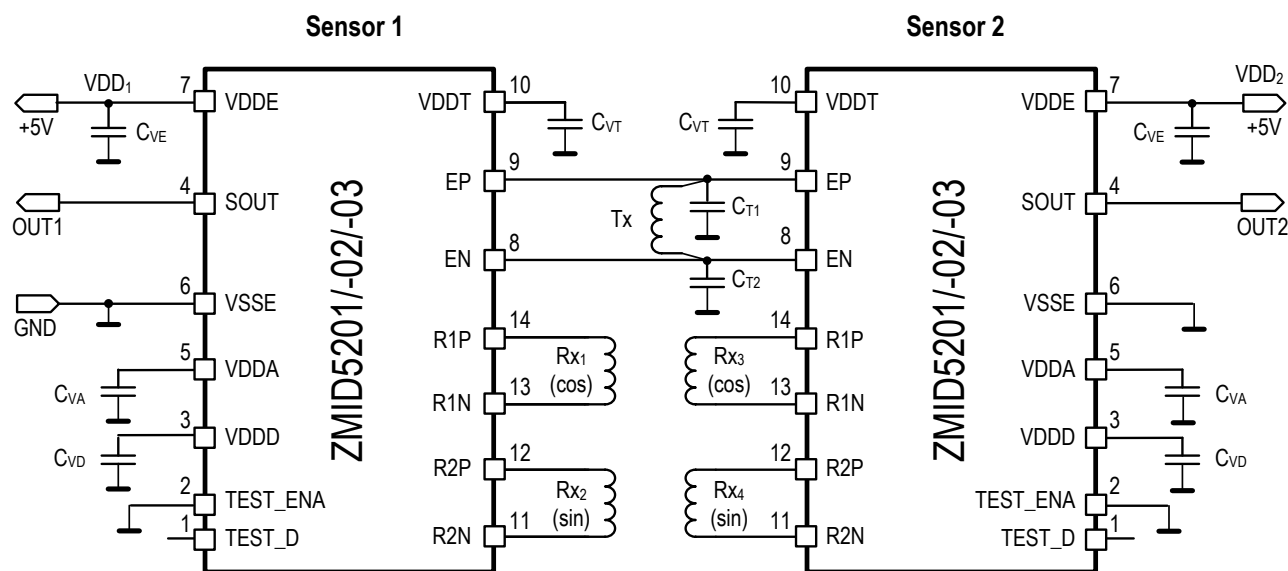
8. Protection and Diagnostics

8.1 I/O Protection

In order to meet the automotive requirements for overvoltage and reverse-polarity protection on both the output and power supply pins, the ZMID5201/-02/-03 ICs include several protection and diagnosis features:

1. Detection of broken power line, interrupted output signal, and broken ground connection on the receiving side

2. Protection against short circuit of output pin to VSSE, output pin to VDDE, and supply VDDE to VSSE

3. Overvoltage protection on supply pin VDDE

4. Overvoltage protection on output pin

5. Reverse-polarity protection on supply pin VDDE to VSSE

6. Reverse-polarity protection on output pin to VSSE

7. Reverse-polarity protection on output pin to VDDE

8.2 Diagnostics

The ZMID5201/-02/-03 monitors a number of features to accommodate ISO26262 diagnostic requirements. The monitored diagnostic features include the following:

1. Supply voltage too low or too high

2. Rx sine coil: open, short, short to ground, or short to Rx cosine coil

3. Rx sine coil: amplitude error or offset error

4. Rx cosine coil: open, short, short to ground, or short to Rx sine coil

5. Rx cosine coil: amplitude error or offset error

6. Tx coil: amplitude too low or open

7. Tx coil: frequency out of range

8. LC oscillator failure

9. CORDIC magnitude too high or too low

10. Missing target

11. Internal EEPROM failure

12. ADC signal processing overflow

8.3 Automotive Safety Integrity Level (ASIL)

The ZMID5201/-02/-03 products are safety-related, intermediate hardware parts supporting up to ASIL-B in regard to random failures, and, as such, they have been qualified according to ISO 26262:2012 Part 8, Clause 13 (Table 6). Integration of ZMID5201/-02/-03 products into safety-related applications requires a safety analysis performed by customers.

9. ZMID5201 Inductive Sensor with Analog Output

Typical interface circuits for the ZMID5201 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.

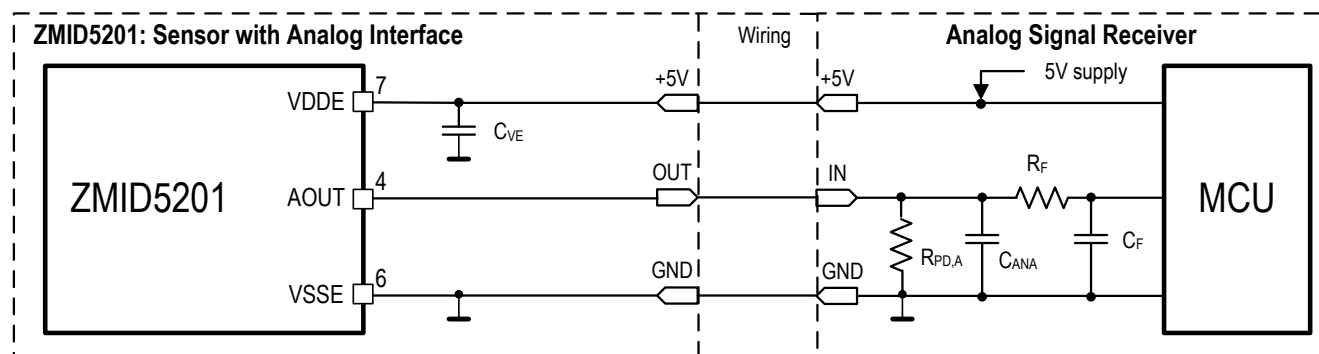**Figure 5. External Components for ZMID5201 Analog Interface with Pull-Down Resistor**

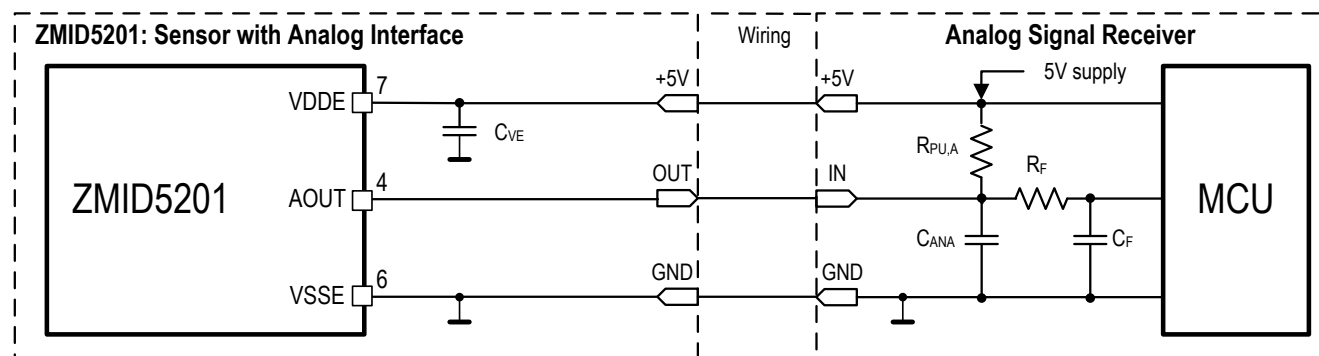**Figure 6. External Components for ZMID5201 Analog Interface with Pull-up Resistor**

Table 6. ZMID5201 Analog Output Buffer Characteristics

Note: Refer to the VDDE 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}=10nF, $R_{PD,A}$=5kΩ, 10% to 90%			160	µs
C_{ANA}	Output capacitor for analog		0.47		27	nF
RES_{ANA}	Analog output resolution		10			bits
$R_{PU,A}$	Output pull-up resistor		3	4.7	10	kΩ
$R_{PD,A}$	Output pull down resistor		3	4.7	10	kΩ

| Symbol	Parameter	Conditions	Minimum	Typical	Maximum	Units
	Normal operating range	Limits are programmable	5		95	%VDDE
Diag_high_ana	Diagnostic high for analog		96			%VDDE
Diag_low_ana	Diagnostic low for analog				4	%VDDE
V_{CL_L}	Clamping level , low [a]	Programmable in 1% steps	5		68	%VDDE
V_{CL_H}	Clamping level, high [a]	Programmable in 1% steps	32		95	%VDDE
Current_limit	Output node short current	Short to VDDE or VSSE			50	mA

[a]   Low clamping level must be programmed lower than the V_{CL_H} high clamping level.

For the ZMID5201, 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 ≤ 200mV and the diagnostic high level is ≥ 4800mV.

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 12 and Figure 7). For example, for a pedal sensor with ratiometric analog output (ZMID5201), having 20° mechanical degrees of movement range and clamping levels of 5% and 95%, the output value 0.25V (5% of VDDE) represents 0° mechanical degrees and the output value 4.75V (95% of VDDE) represents 20° mechanical degrees. Note that the slope can be programmed to either rising (as shown in Figure 7) or falling with increasing electrical angle.

Figure 7.   Example of ZMID5201 Analog Output Transfer Function and Programming Options

Note: The following figure illustrates an example of 5% and 95% clamping levels and a rising slope setting.
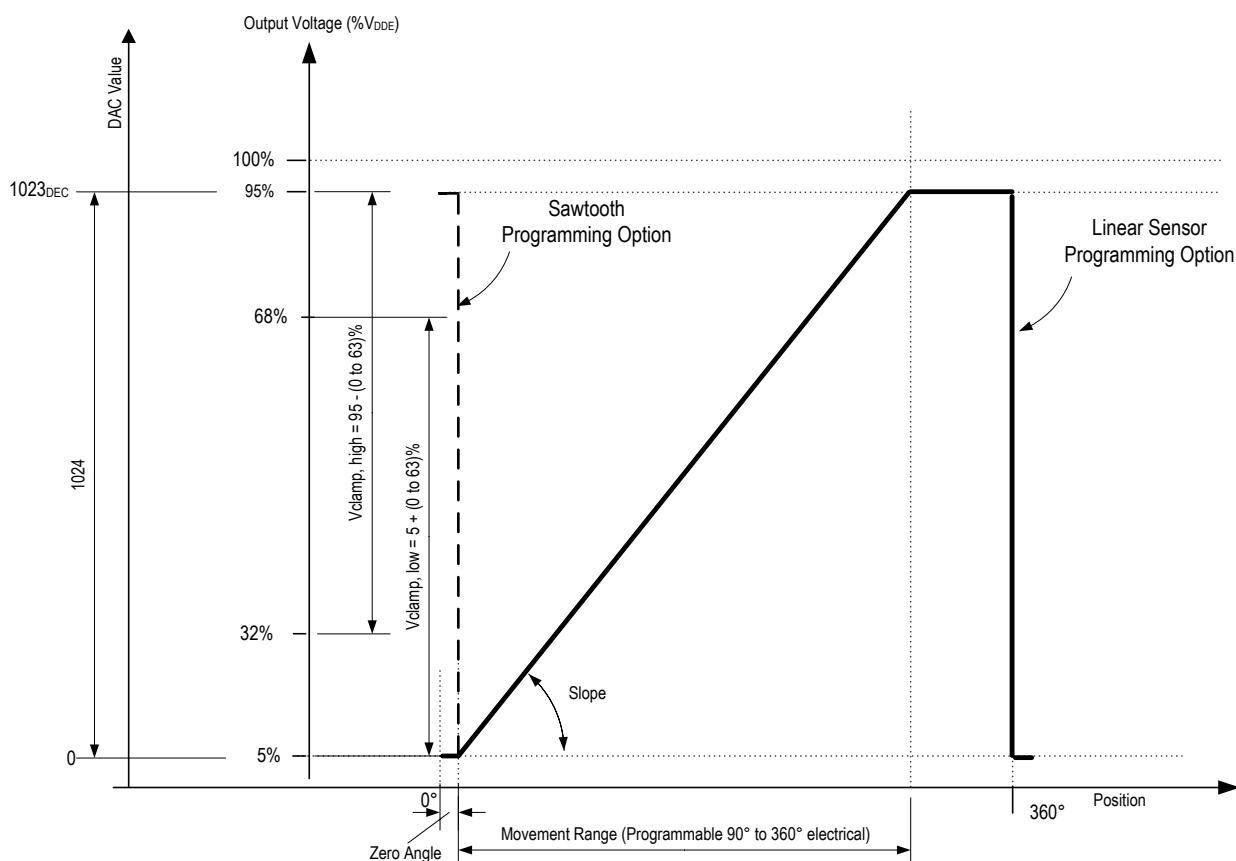
10. ZMID5202 Inductive Sensor with PWM Output

The typical interface circuit for the ZMID5202 is shown in Figure 8.

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

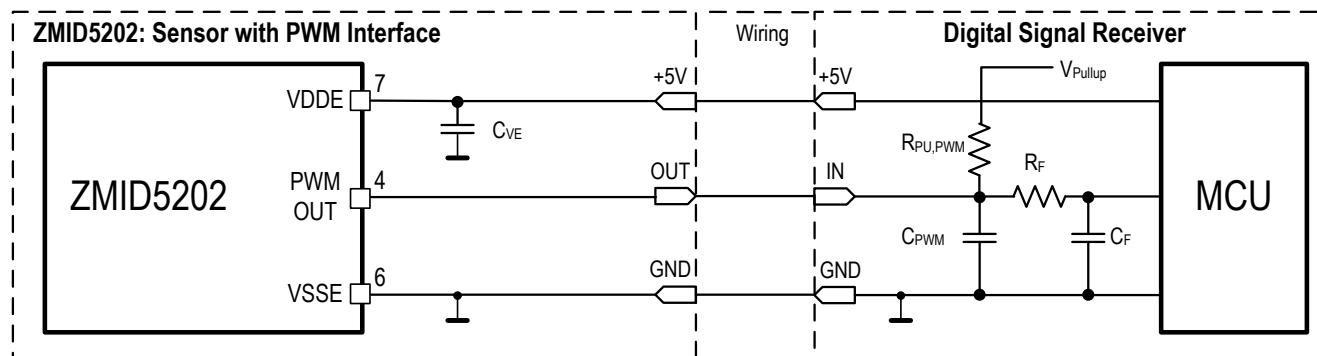**Figure 8.   External Components for ZMID5202 PWM Interface with Pull-Up Resistor**

Table 7.   ZMID5202 PWM Output Buffer Characteristics

Note: Refer to VDDE 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 0.25 0.50 0.75 1.00 1.25 1.50 2.00	Typical + 7%	kHz
t_{PWM_FALL}	PWM fall time	C_{PWM} =4.7nF, $R_{PU,PWM}$=1kΩ, V_{Pullup}=5V, 2 correction bits	2.45		4.55	µs
RES_{PWM}	PWM resolution		10			bits
V_{Pullup}	PWM output voltage (pull-up)				16	V
V_{OL_PWM}	PWM output LOW level	V_{Pullup}=5V to V_{Pullup}=16V			10	%V_{Pullup}
V_{OH_PWM}	PWM output HIGH level	V_{Pullup}=5V to V_{Pullup}=16V	90			%V_{Pullup}
$R_{PU,PWM}$	Pullup resistor for PWM	V_{Pullup}=5V	1		10	kΩ
		V_{Pullup}=16V	3		10	
C_{PWM}	Output capacitor for PWM		1	4.7	20	nF
	Normal operating range	Limits are programmable	5		95	% duty cycle

Symbol	Parameter	Conditions	Minimum	Typical	Maximum	Units
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 [a]	Programmable in 1% steps	5		68	% duty cycle
D_{CL_H}	Clamping level, high [a]	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
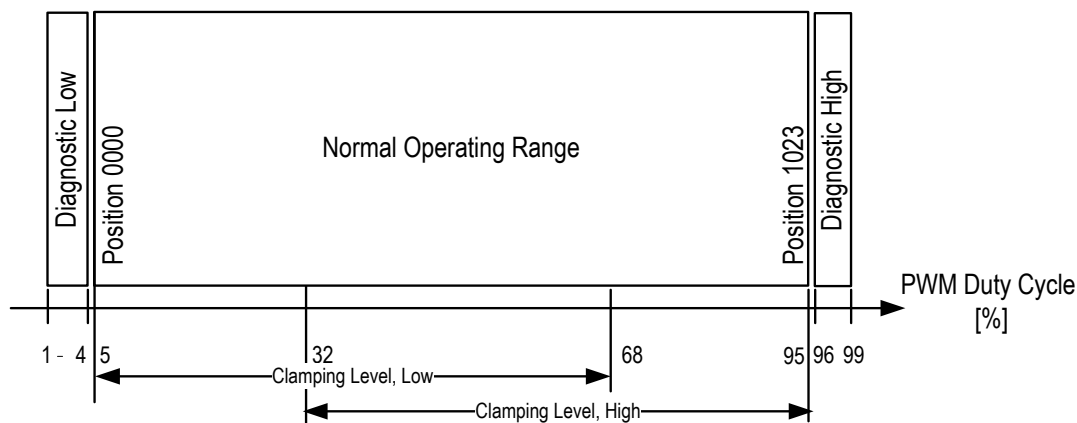
The graph in Figure 10 shows examples of different PWM signals with 5%, 50%, and 95% duty cycle, representing the minimum, 50%, and maximum output values.

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 12 and Figure 11). For example, for a pedal sensor with PWM output (ZMID5202), 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$_{DEC}$ represents 20° mechanical degrees. Note that the slope can be programmed to either rising (as shown in Figure 11) or falling with increasing electrical angle.

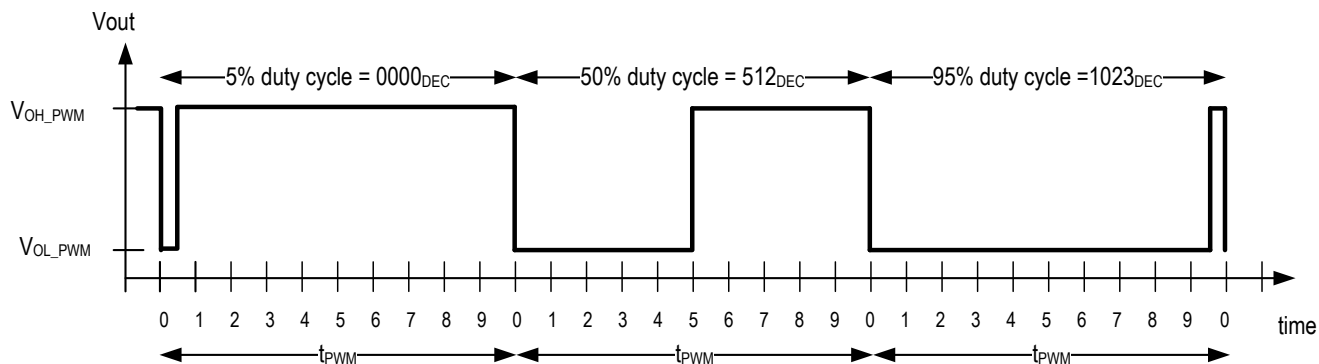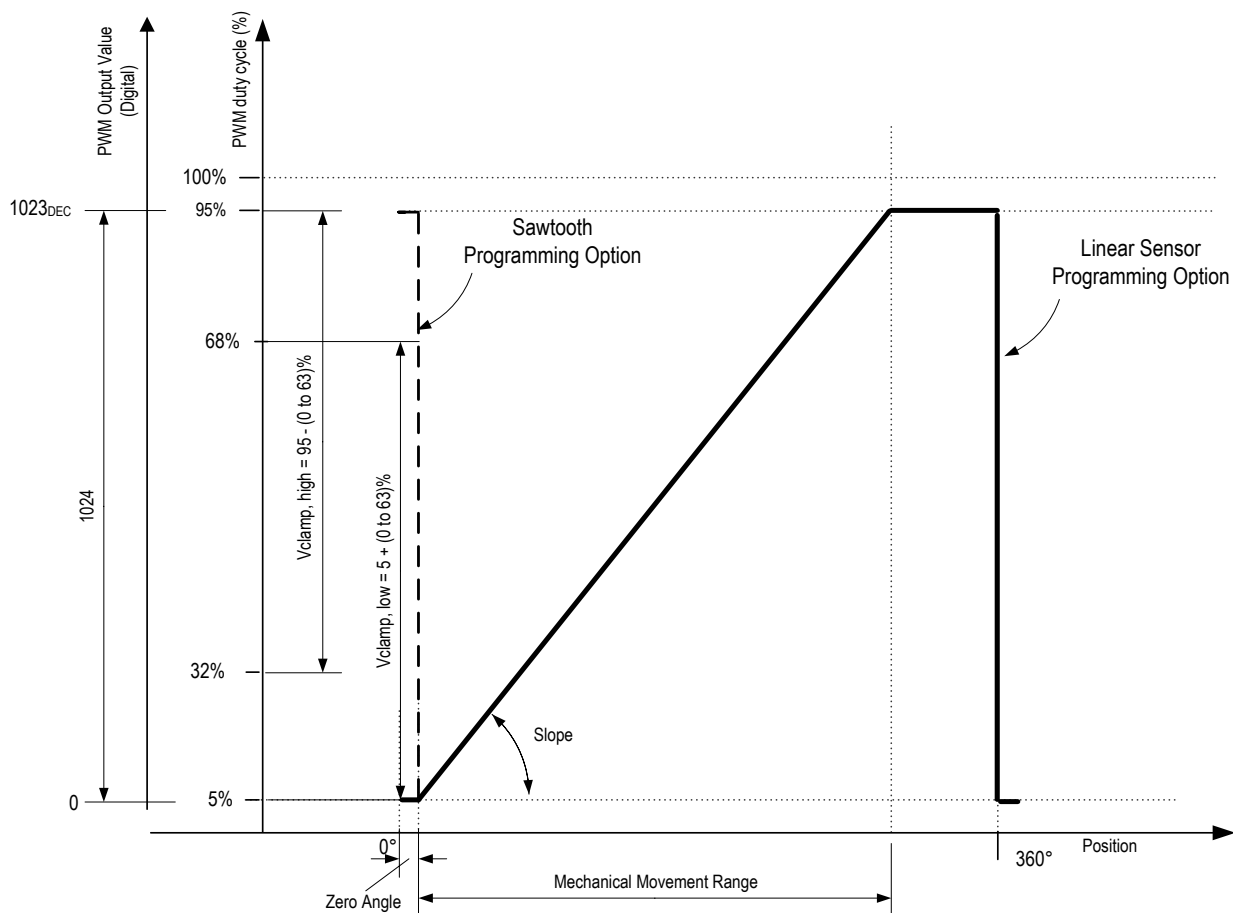**Figure 10. Example of PWM Output Signal**

Figure 11. Example of ZMID5202 PWM Output Transfer Function and Programming Options

Note: The following figure illustrates an example of 5% and 95% clamping levels and a rising slope setting.

11. ZMID5203 Inductive Sensor with SENT Output

Three options for the typical interface circuit for the ZMID5203 are shown in Figure 12, Figure 13, and Figure 14.

Note: R_F, C_F and R_P = optional low pass filter for the SENT interface. Values depend on user's application.

Figure 12. External Components for ZMID5203 SENT Interface, Option A
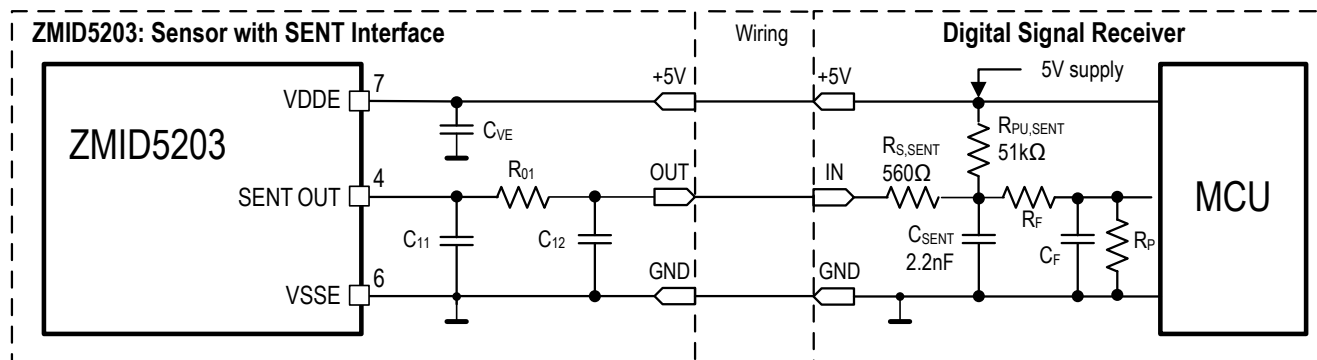
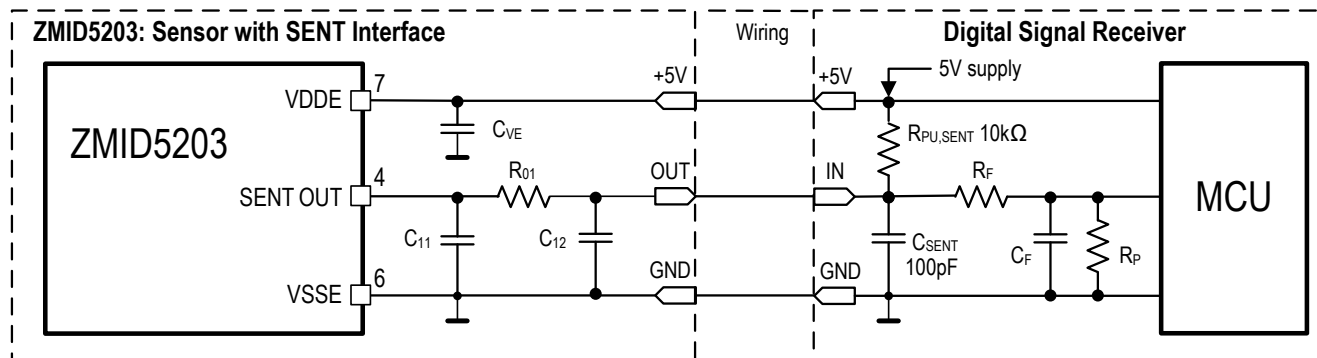**Figure 13. External Components for ZMID5203 SENT Interface, Option B**
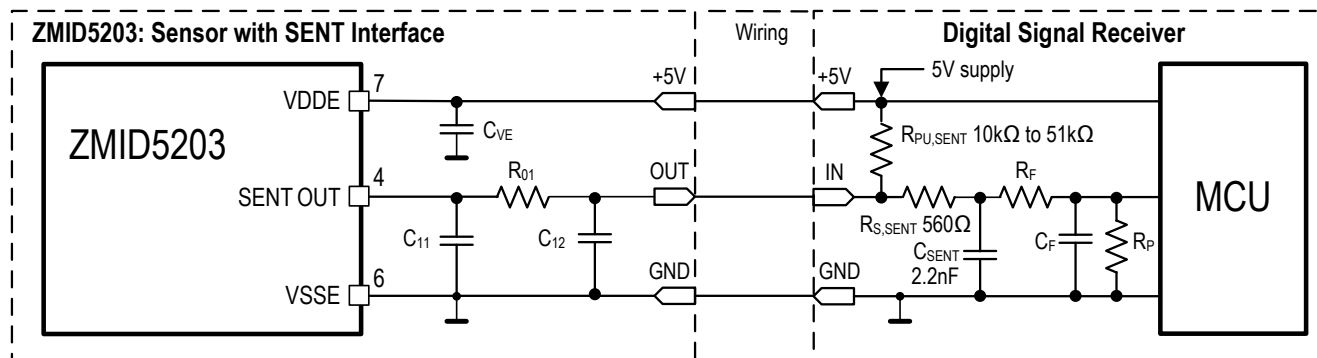
Figure 14. External Components for ZMID5203 SENT Interface, Option C

Table 8. **ZMID5203 SENT Output Buffer Characteristics**

Note: Refer to VDDE 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			µs
V_{OL}	Output LOW level				0.5	V
V_{OH}	Output HIGH level		4.1			V
R_{01}	SENT output pi (π) filter resistor	For application circuits options A,B, and C		120		Ω
C_{11}	SENT output pi (π) filter first capacitor	For application circuits options A, B, and C		2.2		nF
t_{TICK}	Clock tick time		3.0	3.36	3.67	µs
C_{12}	SENT output pi (π) filter, second capacitor	For application circuit option C		3.9		nF
		For application circuits options A and B		2.2		nF

11.1 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} = 3.0µs to 3.67µs (see Table 8).

Table 9. **SENT Nibble Output for Value = 0_{DEC}**
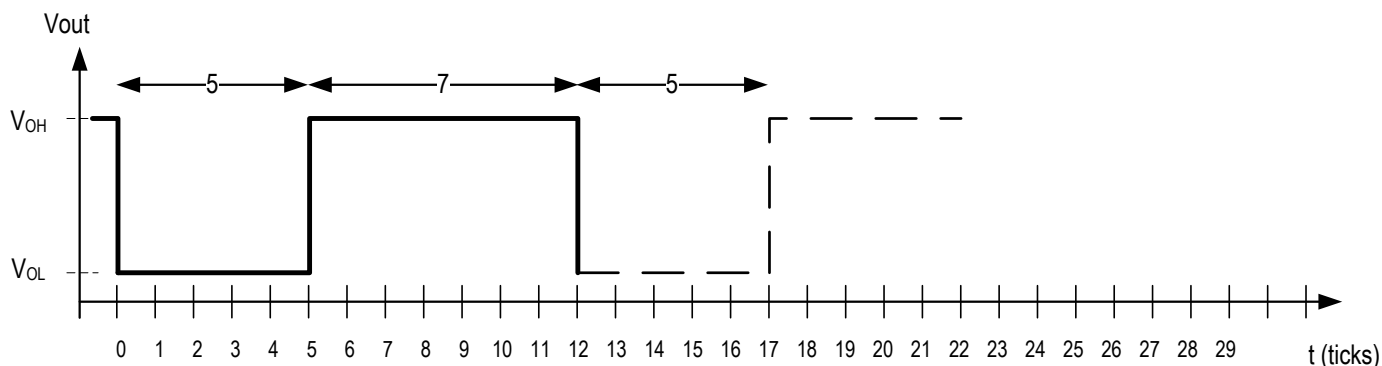
For transmitting a nibble with the value 15_{DEC} (1111_{BIN}, F_{HEX}), 27 clock ticks are required: a fixed LOW period of 5 ticks followed by a HIGH period of 22 ticks. The total time for one nibble can be calculated as with the following equation:

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

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 15. SENT Nibble Output for Value = 15$_{DEC}$
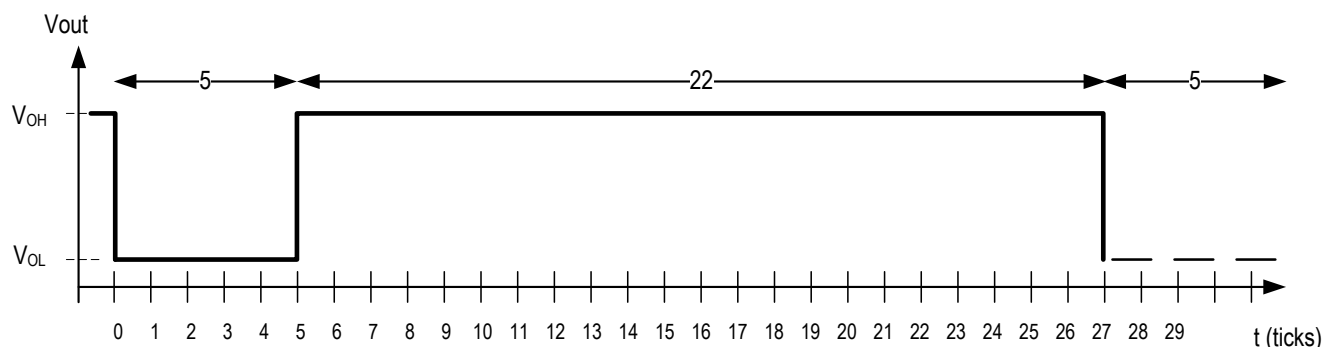
Figure 16. SENT Frame

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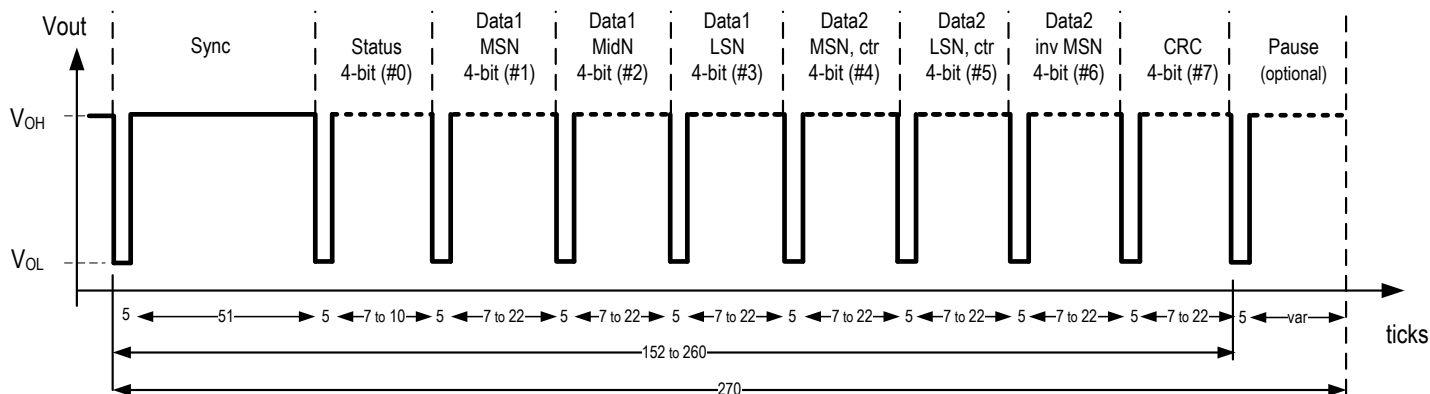
Note that the status nibble has a maximum length of only 5 + 10 = 15 ticks since bits 2 and 3 are always zero:

Status nibble: 0000$_{BIN}$ = Normal operation
   0011$_{BIN}$ = 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 16) + inverted copy of Data1 MSN (nibble #1 in Figure 16) + 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 12 and Figure 17). For example for a pedal sensor with SENT output (ZMID5203) with 20° mechanical degrees of movement range, the output value 0 represents 0° mechanical degrees and the output value 4095_{DEC} represents 20° mechanical degrees. Note that the slope can be programmed to either rising (as shown in Figure 17) or falling with increasing electrical angle.

Figure 17. Example of ZMID5203 Output Transfer Function and Programming Options

Note: The following figure illustrates an example using the rising slope setting.
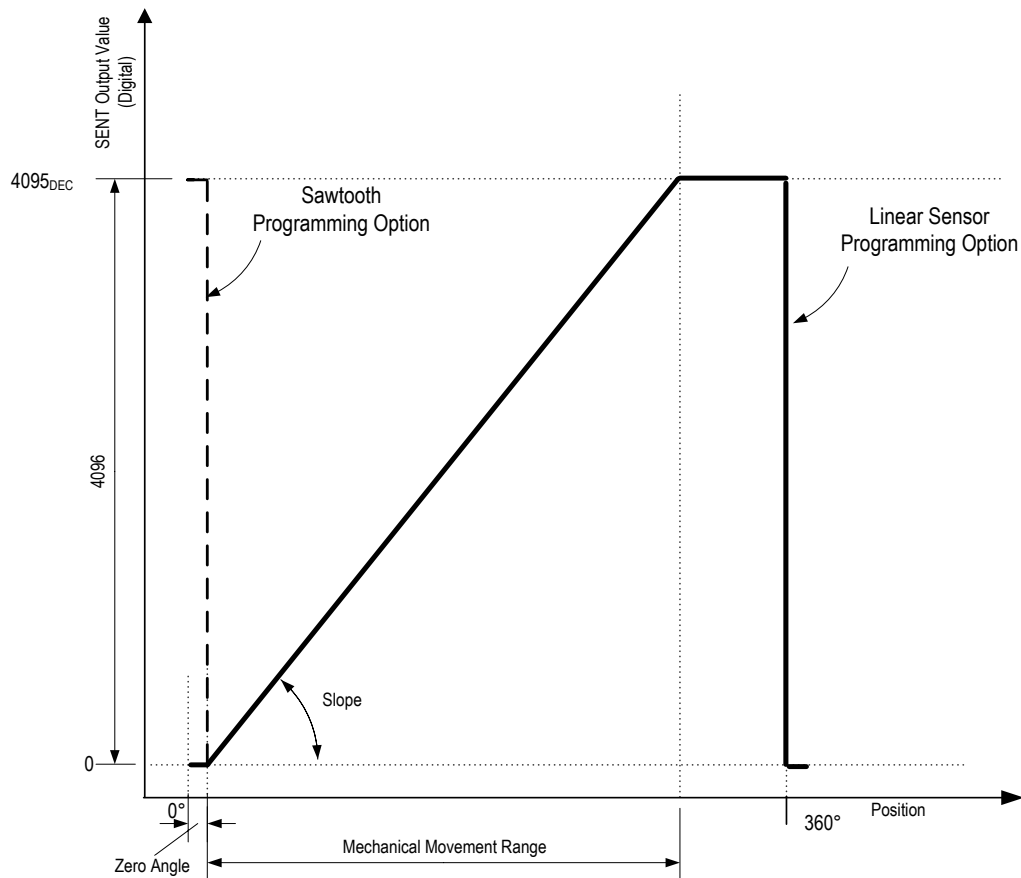
12. Programming Options

The ZMID520x family offers a variety of programming options. The IC is programmed through the output pin 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. Note: A full description of the IDT one-wire interface protocol and a detailed memory map are available on request. The main programming functions are described in Table 11.

Table 11.   Programming Options Overview

Function	Products	Programming Option	Notes
Coil input	All	Reverse coil polarity (increasing or decreasing output relative to target movement)	Invert coils to change the direction of the output values
Input amplifier	All	Offset of sine and cosine channels	Offset correction before CORDIC angle calculation
Slope of transfer function	All	Steepness of slope, rising/falling	Adjustment of angle range
Zero position	All	Zero angle	To match mechanical zero position with electrical zero position
Linearization	All	9-point linearization	To increase accuracy and compensate for imperfections in coil design
Transmit coil	All	Coil driver current and amplitude	To optimize Tx oscillator
Output mode	All	Linear or sawtooth	Single or multiple ramps
Clamp low, clamp high	ZMID5201	Minimum, maximum output voltage	Define normal operating range
	ZMID5202	Minimum, maximum PWM duty cycle	Define normal operating range
Diagnostic levels	ZMID5201	Output voltage in diagnostic mode	To indicate diagnostic alarm
	ZMID5202	PWM duty cycle in diagnostic mode	To indicate diagnostic alarm
PWM fall time	ZMID5202	PWM output signal slew rate	To optimize EMC performance
PWM base frequency	ZMID5202	PWM frequency	Base frequency of PWM signal
SENT CRC	ZMID5203	CRC according to SAE J2716, Rev.2 or Rev.3	Implementation of CRC calculation
SENT Pause	ZMID5203	Optional pause setting according to SAE J2716, Revision 2 or Revision 3	Revision 2: No pause pulse Revision 3: Fixed frame length + pause
SENT Frame	ZMID5203	Type of data transmitted in SENT frame	12-bit position data + 8-bit rolling counter + inverted copy of first data nibble + CRC (see Figure 16) 12-bit position data + "000" data + CRC
Diagnostics	All	CORDIC magnitude upper and lower levels	To trigger alarm if CORDIC magnitude is out of range
		Transmit 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

13. Operation at High Rotation Speeds

The ZMID520x ICs are 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 ZMID520x in high speed applications; however, due to the maximum data rate at the various outputs, the resolution (on a rotary application: number of measurements per revolution) will be reduced with increasing speed.

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

Table 12. Maximum Output Data Rate

Product	Type of Output	Maximum Output Rate, Updates per Second	Notes
ZMID5201	Analog ramp	10000	Linear analog ramp
ZMID5202	PWM	2000	Programmable from 125Hz to 2000Hz
ZMID5203	SENT	1235	270 ticks @ 3µS

With these maximum output data rates, the resolution versus rotation speed relationship is shown in the graph in Figure 18.

Figure 18. Relationship between Resolution and Rotational Speed
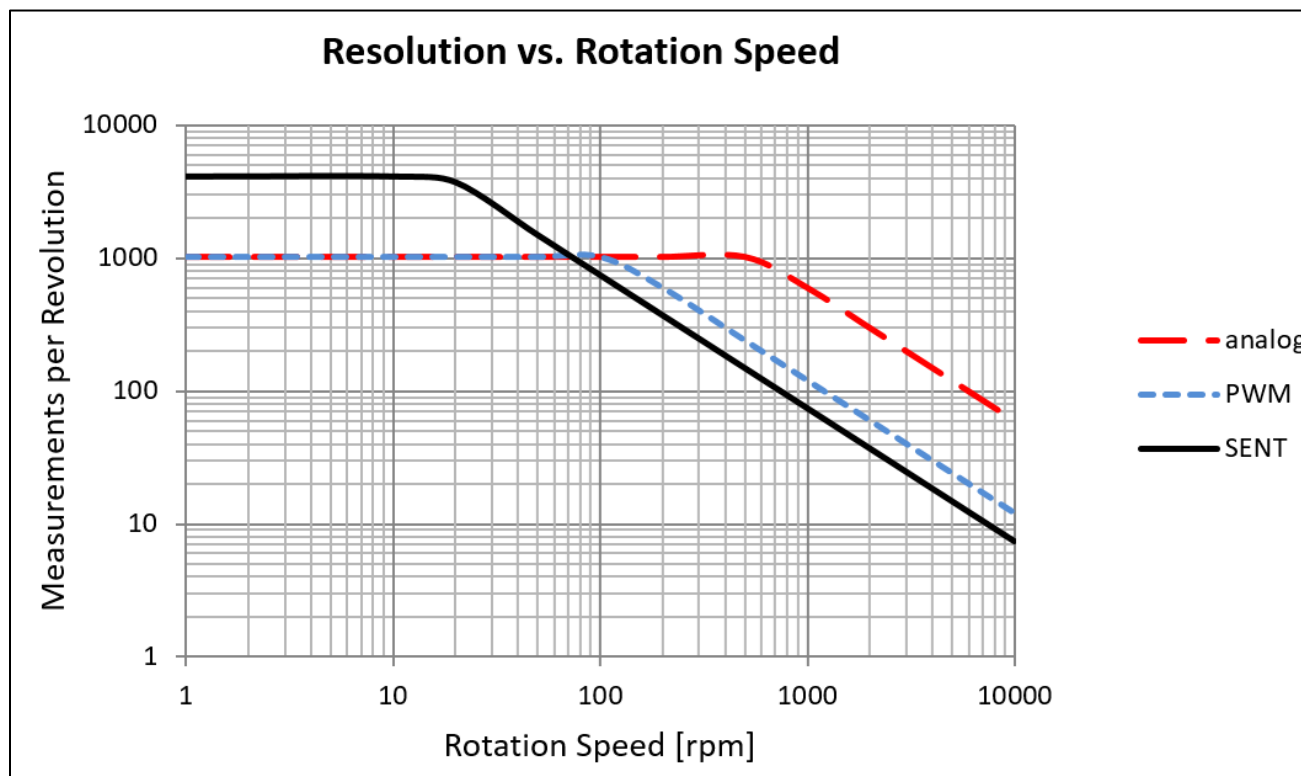
For example, the number of readings per revolution at 10rpm and 1000 rpm are given in Table 13.

Table 13.   Resolution at Different Rotation Speeds

Product	Type of Output	Readings per Revolution at 10rpm	Readings per Revolution at 1000rpm
ZMID5201	Analog ramp	1024 (10-bit)	600 (9.2-bit)
ZMID5202	PWM	1024 (10-bit)	120 (6.9-bit)
ZMID5203	SENT	4096 (12-bit)	74 (6.2-bit)

14. 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 $0° \leq \alpha < 45°$ and optionally for $22.5° \leq \alpha < 67.5°$.

(…)

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

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

15. Application Examples

Typical coil and target arrangements are shown in Figure 19 to Figure 24: 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 IDT 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 19.   Example Setup: Linear Motion
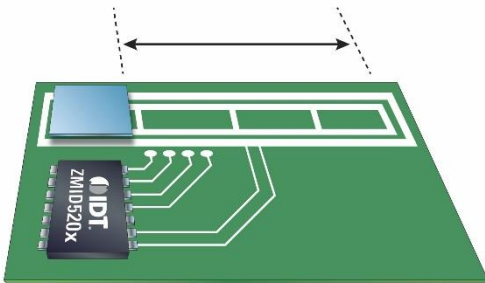
Figure 20.   Example Setup: Arc Motion
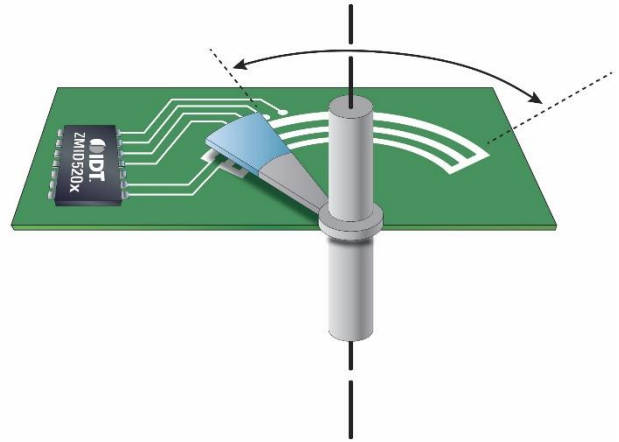
Figure 21.   Example Setup: End-of-Shaft Rotation, On-Axis, 1 × 360°
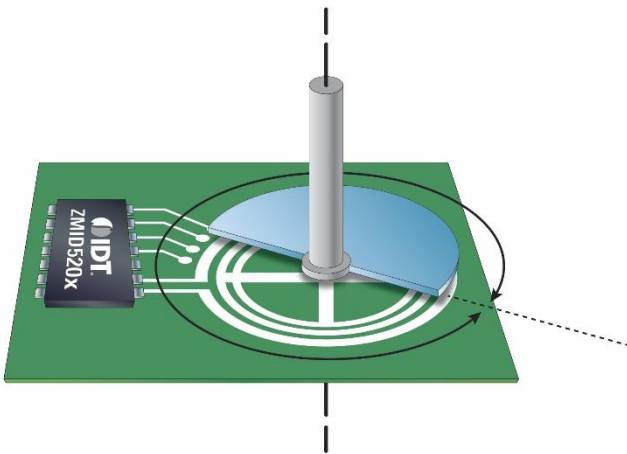
Figure 22.   Example Setup: Side-Shaft Rotation, Off-Axis, 1 × 360°
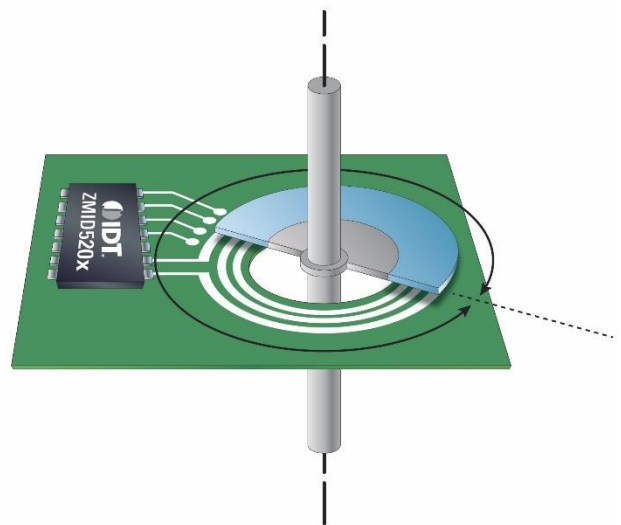
Figure 23. **Example Setup: Side-Shaft Rotation, Off-Axis, 2 × 180°**
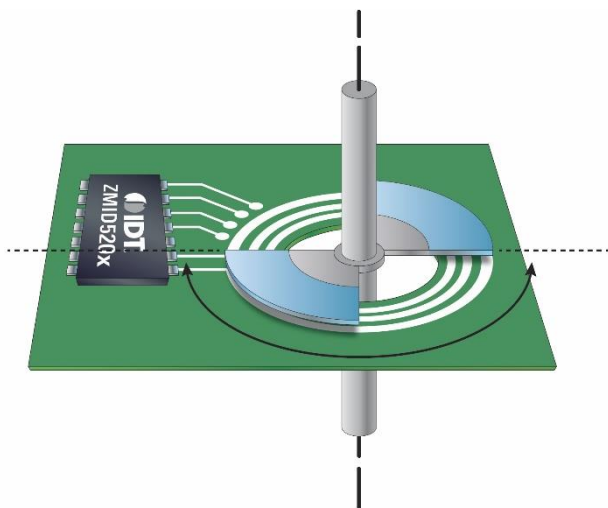
Figure 24. **Example Setup: Side-Shaft Rotation, Off-Axis, 6 × 60°**
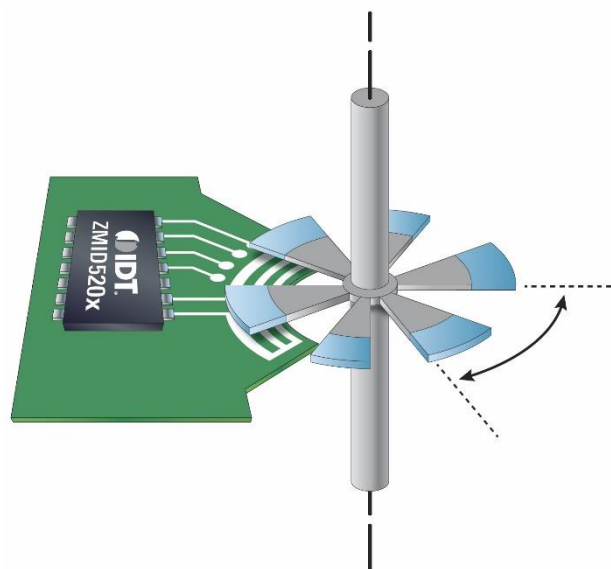
The different coil and target arrangements provide different ranges for the degrees measurement, which affects the measurement resolution (degrees per step). This varies depending on the ZMID520x product. Table 15 gives examples of resolution for various ranges of motion for each product.

Table 15.   Examples of Resolution Differences Depending on Product

Range of Travel for Example Application	Resolution of Measurement	
	ZMID5201 / ZMID5202 (1024 steps per phase)	ZMID5203 (4096 steps per phase)
Linear Position Sensing Range of Travel = Coil Length Minus Target Length (See the example in Figure 19)	(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 20)	(Range of Travel)/1024	(Range of Travel)/4096
1 × 360° (See the examples in Figure 21 and Figure 22)	0.35°/Step	0.088°/Step
2 × 180° (See the example in Figure 23)	0.18°/Step	0.044°/Step
6 × 60° (See the example in Figure 24)	0.059°/Step	0.015°/Step

16. Package Drawing 14-TSSOP

Figure 25. 14-TSSOP Package Outline Drawing
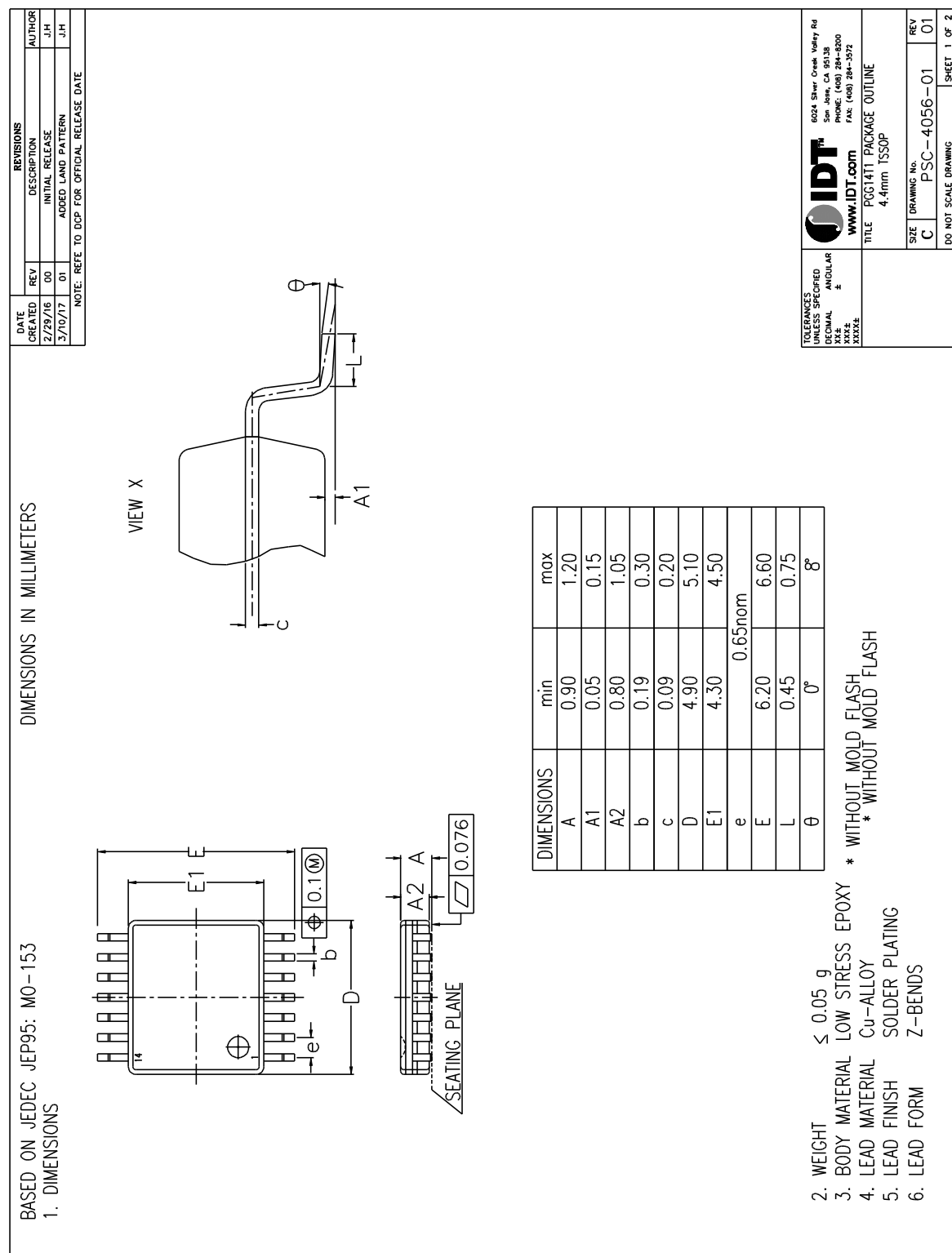
17. Recommended Land Pattern

Figure 26. 14-TSSOP Recommended PCB Land Pattern
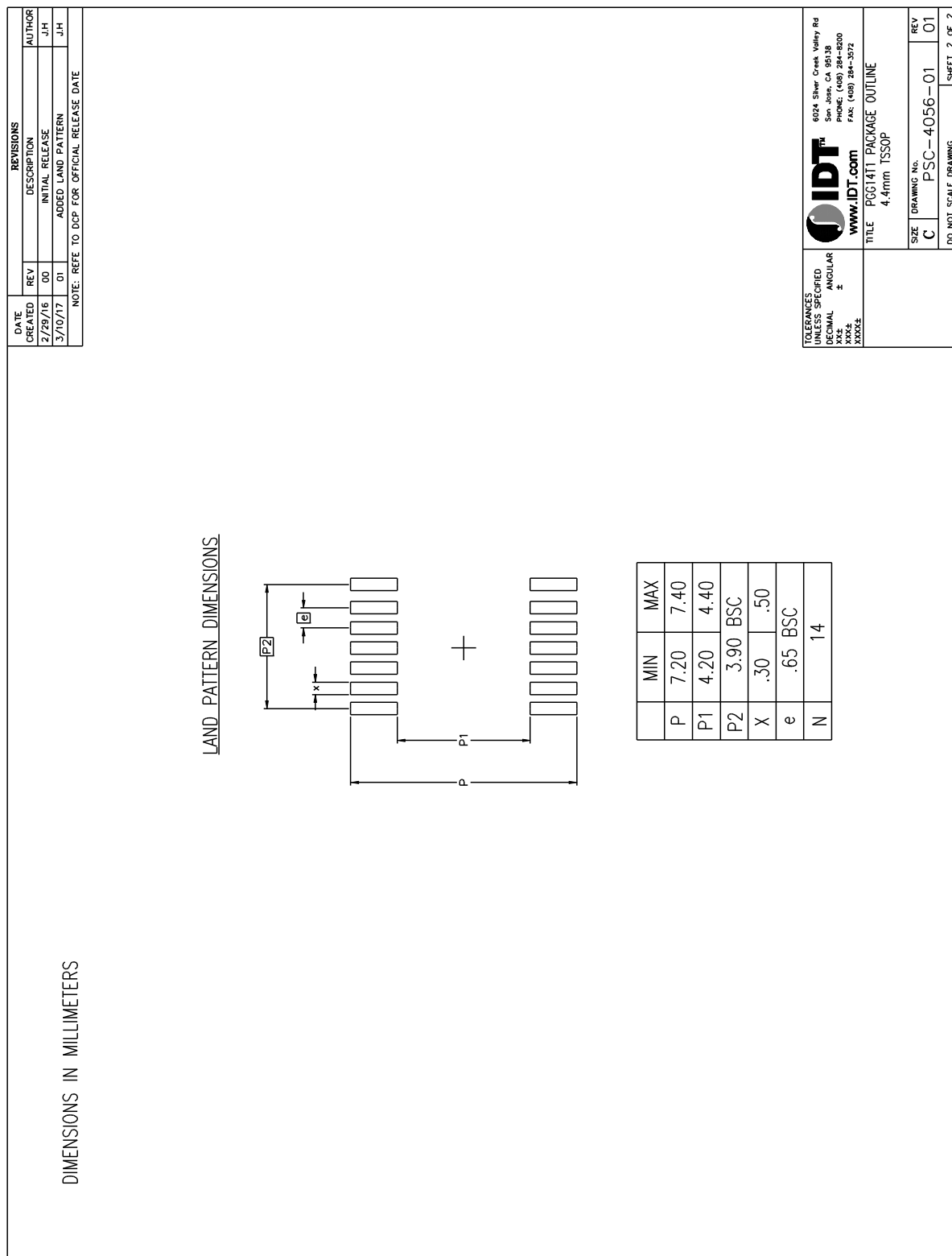
18. Marking Diagram

```
ZMID
520xAE
XXXXXX
YYWW
```

Line 1: First four characters of part code (ZMID)
Line 2: Next four characters of the part code (5201, 5202, or 5203) followed by
A = Design revision
E = Operation temperature range, extended automotive
Line 3: "XXXXXX" = Lot number
Line 4: "YYWW" = Manufacturing date:
YY = last two digits of manufacturing year
WW = manufacturing week

19. Ordering Information

Orderable Part Number	Description and Package	MSL Rating	Shipping Packaging	Temperature
ZMID5201AE1R	ZMID5201; Analog Output; 14-TSSOP	1	Tape and Reel	-40° to +150°C
ZMID5201AE1T	ZMID5201; Analog Output; 14-TSSOP	1	Tube	-40° to +150°C
ZMID5202AE1R	ZMID5202; PWM Output; 14-TSSOP	1	Tape and Reel	-40° to +150°C
ZMID5202AE1T	ZMID5202; PWM Output; 14-TSSOP	1	Tube	-40° to +150°C
ZMID5203AE1R	ZMID5203; SENT Output; 14-TSSOP	1	Tape and Reel	-40° to +150°C
ZMID5203AE1T	ZMID5203; SENT Output; 14-TSSOP	1	Tube	-40° to +150°C
ZMID5201-EVK	ZMID5201 Evaluation Kit: ZMID Communication Board, ZMID5201 Demo Board with printed sensor coil, micro-USB cable			
ZMID5202-EVK	ZMID5202 Evaluation Kit: ZMID Communication Board, ZMID5202 Demo Board with printed sensor coil, micro-USB cable			
ZMID5203-EVK	ZMID5203 Evaluation Kit: ZMID Communication Board, ZMID5203 Demo Board with printed sensor coil, micro-USB cable			

20. Revision History

Revision Date	Description of Change
May 24, 2017	▪ Addition of t_{START} specification to Table 4. ▪ Separation of PDF into full datasheet without page 2 and short-form datasheet with pages 1 and 2.
April 28, 2017	▪ Correction for sine and cosine labels in the following figures: application circuit on page 1, the block diagram on page 2, Figure 3, and Figure 4. ▪ Minor edits.
March 28, 2017	▪ Correction for Table 15 for step values. ▪ Addition of new images for Figure 19 to Figure 24. ▪ Correction of name of ZMID520x Reference Board to ZMID520x Demo Board in kit contents given in part order table.
March 23, 2017	Initial release.