

TLE4998C8D Grade1

High Performance Programmable Dual Linear Hall Sensor

Technical Product Description

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1 Overview



Characteristic	Supply Voltage	Supply Current	Sensitivity Range	Interface	Temperature
Programmable Dual Die Linear Hall Sensor	4.5~5.5 V	6 mA	±50mT ±100mT ±200mT	SPC (Short PWM Code) Open Drain Output	-40°C to 125°C

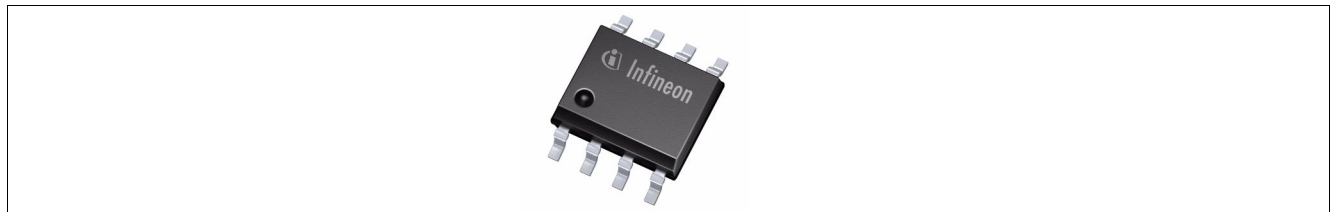


Figure 1-1 SMD package PG-TDSO-8-2 for the TLE4998C8D Grade1

1.1 Features

- Integration of two individual programmable Linear Hall sensor IC's with SPC (Short PWM Code) protocol with enhanced interface features based on SENT (Single Edge Nibble Transmission, defined by SAE J2716)
- 20-bit Digital Signal Processing (DSP)
- Digital temperature and stress compensation
- 16-bit overall resolution
- Operating automotive temperature range -40°C to 125°C
- Minimal drift of output signal over temperature and lifetime
- Programmable parameters stored in EEPROM with single-bit error correction:
 - SPC protocol modes: synchronous transmission, dynamic range selection, ID selection mode
 - SPC unit time
 - Magnetic range and sensitivity (gain), polarity of the output slope
 - Offset
 - Bandwidth
 - Clamping levels
 - Customer temperature compensation coefficients for all common magnets
 - Memory lock
- Re-programmable until memory lock
- Supply voltage 4.5-5.5 V (4.1-16 V extended range)
- Operation between -200 mT and +200 mT within three ranges
- Reverse-polarity and overvoltage protection for all pins
- Output short-circuit protection
- On-board diagnostics (overvoltage, EEPROM error, start up)
- Output of internal magnetic field values and temperature
- Programming and operation of multiple sensors with common power supply
- Two-point calibration of magnetic transfer function without iteration steps
- High immunity against mechanical stress, EMC, ESD

Table 1-1 Ordering Information

Product Name	Marking	Ordering Code	Package
TLE4998C8D Grade1	tbd	tbd	PG-TDSO-8-2

1.2 Target Applications

- Robust replacement of potentiometers: No mechanical abrasion, resistant to humidity, temperature, pollution and vibration
- Linear and angular position sensing in automotive and industrial applications with highest accuracy requirements
- Suited for ASIL applications such as pedal position, throttle position and steering torque sensing
- High-current sensing e.g. for battery management or motor control

1.3 Pin Configuration

Figure 1-2 shows the location of the Hall elements in the chip pin configuration of the package.

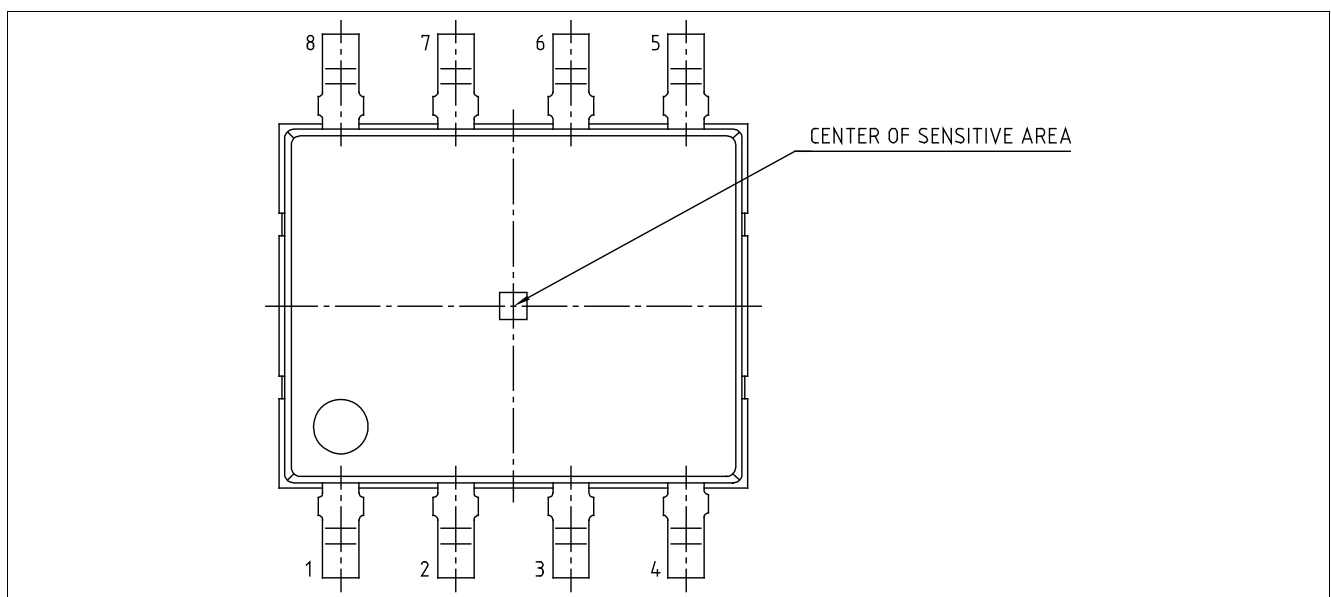


Figure 1-2 Pin Configuration of PG-TDSO-8-2 package

Table 1-2 TLE4998C8D Grade1 Pin Definitions and Functions

Pin No.	Symbol	Function
1	TST	Test pin (top die) (connection to GND is recommended)
2	V_{DD}	Supply voltage / programming interface (top die)
3	GND	Ground (top die)
4	OUT	Output / programming interface (top die)
5	OUT	Output / programming interface (bottom die)
6	GND	Ground (bottom die)
7	V_{DD}	Supply voltage / programming interface (bottom die)
8	TST	Test pin (bottom die) (connection to GND is recommended)

2 General

All further given descriptions are regarded to both implemented sensor IC's, or otherwise noted.

2.1 Block Diagram

Figure 2-1 shows is a simplified block diagram.

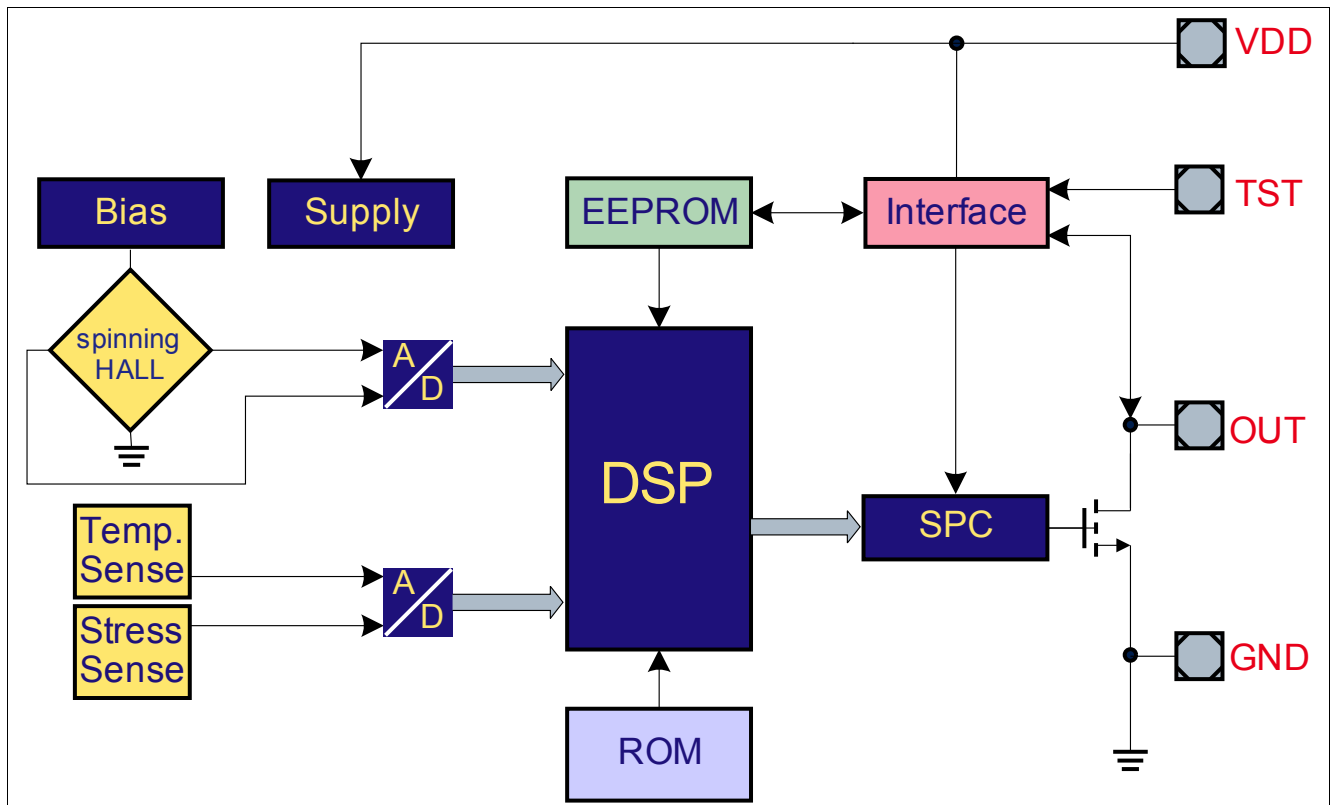


Figure 2-1 Block Diagram of the TLE4998C8D Grade1 with the SPC interface

2.2 Functional Description

The linear Hall IC TLE4998C8D Grade1 has been designed specifically to meet the requirements of highly accurate angle and position detection, as well as for current measurement applications. Especially the dual Die version with electrical insulated sensor IC's, mounted on top and bottom side of the lead frame will give designs/designers a competitive advantage when stringent safety requirements in automotive applications have to be met.

The sensor provides a digital SPC (Short PWM Code) signal, based on the standardized SENT (Single Edge Nibble Transmission, SAE J2716) protocol. The SPC protocol allows transmissions initiated by the ECU. Two further operation modes are available.

- “range selection” for dynamically switching of the measurement range during operation
- “ID selection” to build a bus system with up to 4 IC's on a single output line and a common supply, which can be individually accessed by the ECU.

Each transmission sequence contains an adjustable number of nibbles representing the magnetic field, the temperature value and a status information of the sensor. The interface is further described in [Chapter 9](#).

The output stage is an open-drain driver pulling the output pin to low only. Therefore, the high level needs to be obtained by an external pull-up resistor. This output type has the advantage that the receiver may use an even lower supply voltage (e.g. 3.3 V). In this case the pull-up resistor must be connected to the given receiver supply.

The IC is produced in BiCMOS technology with high voltage capability and it also has reverse-polarity protection. Digital signal processing using a 16-bit DSP architecture together with digital temperature and stress compensation guarantees excellent stability over the whole temperature range and life time.

While the overall resolution is 16 bits, some internal stages work with resolutions up to 20 bits.

2.3 Principle of Operation

- A magnetic flux is measured by a Hall-effect cell
- The output signal from the Hall-effect cell is converted from analog to digital signals
- The chopped Hall-effect cell and continuous-time A/D conversion ensure a very low and stable magnetic offset
- A programmable low-pass filter to reduce noise
- The temperature is measured and A/D converted
- Temperature compensation is done digitally using a second-order function
- Digital processing of the output value is based on zero field and sensitivity value
- The output value range can be clamped by digital limiters
- The final output value is represented by the data nibbles of the SPC protocol

2.4 Further Notes

Product qualification is based on “AEC Q100 Rev. G” (Automotive Electronics Council - Stress test qualification for integrated circuits).

2.5 Transfer Functions

The examples in [Figure 2-2](#) show how different magnetic field ranges can be mapped to the desired output value ranges.

- Polarity Mode:
 - **Bipolar:** Magnetic fields can be measured in both orientations. The limit points do not necessarily have to be symmetrical around the zero field point
 - **Unipolar:** Only north- or south-oriented magnetic fields are measured
- Inversion: Both gain can be set to positive values, negative values or positive/negative values.

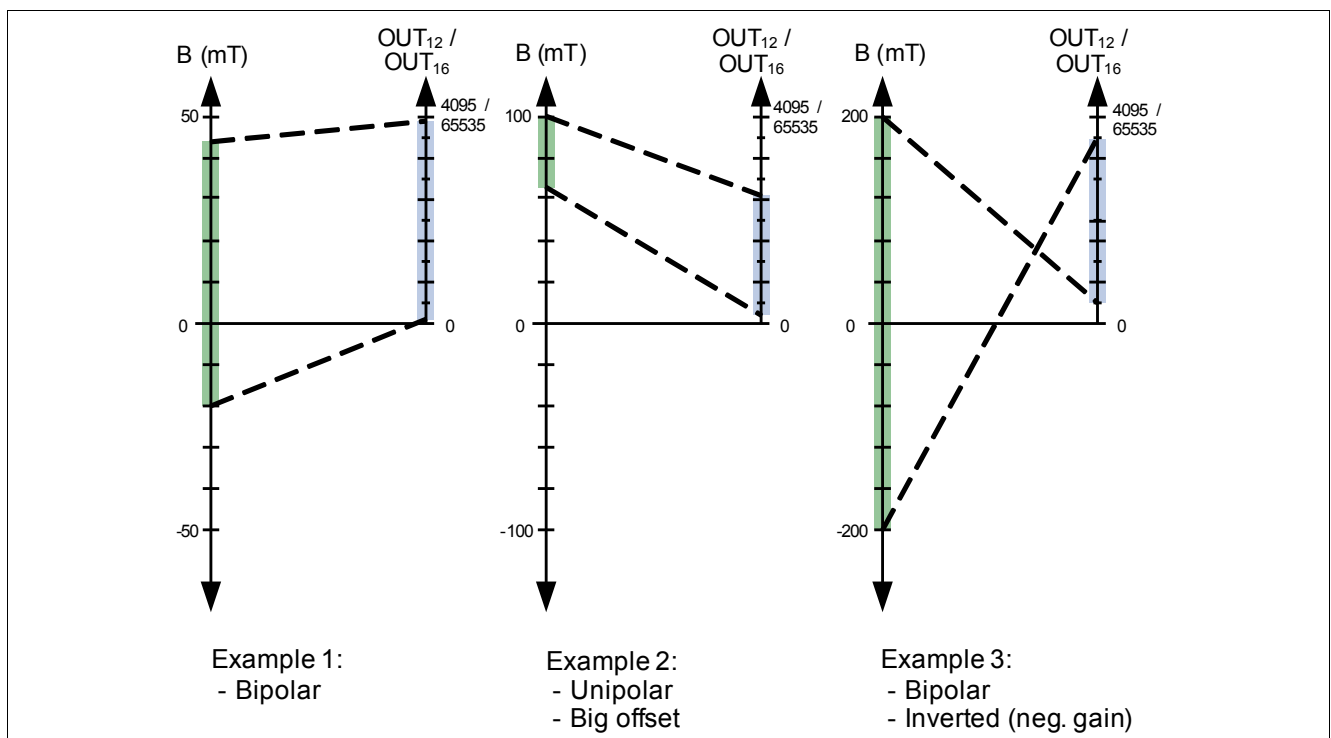


Figure 2-2 Examples of Operation

3 Maximum Ratings

All further given descriptions are regarded to each of the implemented sensors IC's, or otherwise noted.

Table 3-1 Absolute Maximum Ratings

Parameter	Symbol	Values			Unit	Note / Test Condition
		Min.	Typ.	Max.		
Junction temperature	T_J	- 40	–	140	°C	–
Voltage on V_{DD} pin with respect to ground	V_{DD}	-18	–	18.35	V	1)2)
Supply current @ overvoltage V_{DD} max.	I_{DDov}	–	–	15	mA	–
Reverse supply current @ V_{DD} min.	I_{DDrev}	-1	–	0	mA	–
Voltage on output pin with respect to ground	V_{OUT}	-1 ³⁾	–	18.35 ⁴⁾	V	–
Magnetic field	B_{MAX}	-	–	1	T	–
ESD protection	V_{ESD}	-2	-	+2	kV	According HBM JESD22-A114-B ⁵⁾

- 1) Higher voltage stress than absolute maximum rating, e.g. 150% in latch-up tests is not applicable. In such cases, $R_{series} \geq 100 \Omega$ for current limitation is required.
- 2) Max 1h, in operating temperature range.
- 3) I_{DD} can exceed 10 mA when the voltage on OUT is pulled below -1 V (-5 V at room temperature).
- 4) $V_{DD} = 5 V$, open drain permanent low, for max. 10 minutes
- 5) 100 pF and 1.5 k Ω

4 Operating Range

The following operating conditions must not be exceeded in order to ensure correct operation of the TLE4998C8D Grade1. All parameters described in the following sections refer to these operating conditions and each of the implemented sensors IC's if applicable or unless otherwise indicated.

Table 4-1 Operating Range

Parameter	Symbol	Values			Unit	Note / Test Condition
		Min.	Typ.	Max.		
Supply voltage	V_{DD}	4.5	–	5.5	V	–
		4.1 ¹⁾	–	16 ²⁾³⁾	V	Extended range
Supply undervoltage	V_{DDuv}	V_{DDpon} ⁴⁾	–	4.1	V	Extended range
Output pull-up voltage ⁵⁾	$V_{pull-up}$	–	–	18.35	V	–
Load resistance ⁵⁾	R_L	1	–	–	k Ω	–
Output current ⁵⁾	I_{out}	0	–	5	mA	–
Load capacitance ⁵⁾	C_L	1	–	8	nF	–
Junction temperature ⁶⁾	T_J	- 40	–	140 ⁷⁾	$^{\circ}\text{C}$	

1) May have reduced EMC robustness

2) For supply voltages > 12 V, a series resistance $R_{series} \geq 100 \Omega$ is recommended

3) The open drain switch off, due to overvoltage on the V_{DD} line, can take place in the range of 16.65 V to 18.35 V, as defined in [Chapter 7.1](#) of the data sheet. The supply voltage range can be further extended until the overvoltage reset is taking place, but the given accuracy specification in the product data sheet is only applicable until the output switch off occurs

4) V_{DDpon} ... power-on reset level, see [Table 5-1](#)

5) Output protocol characteristics depend on these parameters, R_L must be according to max. output current

6) $R_{THja} \leq 150 \text{ K/W}$.

7) For reduced magnetic accuracy

Note: Keeping signal levels within the limits described in this table ensures operation without overload conditions.

5 Electrical, Thermal and Magnetic Parameters

All further given descriptions are regarded to each of the implemented sensors IC's, or otherwise noted.

Table 5-1 Electrical Characteristics

Parameter	Symbol	Values			Unit	Note / Test Condition
		Min.	Typ.	Max.		
SPC transmission time	t_{SPC}	–	–	1	ms	unit time 3 μs ¹⁾
Supply current	I_{DD}	3	6	8	mA	–
Output current @ OUT shorted to supply lines	I_{OUTsh}	–	95	–	mA	$V_{OUT} = 5 V$, max. 10 minutes
Thermal resistance PG-TDSO-8-2	R_{thJA}	–	150	–	K/W	junction to air
	R_{thJC}	–	85	–	K/W	junction to case
Power-on time ²⁾	t_{Pon}	–	0.7	2	ms	$\leq \pm 5\%$ target out value
			15	20		$\leq \pm 1\%$ target out value
Power-on reset level ³⁾	V_{DDpon}	3.45	3.65	3.87	V	at $-40^{\circ}C$
		3.36	3.55	3.77	V	at $25^{\circ}C$
		3.15?	3.33?	3.54?	V	at $125^{\circ}C$
Output impedance	Z_{OUT}	20	40	70	k Ω	⁴⁾
Output fall time	t_{fall}	2	3.5	5	μs	$V_{OUT} 4.5 V$ to $0.5 V$ ⁵⁾
Output rise time	t_{rise}	–	20	–	μs	$V_{OUT} 0.5 V$ to $4.5 V$ ⁵⁾⁶⁾
Output low saturation voltage	V_{OUTsat}	–	0.3	0.6	V	$I_{OUTsink} = 5 mA$
			0.2	0.4		$I_{OUTsink} = 2.2 mA$
Output noise (rms)	OUT_{noise}	–	1	2.5	LSB ₁₂	⁷⁾
Insulation resistance	R_{DIES}		tbd		k Ω	between Dies

- 1) Transmission time depends on the data values being sent and on internal RC oscillator frequency variation of $\pm 20\%$.
- 2) Response time to set up output data at power on when a constant field is applied. The first value given has a $\pm 5\%$ error, the second value has a $\pm 1\%$ error. Measured with 640-Hz low-pass filter.
- 3) Power-on and power-off
- 4) $V_{DD}=5V$, $V_{OUT}=2.6V$, open drain high state
- 5) For $V_{DD} = 5 V$, $R_L = 2.2 kW$, $C_L = 4.7 nF$, at room temperature, not considering capacitor tolerance or influence of external circuitry
- 6) Depends on External R_L and C_L , See [Figure 5-1](#)
- 7) Range 100 mT, Gain 2.23, internal LP filter 244 Hz, B = 0 mT, $T = 25^{\circ}C$

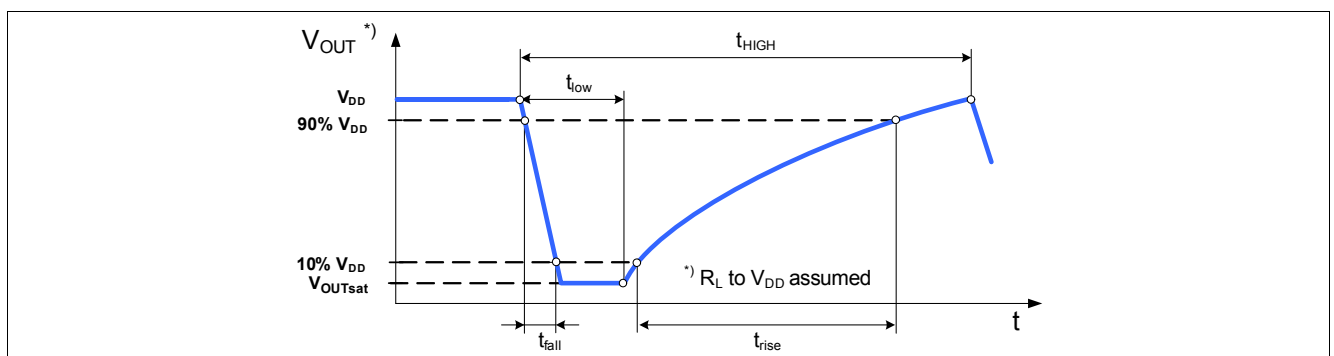


Figure 5-1 Output Characteristic

Magnetic Parameters
Table 5-2 Magnetic Characteristics

Parameter	Symbol	Values			Unit	Note / Test Condition
		Min.	Typ.	Max.		
Sensitivity	S ¹⁾	±8.2	–	±245	LSB ₁₂ /mT	programmable ²⁾
Sensitivity drift	ΔS	-2		+2	%	³⁾ see Figure 5-2
Magnetic field range	MFR	±50	±100 ⁴⁾	±200	mT	programmable ⁵⁾
Integral nonlinearity	INL	–	±0.05	±0.1	%MFR	⁷⁾
Magnetic offset	B _{OS}	–	±100	±400	μT	⁶⁾⁷⁾
Magnetic offset drift	ΔB _{OS}	–	±1	±5	μT/°C	error band ⁷⁾
Magnetic hysteresis	B _{HYS}	–	–	10 20	μT	in 100mT range in 50mT range

1) Defined as ΔOUT / ΔB.

2) Programmable in steps of 0.024%.

3) For any 1st and 2nd order polynomial, coefficient within definition in **Chapter 8**. Valid for characterization at 0 h.

4) This range is also used for temperature and offset pre-calibration of the IC.

5) Depending on offset and gain settings, the output may already be saturated at lower fields.

6) In operating temperature range and over lifetime.

7) Measured at ±100 mT range.

Supply Undervoltage Range
Table 5-3 Electrical and Magnetic Characteristics in Supply Undervoltage Range¹⁾

Parameter	Symbol	Values			Unit	Note / Test Condition
		Min.	Typ.	Max.		
Sensitivity drift	S _{E(T)}	–	–	+2.5/-7.5	%	Error band
Magnetic offset drift	ΔB _{OS}	–	–	±400	μT	Error band
Integral nonlinearity	INL	–	–	±0.2	%MFR	Error band
Output noise (rms)	OUT _{noise}	–	–	37.5	LSB ₁₂	50mT range, LP=1.39kHz, Gain=1.5, B=0mT

1) The operation in supply undervoltage range is not intended for continuous operation, it has to be understood as an extraordinary operation condition in order to cover the needs in safety relevant applications

5.1 Magnetic Field Direction Definition

Figure 5-2 shows the definition of the magnetic field direction. By standard the south pole field defines the positive field values of the top die of TLE4998C8D Grade1.

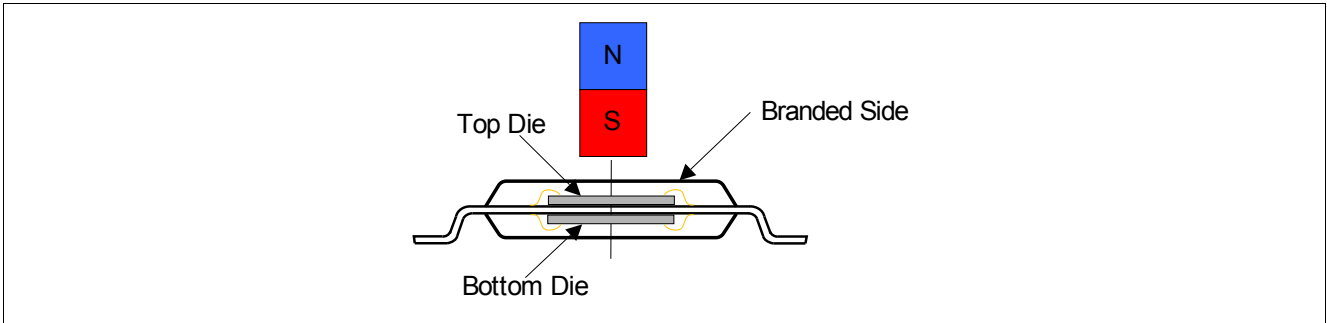


Figure 5-2 Definition of magnetic field direction of the PG-TDSO-8-2

Without reconfiguration the bottom die measures the inverted field value of the top die. This leads to a characteristics as shown in [Figure 5-3](#).

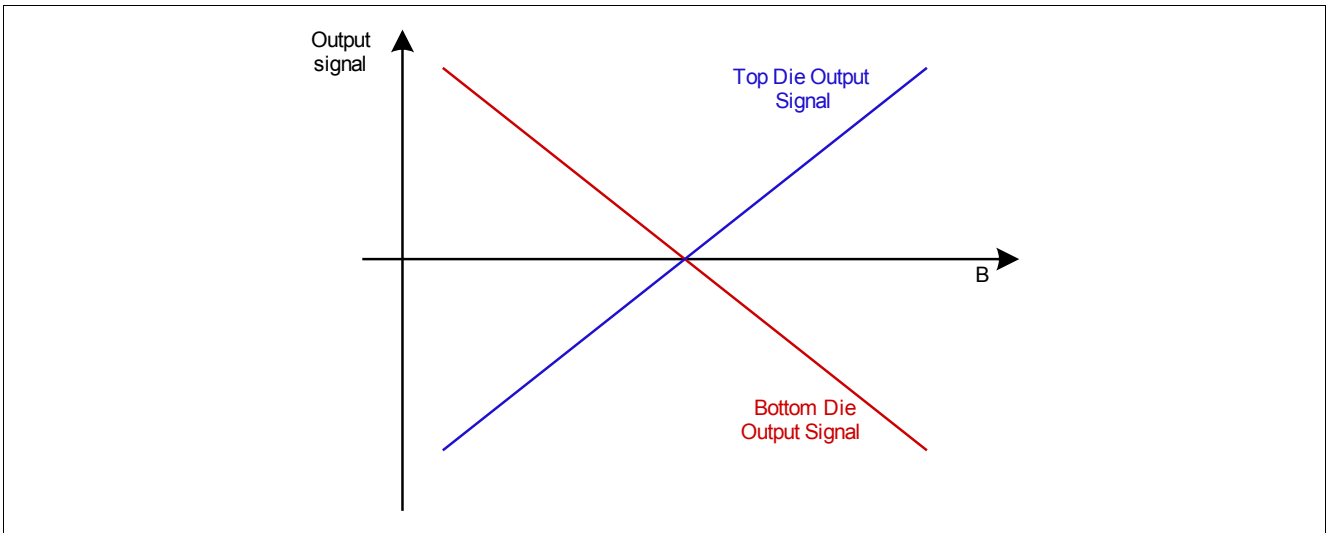


Figure 5-3 Example of the dual die output signaling

6 Application Circuit

Figure 6-1 shows the connection of two Linear Hall sensors to a micro controller.

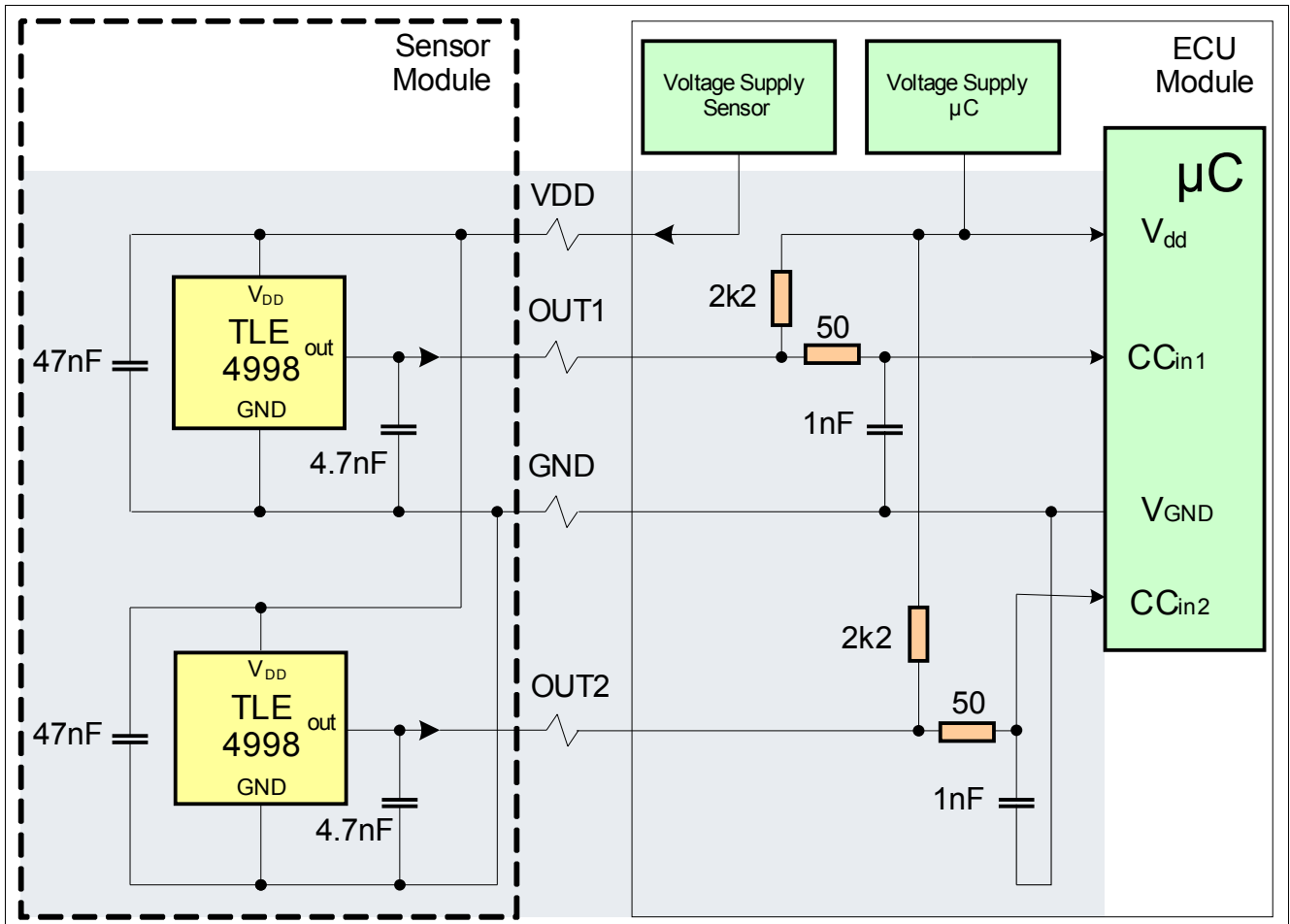


Figure 6-1 Application Circuit

Note: For calibration and programming, the interface has to be connected directly to the OUT pin.

The application circuit shown should be regarded as an example only. It will need to be adapted to meet the requirements of other specific applications. Further information is given in [Chapter 9](#).

7 PG-TDSO-8-2 Package Outlines

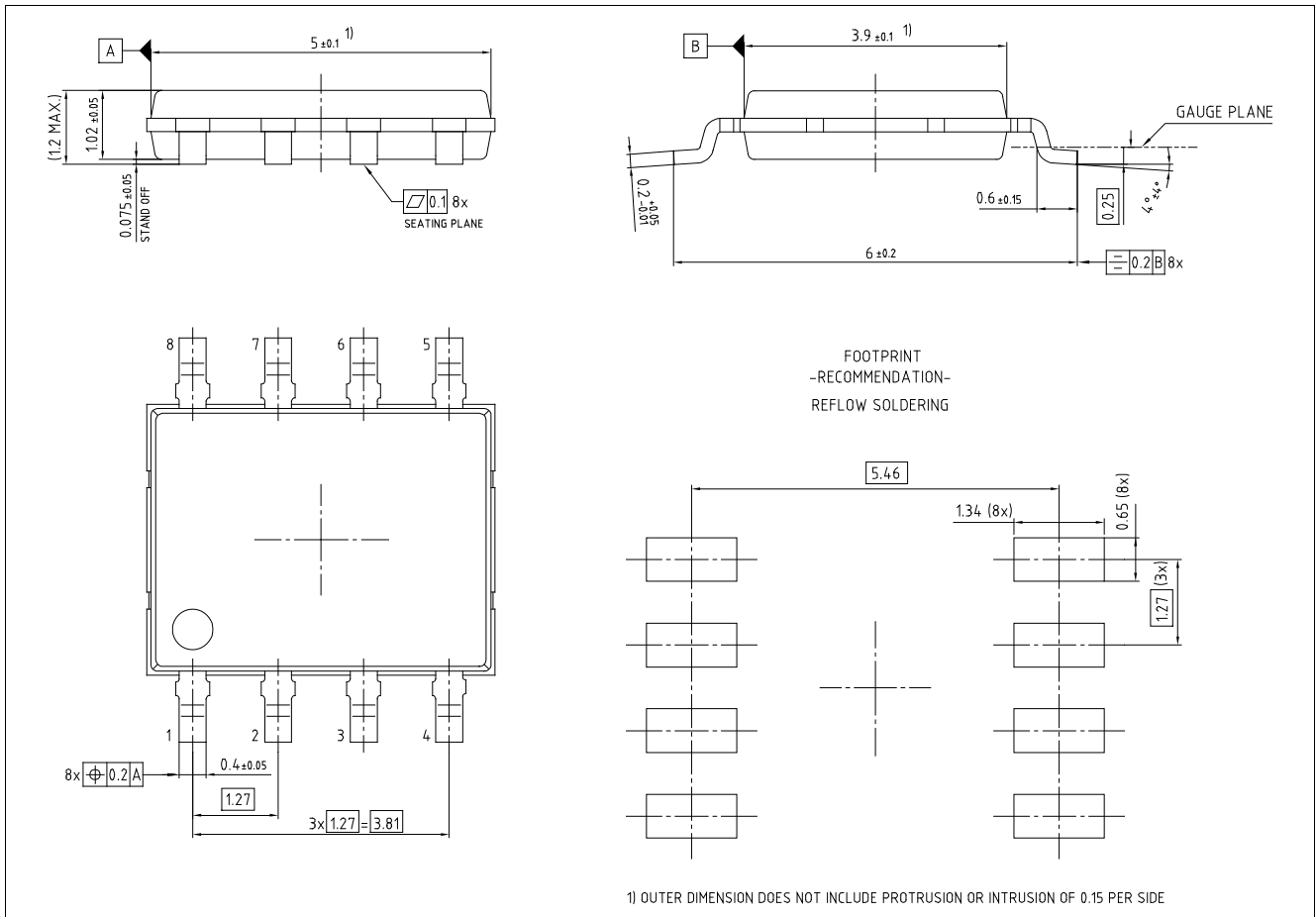


Figure 7-1 PG-TDSO-8-2 (PG-TDSO-Plastic Green Thin Dual Small Outline), Package Dimensions

7.1 Distance Chip to package

Figure 7-2 shows the distance of the chip surface to the PG-TDSO-8-2 surface.

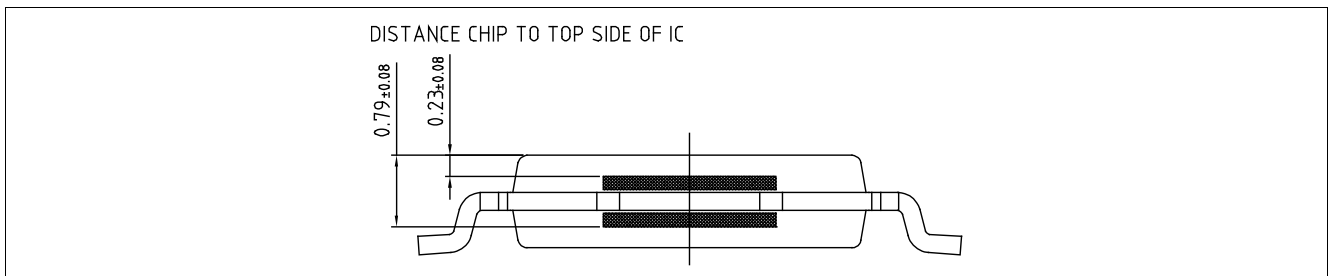


Figure 7-2 Distance of chip surface to package surface

7.2 Moisture Sensitivity Level (MSL)

The PG-TDSO-8-2 fulfills the MSL level 3 according to IPC/JEDEC J-STD-033B.1.

8 PG-TDSO-8-2 Package Marking

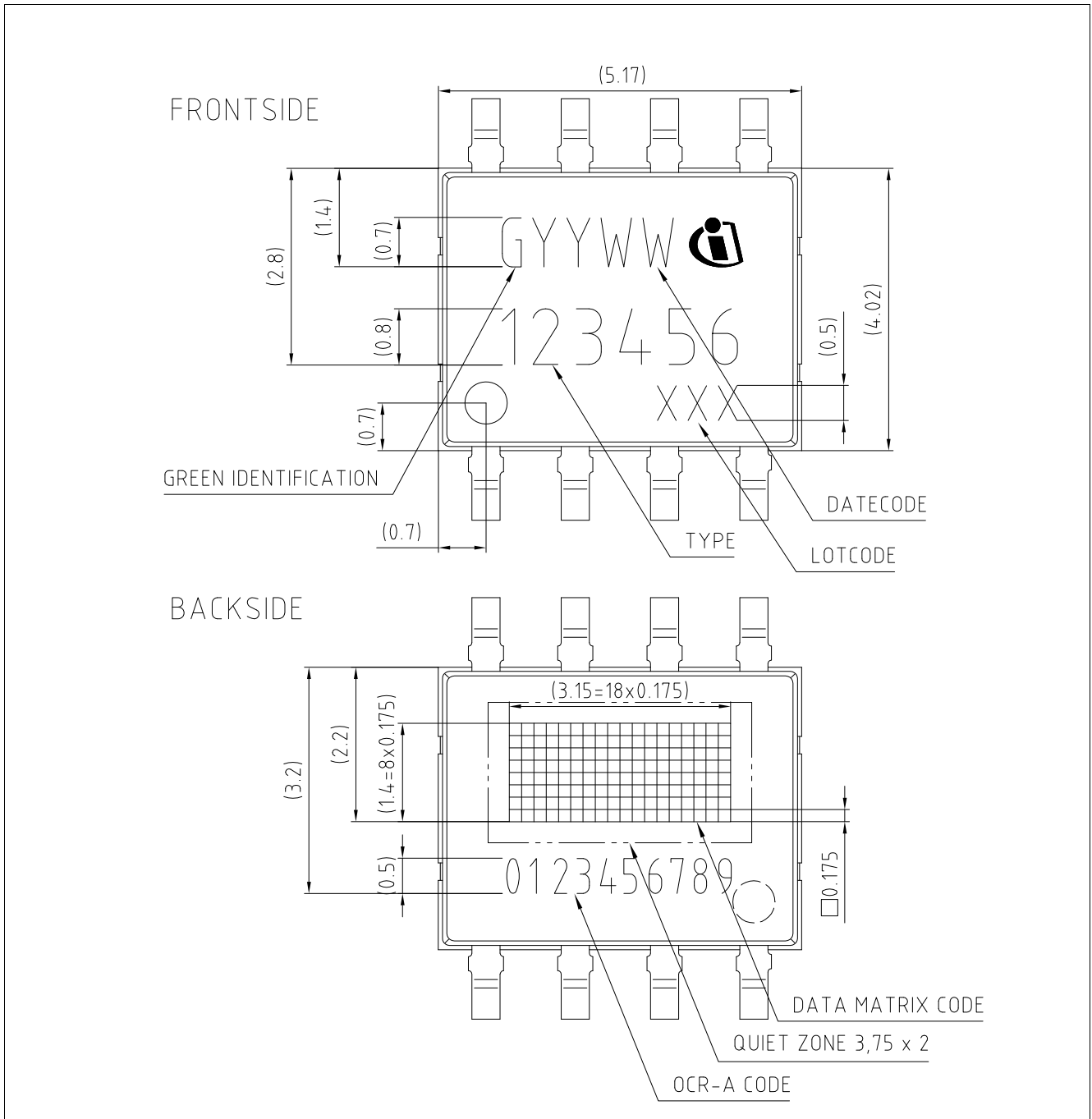


Figure 8-1 PG-TDSO-8-2 (PG-TDSO-Plastic Green Thin Dual Small Outline), Package Marking

9 SPC Output Definition

The sensor supports a SPC (Short PWM Code) protocol, which enhances the standardized SENT protocol (Single Edge Nibble Transmission) defined by SAE J2716. SPC enables the use of enhanced protocol functionality due to the ability to select between “synchronous”, “range selection” and “ID selection” protocol mode. The following tables give an overview of relevant registers to chose the appropriate SPC mode.

Table 9-1 SPC Mode Registers

Parameter	Symbol	Values			Unit	Note / Test Condition
		Min.	Typ.	Max.		
Protocol register	P		2		bit	
ID register	ID		2		bit	1)

1) The ID register is only actively used in ID selection mode.

Table 9-2 SPC Mode Selection

Mode	Parameter PMSB	Parameter PLSB	Explanation
Synchronous	0	No effect	Section 9.2.2
Dynamic range selection	1	0	Section 9.2.3
ID selection	1	1	Section 9.2.4

9.1 Basic SPC Protocol Definition

As in SENT, the time between two consecutive falling edges defines the value of a four bit nibble, thus representing numbers between 0 and 15. The transmission time therefore depends on the transmitted data values. The single edge is defined by a 3 unit time (UT) low pulse on the output, followed by the high time defined in the protocol (nominal values, may vary by tolerance of internal RC oscillator, not including analog delay of the open drain output and influence by external circuitry, unit time programming see [Section 9.2](#)). All values are multiples of a unit time frame concept. A transfer consists of the following parts, depicted in [Figure 9-1](#):

- A trigger pulse by the master, which initiates the data transmission
- A synchronization period of 56 UT (in parallel, a new sample is calculated)
- A status nibble of 12-27 UT
- Between 3 and 6 data nibbles of 12-27 UT each (number is programmable, see [Table 9-4](#)), representing the Hall value and temperature information
- A CRC nibble of 12-27 UT
- An end pulse to terminate the SPC transmission.

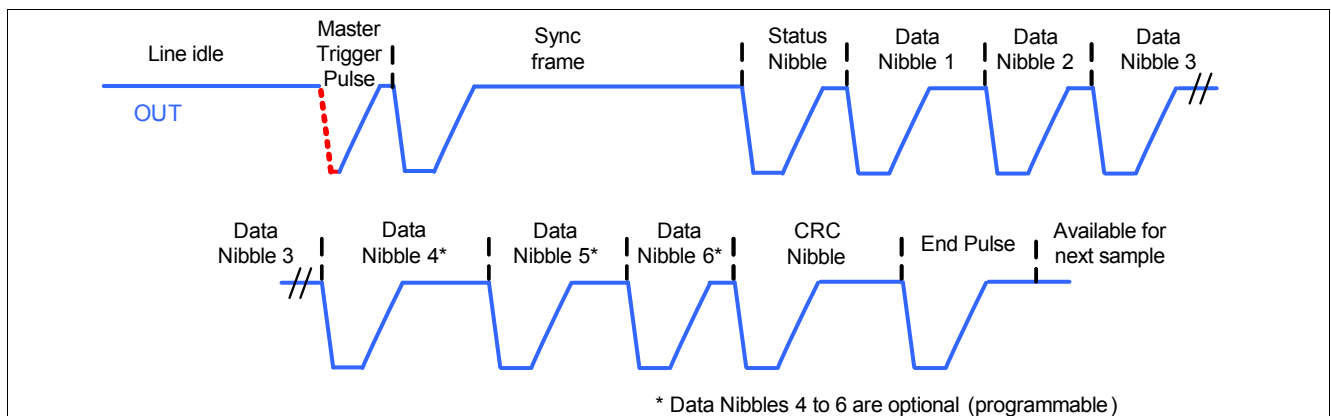


Figure 9-1 SPC Frame

SPC Output Definition

The CRC checksum includes the status nibble and the data nibbles and can be used to check the validity of the decoded data. The sensor is available for the next sample 90 μ s after the falling edge of the end pulse. The sampling time (when values are taken for temperature compensation) is always defined as the beginning of the synchronization period. During this period, the resulting data is always calculated from scratch.

The number of transmitted SPC nibbles is programmable to customize the amount of information sent by the sensor. The frame contains a 16 bit Hall value and an 8bit temperature value in the full configuration.

Table 9-3 Frame Register

Parameter	Symbol	Values			Unit	Note / Test Condition
		Min.	Typ.	Max.		
Frame register	F		2		bit	–

Table 9-4 Frame Selection

Frame Type	Parameter F	Data Nibbles
16 bit Hall, 8 bit temperature	0	6 nibbles
16 bit Hall	1	4 nibbles
12 bit Hall, 8 bit temperature	2	5 nibbles
12 bit Hall	3	3 nibbles

The temperature is coded as an 8 bit value. The value is transferred in unsigned integer format and corresponds to the range between -55 °C and +200 °C, so a transferred value of 55 corresponds to 0 °C. The temperature is additional information and although it is not calibrated, may be used for a plausibility check, for example. [Table 9-5](#) shows the mapping between junction temperature and the transmitted value in the SPC frame.

Table 9-5 Mapping of Temperature Value

Junction Temperature	Typ. Decimal Value from Sensor	Note
- 55 °C	0	Theoretical lower limit ¹⁾
0 °C	55	–
25 °C	80	–
200 °C	255	Theoretical upper limit ¹⁾

1) Theoretical range of temperature values, not operating temperature range.

The status nibble allows to check internal states and conditions of the sensor.

- Depending on the selected SPC mode, the first two bits of the status nibble contain either the selected magnetic range or the ID of the sensor and allow therefore an easy interpretation of the received data.
- The third bit is set to 1 for the first transmission after the sensor returns from an overvoltage operation with disabled open drain stage to regular operation (see [Chapter 7](#)).
- The fourth bit is switched to 1 for the first data package transferred after a reset. This allows the detection of low-voltage situations or EMC problems of the sensor.

9.2 Unit Time Setup

The basic SPC protocol unit time granularity is defined as 3 μ s. Every timing is a multiple of this basic time unit. To achieve more flexibility, trimming of the unit time can be used to:

- Allow a calibration trim within a timing error of less than 20% clock error (as given in SAE standard)
- Allow a modification of the unit time for small speed adjustments

This enables a setup of different unit times, even if the internal RC oscillator varies by $\pm 20\%$. Of course, timing values that are too low could clash with timing requirements of the application and should therefore be avoided, but in principle it is possible to adjust the timer unit for a more precise protocol timing. The output characteristic depends on the external load, the wiring, as well on the pull-up voltage and the temperature. Furthermore, sufficient driving capability of the sensor counterpart (ECU) is mandatory, in order to be able to maintain the herein given master pulse requirements. All these parameters have considerable influence to find the proper unit time setup.

Table 9-6 Pre-divider Setting

Parameter	Symbol	Values			Unit	Note / Test Condition
		Min.	Typ.	Max.		
Register size	Prediv		4		bit	Pre-divider ¹⁾
Unit time	t_{UNIT}	2.0		3.88	μ s	$Clk_{UNIT}=8\text{ MHz}^2)$

- 1) Prediv default is decimal = 8 for 3 μ s nominal SPC unit time.
- 2) RC oscillator frequency variation $\pm 20\%$.

The nominal unit time is calculated by:

$$f_{UNIT} = (\text{Prediv} + 16) / Clk_{UNIT}$$

$$Clk_{UNIT} = 8\text{MHz} \pm 20\% \tag{9.1}$$

9.2.1 Master Pulse Requirements

An SPC transmission is initiated by a Master pulse on the OUT pin. To detect a low-level on the OUT pin, the voltage must be below a threshold V_{thf} . The sensor detects that the OUT line has been released as soon as V_{thr} is crossed. **Figure 9-2** shows the timing definitions for the master pulse. The master low time $t_{m\text{low}}$ as well as the total trigger time $t_{m\text{tr}}$ are individual for the different SPC modes and are given in the subsequent sections.

It is recommended to choose the typical master low time exactly between the minimum and the maximum possible time: $t_{m\text{low,typ}} = (t_{m\text{low,min}} + t_{m\text{low,max}}) / 2$. Although the allowed timing windows are larger for longer low times, the master should use a crystal oscillator clock source to provide a high timing accuracy (approx. 1%). For improved robustness, the master pulse can be adopted by the master once the effective unit time is known through the sensor's synchronisation period length. If the master low time exceeds the maximum low time, the sensor does not respond and is available for a next triggering 30 μ s after the master pulse crosses V_{thr} . $t_{md,tot}$ is the delay between internal triggering of the falling edge in the sensor and the triggering of the ECU.

Table 9-7 Master Pulse Parameters

Parameter	Symbol	Values			Unit	Note / Test Condition
		Min.	Typ.	Max.		
Falling edge threshold	V_{thf}	1.1	1.3	1.7	V	–
Rising edge threshold	V_{thr}	1.25	1.43	1.8	V	–
Total trigger time	t_{mtr}	10.8	13	16.3	UT	Synchronous mode ¹⁾²⁾
		46.6	56	70	UT	Dyn. range mode ¹⁾²⁾
		75	90	113	UT	ID selection mode ¹⁾²⁾
Master delay time	$t_{md,tot}$	3.7	5.8	7.9	μ s	³⁾

- 1) UT = Programmed nominal SPC unit time
- 2) Trigger time in the sensor is fixed to the number of unit times described in the “typ.” column, but the effective trigger time varies due to the sensor’s clock variation
- 3) For $V_{DD} = 5\text{ V}$, $R_L = 2.2\text{ kW}$, $C_L = 4.7\text{ nF}$, ECU trigger level $V_{th,ECU} = 2\text{ V}$

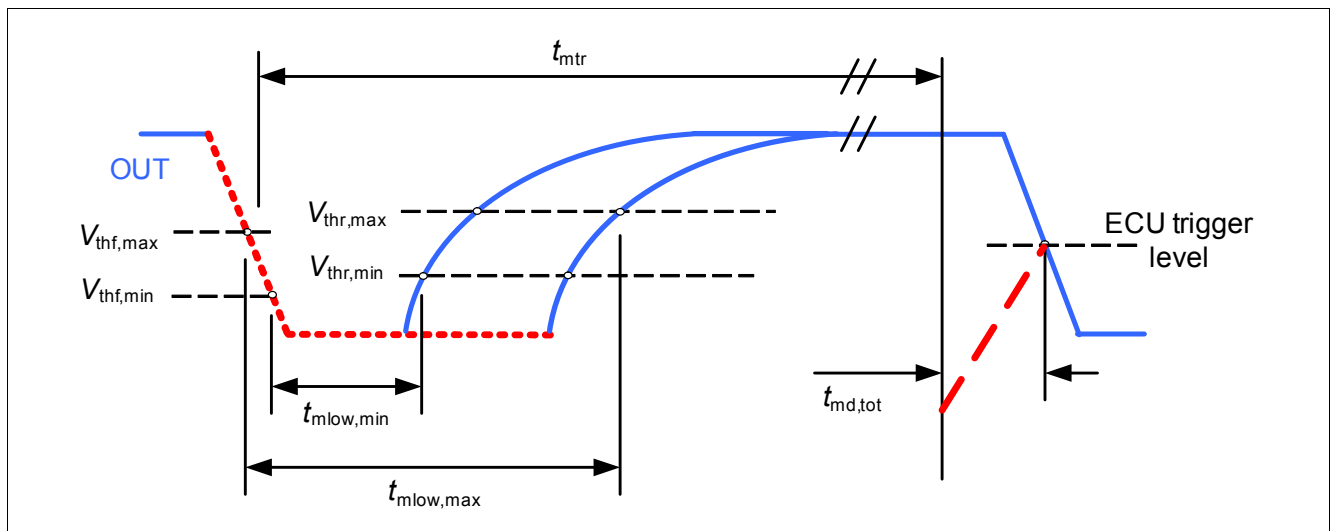


Figure 9-2 SPC Master Pulse Timing

9.2.2 Synchronous Transmission

In the “synchronous” mode, the sensor (slave) starts to transfer a complete data frame only after a low pulse is forced by the master on the OUT pin. This means that the data line is bidirectional - an open drain output of the micro controller (master) sends the trigger pulse. The sensor then initiates a sync pulse and starts to calculate the new output data value. After the synchronization period, the data follows in form of a standard SENT frame, starting with the status, data and CRC nibbles. At the end, an end pulse allows the CRC nibble decoding and indicates that the data line is idle again. The timing diagram in [Figure 9-1](#) visualizes a synchronous transmission.

Table 9-8 Master Pulse Timing Requirements for Synchronous Mode

Parameter	Symbol	Values			Unit	Note / Test Condition
		Min.	Typ.	Max.		
Master low time	t_{mlo}	1.5	2.75	4	UT ¹⁾	–

- 1) UT = Programmed nominal SPC unit time.

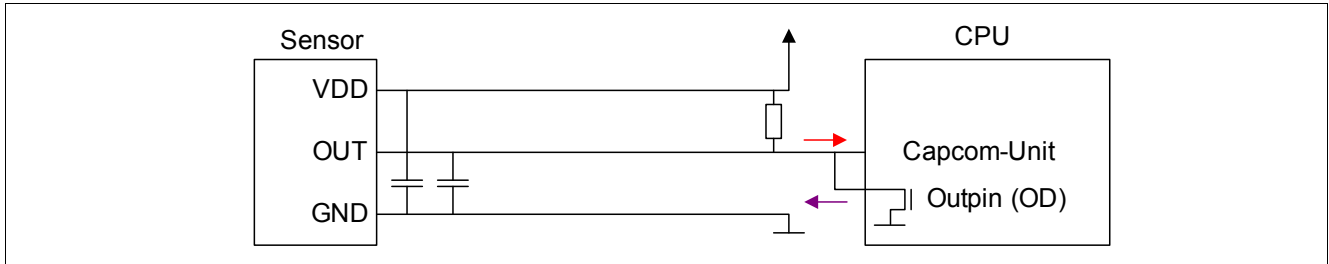


Figure 9-3 Bidirectional Communication in Synchronous Mode

9.2.3 Synchronous Transmission Including Range Selection

The low time duration of the master can be used to select the magnetic range of the sensor in SPC dynamic range selection mode.

Table 9-9 Master Pulse Timing Requirements for Dynamic Range Mode

Parameter	Symbol	Values			Unit	Note / Test Condition
		Min.	Typ.	Max.		
Master low time	$t_{m\text{low}}$	1.5	3.25	5	UT ¹⁾	Range = 200 mT ($R=0$)
		9	12	15	UT	Range = 100 mT ($R=1$)
		24	31.5	39	UT	Range = 50 mT ($R=3$)

1) UT = Programmed nominal SPC unit time.

The range information in the status bit can be used to determine whether the range has been properly identified. Changing the range takes some time due to the settling time of internal circuitry. The first sample after a range switch therefore still displays a value sampled with the old range setting and the second transmission after changing the range displays the new range with reduced accuracy.

9.2.4 Synchronous Mode with ID Selection

This functionality is similar to the previous mode, but instead of switching the range of one sensor, one of up to four sensors are selectable on a bus (bus mode, 1 master with up to 4 slaves). This allows parallel connection of up to 4 sensors using only three lines (VDD, GND, OUT), as illustrated in [Figure 9-4](#).

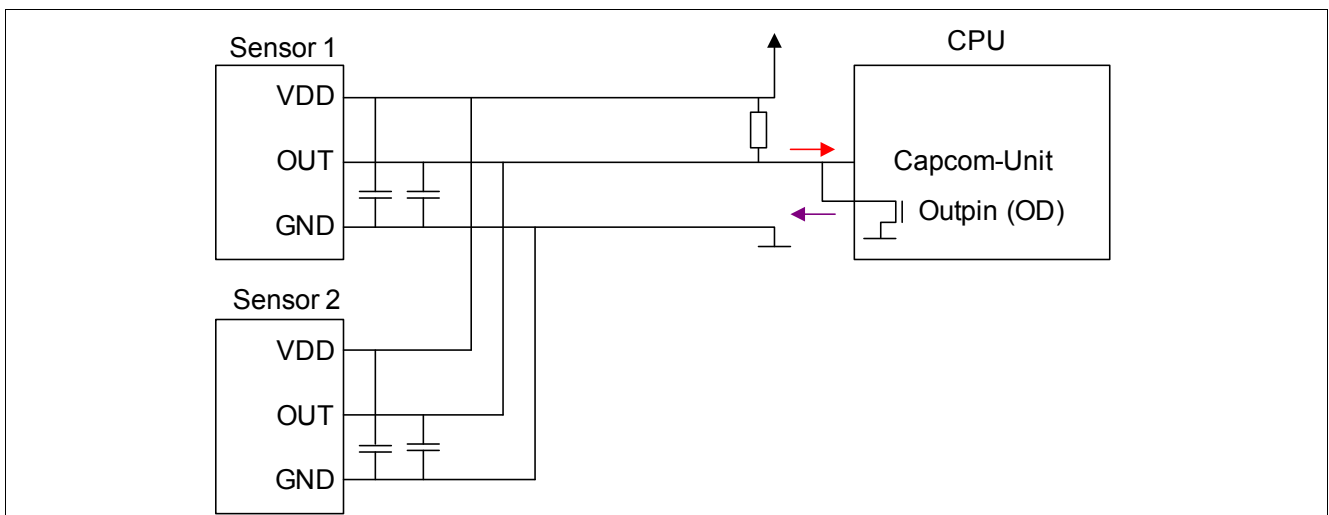


Figure 9-4 Bidirectional Communication with ID Selection

In this mode, the sensor starts to transfer complete packages only after receiving a master low pulse with an ID that is equivalent to the programmed value in its ID register. The mapping between master low time and ID is given in [Table 9-10](#). A proper addressing requires the different sensors on a same bus to be programmed with the same nominal SPC unit time. Alternatively, the sensors can be trimmed using the pre-divider settings to further reduce their relative unit time difference for more robustness.

Table 9-10 Master Pulse Timing Requirements for ID Selection Mode

Parameter	Symbol	Values			Unit	Note / Test Condition
		Min.	Typ.	Max.		
Master low time	$t_{m\text{low}}$	9	10.5	12	UT ¹⁾	ID = 0
		19	21	23	UT	ID = 1
		35.5	38	40.5	UT	ID = 2
		61.5	64.5	67.5	UT	ID = 3

1) UT = Programmed nominal SPC unit time.

SPC Output Definition

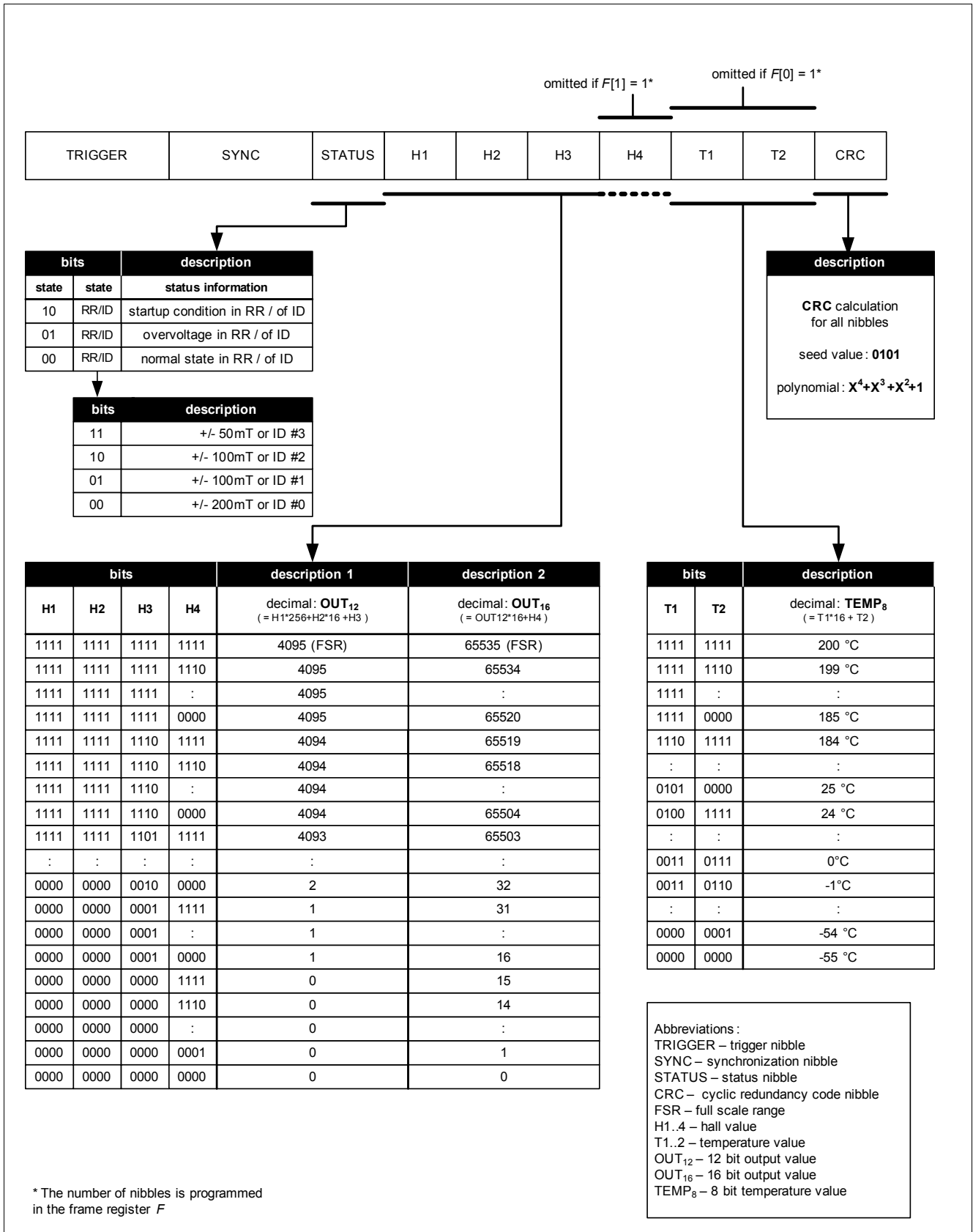


Figure 9-5 Content of a SPC Data Frame (5-8 Nibbles)

9.2.5 Checksum Nibble Details

The Checksum nibble is a 4-bit CRC of the data nibbles including the status nibble. The CRC is calculated using a polynomial $x^4 + x^3 + x^2 + 1$ with a seed value of 0101.

In the TLE4998C8D Grade1 it is implemented as a series of XOR and shift operations as shown in the following flowchart:

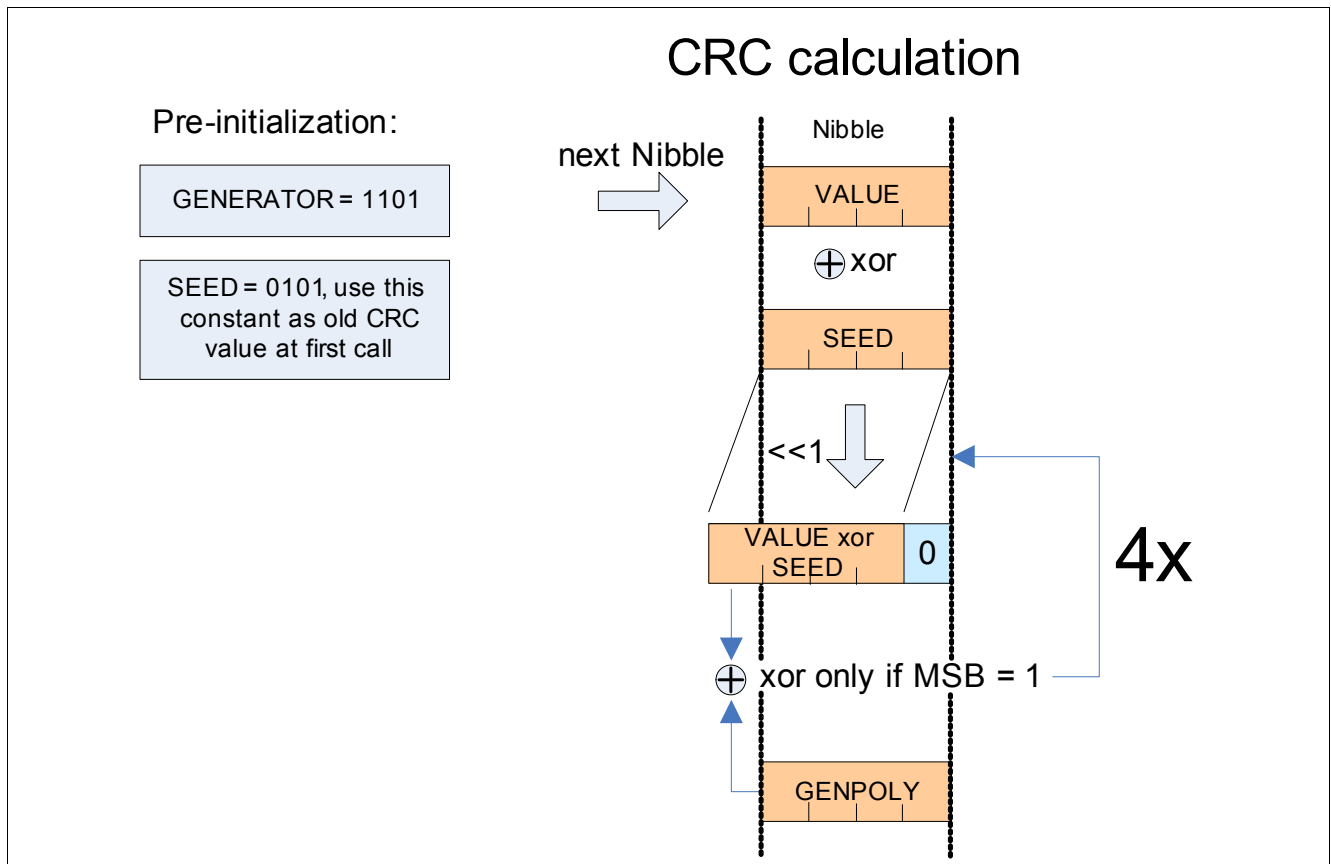


Figure 9-6 CRC Calculation

A micro controller implementation may use an XOR command plus a small 4-bit lookup table to calculate the CRC for each nibble.

```
// Fast way for any µC with low memory and compute capabilities
char Data[8] = {...}; // contains the input data (status nibble, 6 data nibble, CRC)
// required variables and LUT
char CheckSum, i;
char CrcLookup[16] = {0, 13, 7, 10, 14, 3, 9, 4, 1, 12, 6, 11, 15, 2, 8, 5};
CheckSum = 5; // initialize checksum with seed "0101"
for (i=0; i<7; i++) {
    CheckSum = CheckSum ^ Data[i];
    CheckSum = CrcLookup[CheckSum];
}
; // finally check if Data[7] is equal to CheckSum
```

Figure 9-7 Example Code for CRC Generation

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