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AS5161

12-Bit Magnetic Angle Position Sensor

General Description

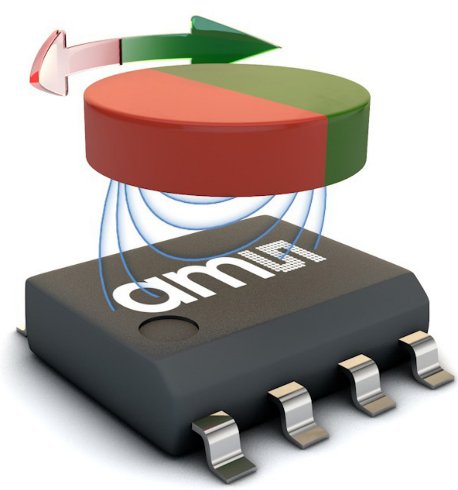
The AS5161 is a contactless magnetic angle position sensor for accurate angular measurement over a full turn of 360°. A sub range can be programmed to achieve the best resolution for the application. It is a system-on-chip, combining integrated Hall elements, analog front end, digital signal processing and best in class automotive protection features in a single device.

To measure the angle, only a simple two-pole magnet, rotating over the center of the chip, is required. The magnet may be placed above or below the IC.

The absolute angle measurement provides instant indication of the magnet's angular position with a resolution of 0.022° = 16384 positions per revolution. According to this resolution the adjustment of the application specific mechanical positions are possible. The angular output data is available over a 12 bit pulse width modulated (PWM) output.

The AS5161 operates at a supply voltage of 5V and the supply and output pins are protected against overvoltage up to +20V. In addition the supply pins are protected against reverse polarity up to –20V.

Figure 1:
Typical Arrangement of AS5161 and Magnet



Ordering Information and Content Guide appear at end of datasheet.

Key Benefits & Features

The benefits and features of AS5161, 12-Bit Magnetic Angle Position Sensor are listed below:

Figure 2:
Added Value of Using AS5161

Benefits	Features
• Great flexibility on angular excursion	• 360º contactless high resolution angular position sensing
• Simple programming	• User programmable start and end point of the application region • Saw tooth mode 1-4 slopes per revolution • Clamping levels • Transition point
• Failure diagnostics	• Broken GND and VDD detection for all external load cases
• High-resolution output signal	• 12-Bit pulse width modulated (PWM) output
• Ideal for applications in harsh environments due to contactless position sensing	• Wide temperature range: - 40°C to 150°C

Applications

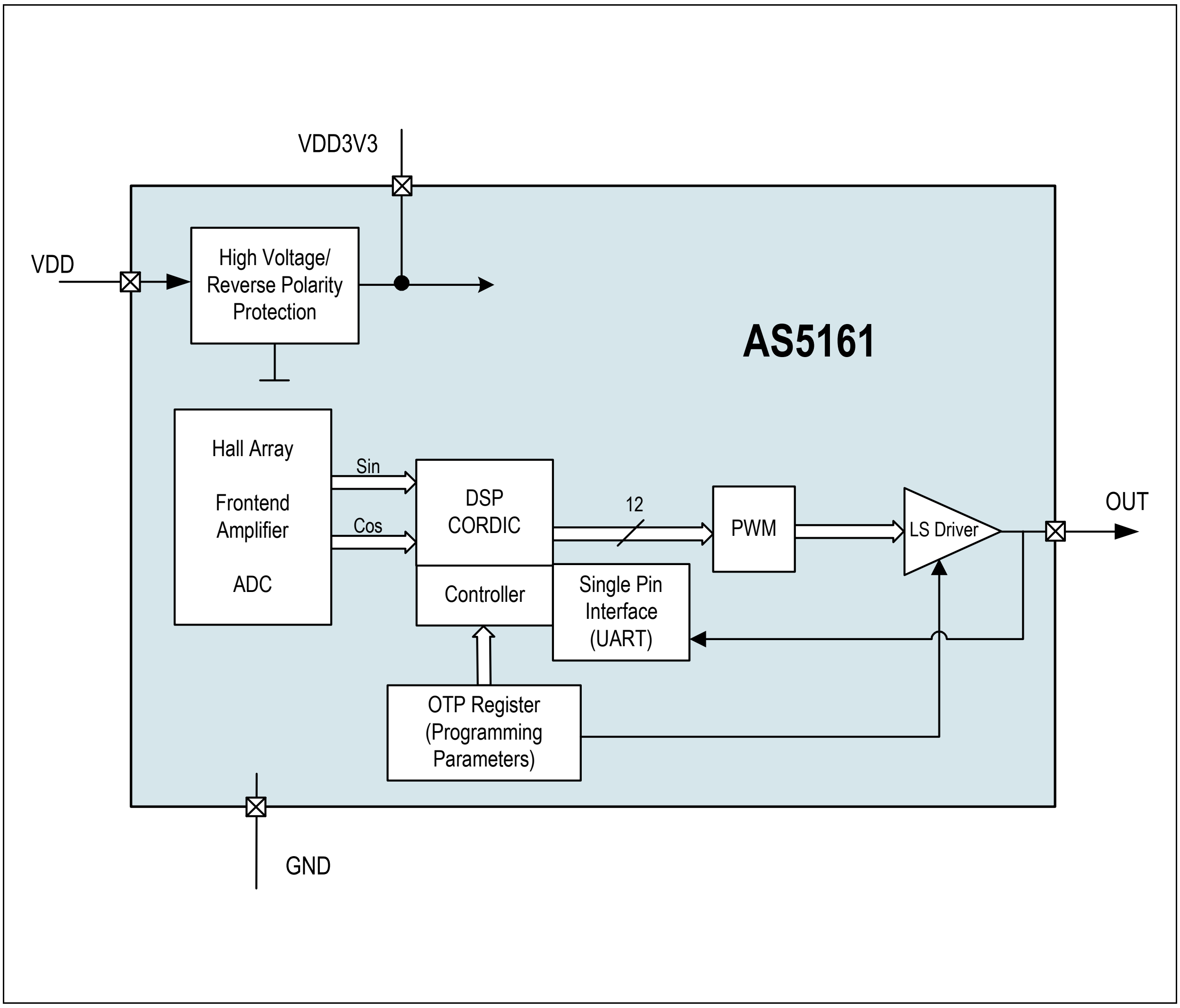
The AS5161 is ideal for automotive applications like:

- Throttle and valve position sensing
- Gearbox position sensor
- Tumble flap
- Chassis height level
- Pedal position sensing
- Contactless potentiometers

Block Diagram

The functional blocks of this device are shown below:

Figure 3:
AS5161 Block Diagram



Pin Assignment

Figure 4:
SOIC-8 Pin Configuration

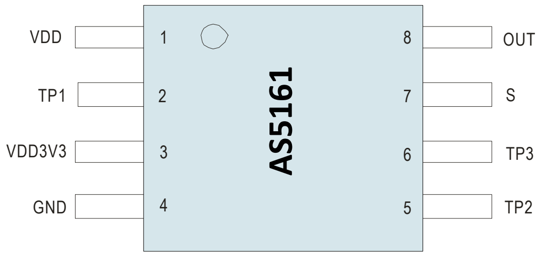


Figure 5:
Pin Description

Pin Number	Pin Name	Pin Type	Description
1	VDD	Supply pin	**Positive supply pin.** This pin is over voltage protected.
2	TP1	DIO/AIO multi purpose pin	**Test pin for fabrication.** Connected to ground in the application board.
3	VDD3V3	AIO	Output of the internal voltage regulator
4	GND	Supply pin	**Ground pin.** Connected to ground in the application.
5	TP2	DIO/AIO multi purpose pin	**Test pin for fabrication.** Connected to ground in the application board.
6	TP3	DIO/AIO multi purpose pin	**Test pin for fabrication.** Open in the application.
7	S	AIO	**Test pin for fabrication.** Connected to OUT in the application board.
8	OUT	DIO/AIO multi purpose pin	**Digital PWM output pin.** Over this pin the programming is possible. Open drain configuration.

Absolute Maximum Ratings

Stresses beyond those listed in Absolute Maximum Ratings may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated in Electrical Characteristics is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

Figure 6:
Absolute Maximum Ratings

Symbol	Parameter	Min	Max	Units	Comments
Electrical Parameters					
V_{DD}	DC supply voltage at pin VDD Overvoltage	-20	20	V	No operation
V_{OUT}	Output voltage OUT	-0.3	20	V	Permanent
V_{diff}	Voltage difference at pin VDD and OUT	-20	20	V	
V_{DD3V3}	DC supply voltage at pin V_{DD3V3}	-0.3	5	V	
I_{scr}	Input current (latchup immunity)	-100	100	mA	Norm: AEC-Q100-004
Electrostatic Discharge					
ESD	Electrostatic discharge	±2		kV	Norm: AEC-Q100-002
Temperature Ranges and Storage Conditions					
T_{strg}	Storage temperature	-55	150	ºC	Min -67ºF; Max 302ºF
T_{Body}	Body temperature		260	ºC	The reflow peak soldering temperature (body temperature) specified is in accordance with IPC/JEDEC J-STD-020 “Moisture/Reflow Sensitivity Classification for Non-Hermetic Solid State Surface Mount Devices”. The lead finish for Pb-free leaded packages is matte tin (100% Sn).
RH_{NC}	Relative humidity non-condensing	5	85	%	
MSL	Moisture Sensitivity Level	3			Represents a maximum floor life time of 168h

Electrical Characteristics

Operating Conditions

In this specification, all the defined tolerances for external components need to be assured over the whole operation conditions range and also over lifetime.

Figure 7:
Operating Conditions

Symbol	Parameter	Conditions	Min	Typ	Max	Units
T_{AMB}	Ambient temperature		-40		150	ºC
I_{supp}	Supply current				10	mA
V_{DD}	Supply voltage at pin VDD		4.5	5.0	5.5	V

Magnetic Input Specification

T_{AMB} = -40ºC to 150ºC, V_{DD} = 4.5V to 5.5V (5V operation), unless otherwise noted.

Two-Pole Cylindrical Diametrically Magnetized Source

Figure 8:
Magnetic Input Specification

Symbol	Parameter	Conditions	Min	Typ	Max	Units
B_{pk}	Magnetic input field amplitude	Required vertical component of the magnetic field strength on the die's surface, measured along a concentric circle with a radius of 1.25 mm	30		70	mT
B_{pkext}	Magnetic input field amplitude (extended) default setting	Required vertical component of the magnetic field strength on the die's surface, measured along a concentric circle with a radius of 1.25 mm. Increased sensor output noise.	10		90	mT
B_{off}	Magnetic offset	Constant magnetic stray field			± 5	mT
D_{isp}	Displacement radius	Offset between defined device center and magnet axis including eccentricity. Dependent on the selected magnet.		1		mm

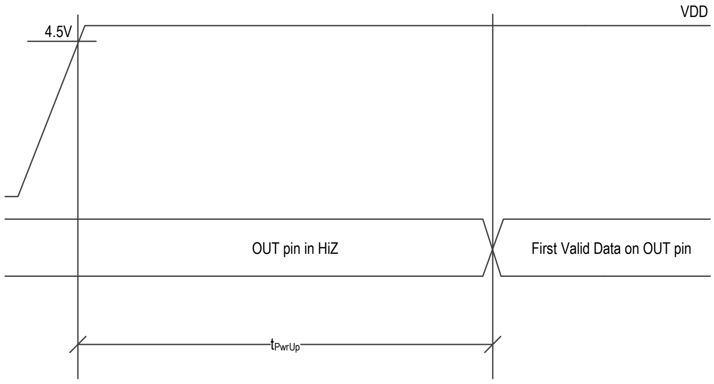
Electrical System Specifications

T_{AMB} = -40ºC to 150ºC, V_{DD} = 4.5V to 5.5V (5V operation), Magnetic Input Specification, unless otherwise noted.

Figure 9:
Electrical System Specifications

Symbol	Parameter	Conditions	Min	Typ	Max	Units
RES	Resolution PWM Output	Range > 90º			12	bit
INL_{opt}	Integral non-linearity (optimum)	Best aligned reference magnet at 25ºC over full turn 360º			0.5	deg
INL_{temp}	Integral non-linearity (optimum)	Best aligned reference magnet over temperature -40º to 150º over full turn 360º			0.9	deg
INL	Integral non-linearity	Best aligned reference magnet over temperature -40º to 150º over full turn 360º and displacement			1.4	deg
DNL	Differential non-linearity	Monolitic		0.05		deg
ON	Output noise (360º segment)	1 LSB after filter peak/peak rms value		0.2		% DC
t_{PwrUp}	Power-up time 0-5V	See Figure 10			10	ms
t_{delay}	System propagation delay absolute output: delay of ADC, DSP and absolute interface	10kΩ, 100 µF RC filter			300	µs

Figure 10:
Power-Up Timing Diagram



Timing Characteristics

Figure 11:
Timing Conditions

Symbol	Parameter	Conditions	Min	Typ	Max	Units
T_{DETWD}	WachDog error detection time				12	ms

Power Management - Supply Monitor

Figure 12:
Power Management - Supply Monitor Conditions

Symbol	Parameter	Conditions	Min	Typ	Max	Units
VDD_{UVTH}	VDD undervoltage upper threshold		3.5	4.0	4.5	V
VDD_{UVTL}	VDD undervoltage lower threshold		3.0	3.5	4.0	V
VDD_{UVHYS}	VDD undervoltage hysteresis		300	500	900	mV
VDD_{UVDET}	VDD undervoltage detection time		10	50	250	µs
VDD_{UVREC}	VDD undervoltage recovery time		10	50	250	µs
VDD_{OVTH}	VDD overvoltage upper threshold		6.0	6.5	7.0	V
VDD_{OVTL}	VDD overvoltage lower threshold		5.5	6	6.5	V
VDD_{OVHYS}	VDD overvoltage hysteresis		300	500	900	mV
ANA_{TOVDET}	VDD overvoltage detection time (analog path)		10	50	250	µs
ANA_{TOVREC}	VDD overvoltage recovery time (analog path)		10	50	250	µs

Detailed Description

The AS5161 is manufactured in a CMOS process and uses a spinning current Hall technology for sensing the magnetic field distribution across the surface of the chip.

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

Through Sigma-Delta Analog / Digital Conversion and Digital Signal-Processing (DSP) algorithms, the AS5161 provides accurate high-resolution absolute angular position information. For this purpose a Coordinate Rotation Digital Computer (CORDIC) calculates the angle and the magnitude of the Hall array signals.

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

A small low cost diametrically magnetized (two-pole) standard magnet provides the angular position information.

The AS5161 senses the orientation of the magnetic field and calculates a 14-bit binary code. This code is mapped to a programmable output characteristic in a PWM duty cycle format. This signal is available at the pin (**OUT**).

The application angular region can be programmed in a user friendly way. The start angle position **T1** and the end point **T2** can be set and programmed according the mechanical range of the application with a resolution of 14 bits. In addition the **T1Y** and **T2Y** parameter can be set and programmed according the application. The transition point 0 to 360 degree can be shifted using the break point parameter **BP**. The voltage for clamping level low **CLL** and clamping level high **CLH** can be programmed with a resolution of 9 bits. Both levels are individually adjustable.

The output parameters can be programmed in an OTP register. No additional voltage is required to program the AS5161. The setting may be overwritten at any time and will be reset to default when power is cycled. To make the setting permanent, the OTP register must be programmed by using a lock bit the content could be frozen for ever.

The AS5161 is tolerant to magnet misalignment and unwanted external magnetic fields due to differential measurement technique and Hall sensor conditioning circuitry.

Operation

VDD Voltage Monitor

VDD Over Voltage Management. If the supply voltage at pin **VDD** exceeds the over-voltage upper threshold for longer than the detection time the output is turned off. When the over voltage event has passed and the voltage applied to pin **VDD** falls below the over-voltage lower threshold for longer than the recovery time the device enters the normal mode and the output is enabled.

VDD Under Voltage Management. When the voltage applied to the **VDD** pin falls below the under-voltage lower threshold for longer than the detection time the output is turned off. When the voltage applied to the **VDD** pin exceeds the under-voltage upper threshold for longer than the detection time the device enters the normal mode and the output is enabled.

PWM Output

By default (after programmed **CUST_LOCK** OTP bit) the PWM output mode is selected. The pin **OUT** provides a modulated signal that is proportional to the angle of the rotating magnet. Due to an intelligent approach a permanent short circuit will not damage the device. This is also feasible in a high voltage condition up to 20 V and at the highest specified ambient temperature.

After the digital signal processing (DSP) a PWM engine provides the output signal.

The DSP maps the application range to the output characteristic. An inversion of the slope is also programmable to allow inversion of the rotation direction.

An on-chip diagnostic feature handles the error state at the output. Depending on the failure the output is in HiZ condition or indicates a PWM signal within the failure bands of 4 –96% duty cycle (see Figure 20).

Programming Parameters

The PWM output characteristic is programmable by OTP. Depending on the application, the output can be adjusted. The user can program the following application specific parameters.

Figure 13:
Programming Parameters

Parameter	Description
T1	Mechanical angle start point
T2	Mechanical angle end point
T1Y	% duty cycle level at the T1 position
T2Y	% duty cycle level at the T2 position
CLL	Clamping Level Low
CLH	Clamping Level High
BP	Break point (transition point 0 to 360º)

These parameters are input parameters. Using the available programming software and programmer these parameters are converted and finally written into the AS5161 128 bit OTP memory.

Application Specific Angular Range Programming

The application range can be selected by programming **T1** with a related **T1Y** and **T2** with a related **T2Y** into the AS5161. The clamping levels **CLL** and **CLH** can be programmed independent from the **T1** and **T2** position and both levels can be separately adjusted.

Figure 14:
Programming of an Individual Application Range

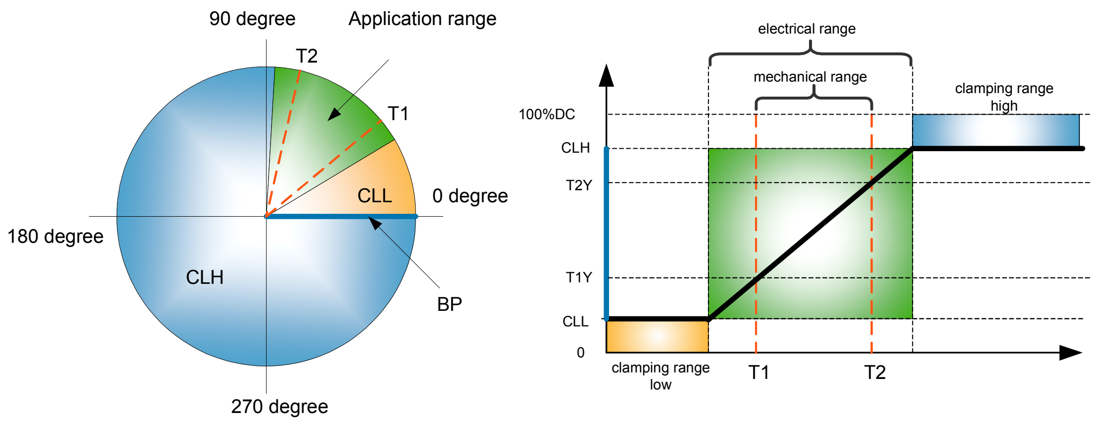
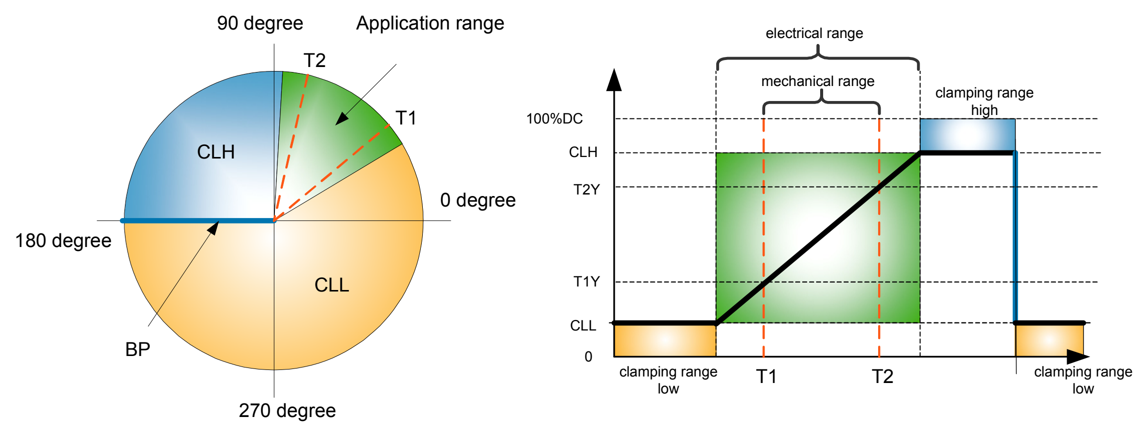


Figure 14 shows a simple example of the selection of the range. The mechanical starting point **T1** and the mechanical end point **T2** are defining the mechanical range. A sub range of the internal CORDIC output range is used and mapped to the needed output characteristic. The PWM output signal has 12 bit, hence the level **T1Y** and **T2Y** can be adjusted with this resolution. As a result of this level and the calculated slope the clamping region low is defined. The break point **BP** defines the transition between **CLL** and **CLH**. In this example the **BP** is set to 0 degree. The **BP** is also the end point of the clamping level high **CLH**. This range is defined by the level **CLH** and the calculated slope. Both clamping levels can be set independently form each other.

Application Specific Programming of the Break Point

The break point **BP** can be programmed as well with 14 bits. This is important when the default transition point is inside the application range. In such a case the default transition point must be shifted out of the application range. The parameter **BP** defines the new position.

Figure 15:
Individual Programming of the Break Point BP



Multiple Slope Output

The AS5161 can be programmed to multiple slopes. Where one programmed reference slope characteristic is copied to multiple slopes. Two, three and four slopes are selectable by the user OTP bits QUADEN (1:0). In addition to the steepness of the slope the clamping levels can be programmed as well.

Figure 16:
Two Slope Mode

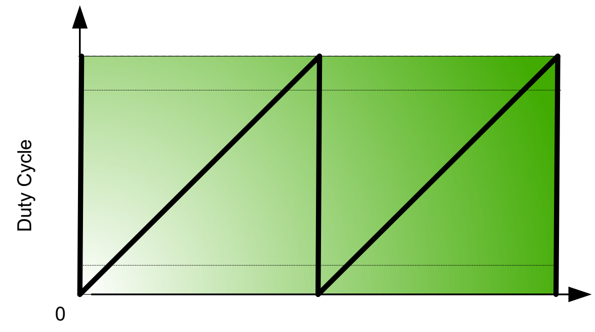
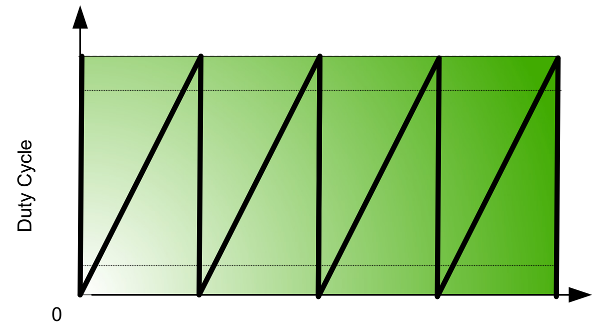


Figure 17:
Four Slope Mode



Resolution of Parameters

The programming parameters have a wide resolution of up to 14 bits.

Figure 18:
Resolution of the Programming Parameters

Symbol	Parameter	Resolution	Note
T1	Mechanical angle start point	14 bits	
T2	Mechanical angle stop point	14 bits	
T1Y	Mechanical start voltage level	12 bits	
T2Y	Mechanical stop voltage level	12 bits	
CLL	Clamping level low	9 bits	
CLH	Clamping level high	9 bits	
BP	Break point	14 bits	

Figure 19:
Overview of the Output Range

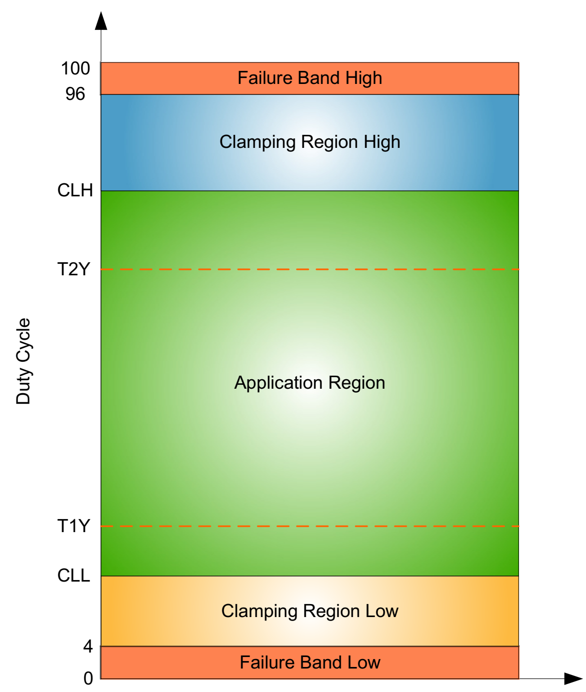


Figure 19 gives an overview of the different ranges. The failure bands are used to indicate a wrong operation of the AS5161. This can be caused due to a broken supply line. By using the specified load resistors, the output level will remain in these bands during a fail. It is recommended to set the clamping level **CLL** above the lower failure band and the clamping level **CLH** below the higher failure band.

Figure 20:
Different Failure Cases of AS5161

Type	Failure Mode	Symbol	Failure Band	Note
Internal alarms (failures)	Out of magnetic range (too less or too high magnetic input)	MAGRng	High/Low	Programmable by OTP bit **DIAG_HIGH**
	CORDIC overflow	COF	High/Low	Programmable by OTP bit **DIAG_HIGH**
	Offset compensation finished	OCF	High/Low	Programmable by OTP bit **DIAG_HIGH**
	Watchdog fail	WDF	High/Low	Programmable by OTP bit **DIAG_HIGH**
	Oscillator fail	OF	High/Low	Programmable by OTP bit **DIAG_HIGH**
Application related failures	Overvoltage condition	OV	High	Dependant on the load resistor Pull up → failure band high
	Broken VDD	BVDD		
	Broken VSS	BVSS		
	Short circuit output	SCO	High	Switch off → short circuit dependent

For efficient use of diagnostics, it is recommended to program to clamping levels **CLL** and **CLH**.

PWM Output Driver Parameters

The output stage is configured in a open drain output.

The PWM duty cycle represents the angular output data. All programming features are available for the PWM mode as well. The PWM period is programmable in four steps and can be programmed by **PWMF<2:0>**.

$C_{LOAD} \leq$ 33 nF, R_{PU}= 1kΩ to 10kΩ

Figure 21:
PWM Parameters Output Driver

Symbol	Parameter	Conditions	Min	Typ	Max	Units
PWMF1	PWM frequency 7	PWMF<2:0>=111	109.86	122	134.28	Hz
PWMF2	PWM frequency 6	PWMF<2:0>=110	179.78	200	219.73	Hz
PWMF3	PWM frequency 5	PWMF<2:0>=101	219.73	244	268.55	Hz
PWMF4	PWM frequency 4	PWMF<2:0>=100	329.59	366	402.83	Hz
PWMF5	PWM frequency 3	PWMF<2:0>=011	494.38	549	604.25	Hz
PWMF6	PWM frequency 2	PWMF<2:0>=010	659.18	732	805.66	Hz
PWMF7	PWM frequency 1	PWMF<2:0>=001	988.77	1100	1208.50	Hz
PWMF8	PWM frequency 0	PWMF<2:0>=000	1977.54	2197	2416.2	Hz
PWMDC	PWM duty cycle range	info parameter	4		96	%
PWMVOL	Output voltage low	IOUT=5mA	0		0.4	V
PWMSRF	PWM slew rate (falling edge)	Between 75% and 25% RPUOUT=4KΩ; CLOUT=1nF VDD=5V	1	2	4	V / µs

Hysteresis Function

AS5161 device includes a hysteresis function to avoid sudden jumps from CLH to CLL and vice versa caused by noise in the full turn configuration.

The hysteresis amplitude can be selected via the OTP bits **HYSTSEL<1:0>**.

Application Information

Recommended Application Schematic

Figure 22 shows the recommended schematic in the application. All components marked with (*) are optional and can be used to further increase the EMC.

Figure 22:
Recommended Schematic of Pull-Up Configuration

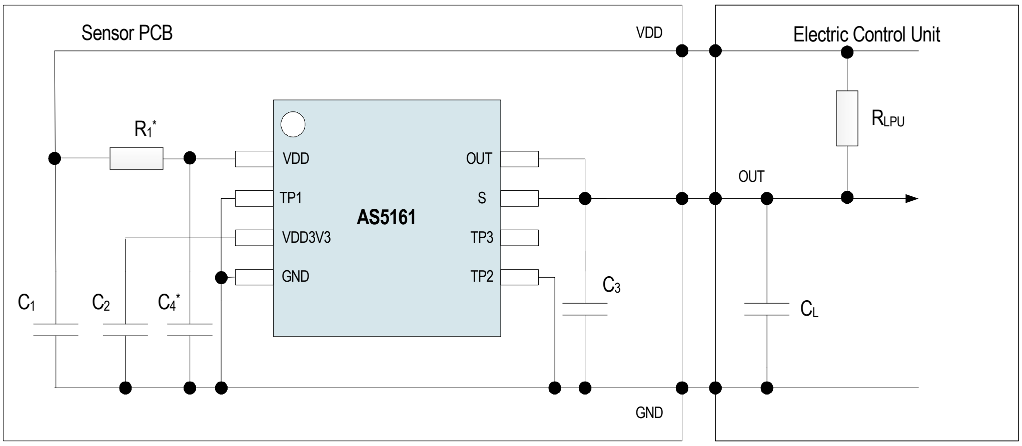


Figure 23:
External Components

Symbol	Parameter	Min	Typ	Max	Units	Note
C_1	VDD buffer capacitor	0.8	1	1.2	µF	Low ESR 0.3 Ω
C_2	VDD3V3 regulator capacitor	0.8	1	1.2	µF	Low ESR 0.3 Ω
C_3	OUT load capacitor (sensor PCB)	0		4.7	nF	
C_4^*	VDD capacitor (optional)		4.7		nF	Do not increase due to programming over output.
R_1^*	VDD serial resistor (optional)		10		Ω	
C_L	OUT load capacitor (ECU)	0		33	nF	
R_{LPU}	OUT pull-up resistance	1		10	kΩ	

Programming the AS5161

The AS5161 programming is a one-time-programming (OTP) method, based on polysilicon fuses. The advantage of this method is that no additional programming voltage is needed. The internal LDO provides the current for programming.

The OTP consists of 128 bits; several bits are available for user programming. In addition factory settings are stored in the OTP memory. Both regions are independently lockable by build in lock bits.

A single OTP cell can be programmed only once. Per default, the cell is "0"; a programmed cell will contain a "1". While it is not possible to reset a programmed bit from "1" to "0", multiple OTP writes are possible, as long as only unprogrammed "0"-bits are programmed to "1".

Independent of the OTP programming, it is possible to overwrite the OTP register temporarily with an OTP write command. This is possible only if the user lock bit is not programmed.

Due to the programming over the output pin the device will initially start in the communication mode. In this mode the digital angle value can be read with a specific protocol format. It is a bidirectional communication possible. Parameters can be written into the device. A programming of the device is triggered by a specific command. With another command (pass2func) the device can be switched into operation mode. In case of a programmed user lock bit the AS5161 automatically starts up in the functional operation mode. No communication of the specific protocol is possible after this.

A standard half duplex UART protocol is used to exchange data with the device in the communication mode.

UART Interface for Programming

The AS5161 uses a standard UART interface with an address byte and two data bytes. The read or write mode is selected with bit R/Wn in the first byte. The timing (baudrate) is selected by the AS5161 over a synchronization frame. The baud rate register can be read and overwritten (optional). Every start bit is used for synchronization.

A time out function detects not complete commands and resets the AS5161 UART after the timeout period.

Frame Organization

Each frame is composed by 24 bits. The first byte of the frame specifies the read/write operation with the register address. 16 data bits contains the communication data. There will be no operation in case of the usage of a not specified CMD. The UART programming interface block of the AS5161 can operate in slave communication or master communication mode. In the slave communication mode the AS5161 receives the data. The programming tool is the driver of the single communication line. In case of the master communication mode the AS5161 transmits data in the frame format. The single communication line can be pulled down by the AS5161.

The UART frame consists of 1 start bit (low level), 8 data bit, 1 even-parity bit and 1 stop bit (high level). Data are transferred from LSB to MSB.

Figure 24:
General UART Frame

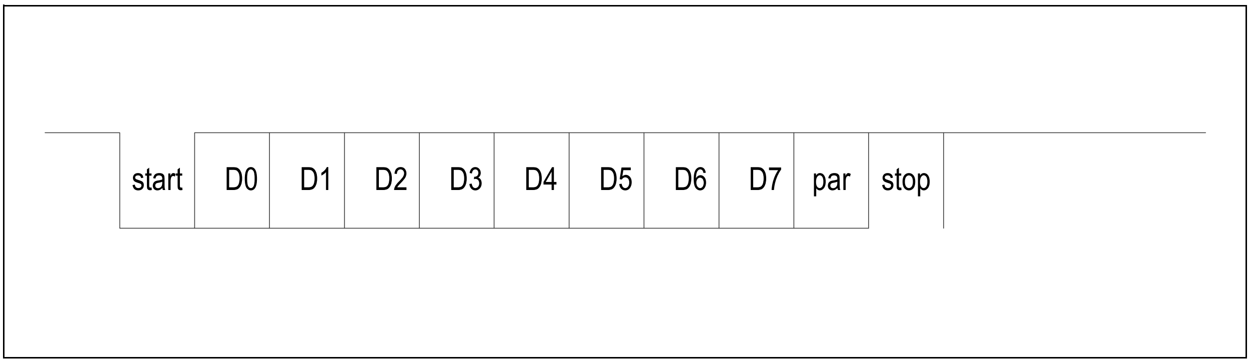


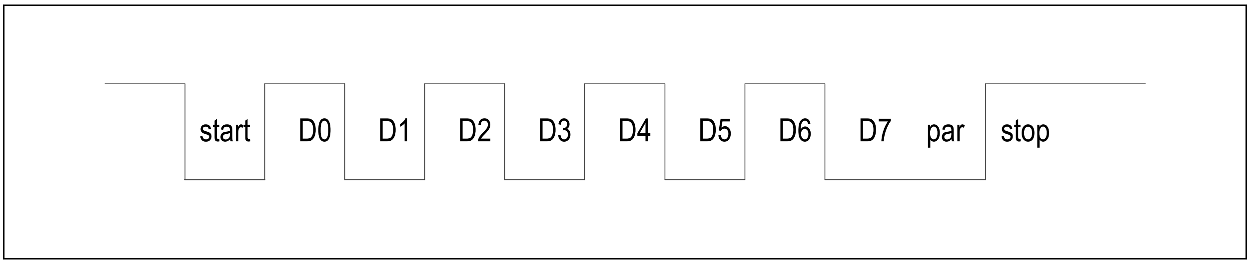
Figure 25:
Bit Timing

Symbol	Parameter	Min	Typ	Max	Unit	Note
START	Start bit		1		TBIT	
Dx	Data bit		1		TBIT	
PAR	Parity bit		1		TBIT	
STOP	Stop bit	1			TBIT	
TSW	Slave/Master Switch Time		7		TBIT	

Each communication starts with the reception of a request from the external controller. The request consists of two frames: one synchronization frame and the command frame.

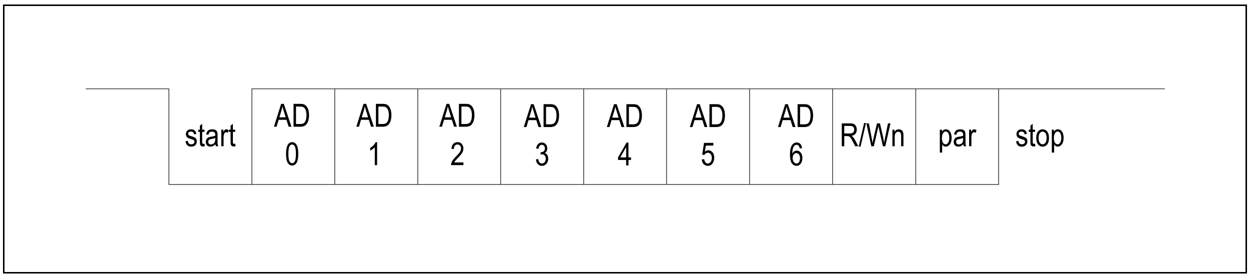
The synchronization frame contains the data 0x55 and allows the UART to measure the external controller baud rate.

Figure 26:
Synchronization Frame



The second frame contains the command Read/ Write (1 bit) and the address (7 bits).

Figure 27:
Address and Command Frame



Only two commands are possible. In case of read command the idle phase between the command and the answer is the time TSW. In case of parity error command is not executed.

Figure 28:
Possible Commands

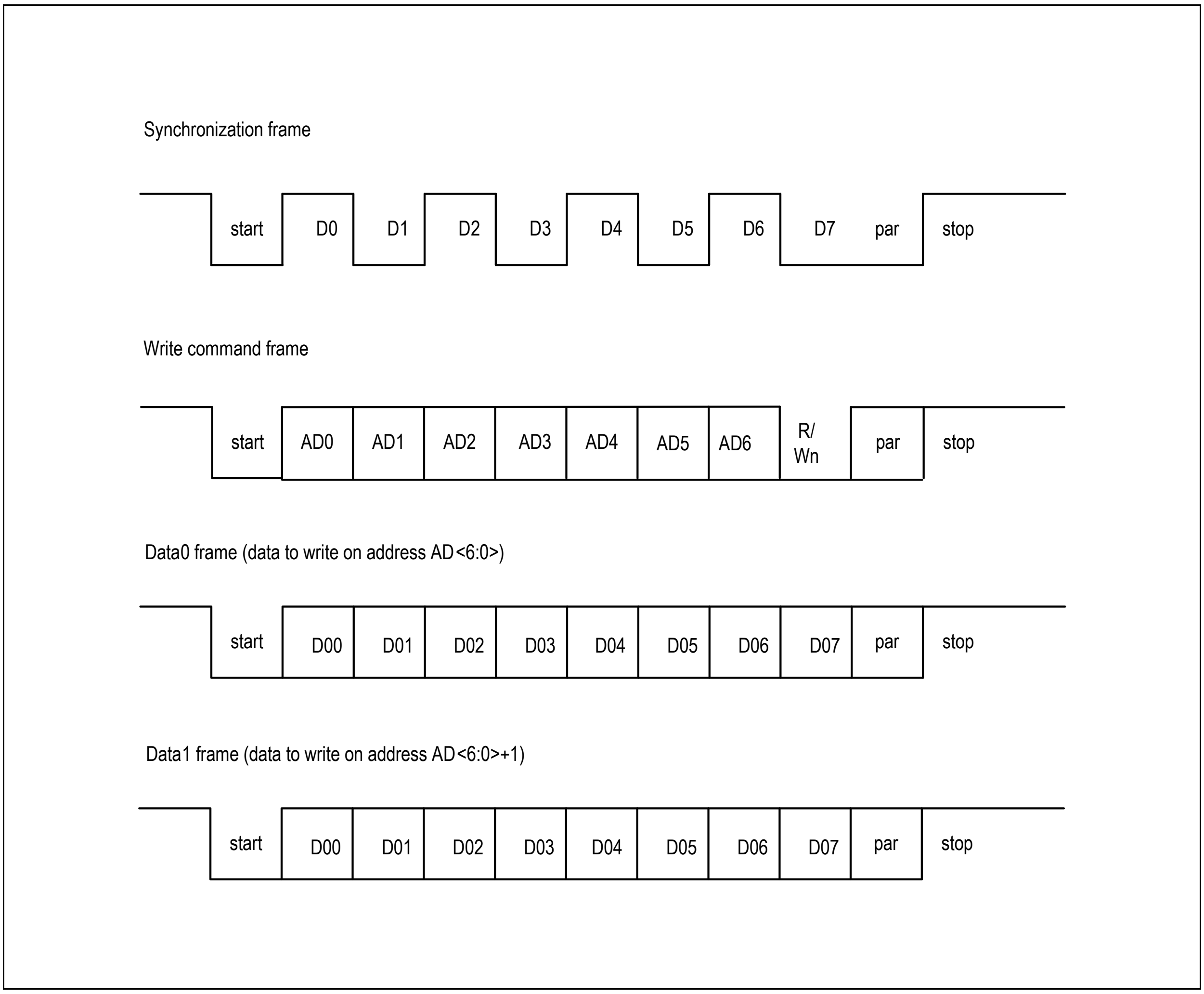
Possible Interface Commands	Description	AS5X63 Communication Mode	Command CMD
WRITE	Write data to the OTP memory or Registers	SLAVE	0
READ	Read data to the OTP memory or Registers	SLAVE & MASTER	1

Note(s) and/or Footnote(s):

1. In case of Write command the request is followed by the frames containing the data to write.
2. In case of Read command the communication direction will change and the AS5161 will answer with the frames containing the requested data.

WRITE (Command Description)

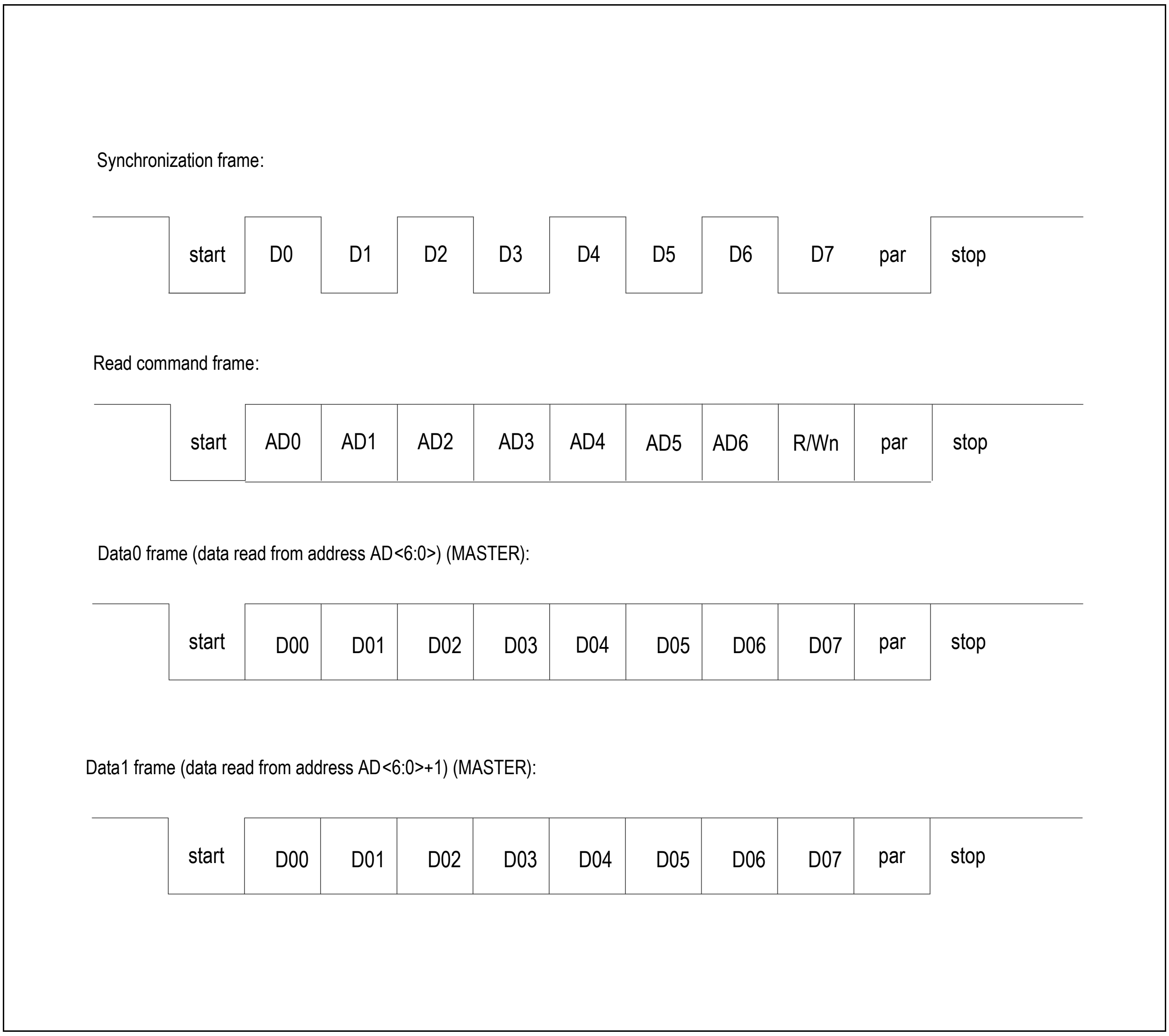
Figure 29:
Full Write Command



- Writing the AS5161 KEY in the fuse register (address 0x41) triggers the transfer of the data from the OTP RAM into the Poly Fuse cell.
- Writing the AS5161 KEY in the Pass2Func Register (address 0x60) forces the device into normal mode.

READ (Command Description)

Figure 30:
Full Read Command



Baud-Rate Automatic Detection

The UART includes a built-in baud-rate monitor that uses the synchronization frame to detect the external controller baud-rate. This baud-rate is used after the synchronization byte to decode the following frame and to transmit the answer and it is stored in the BAUDREG register.

Baud-Rate Manual Setting (Optional)

The BAUDREG register can be read and over-written for a possible manual setting of the baud-rate: in case the register is overwritten with a value different from 0, this value will be used for the following UART communications and the synchronization frame must be removed from the request.

Figure 31:
Manual Baud-Rate Setting

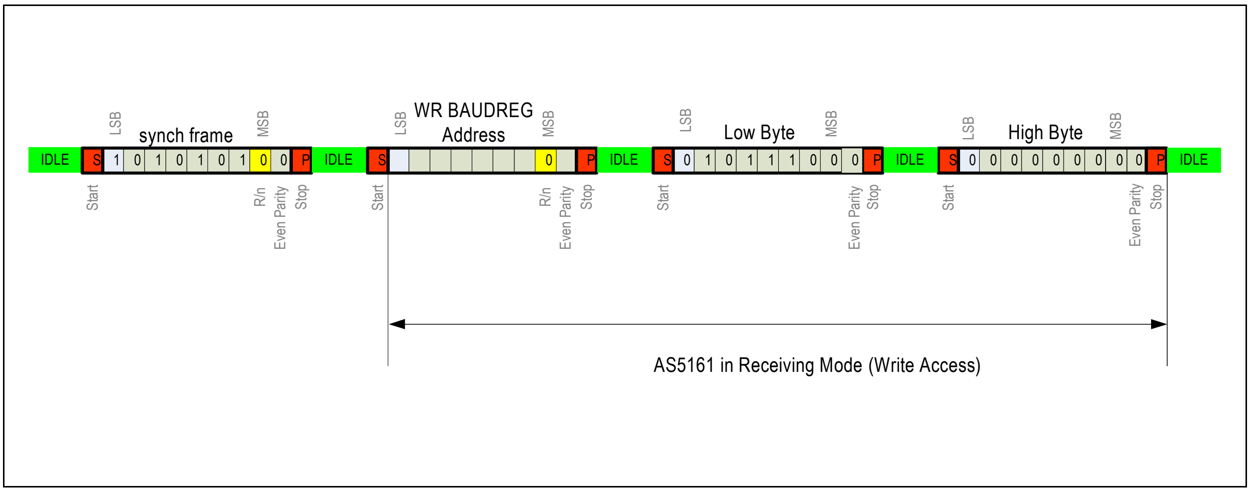
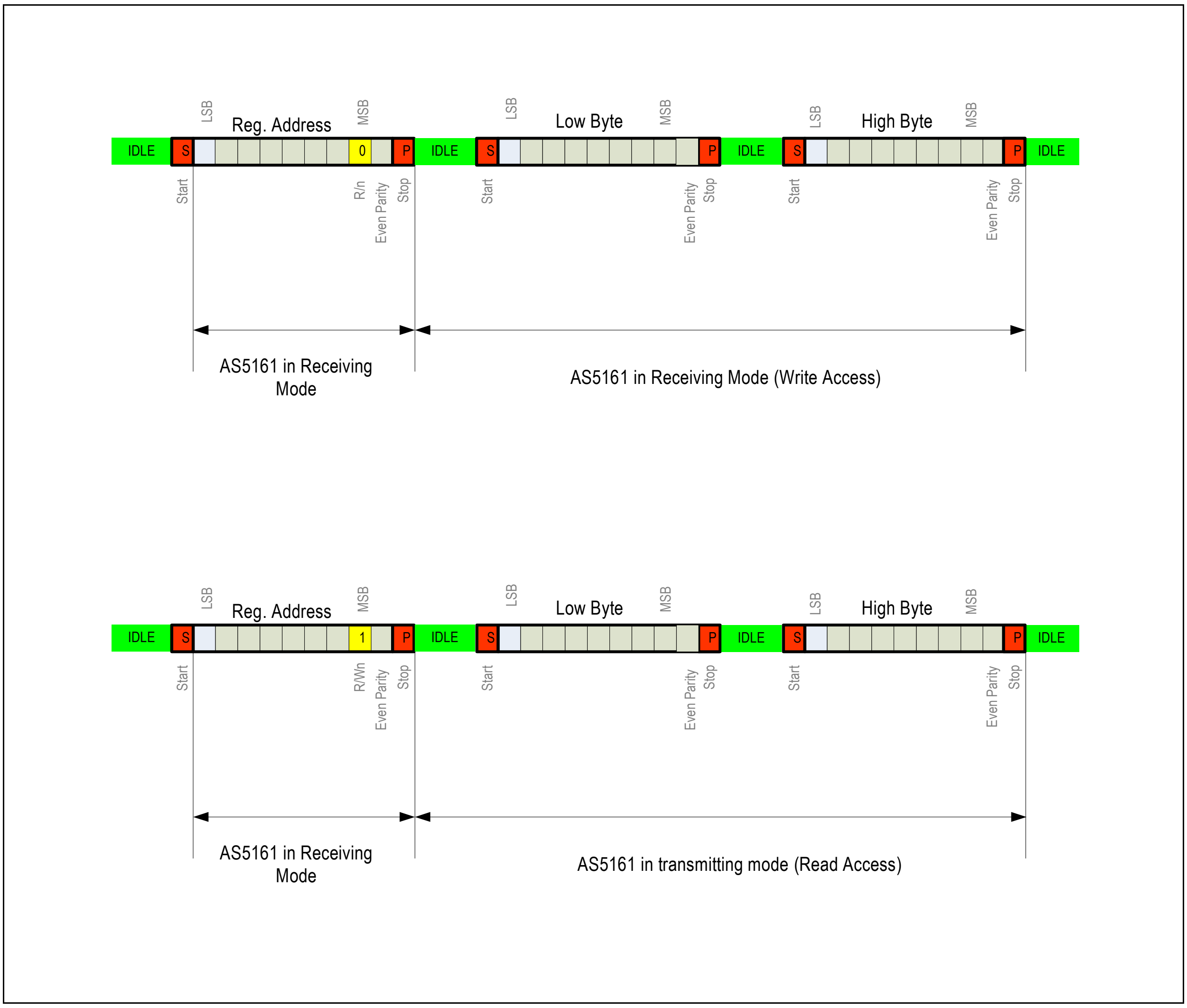


Figure 32:
Simple Read and Write



OTP Programming Data

Figure 33:
OTP Memory Map

Data Byte	Bit Number	Symbol	Default	Description	
DATA15 (0x0F)	0	Factory Settings	0	**ams** (reserved)	Factory Settings
	1		0		
	2		0		
	3		0		
	4		0		
	5		0		
	6		0		
	7		0		
DATA14 (0x0E)	0		0		
	1		0		
	2		0		
	3		0		
	4		0		
	5		0		
	6		0		
	7		0		
DATA13 (0x0D)	0		0		
	1		0		