RAA2P4200

Single Coil Inductive Position Sensor IC with I2C, PWM and Analog Interfaces

RAA2P4200 is a magnet-free, inductive position sensor ICs that can be used for absolute rotary, linear, or arc position sensing applications in industrial, medical, and consumer applications. It operates on the principle of eddy currents to detect the position of a simple metallic target that is moving above a set of coils, comprising one transmitter coil and two receiver coils.

These coils are typically copper traces on a printed circuit board (PCB). The transmitter coil induces a secondary voltage in the receiver coils, which varies depending on the position of the metallic target above them.

A signal representative of the target's position relative to the coils is calculated by demodulating and processing the secondary voltages from the receiver coils. The target can be made of various metals, including aluminum, steel, or a PCB with a printed copper layer.

The RAA2P4200 is equipped with:

- 14-bit I2C interface (up to 400Kbit/s)
- 12-bit Analog Output
- 12/14-bit PWM Output
- Additional analog voltage input for external devices.
- Digital input for reading both static or PWM coded external digital sensors. The information from external analog or digital inputs is available over the I2C interface.

Available Support

Renesas provides application modules that demonstrate RAA2P4200 rotary, arc, and linear position sensing applications.

Features

- Cost-effective: no magnet required
- Immune to magnetic stray fields: no shielding required
- Suitable for harsh environments and high temperatures
- I2C, Analog or PWM interfaces
- Auxiliary 12-bit analog voltage input and 16-bit PWM input for external sensors
- Programmable through single wire UART and I2C protocol
- Nonvolatile memory enabling multiple programming options
- Single IC supports on-axis and off-axis rotation, linear motion, and arc motion sensing
- Adaptable to any full-scale angle range through coil design
- High accuracy position with I2C and PWM ≤0.1% full scale (with ideal coils), enabling sensor solutions up to 11-bit electrical accuracy
- Overvoltage and reverse polarity protection: ±18V on both supply and output pins
- Supply voltage programmable for: 3.3V ±0.3V or 5.0V ±0.5V
- Qualified for industrial application use from -40°C to +125°C ambient temperature
- 48 bits nonvolatile user ID memory space
- Small 16-TSSOP package (4.4mm × 5.0mm)

Typical Applications

- Linear / Angle position sensing in industrial and consumer electronics

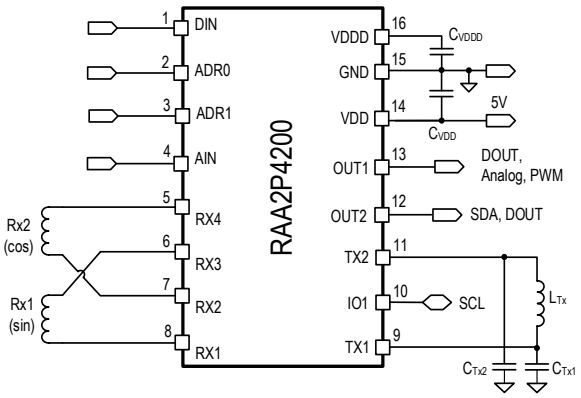

Figure 1. Application Circuit Example

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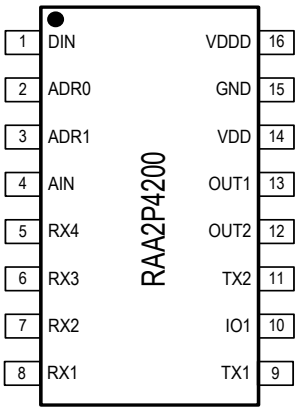


Figure 2. RAA2P4200

Table 1. Pin Description

Pin Number	Name	Type	Description
1	DIN	Digital Input	Auxiliary digital input for static or PWM signals, readable over I2C interface
2	ADR0		Address selection bit0 input for I2C interface (bit-strapping)
3	ADR1		Address selection bit1 input for I2C interface (bit-strapping)
4	AIN	Analog Input	Auxiliary analog (12-bit) input for external analog signal, readable over I2C interface
5	RX4	Sensor Input	Receiver coil (COS_N)
6	RX3		Receiver coil (SIN_N)
7	RX2		Receiver coil (COS)
8	RX1		Receiver coil (SIN)
9	TX1	Transmitter Output	Connect the transmitter coil between the TX1 and TX2 pins, using series resistors R_{Tx1} and R_{Tx2}. The resonant frequency is adjusted with capacitors C_{Tx1} and C_{Tx2} from each coil terminal to GND
10	IO1	Digital I/O	I2C: SCL Analog: Not used PWM: Not used / PWM inverted
11	TX2	Transmitter Output	Connect the transmitter coil between the TX1 and TX2 pins, using series resistors R_{Tx1} and R_{Tx2}. The resonant frequency is adjusted with capacitors C_{Tx1} and C_{Tx2} from each coil terminal to GND
12	OUT2	Digital I/O	I2C: SDA Analog: Digital output PWM: Digital output / PWM output (differential PWM)
13	OUT1	Analog output Digital I/O	I2C: Digital output Analog: 12-bit analog ramp output AOUT PWM:12-bit /14-bit PWM output Single wire programming interface
14	VDD	Supply	External supply voltage (3.3V or 5.0V)
15	GND	Supply	Common ground connection
16	VDDD	Supply	Internally regulated digital supply voltage

2. Specification

2.1 Absolute Maximum Ratings

The absolute maximum ratings listed in Table 2 are stress ratings only. Exceeding these limits can cause permanent damage to the device. The functional operation of the RAA2P4200 at these maximum ratings is not guaranteed. Exposure to the absolute maximum rating conditions could impact device's reliability. All voltage levels are referenced to GND.

Table 2. Absolute Maximum Ratings

Symbol	Parameter	Conditions	Minimum	Maximum	Units
V_{VDDmax}	External supply voltage: VDD	Continuous	-18	18	V
V_{IO1}	Digital input pin voltage				
V_{OUT2}	Digital I/O pin voltage				
V_{OUT1}	Analog/Digital output pin voltage				
V_{RX1}	Sensor receiver coil input pin Voltage (RX1)	Continuous	-12	12	V
V_{RX2}	Sensor receiver coil input pin Voltage (RX2)				
V_{RX3}	Sensor receiver coil input pin Voltage (RX3)				
V_{RX4}	Sensor receiver coil input pin Voltage (RX4)				
V_{DIN}	Digital input pin voltage				
V_{ADR0}	Digital input pin voltage				
V_{ADR1}	Digital input pin voltage				
V_{AIN}	Analog input pin voltage				
V_{Tx1}	Transmitter output pin (TX1) voltage	Continuous	-0.3	5.5	V
V_{Tx2}	Transmitter output pin (TX2) voltage				
$V_{VDDDmax}$	Internal digital supply voltage, VDDD	VDDD is internally regulated with an external capacitor to GND	-0.3	2.0	V
T_{AMB}	Ambient temperature		-40	125	ºC
T_J	Junction temperature		-40	135	ºC
T_{STOR}	Storage temperature	Unmounted units must be limited to 10 hours at temperatures above 125°C to prevent pre-aging	-55	160	ºC
R_{THJA}	Thermal resistance junction to ambient: 16-TSSOP package	Velocity = 0m/s with 2s2p PCB test board (JEDEC 51-2, JEDEC 51-7)		89.5	K/W
R_{THJC}	Thermal resistance junction to case: 16-TSSOP package	Junction to top of package		38.38	K/W

2.2 ESD Ratings

Table 3. ESD Ratings

Symbol	Parameter	Conditions	Maximum	Units
V_{ESD}	ESD tolerance for all pins Human Body Model: 100pF/1.5kΩ	According to JEDEC JS-001, classification 2	±2	kV
V_{CDM}	ESD tolerance for all pins: Charged-Device Model (CDM)	According to JEDEC JS-002, classification C2b	±750	V

2.3 Operating Conditions

All minimum/maximum specification limits are guaranteed by design, production testing, and/or statistical characterization. Conditions: T_{AMB} = -40°C to 125°C unless otherwise specified. C_{VDD} = 470nF, C_{VDDD} = 100nF.

Typical values are based on characterization results at default measurement conditions and are informative only.

Table 4. Electrical Characteristics, 5V and 3.3V Modes

Symbol	Parameter	Description	Minimum	Typical	Maximum	Units
V_{VDD5}	Supply voltage, 5V mode		4.5	5.0	5.5	V
$V5_{UV}$	Undervoltage detection level, 5V mode	An undervoltage alarm is created if VDD falls below this limit	3.95	4.1	4.45	V
$V5_{OV}$	Overvoltage detection level, 5V mode	An overvoltage alarm is created if VDD rises above this limit	5.55	6.15	6.5	V
V_{VDD3}	Supply voltage, 3.3V mode		3.0	3.3	3.6	V
$V3_{UV}$	Undervoltage detection level, 3.3V mode	An undervoltage alarm is created if VDD falls below this limit	2.7	2.8	2.98	V
$V3_{OV}$	Overvoltage detection level, 3.3V mode	An overvoltage alarm is created if VDD rises above this limit	3.65	3.85	4.04	V
$V_{VDD\_TH\_H}$	Power-on reset (POR), high threshold	Power-on reset (POR): the device is activated when VDD increases above this threshold		2.36	2.45	V
$V_{VDD\_TH\_L}$	Power-on reset (POR), low threshold	The device is deactivated when VDD decreases below this threshold	2.08	2.16		V
$V_{VDD\ POR\_HYST}$	Power-on reset hysteresis		170	200	235	mV
$t_{stup\ PE}$	Start-up times	Power-on reset (POR) to valid output signal, programming enabled			5	ms
$t_{stup\ PL}$		Power-on reset (POR) to valid output signal, programming locked			3	ms
$t_{stup\ cmd}$	Command timeout time	Time to wait before sending first command	1.5			ms
t_{ProgEn}	Programming window enable time	Timeout window after POR, in which a first programming enable command must be sent			5	ms
t_{ProgUL}	Programming window unlock time	Timeout window after programming enable in which a second unlock command must be completely sent[i]			75	ms

Symbol	Parameter	Description	Minimum	Typical	Maximum	Units
V_{VDDD}	Digital supply voltage	Internally regulated. Connect capacitor C_{VDDD} = 100nF from VDDD to GND.	1.75	1.8	1.85	V
I_{AUXIN}	Auxiliary Input on VDDD maximum external load current	VDDD must be connected to a capacitor C_{VDDD}.	0		4	mA
$I_{SHORT\ VDDD}$	VDDD short circuit current limitation		18.5	27	40	mA
I_{CC}	Current consumption[1]	Without coils, no load	10	15	20	mA
C_{VDDD}	Capacitor from VDDD pin to GND		100			nF
C_{VDD}	Capacitor from VDD pin to GND	Nominal value	100	470		nF

[1] With maximum position sampling rate (afe_lp_cfg = 0)

Table 5. Position Resolution and Update Rate

Symbol	Parameter	Description	Minimum	Typical	Maximum	Units
RES_{I2C}	Position resolution I2C interface			14		bit
RES_{AOUT}	Position resolution Analog Output interface			12		bit
RES_{Pwm}	Position resolution PWM interface		12		14	bit
$Acc_{I2C\ PWM}$	Position accuracy I2C and PWM interface	Ambient temperature, nominal supply	-0.1		0.1	%FS
		Over temperature and supply range	-0.2		0.2	%FS
Acc_{AOUT}	Position accuracy Analog Output interface	Ambient temperature, nominal supply	-0.5		0.5	%FS
		Over temperature and supply range	-0.7		0.7	%FS
t_{POS}	Position refresh rate	Internal refresh rate of position information	2		3	µs

Table 6. Non-volatile Memory Parameters [1]

Parameter	Conditions	Minimum	Typical	Maximum	Units
Data retention	Qualified according to JEDEC 22-A117	15 @T_J = 100°C			Years
	Over product lifetime		>100 @T_J = 25°C		
Write temperature	Allowed ambient temperature range for read and write access	-40		125	°C
Read temperature		-40		125	ºC
Endurance [1]	Over product lifetime			1000	NVM Write Cycles
Read Cycles		5x 10^{11}	1x 10^{12}		NVM Read events

[1] Guaranteed by memory supplier
[2] Verified number of program/erase cycles. Qualified with 2000 cycles.

Table 7. LC Oscillator Specifications

Symbol	Parameter	Description	Minimum	Typical	Maximum	Units
f_{LC}	Excitation frequency	LC oscillator frequency is determined by external components L and C.	2		5.5	MHz
R_{Peq}	Equivalent parallel resistance of the LC resonant circuit		250			Ω
V_{TX_PP}	LC oscillator amplitude at VDD = 5.0V ±10%	Peak-to-peak voltage; pins TX1 vs. TX2; all modes. Adjustable by coil current.			8.8	Vpp
	LC oscillator amplitude at VDD = 3.3V ±10%				2* V_{VDD3}	
I_{LC}	Programmable transmitter coil drive current	$T_{ambient}$ = -40 to +125°C	0	[1]	16	mA
R_{Tx1}, R_{Tx2}	LC oscillator series resistors	Depending on coil design and excitation frequency (f_{LC})		10		Ω

[1] The required transmitter coil current is determined by the equivalent parallel resistance of the LC circuit, depending on coil design.

Table 8. Receiver Coils Front-End Specifications

Symbol	Parameter	Description	Minimum	Typical	Maximum	Units
V_{RX}	RX coil amplitude	Differential coil input	5		200	mV_{pp}
A_{IN_mm}	Maximum amplitude mismatch correction	Programmable gain mismatch correction of RX coil signals (SIN and COS)			15	%
$A_{IN\_OFFS\_RANGE\%}$	Input offset correction range	Differential input offsets of sine or cosine signal, percentage of transmitter coil amplitude.	-0.2		0.2	%
D_{OFFSET}	Coil input offset temperature drift	Over temperature range T_{AMB}	-2.5		2.5	%
C_{RX1} to C_{RX8}	Receiver input filter capacitors	For improved EMC immunity		220		pF
$Noise_{SP}$	Signal path noise level	Digital filtering = OFF V_{RX}= 50mV			0.1	° el. rms
		Digital filtering = OFF V_{RX}= 5mV			0.5	° el. rms

2.4 Interface Pin Characteristics

Table 9. I2C Specifications

Symbol	Parameter	Description	Minimum	Typical	Maximum	Units
f_{I2C}	I2C clock rate				400	Kbit/s
t_{SCL_LOW}	Low level state of SCL clock	Normal mode	4.7			µs
		Fast mode	1.3			µs
t_{SCL_HIGH}	High level state of SCL clock	Normal mode	4.0			µs
		Fast mode	0.6			µs
$t_{R\_SDA\_SCL}$	Rise time of SDA/SCL (30% to 70%) $R_{SDA/SCL}$ = 2kΩ	Normal mode			1000	ns
		Fast mode	20		300	ns
$t_{F\_SDA\_SCL}$	Fall time of SDA/SCL (70% to 30%) $R_{SDA/SCL}$ = 2kΩ	Normal mode	20		300	ns
		Fast mode	20			ns
V_{IH_I2C}	High level input voltage	SCL clock input, SDA data input DIN, ADR0, ADR1	0.7×VDD		VDD+0.5	V
V_{IL_I2C}	Low level input voltage		-0.5		0.3×VDD	V
V_{I2C_hyst}	Hysteresis of Schmitt trigger input	SCL clock input SDA, DIN, ADR0, ADR1	0.05 × VDD			V
I_{LEAK}	Input leakage current	VDD = 0V to 5.5V	-10		10	µA
$I_{SDA\ lim\ thr}$	SDA current limitation threshold	OUT2 pin 12 (SDA)	8		30	mA
$I_{SDA\ sc\ lim}$	SDA output short current limitation[1]	Short to VDD, GND VDD = 3.3V, 5V	14		26	mA
V_{OL_SDA}	Output low voltage SDA low level output voltage open drain	3mA sink current VDD = 3.0 to 5.5V	0		0.4	V
I_{OL}	Low level output current	V_{OL} = 0.4V, VDD = 5.5V, $R_{SDA/SCL}$ = 2kΩ	3			mA
t_{SP}	Input spike suppression	Spikes shorter than t_{SP} are suppressed	400		426	ns
C_B	External capacitive load for each bus line				400	pF
R_{SDA}, R_{SCL}	External pull-up resistor at pins SDA and SCL	Resistor value and capacitive load on these pins are limiting the maximum clock frequency	1.8	4.7		kΩ
R_{ADR}	External resistor at pin ADR for I2C address selection	Pull-up/pull-down, depending on I2C address setting.	1.8	3.3		kΩ
$I_{DOUT\ lim\ thr\ I2C}$	DOUT current limitation threshold[2]	OUT1 pin 13 in overload condition	35		56	mA
$I_{DOUT\ sc\ lim\ I2C}$	DOUT output short current limitation[2]	OUT1 pin 13	28		58	mA

[1] With OUT2 drive strength set to “00” (out2_io1_drv = “00”)

[2] With digital mode configuration (out1_drv=”10”)

Table 10. Analog Output

Symbol	Parameter	Description	Minimum	Typical	Maximum	Units
A_{OUT}	AOUT voltage range		5		95	%VDD
$I_{AOUT\ lim\ thr}$	AOUT current limitation threshold [1]	OUT1 pin 13 in overload condition	19		33	mA
$I_{AOUT\ sc\ lim}$	AOUT output short current limitation	OUT1 pin 13 Short to VDD / GND VDD = 3.3V or 5V	23		38	mA
$I_{DOUT\ lim\ thr\ AOUT}$	DOUT current limitation threshold	OUT2 pin 12 in overload condition	8		30	mA
$I_{DOUT\ sc\ lim\ AOUT}$	DOUT output short current limitation [2]	OUT2 pin 12 Short to VDD/GND VDD = 3.3V or 5V	14		26	mA
$C_{L,AOUT}$	Output buffer Load capacitance	Capacitor from AOUT to GND		47	100	nF
$SR_{\_AOUT}$	Output Buffer Slew Rate	At maximum load conditions	0.1			V/µs

[1] With Analog Out configuration (out1_drv="01")

[2] With OUT2 slow configuration (out2_io1_drv="00")

Table 11. PWM Interface Parameters

Symbol	Parameter	Description	Minimum	Typical	Maximum	Units
$I_{OUT1\ lim\ thr\ PWM}$	PWM Out limitation threshold [1]	Pin 13 (OUT1) PWM SE In overload condition	35		56	mA
$I_{OUT1\ sc\ lim\ PWM}$	PWM output short current limitation [1]	Pin 13 (OUT1) PWM SE Short to VDD / GND VDD = 3.3V,5V	28		58	mA
$I_{\ OUT2\ IO1\ lim\ thr\ PWM}$	OUT2 and IO1 current limitation threshold	Pin 12 (OUT2) Pin 10 (IO1) In overload condition	6		30	mA
$I_{\ OUT2\ IO1\ sc\ lim\ PWM}$	Output short current limitation[2]	Pin 12 (OUT2) Pin 10 (IO1) Short to VDD / GND VDD = 3.3V,5V	32		70	mA
$V_{OH\_OUT2\_PWM}$	Output high voltage Push-pull mode Pin 12 (OUT2)	VDD= 3.3V	2.64			V
		VDD= 5V	4			V
$V_{OL\_OUT2\_PWM}$	Output low voltage Push-pull mode Pin 12 (OUT2)	VDD= 3.3V, 5V			0.4	V
DC_{PWM}	PWM duty cycle	Normal operation	5.56		94.44	%
DC_{PWM_DHI}	PWM duty cycle	Diagnostic low mode		2.78		%
DC_{PWM_DLO}	PWM duty cycle	Diagnostic high mode		97.24		%
ft_{PWM}	PWM frequency tolerance		-5		5	%
t_{PWM_r}	PWM output rising edge, push-pull mode.	Load capacitance 4.7nF Output voltage rising from 10% to 90% @ 5V			5	us
t_{PWM_f}	PWM output falling edge, push-pull mode	Load capacitance 4.7nF Output voltage falling from 90% to 10% @ 5V			5	us
$R_{PULL-UP}$	Output Pull-up Resistance		1	2	10	kΩ

[1] With digital mode configuration (out1_drv="10")

[2] With OUT2 fast configuration (out2_io1_drv="11")

3. Detailed Description

3.1 Overview

The RAA2P4200 sensor IC is designed to drive a single transmitter coil and receive signals from one pair of receiver coils, typically created as traces on a printed circuit board. The receiver coils consist of two wire loops connected in anti-serial fashion, with the “sine” and “cosine” coils shifted by 90 electrical degrees. A metal target is placed above this coil arrangement.

When the IC drives an AC current into the transmitter coil, it generates an alternating magnetic field. This magnetic field induces secondary voltages in the receiver coils. Without a target, the induced voltages in the loops of the receiver coils cancel each other out, resulting in a net receiver voltage of zero.

When a metal target is placed above the coils, the magnetic field generates eddy currents on its surface. These eddy currents create a counter magnetic field, reducing the total flux density underneath. This leads to a reduction in the voltage induced in the receiver coil areas underneath the target, creating an imbalance in the anti-serial coil segment voltages.

The IC demodulates, offsets and corrects the amplitude of the signals from the two receiver coils with a 90° electrical phase shift design, which generates sine and cosine shaped voltages as the target is moving.

The RAA2P4200 IC amplifies, rectifies, and filters the receiver voltages, converting them into digital representation with an ADC. The digital sine and cosine signals are converted into a 0°to 360° absolute position. The signal accuracy can be further enhanced through a 2-dimentional,16-point linearization process.

The absolute position can be read over I2C interface, or PWM, or analog output.

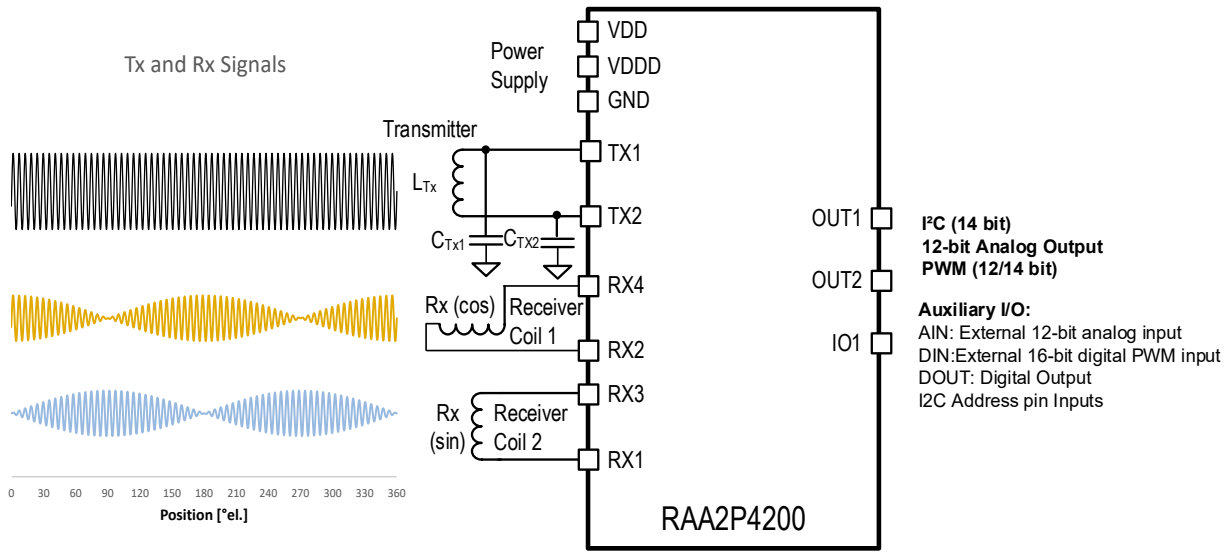


Figure 3. RAA2P4200 Input/Output Signals

3.2 Block Diagram

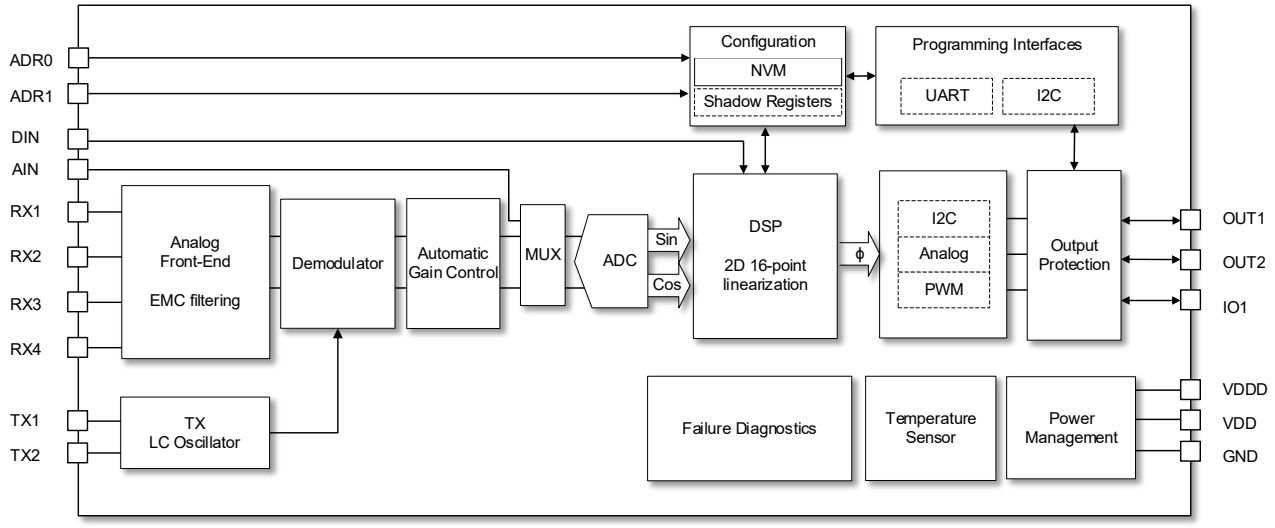


Figure 4. Block Diagram

The main building blocks include:

- Analog front-end: Input EMC filter, offset, and gain control for the receiver signals.
- Demodulator: Converting RF modulated position signals to LF demodulated raw sine and cosine signals.
- Automatic Gain Control: Automatically adjusts the raw sine and cosine signal levels.
- High Speed ADC: Converts raw signals into digital format for further processing.
- Digital signal processing: Converts digital sine and cosine raw signals into synchronized absolute position information.
- 2D 16-point linearization: Supports up to 16 two-dimensional linearization points with freely programmable X- and Y- coordinates for each point (X= Position input, Y= Position output).
- Analog, I2C, PWM: Carries out post processing, clamping, signal integrity checks, and decodes channel information and other diagnostics information into the selected output format.
- TX Oscillator: Generates the transmitter coil signal.
- Temperature sensor: Internal temperature sensor used for chip diagnostics.
- Protection: All outputs are fully protected against overvoltage, reverse polarity and short circuit, enabling direct cable connection to these outputs and eliminating the need for additional line driver ICs.
- Power Management: Operates with supply voltages ranging from 3.0V to 5.5V. External capacitors are required for the supply voltage VDD, and for the digital power supply, VDDD.
- Programming interface: Accessible via one-wire UART interface or I2C interface.
- Configuration, NVM: Stores non-volatile storage for factory and user-programmable settings. User configuration parameters can be programmed multiple times.
- On-chip failure diagnostics: Performs internal diagnosis of critical blocks.
- ADR: Selects the address input for the I2C interface, see Table 19.
- Auxiliary I/O including DIN (Digital input), AIN (12-bit analog input for external analog signals), DOUT (Diagnostic Output) accessible over I2C interface.

3.3 LC Oscillator

The transmitter circuit of the RAA2P4200 generates the required RF magnetic field for operating the sensor as determined by an external parallel LC circuit, see Figure 5. To ensure low emission of harmonics, the capacitive part of the LC circuit is split into two equal-value capacitors: C_{Tx1} and C_{Tx2}. Additionally, two series resistors R_{Tx1} and R_{Tx2} are added as shown Figure 5.

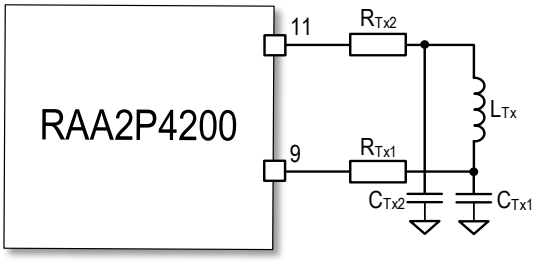


Figure 5. TX LC Oscillator Connection

3.3.1 Parallel LC Resonator Calculations

A resonator, comprising an inductor (L) and a capacitor (C) in parallel, is essential for generating specific frequencies in RF applications. Accurate calculations of the equivalent parallel resistance (R-Peq) ensure proper resonator function. In the RAA2P4200 transmitter circuit, this resonator minimizes harmonic emissions.

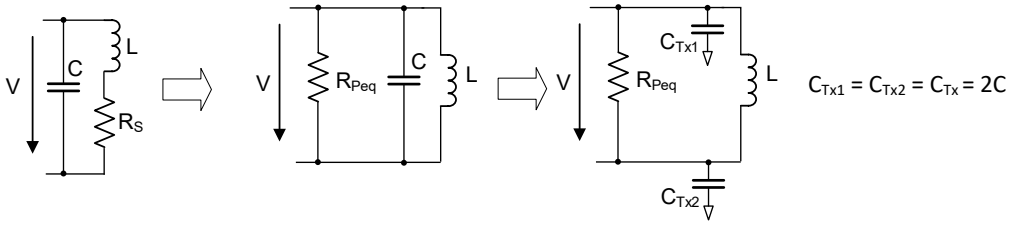


Figure 6. Parallel Resonator Circuit

Equivalent parallel resistance from Coil series resistance:

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

For $C_{Tx1} = C_{Tx2} = C_{Tx} = 2C$:

$$R_{Peq} = \frac{1}{R_S} \times \frac{2 \times L}{C_{Tx}}$$ **Equation 2**

Equivalent parallel resistance from Quality factor Q:

$$R_{Peq} = Q \times \sqrt{\frac{L}{C}} = Q \times \sqrt{\frac{2L}{C_{Tx}}}$$ **Equation 3**

Ideal LC Oscillator frequency with split Tx capacitors C_{Tx}

$$f_{TX} = \frac{1}{2\pi\sqrt{L\frac{C_{Tx}}{2}}}$$ **Equation 4**

Oscillator frequency with split Tx capacitor C_{Tx} and coil series resistor R_s

$$f_{TX} = \frac{1}{2\pi}\sqrt{\frac{2}{LC_{Tx}} - \left(\frac{R_S}{L}\right)^2}$$ **Equation 5**

Oscillator frequency with split Tx capacitor C_{Tx} and equivalent parallel resistor R_{Peq}

$$f_{TX} = \frac{1}{2\pi}\sqrt{\frac{2}{LC_{Tx}} - \left(\frac{2}{R_{Peq}C_{Tx}}\right)^2}$$ **Equation 6**

$$Q = R_{Peq}\sqrt{\frac{C}{L}} = \frac{1}{R_S}\sqrt{\frac{L}{C}}$$ **Equation 7**

Coil quality factor

$$Q = \omega\frac{L}{R_S} = 2\pi f_{TX}\frac{L}{R_S}$$ **Equation 8**

Where:

R_{Peq}	Equivalent parallel resistance of the LC circuit at the transmitter frequency in Ohms
R_S	Serial resistance of the transmitter coil at the transmitter frequency in Ohms
f_{Tx}	Resonant circuit frequency in Hertz, 1/s
L	Resonant circuit coil impedance in Henry
C	Resonant circuit capacitance in Farad
C_{Tx1}, C_{Tx2}	Capacitance of the split capacitors in Farad
Q	Resonant circuit quality factor (unitless)
ω	Angular frequency $2*\pi*f_{Tx}$ in Hertz, 1/s

3.4 Coil Design

Figure 7 shows an example of a linear motion sensor with one transmitter coil (transmitter loop) and two receiver coils (Sin loop and Cos loop). Due to the alternating clockwise and counterclockwise winding direction of each segment in a loop (for example RxCos = clockwise Cos Loop1 + counterclockwise Cos Loop 2), the induced voltages in each segment have alternating opposite polarity.

$$V_{Cos\ Loop1} = -V_{Cos\ Loop2}$$ **Equation 9**

In the absence of a target, the secondary voltages balance out as follows:

$$V_{Cos} = V_{Cos\ Loop1} - V_{Cos\ Loop2} = 0V$$ **Equation 10**

With a target placed above the coils, the secondary voltage induced in the covered area decreases compared to the secondary voltage when no target is present above it.

$$V_{Cos\ Loop1} \neq -V_{Cos\ Loop2}$$ **Equation 11**

This creates an imbalance of the secondary voltage segments, and thus, a secondary voltage ≠ 0V is generated, depending on the location of the target.

$$V_{Cos} = V_{Cos\ Loop1} - V_{Cos\ Loop2} \neq 0V$$

Equation 12

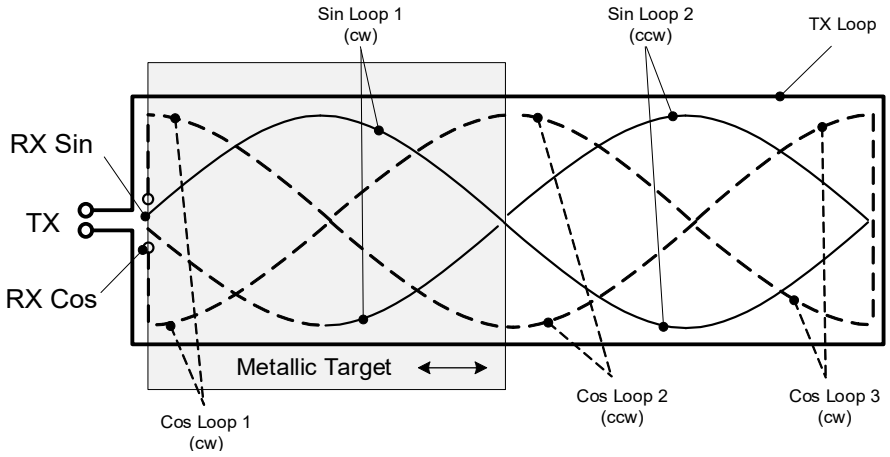


Figure 7. Coil Design for a Linear Motion Sensor

The same principles shown for the linear motion sensor can be applied to a rotary sensor as shown in Figure 8.

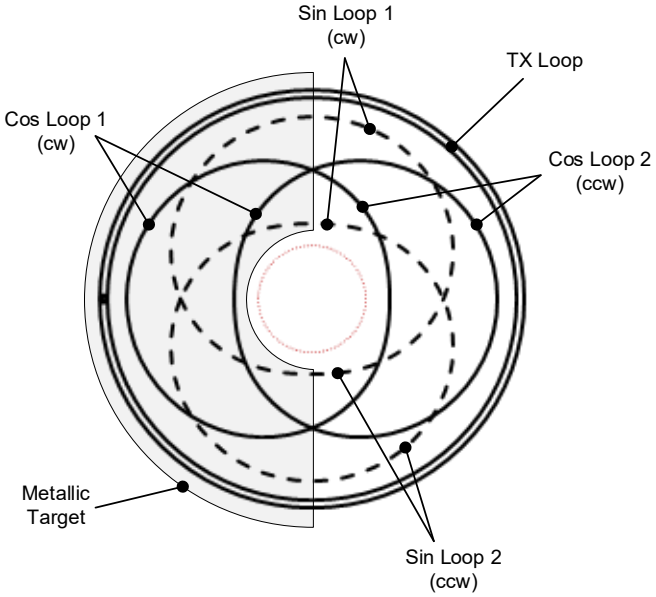


Figure 8. Coil Design for a 360° Rotary Sensor

3.4.1 Multi-periodic Coil Design Application Examples

Applying the same fundamental design principles, coils with multiple periods per turn can be designed. Multi-periodic designs improve mechanical accuracy compared to single-periodic coil designs. For example, a 4-periodic coil design (4 × 90°) improves mechanical accuracy by a factor of 4. Consequently, for angular designs, requiring < 360° movement range, coil designs with multiple periods are recommended.

3.4.2 Electrical vs. Mechanical Degrees

The RAA2P4200 converts the movement of a target across a single period of the receiver coil into a precise electrical signal. This conversion spans the full angular range from 0°to 360°, producing a digital output ranging from 0 to (2^N-1) LSBs. The position output is thus absolute over a full turn of 360 mechanical degrees.
As illustrated in Figure 9, the single-periodic coil design establishes a direct 1:1 relationship between electrical and mechanical domains as the following:

- Coil Period: 360° electrical
- Mechanical Range: 360° mechanical
- Conversion Factor: 1:1 (1°el. = 1° mechanical)

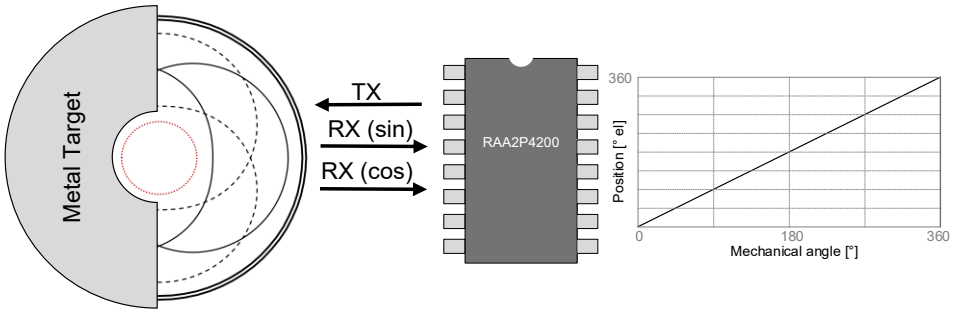


Figure 9. Coil Design Using Single-Periodic Coil

As illustrated in Figure 10, a coil design with four receiver coil periods within a single full mechanical turn, results in four electrical rotations for every complete mechanical turn and provides the following advantages in accuracy and resolution.

- Higher Resolution: Position output resolution increases proportionally with period count by

$$\text{Mechanical Resolution} = \text{Sensor\_Periods} * \text{Electrical Resolution}$$

  In this configuration one electrical degree (°el) equals 0.25 mechanical degrees (°). The provided output resolution is four times higher compared to the single-periodic design

- Improved accuracy: Mechanical error is reduced by the period factor

$$Mechanical\ Error = \frac{Electrical\ Error}{Sensor\ Periods}$$

This configuration is particularly well-suited for:

- Multi-pole motors requiring precise commutation
- Limited-range applications (<180° mechanical travel)
- Systems demanding high-resolution incremental feedback

Select the number of periods based on application requirements to optimize measurement performance. Proper period selection is critical for achieving maximum system accuracy.

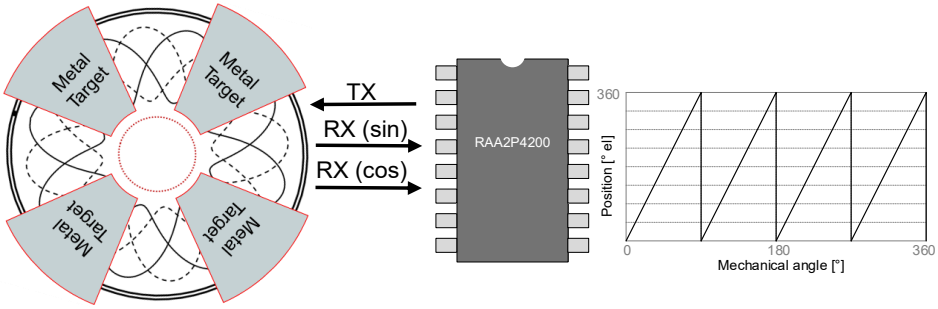


Figure 10. Coil Design Using 4-Periodic Coil

4. Linearization

The RAA2P4200 offers a very flexible linearization feature to enhance sensor accuracy. The linearization algorithm is applied digitally after an angle calculation. The linearization is performed with 12-bits resolution over a 360° electrical range (el.). Up to 16 programmable linearization points can be positioned within a grid of 0.088° in both X (position) and Y (expected output) directions.

Figure 11 illustrates an example of the impact of linearization, showing that the total error is significantly reduced.

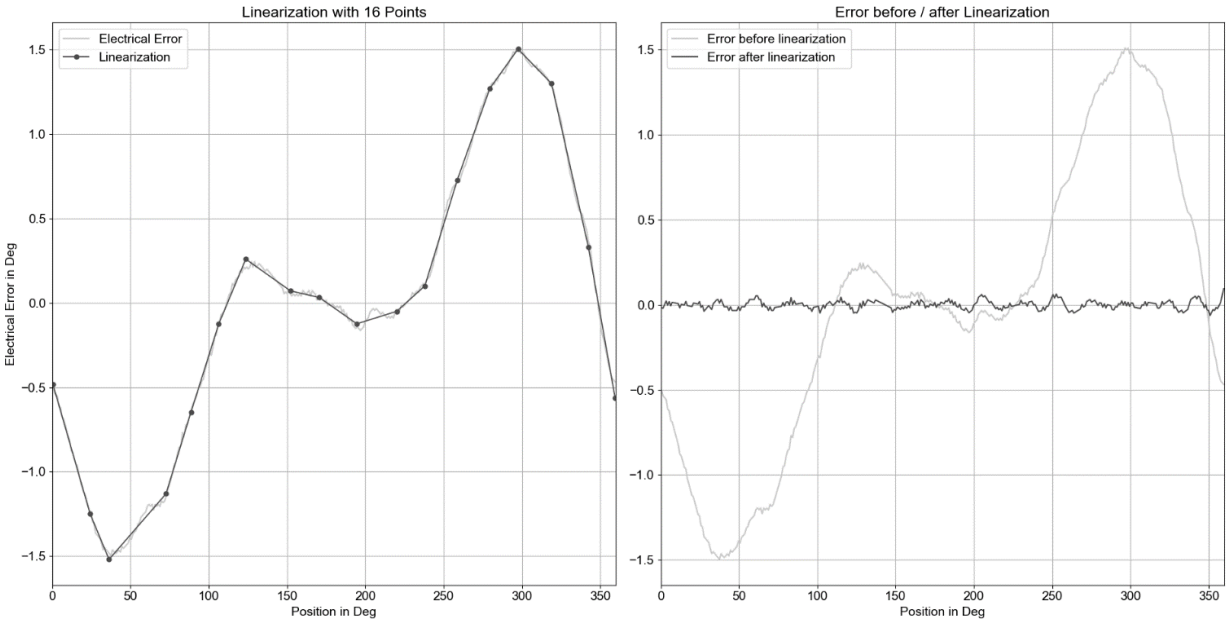


Figure 11. Example of 16-Point Linearization

Table 12. Linearization Parameters

Symbol	Parameter	Conditions	Minimum	Typical	Maximum	Units
N_{P_Lin}	Number of linearization points				16	
$Grid_{LIN}$	Placement grid of linearization points	In X and Y		0.088		°el
Res_{Lin}	Resolution of linearization transfer function	X and Y coordinates		12		bits

Note: The slope of each segment ($\Delta Y / \Delta X$) is automatically calculated from the X and Y parameters of adjacent linearization points. If two adjacent points are positioned with a slope outside the specified range (see Table 12), the slope is reset to 0 to prevent an overflow of the calculated slope value.

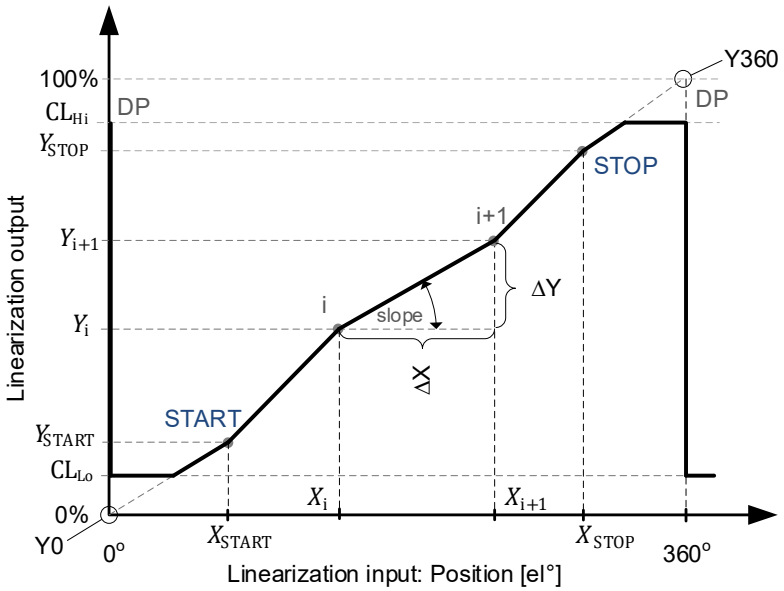


Figure 12. Linearization Transfer Function Parameters

Table 13. Linearization Parameter Settings

Parameter	Description	Programming Options	Resolution
P_{Lin}	Number of linearization options	0,2,4,6,8,16	
D_P	Discontinuity point, Zero position transition from 0°/360°	0° to <360° el.	0.088°el. per LSB
X_{Start}	Mechanical start position, first linearization point		
Y_{Start}	Expected output at XStart, first linearization point		
X_i	Mechanical position of linearization point (i = 1 to 16, including start and stop)		
Y_i	Expected output at linearization point (i = 1 to 16 including start and stop)		
X_{Stop}	Mechanical end position, last linearization point		
Y_{Stop}	Expected output at XStop, last linearization point		
CL_{Hi}	Output Clamping level, high	0% to 100% VDD	12 bits (VDD / 4096) per LSB
CL_{Lo}	Output Clamping level, low		
Y0	Position at DP, start value at X = 0°	0° / 360° el.	
Y360	Position at DP, stop value at X = 360°	0° / 360° el.	

5. Interfaces

The RAA2P4200 offers an I2C that can reach 400 KHz, an Analog Output and a PWM interface. A summary of the maximum speed for each high-speed interface is shown in Table 14.

Table 14. Interfaces Overview

Interfaces	Number of I/f Wires	Resolution	Features	Other Options
I2C	2	14 bit	Interface speed: 400KHz Fastest position update rate 5.4KHz	Digital Output (pin 13)
Analog Output	1	12 bit	Analog out Position update rate: 20KHz	Digital Output (pin 12)
PWM	1/2	12 / 14 bit	PWM output (push-pull or open drain) PWM frequency: 109 Hz to 4376 Hz	Digital Output (pin 12)

5.1 I2C Interface

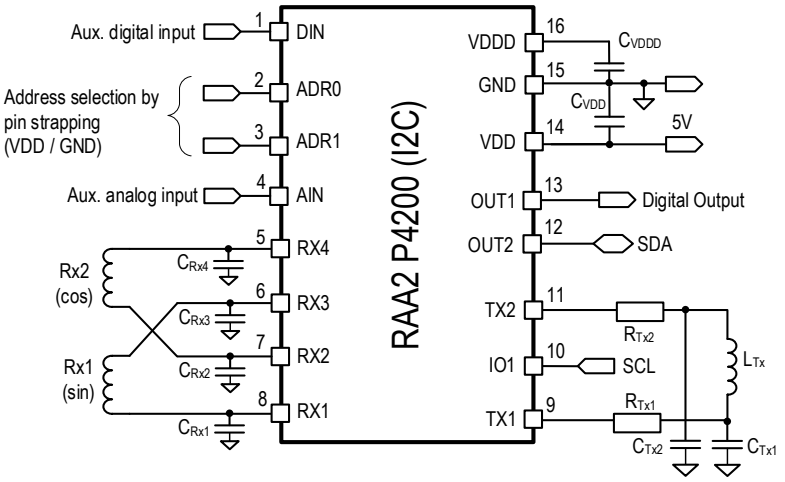


Figure 13. I2C Interface Input/Output Pins

The RAA2P4200 can be programmed for an I2C interface according to the UM10204 I2C-bus specification, utilizing pins 10 (SCL) and 12 (SDA) to address up to 14 slaves over the same 2-wire interface. The interface does not support clock stretching, 10-bit slave address, general call address, software reset, or device ID.

5.1.1 I2C Addressing

The I2C address is programmable in the NVM, and two hardware address select pins, pin 2 (ADR0) and pin 3 (ADR1), provide interface address selection by hardware pin strapping.

Figure 14 shows an example where one device is pin strapped to I2C address 0x72, while the second device is pin strapped to address 0x70. Once each device is separately selected, it can be addressed using its unique NVM I2C address.

Table 15. I2C Interface User Programming Options

I2C Programming Parameter	Number of Options	Programming Option
I2C slave address	14	See Table 16
I2C address select by pin strapping	1	Enable/Disable (2 LSBs)
I2C CRC check for Rx data	1	Enable/Disable
I2C CRC check for command data	1	Enable/Disable
I2C protocol error detection	1	Enable/Disable

Table 16 details the various options for selecting the I2C Address, utilizing combinations of pin addressing and NVM address register setting.

Table 16. I2C Address Selection Options in NVM

Address Selection Mode	A6	A5	A4	A3	A2	A1	A0
Default setting	1	1	1	0	0	Pin 3 = ADR1	Pin 2 = ADR0
User programmable range, with I2C address selection by pins 2 and 3	0x02 to 0x1D					Pin 3 = ADR1	Pin 2 = ADR0
User programmable range, with fixed I2C address	0x08 to 0x77						

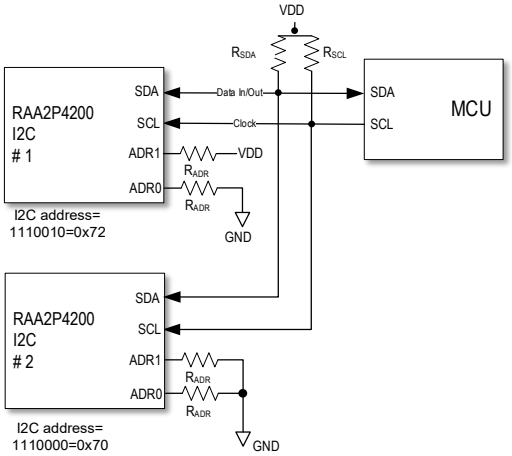


Figure 14. I2C Interface with Address Select

5.1.2 I2C Register Write

To access a register, the slave address must be sent by the master, followed by two bytes of register address (*MemAddr*), one byte of CRC data, and then by the write data *WrData*. If the CRC check is disabled, keep the CRC frame at zero. The write data consists of two bytes of data followed by one byte of CRC data as shown in Figure 15.

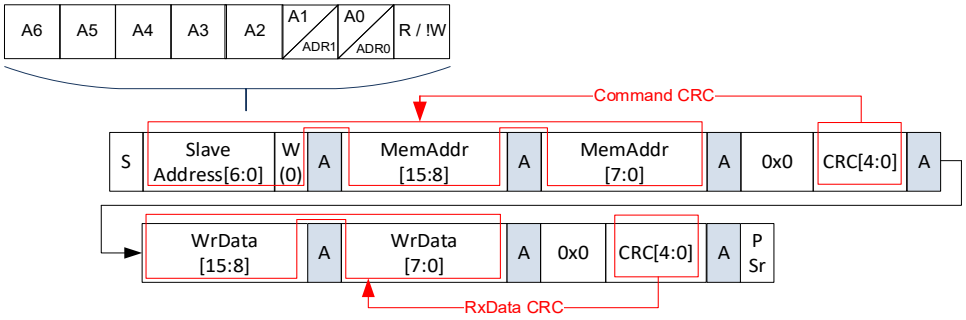


Figure 15. I2C Register Write Access

5.1.3 I2C Register Read

To read a register over the I2C interface, the master sends a write register command frame followed by a repeated start (*PSr*) and slave address with a read bit set. Upon acknowledgement, the device responds with two bytes of data followed by one byte CRC as shown in Figure 16.

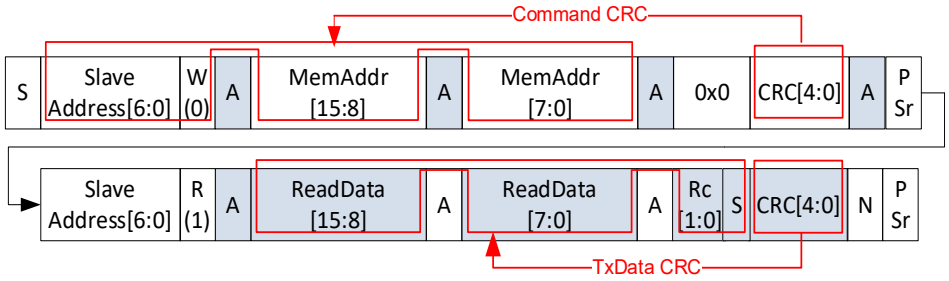


Figure 16. I2C Register Read Access

5.1.4 I2C CRC Check

For optimal communication with the RAA2P4200, it is recommended to enable the CRC check for I2C communication. Enabling it ensures that the device only responds to command frames that include correct CRC data. For more details, please refer to the *RAA2P4200 Programming Manual* document.

5.2 Analog Interface

An analog interface is included to accommodate legacy applications that utilize potentiometers or position sensors with linear ramp output, such as magnetic position sensors.

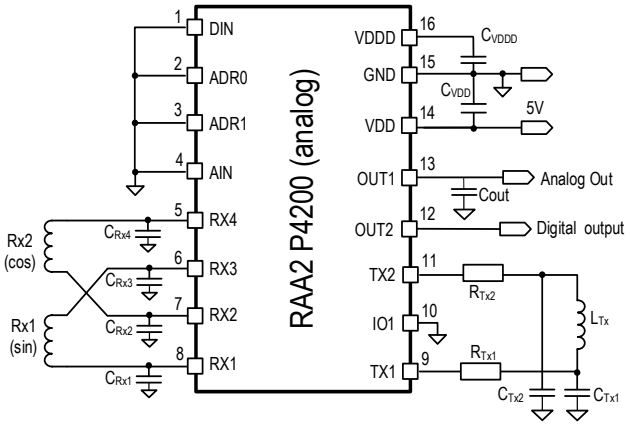


Figure 17. Analog Interface Input/Output Pins

The analog output is generated by converting the digitally processed angle data into an analog voltage through a 12-bit DAC and an analog output buffer. This buffer is protected against overvoltage, reverse polarity, overcurrent, and short circuits to GND and positive supply voltage.

The full electrical 360° range is operational, with programmable clamping levels from 5%VDD to 95%VDD, see Figure 18 and Table 17). The analog position is indicated as a linear ramp between these clamping levels, and the output voltage is ratiometric to the supply voltage VDD, ensuring stability against supply voltage changes.

Adjusting the clamping level limits allows for full range mapping (0° to 360°) over a 5 to 95 VDD% voltage range. Diagnostic mode is indicated by a high-ohmic tri-state mode, detectable as an out-of-range voltage level with external pull-up or pull-down resistors. Broken ground or broken supply condition can also be detected this way.

A separate digital output pin (pin 12) indicates additional information, such as an out-of-range position or out-of-range magnitude or magnitude value (PWM).

Table 17. Analog Interface User Programming Options

Analog Interface Programming Parameter	Number of Options	Programming Option
Output high clamp level	4096	0% to 100% VDD in 12-bit steps
Output low clamp level	4096	0% to 100% VDD in 12-bit steps

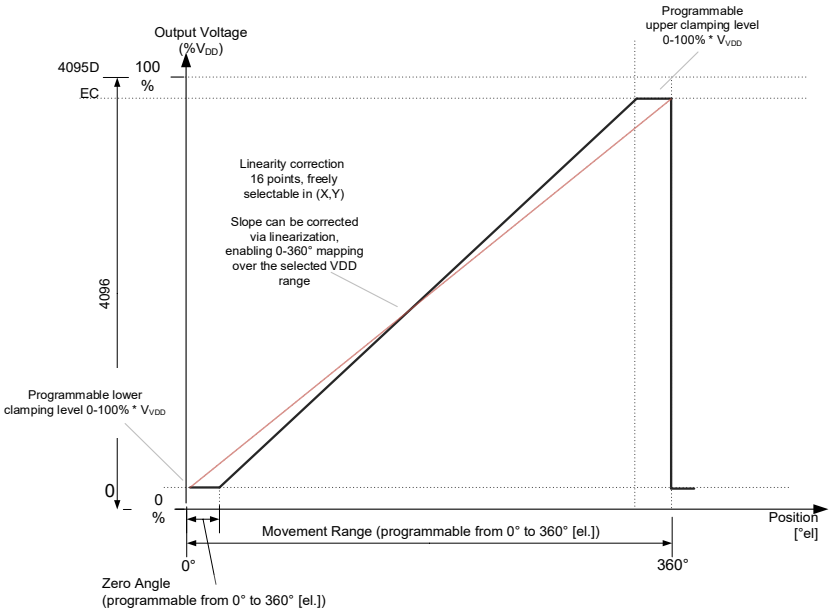


Figure 18. Analog Output Transfer Function

5.3 PWM Interface

The PWM interface can be configured for single wire PWM interface with push-pull or open drain output, as well as a dual wire differential PWM interface with push-pull outputs. In differential mode, an inverted signal is provided on pin 10 as shown in Figure 19.

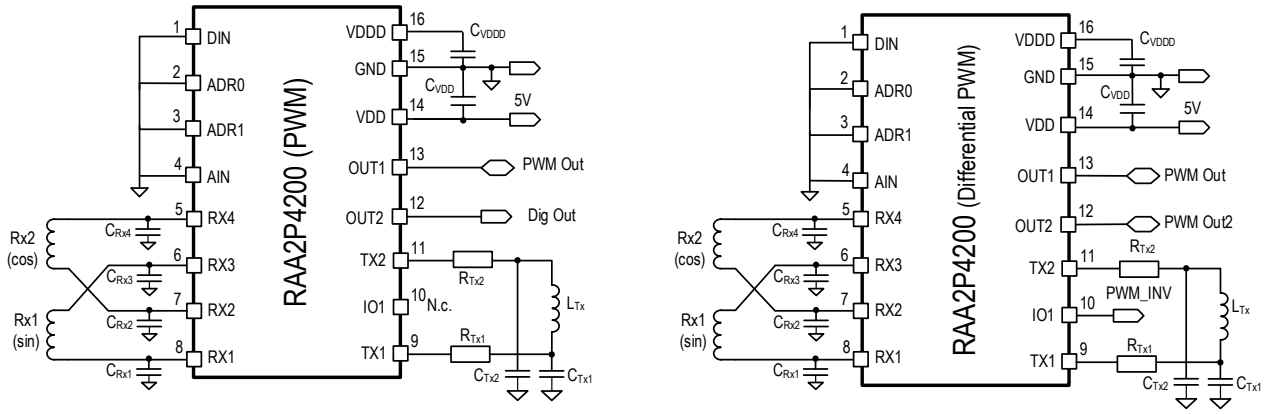


Figure 19. PWM Interfaces (Standard and Differential Mode) Input/Output Pins

Table 18. PWM Interface User Programming Options

PWM Programming Parameter	Number of Options	Programming Option
PWM frequency	8	109Hz, 219Hz, 547Hz, 1094Hz, 1641 Hz, 2188Hz, 3282Hz, or 4376Hz
PWM output mode	2	Push-pull or Open-drain
PWM polarity	2	Position information is Active Low or Active High
PWM resolution	2	12-bit (all PWM frequencies) or 14-bit (PWM frequencies: 109Hz to 1094Hz)
Diagnostic mode indicated by PWM signal	3	Disabled, Diagnostic mode enabled with low duty cycle, Diagnostic mode enabled with high duty cycle

The 12-bit non-inverted PWM signal frame consists of a 256 LSB high level header, followed by the 12-bit Position Data, which ranges from 0 to 4095 LSBs high-level and the corresponding number of low-level LSBs to complete a total length of 4095 LSBs. The frame is terminated with a 256 LSBs low-level trailer as shown in Figure 20. The PWM signal can also be inverted, resulting the signal frames shown in Figure 20 and Figure 21.

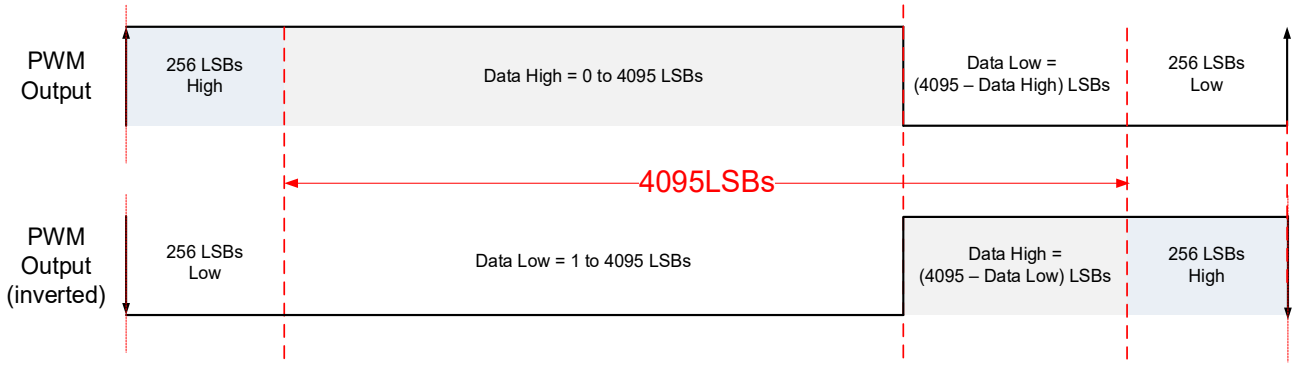


Figure 20. 12-bit PWM Signal in Normal Operation Mode

The minimum 12-bit duty cycle can be calculated with Position data = 0 LSB high, 4095 LSBs low:

Equation 13

$$DC_{min} = \frac{t_{ON}}{t_{ON} + t_{OFF}} = \frac{256}{256 + (4095 + 256)} = 5.557\%$$

The maximum 12-bit duty cycle can be calculated with Position data = 4096 LSBs high, 0 LSBs low:

Equation 14

$$DC_{max} = \frac{t_{ON}}{t_{ON} + t_{OFF}} = \frac{256 + 4095}{(256 + 4095) + 256} = 94.443\%$$

The 14-bit PWM signal frame shown in Figure 21 is structured similarly to the 12-bit PWM signal frame shown in Figure 20, with the key difference being an increased resolution by a factor of 4.

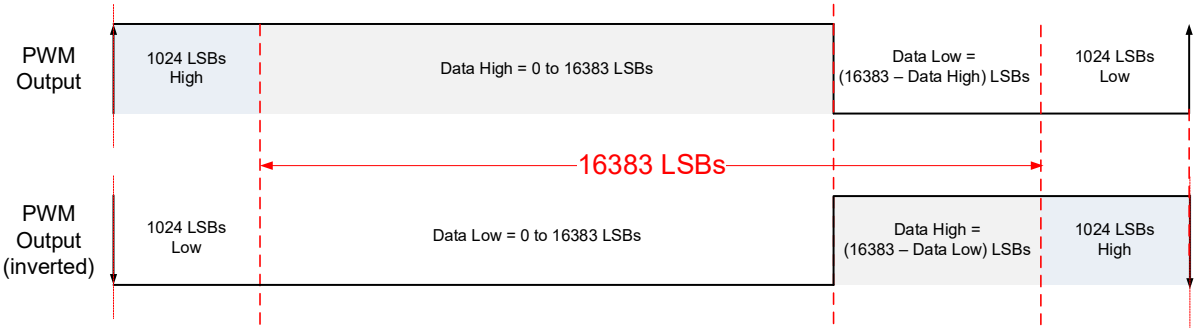


Figure 21. 14-bit PWM Signal in Normal Operation Mode

The minimum 14-bit duty cycle can be calculated with Position data = 0 LSB High, 16383 LSBs low:

Equation 15

$$DC_{min} = \frac{t_{ON}}{t_{ON} + t_{OFF}} = \frac{1024}{1024 + (16383 + 1024)} = 5.556\%$$

The maximum 14-bit duty cycle can be calculated with Position data = 16384 LSBs High, 0 LSBs low:

Equation 16

$$DC_{max} = \frac{t_{ON}}{t_{ON} + t_{OFF}} = \frac{1024 + 16383}{(1024 + 16383) + 1024} = 94.44\%$$

5.3.1 PWM Diagnostics Mode

In PWM diagnostics mode, the duty cycle is forced to a range not utilized in normal operation. This mode can be configured as the following:

- Diagnostic low mode, see Figure 22 and Figure 24;
- Diagnostic high mode, see Figure 23 and Figure 25;

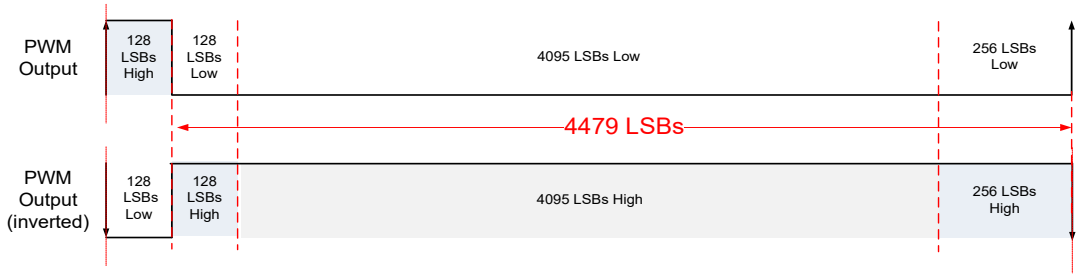


Figure 22. 12-bit PWM Signal in Diagnostics Low Mode

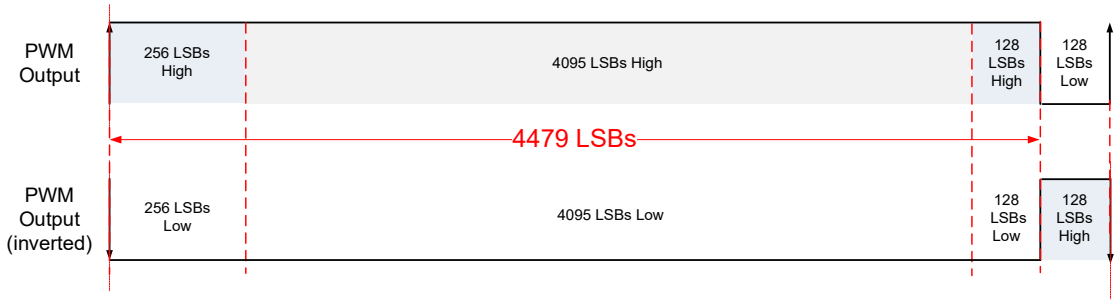


Figure 23. 12-bit PWM Signal in Diagnostics High Mode

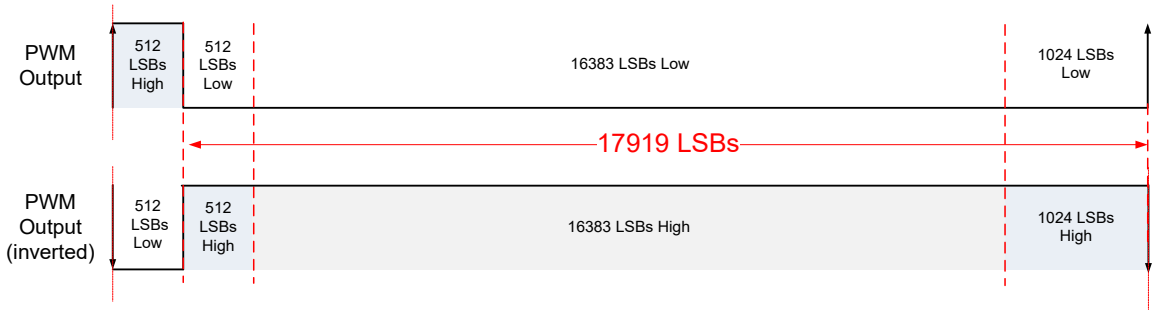


Figure 24. 14-bit PWM Signal in Diagnostics Low Mode

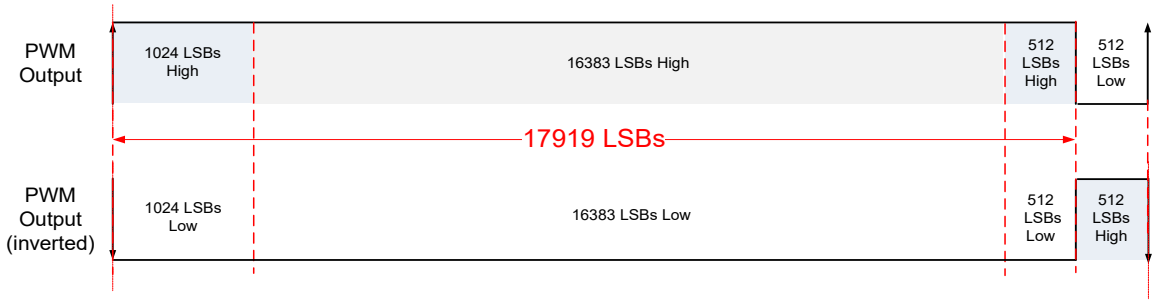


Figure 25. 14-bit PWM Signal in Diagnostics High Mode

5.4 UART Single Wire Programming Interface

Any user programmable parameter can be accessed through the single wire programming process, using a half-duplex UART protocol.

Performing an end-of-line calibration or in-line programming of a position sensor module containing the RAA2P4200, requires no additional wires. The chip is programmed through the OUT1 output at the operative supply voltage range (5V ±10%, 3.3V ±10%).

A short programming window is enabled after POR and requires a digital unlock password to enable programming. If no password is sent, the chip resumes its normal operating mode.

For more details, please refer to the *RAA2P4200 Programming Manual* document.

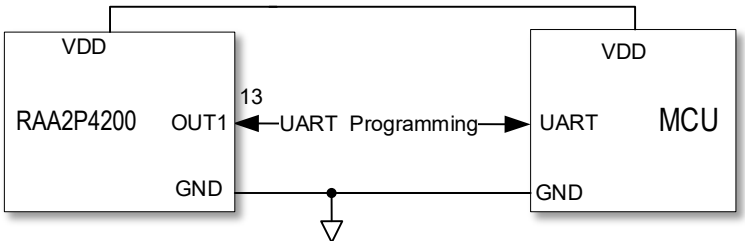


Figure 26. UART Single Wire NVM Programming

5.4.1 Lock Feature

The RAA2P4200 includes a user configurable lock bit option, which can be set to restrict write and/or read access. Once the lock bits are enabled, further write or read operations to the RAA2P4200 are prohibited. Note that once a RAA2P4200 part is locked, it cannot be unlocked.

For more details, please refer to the *RAA2P4200 Programming Manual* document.

6. Auxiliary Inputs and Outputs

Two auxiliary inputs are available for connecting external devices with analog or digital PWM interface, that can be read through the I2C interface. Further, a digital output pin is available indicating user programmable features. A summary is shown in Table 19.

Table 19. Auxiliary Inputs and Digital Output Options

Interface	Analog Input	Digital Input	Digital Output				
			Range Alarm (OD)	New Position Flag (OD)	Register Flag (OD)	Magnitude Alarm (OD)	Magnitude PWM (PP/OD)
I2C	Yes (pin 4)	Yes (pin 1)	n/a	Yes (pin 13)	Yes (pin 13)	n/a	n/a
Analog	n/a	n/a	Yes (pin 12)	n/a	n/a	Yes (pin 12)	Yes (pin 12)
PWM	n/a	n/a	Yes (pin 12)	n/a	n/a	Yes (pin 12)	n/a
Differential PWM	n/a	n/a	n/a	n/a	n/a	n/a	n/a

6.1.1 Digital Input

The digital input (DIN) available on pin 1 can read both a static (high/low) signals and PWM input signals. A PWM input signal is processed through two 16-bit timer registers: one register captures the duration of the low state of the input signal, the other the high state. The timer is programmable by setting the appropriate pre-scaler.

Table 20. Digital Input

Symbol	Parameter	Conditions	Minimum	Typical	Maximum	Units
RES_{PWMHI}	Resolution of PWM input high register	Duration of PWM input = high		16		bits
RES_{PWMLO}	Resolution of PWM input low register	Duration of PWM input = low		16		bits
$t_{PWM\_IN\_PRSC}$	Clock timing for PWM input timer pre-scaler	Setting 1x, per LSB	15.3	16.5	17.4	ns
		Setting 2x, per LSB	30.6	33	34.8	
		Setting 4x, per LSB	61.2	66	69.6	
		Setting 8x, per LSB	122.4	132	139.2	

The PWM code can be calculated externally by:

$$PWM_{code} = \frac{timer_{LOW} + timer_{HIGH}}{timer_{LOW}}$$ for an active low PWM signal **Equation 17**

$$PWM_{code} = \frac{timer_{LOW} + timer_{HIGH}}{timer_{HIGH}}$$ for an active high PWM signal **Equation 18**

The absolute accuracy of the timer pre-scaler is not critical, because the PWM is calculated ratiometrically, as outlined in Equation 18 and Equation 17. Depending on the setting of the pre-scaler (1, 2, 4, 8), the high/low level of the PWM input signal can reach a length up to 2^{16} = 65536 counts of the pre-scaler time.

6.1.2 Analog Input

The analog input available on pin 4 (AIN) can be used to read analog voltages coming from external sensors via I2C interface. See Table 21 for the key parameters of this input. The analog value must be in relation to VDDD.

Table 21. AIN Analog Input Parameters

Symbol	Parameter	Conditions	Minimum	Typical	Maximum	Units
V_{IN_AIN}	AIN voltage range		0.1		1.2	V
RES_{AIN}	ADC resolution			12		bits
T_{Smp_AIN}	Sampling rate		4.4			kHz
ACC_{AIN}	Analog Input Accuracy		-1.2		1.2	% VDDD

Both the analog input voltage and the VDDD reference voltage are internally measured and stored in registers. The external load on VDDD cannot exceed 4 mA as specified in Table 4.

6.1.3 Digital Output

An optional digital output is available and can be configured for various functions, depending on the selected interface, as shown in Table 19.

6.1.3.1 New Position Flag

In this mode, available for I2C configuration, the output indicates when a new position is internally calculated and available. When a new position is available, the new position flag on DOUT is set and is reset by a read command performed over an I2C read command.

6.1.3.2 Register Flag

In this mode, available for I2C configuration, the DOUT output can be used to drive external circuits on pin. It is controlled by writing either of the following options to the address 0x029E [0]:

- Register bit 0: FLG output is low
- Register bit 1: FLG output is high

This function can be integrated with a heartbeat feature to provide diagnostic status information alongside the flag value. This status is indicated by a 1.5KHz pulse, see Figure 27 with a duty cycle of 97% when the flag is high and 3% when the flag is low.

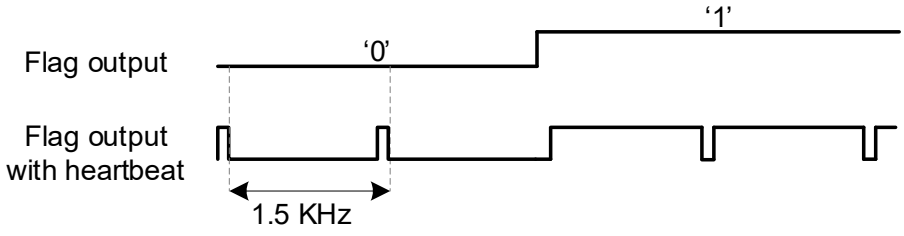


Figure 27. Flag Output Configurations

6.1.3.3 Magnitude Information over PWM

If the analog interface is selected, the magnitude information of the receiver coils is available in PWM format on the digital output with the same 12-14 bit resolution as described in section 5.3.

7. On-Chip Diagnostics

The RAA2P4200 includes on-chip diagnostics featuring an extensive number of internal Diagnostic Monitors (DM).

For detailed description, see the *RAA2P4200 Programming Manual* document.

Table 22. Diagnostic Parameters

Symbol	Parameter	Conditions	Minimum	Typical	Maximum	Units
T_{FDTI}	Failure detection time interval (time to detect and internally set a flag describing the error condition)	fdti_cfg=1			2.3	ms
		fdti_cfg=0			20	ms

Table 23. Diagnostic Monitors

Category	Diagnostic Monitors	Description
Monitoring of external supply	VDD Monitor	External VDD supply out of range
Monitoring of internal supplies	VDDA Monitor	Internal VDDA (Analog supply) out of range / undervoltage /overvoltage
	VDDD Monitor	▪ Internal VDDD (Digital supply) out of range ▪ Short on VDDD ▪ Overcurrent at VDDD pin
	Internal Supply Monitor	Internal supply out of range
	Internal pre-regulators Monitor	▪ Internal pre-regulator for power management (bandgap, analog parts) out of range ▪ Internal pre-regulator for output stages out of range
	Driver Regulator Monitor	OUT2 regulator driver out of range
	Oscillator Regulator Monitor	LC oscillator regulator out of range
	Bias Current Monitor	Bias current diagnostic out of range
Monitoring of RX coils	RX coil Sine Monitor	▪ Short of the RX vs GND or VDD ▪ Broken wire detected on RX SIN
	RX coil Cosine Monitor	▪ Short of the RX vs GND or VDD ▪ Broken wire detected on RX COS
	RX coil Sine/Cosine neighbor inputs short	Short check between Sine/Cosine coil set detected
Monitoring of TX coils	TX Voltage Monitor	▪ Common mode voltage of TX1/TX2 out of range ▪ Flag for broken pins of LC oscillator
	LC Oscillator Monitor	▪ LC oscillator stuck detected ▪ LC oscillator frequency out of range
Monitoring of system clock	System clock Monitor	▪ Fault in internal system clock: frequency out of range ▪ Fault in internal system clock: stuck detected
Monitoring of the internal communication channel	Internal digital logic failure Monitor	Internal digital logic failure detected such as APB Diagnostic failure, IC internal registers failure, FSM failure, CORDIC failure, other digital failures.
Monitoring the internal memory	Non-Volatile Memory Monitor	▪ CRC mismatch over the NVM or internal shadow register ▪ NVM read timeout fail
Data path diagnostics	Data path WD/OF/UF/DO Monitor	Internal errors, such as overflow, underflow, division by 0, or watchdogs
Position Range Monitoring	Position Range Monitor	Position outside of the defined range failure
Temperature monitoring	Temperature Monitor	▪ Temperature warning detected ▪ Temperature error (shutdown) detected

Category	Diagnostic Monitors	Description
Magnitude evaluation	Magnitude static Monitor	Magnitude static check error detected on RX coils
Monitoring of analog signal path offset	ADC temperature sensor offset fail Monitor	Compensation of the internal offset not sufficient
Monitoring of the mechanical stress /cracks	Broken chip check Monitor	IC die mechanical failures detected
LPF check for signal path	LPF Monitoring	Failure in internal LPF
AGC monitoring	AGC error Monitoring	▪ Automatic gain control loop not converging ▪ Pre-defined acceptable gains for the AGC not sufficient for RX
Monitoring of the output interfaces	Output Interfaces monitors	▪ Failure of the I2C interface ▪ Failure of the PWM interface
Analog input	Analog Input Monitoring	Failure on analog input range
OUT2 and IO1 pins monitoring	OUT2/IO1 pins Monitoring	▪ Overvoltage/undervoltage ▪ Short on OUT2/IO1 detection

A fault from a broken or short wire refers to the connection between sensor IC and control unit (MCU, ECU), including the soldering of the IC pins, PCB traces, connectors and cables. In this case, the diagnostic state depends on whether pull-up/pull-down resistors are installed at the receiver side.

7.1 Broken Wires

In analog output mode during normal operation, the analog output can be programmed to operate between VOUT ≥5% VDD and VOUT ≤95% VDD. In case of a diagnostic error, the output is turned off and enters a high-ohmic state. External pull-up/pull-down resistors are pulling the output voltage VOUT outside of its functional operating range thus indicating the error condition.

Most broken supply, broken GND, or analog output signal connection errors can be detected by monitoring the DC voltage levels at the analog output pin AOUT, see the uncritical error cases on Figure 28. If a diagnostic error or broken signal wire occurs, the DC voltage level at the affected pin is pulled into the diagnostic range (diagnostic high: VOUT >95% VDD or diagnostic low: VOUT <5% VDD) through the external pull-up/pull-down resistors.

For the following cases, a parasitic current inside the RAA2P4200 may cause unwanted, too high voltage drops across the pull-up/pull-down resistors. Depending on the value of the external resistor, this may not properly indicate the error condition:

- a broken VDD supply wire with external pull-up resistors at the receiving end, see Figure 28.
- a broken GND wire with external pull-down resistors at the receiving end, see Figure 28.

For these special cases, the maximum resistance value for these resistors must be observed, see Table 24 and Table 25.

Table 24. Diagnostic Levels with Pull-Up Resistors

Diagnostic Level	>96% VDD	Unit
Error indication during normal operation	≤9.1	kΩ
Broken GND line	Not critical, see the uncritical error cases.	kΩ
Broken VDD line, 5V mode	≤2	kΩ
Broken VDD line, 3.3V mode	≤2	kΩ

Table 25. Diagnostic Levels with Pull-Down Resistors

Diagnostic level	<4% VDD	Unit
Error indication during normal operation	≤9.1	kΩ
Broken VDD line	Not critical, see the uncritical error cases.	kΩ
Broken GND line, 5V mode	≤2	kΩ
Broken GND line, 3.3V mode	≤2	kΩ

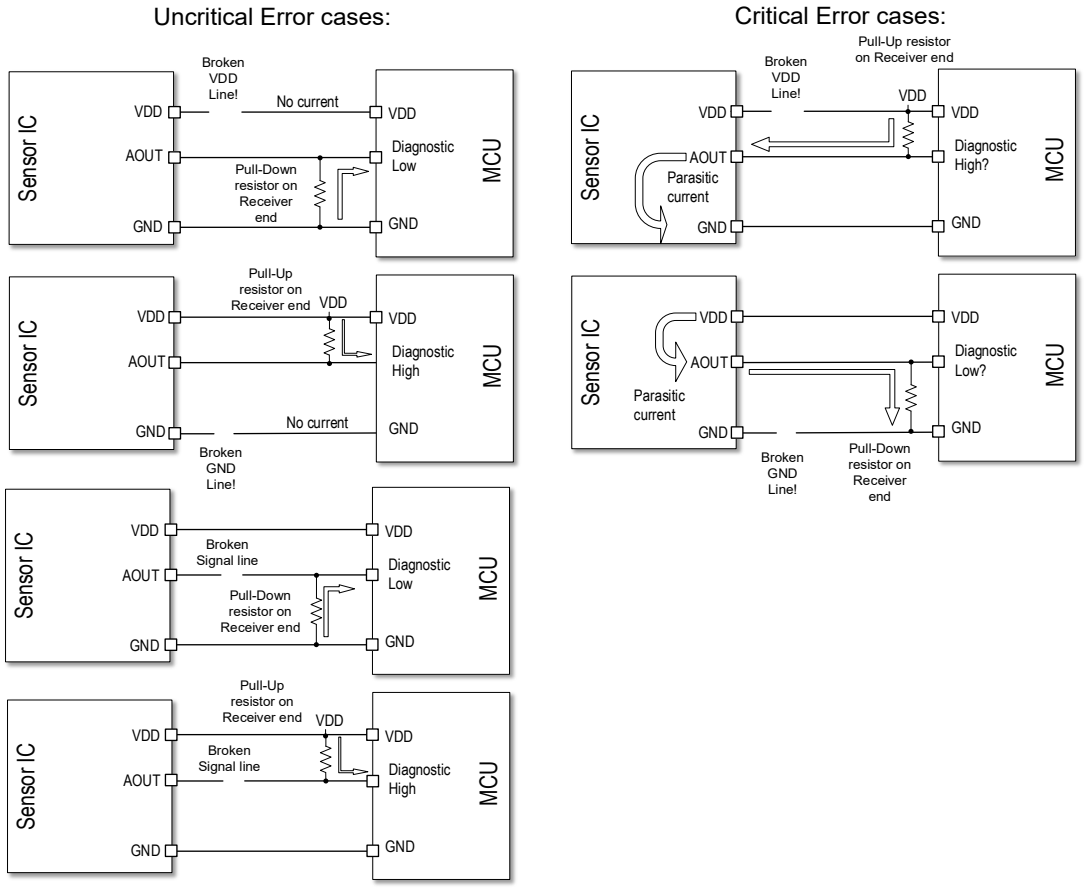


Figure 28. Parasitic Currents on Analog Outputs with Broken VDD or Broken GND Lines

8. User Programming Options

Table 26 shows an extract of the main configuration options. A detailed description is provided in the RAA2P4200 programming manual, available on request from Renesas.

Table 26. Global Programming Options

Programming Option	Number of options	Description
Power supply mode	2	3.3V ±10% or 5.0V ±10%
Interface options	4	I2C, Analog, PWM, PWM differential
Initial receiver gain coil	28	Initial receiver gain
Automatic gain control AGC	2	Enabled/disabled
Hysteresis	8	0 to 112 LSBs
AGC upper and lower alarm limits	2 x 5-bit	Enabled/disabled 5-bit programmable higher/lower gain alert
Position upper and lower limit alarm	12-bit	0° to <360° position range limits that trigger an alarm if exceeded

Programming Option	Number of options	Description
Number of linearization points	16 points	2/4/6/8/16 linearization points, programmable in x and y
Linearization points resolution	12-bit	Up to 16 linearization points are freely programmable in X (position) and Y (value) with 12-bit resolution
Magnitude alarm reference limits	2 x 14-bit	Upper and Lower limits programmability
Zero (discontinuity) point	12-bit	0° to <360° in 12-bit steps, position output switches from maximum to minimum value (with increasing position movement) or from minimum to maximum value (with decreasing position movement) at this position
Sine and cosine signal offset correction	2 x 8-bit	±127 LSBs for sine and cosine
Sine and cosine amplitude mismatch correction	2 x 15-bit	0% to 199% adjustment range per channel
Digital low pass filter	8	Depth of digital low pass filter for position output
Turns counter option	2	Behavior of 12bit turns counter when overflowing: stop at max/min, wrap around
Customer ID	48-bit	Scratchpad register for customer specific data

9. Related Documents

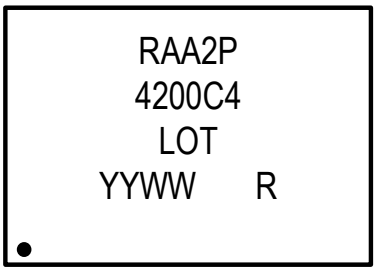
- RAA2P4200 Programming Manual

10. 16-TSSOP Package Outline Drawings

The package outline drawings are accessible from the link below. The package information is the most current data available.

16-TSSOP Package Outline Drawing 4.4mm Body, 0.65mm Pitch PGG16T1

11. Marking Diagram



Line 1: First characters of part code RAA2P
Line 2: Next five characters of the part code:
4200C: Single Coil Low Speed
followed by:
4 = Operation temperature range, Industrial
Line 3: “LOT” = Lot number
Line 4: “YYWW” = Manufacturing date:
YY = last two digits of manufacturing year
WW = manufacturing week
R = RoHS compliant statement

12. Ordering Information

Orderable Part Number	Description and Package	MSL Rating	Carrier Type	Temperature
RAA2P4200C4GSP#HA0	16-TSSOP, 4.4 ×5.0 mm	1	13” Reel, 4000 parts / reel	-40° to +125°C
For communication and programming, Renesas offers a RAA2P4200 Application Modules with a RAA2P-COMBOARD. A development programmer is available separately.				

13. Glossary

Term	Description
AC	Alternating Current
ADC	Analog to Digital Converter
AGC	Automatic Gain Control
APB	Advanced Peripheral Bus
CDM	Charged-Device Model
CORDIC	Coordinate Rotation Digital Computer
CRC	Cyclic Redundancy Check
DC	Direct Current
DP	Discontinuity Point
ECU	Electronic Control Unit
EMC	Electromagnetic compatibility
ESD	Electrostatic Discharge
FSM	Finite-State Machine
GND	Ground
FSM	Finite State Machine
HK	House Keeping
I/O	Input / Output
I2C	Inter-Integrated Circuit Interface
IC	Integrated Circuit
ID	Identification
LC	Resonant Inductor-Capacitor Circuit
LF	Low Frequency
LPF	Low Pass Filter
LSB	Least Significant Bit
MCU	Micro Controller Unit
MSB	Most Significant Bit
MUX	Multiplexer
NVM	Non Volatile Memory
OD	Open Drain
PCB	Printed Circuit Board
PP	Push-Pull
RF	Radio Frequency
RX	Receiver
SCL	I2C Clock
SDA	I2C Data
TSSP	Thin Shrink Small Outline Package
TX	Transmitter
UART	Universal Asynchronous Receiver Transmitter

14. Revision History

Revision	Date	Description
1.1	Dec 8, 2025	Reworked Table 11, Table 7
1.0	Aug 7, 2025	Initial release

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