TLE4999C User’s manual

Product Family: TLE4999C

About this document

Scope and purpose

This document is valid for the TLE4999C. It describes the digital programming interface and the programming flow to be used to configure the sensor IC. The configuration parameters of the TLE4999C are stored in an EEPROM. The specification for electrical and timing parameters given in this document are to be understood directly on the sensor pins. Additional effects relating to the external circuitry, the attached programming equipment or environmental influence are not considered.

The general behavior and a top-level block diagram of the TLE4999C are described in the TLE4999C data sheet.

Intended audience

This document is intended for anyone who needs to program and calibrate the TLE4999C programmable linear Hall sensor with fast SPC interface.

Table of Contents

1 TLE4999C Signal processing

Both channels of the TLE4999C use a fully digital signal processing concept.

The analog values from the Hall probes are directly converted to digital signals by the Hall ADC and are then processed in the digital signal processing units (DSPs).

The DSPs are using configuration parameters stored in the EEPROM as well as temperature and stress data acquired by the corresponding temperature and stress sensing elements.

User configurable second-order temperature polynomials are implemented for main and sub channel to compensate the thermal reduction of the magnetic flux of a permanent magnet used in a position sensing application. Additionally, an application-specific output characteristic can be set by configuring the EEPROM parameters gain, zero point and by performing a digital multipoint calibration of the linear output.

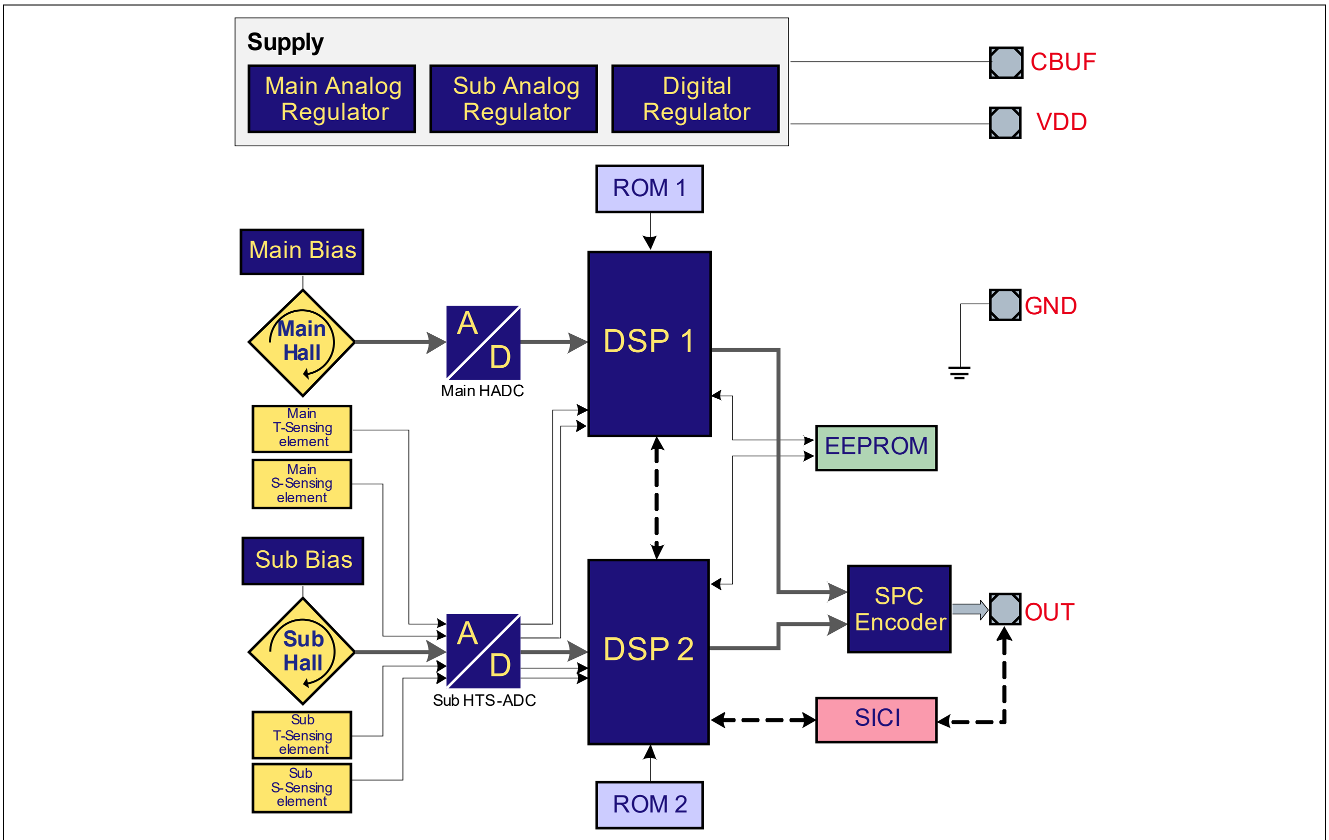

Figure 1 Simplified signal flow diagram of the TLE4999C

Figure 1 shows the signal flow diagram for stress and temperature compensation and output characteristic of the TLE4999C.

In the simplified signal flow diagram showed on **Figure 1**, it is shown that the main ADC is used for conversion of the main Hall signal. The sub ADC is muliplexed for conversion of main and sub temperature and stress signals and sub Hall signal. The Hall signals are processed in the following sequence of steps:

1. The analog Hall signals are converted by the main and sub ADC.
2. The digital values are filtered by digital low-pass filters which operate at a configurable filter frequency given by the main and sub "LP filter"-setting.
3. The signals from the Hall ADCs are compensated internally for stress and temperature drifts in the respective DSPs. The compensated values are stored in the main and sub HCAL registers. Also, the converted signals from the temperature sensors are stored in the main and sub TINT registers.
4. The main and sub HCAL values are multiplied by the respective user gain settings stored in the EEPROM and the results of the main and sub user temperature compensation polynomials.
5. The main and sub zero point settings are added to the resulting Hall values.
6. The linearization of the digital Hall values is applied, according to the selected multipont calibration version.
7. The digital Hall values are clamped according to the configured upper and lower clamping limits for main and sub channel. The output values of the clamping stages are stored in the OUT_main and OUT_sub registers.
8. An output protocol is generated from the resulting OUT_main and OUT_sub values and transmitted on the OUT pin.

2 Programming

2.1 Programmer connection

Figure 2 shows the connection of the TLE4999C to the programming equipment.

The external components C_L, C_S and C_{Buf} are set according to the TLE4999C data sheet. The line capacitance affects the maximum possible data rate of the programming interface. For high line capacitances, for example due to a long cable connection, a slow data rate shall be used to ensure robust transmission.

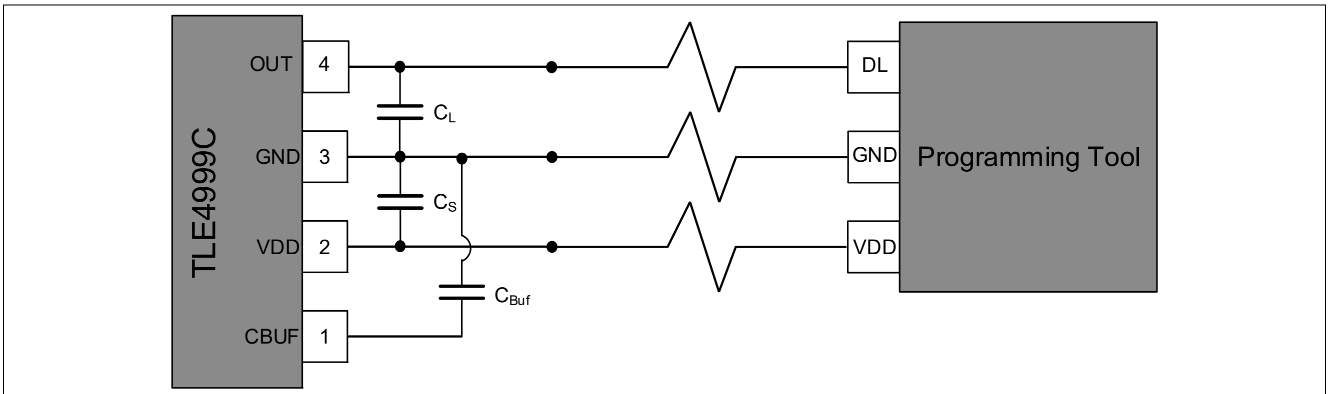

Figure 2 TLE4999C Circuitry for programming

2.2 Programming Interface

The TLE4999C sensor allows end-of-line programming of the EEPROM and read access to all internal registers via the SICI (Serial Inspection and Configuration Interface) interface. The bidirectional communication mode can be entered during a limited time window directly after power on by sending the "activate programming mode" command.

The communication via the SICI interface is based on transmitting a single bit to the sensor and immediately receiving a bit. These bits form a 18-bit word. It makes the interface bit-synchronous, robust and very flexible in timing. Bidirectional data transmission can thus be realized using only a single wire without a trimmed oscillator on sensor or programmer side. To enhance the robustness of the interface, the sensor repeats the 18-bit command word sent by the programmer in order to have a confirmation of the correct understanding of the message, and transmits a safety word after each communication. Additionally, a time-out feature is implemented: If during a communication the sensor does not receive a bit from the programmer within a certain time span (see **Table 1**, Interface reset time), the interface is reset and a new command can be sent.

2.2.1 Bit encoding

Bits from the programmer are encoded as the difference in duration of consecutive "high" and "low" voltage levels. To transmit a bit to the sensor, the programmer sends one single high/low PWM signal with a period *T*. The logic value of the bit is then encoded as the difference between "high" and "low" time:

- to transmit a "0" to the sensor, the programmer drives the line "low" for a short time t_{1_0}, then releases it to "high" for a long time t_{2_0} (typically t_{1_0}= 0.33*T).
- to transmit a "1" to the sensor, the programmer drives the line "low" for a long time t_{1_1}, then releases it to "high" for a short time t_{2_1} (typically t_{1_1} = 0.67*T).

The sensor recognizes the total bit-time interval T as the duration between two consecutive rising edges from the programmer. The bit encoding scheme is illustrated in **Figure 3**.

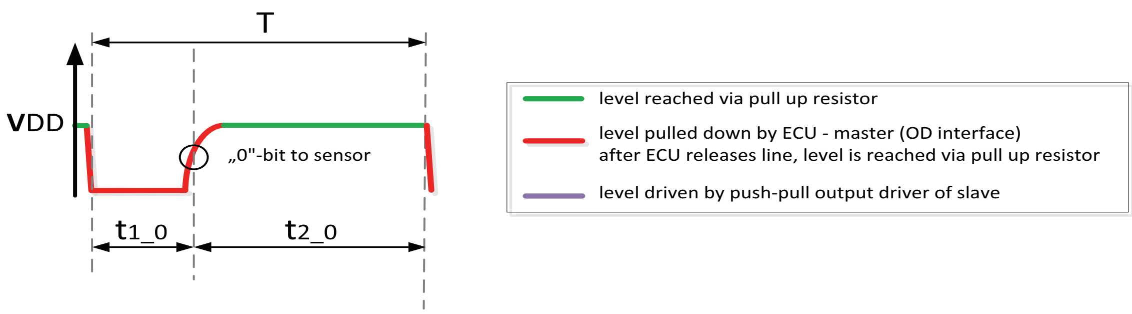

Figure 3 Timing description of programmer bit

After receiving a bit from the programmer, the sensor answers by transmitting one bit:

- the sensor transmits a "1" by pulling the SICI-line "low" for the time difference between "high" and "low" level given by the received PWM signal.
- the sensor transmits a "0" by keeping the line "high".

To read the bit transmitted by the sensor t_r, the programmer has to check the level of the line after t_3 (programmer low pulse) but before time t_4 (difference between programmer low and high level) has expired (recommended t_r= 0.5* t_4, see **Figure** 4)

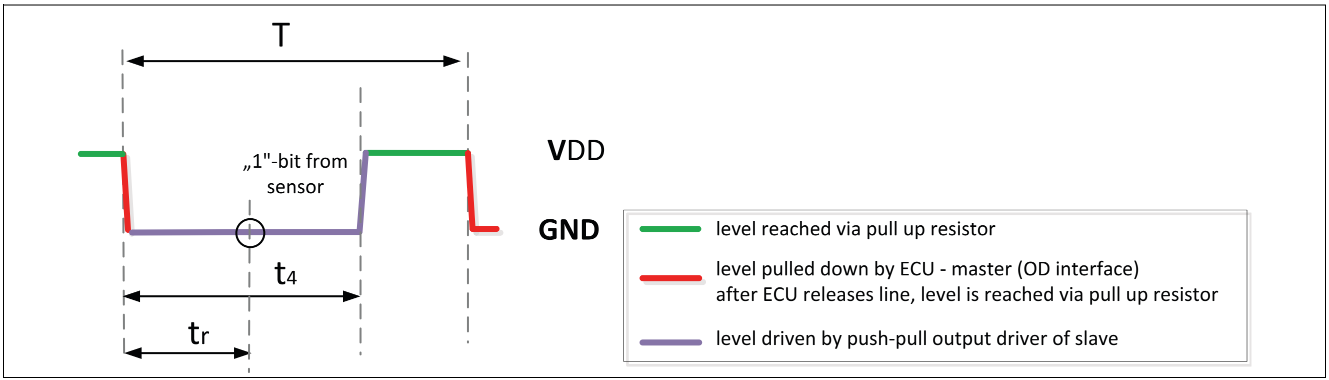

Figure 4 Timing description of response bit from sensor

After receiving the response bit from the sensor, the programmer can pause for a time before transmitting the next bit. This timing has to be shorter than the time-out limit (see **Table 1**, interface reset time), otherwise the interface is reset. **Figure** 5 shows an example communication between programmer and sensor.

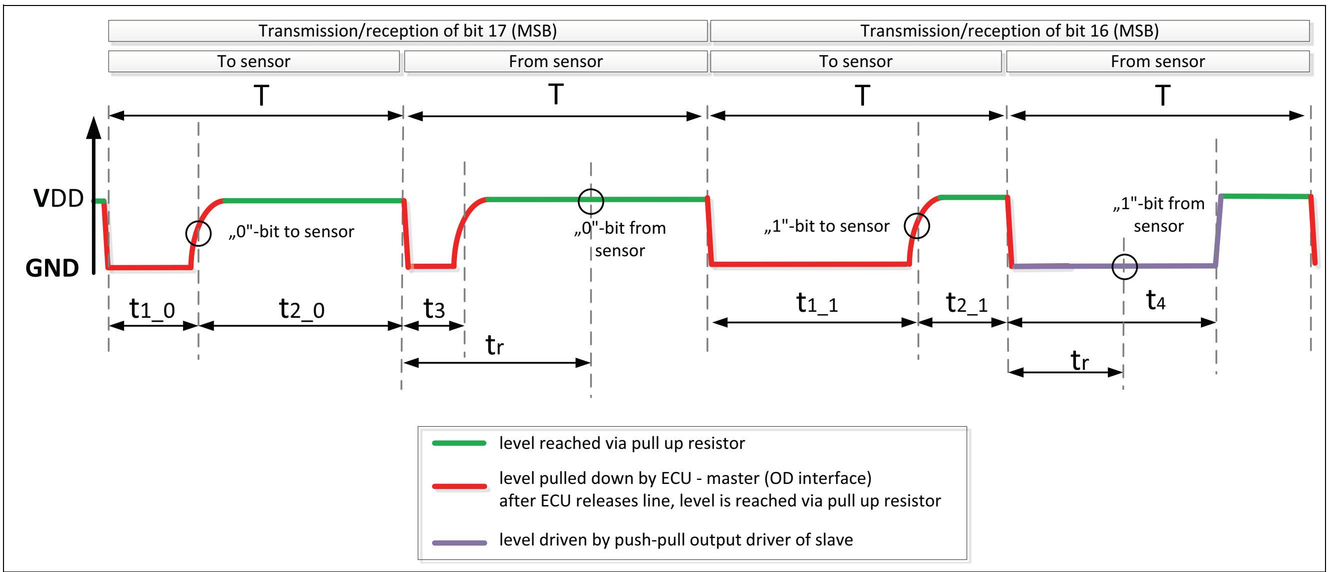

Figure 5 SICI communication example

The transmission rate of the interface is determined by the width T of the PWM signal sent by the programmer. A maximum transmission speed of 25 kbit/s can be reached for *T*= 40µs. Lowering the transmission rate generally increases the robustness of the communication in distorted environments and/or with high capacitive loads on the line. The optimum communication speed thus depends on the application circuitry. The timing specification of the SICI interface is given in **Table 1**

Table 1 SICI Interface electrical and timing characteristics

Parameter	Symbol	Values			Unit	Note or Test Condition
		Min.	Typ.	Max.		
Programmer PWM period	T	40[1]	–	120	µs	Determines interface transmission rate[2]
Programmer low time to transmit "0"	t_{1_0}	0.28*T	0.33*T	0.38*T	µs	$t_{2\_0}=T - t_{1\_0}$ [2]
Programmer low time to transmit "1"	t_{1_1}	0.62*T	0.67*T	0.72*T	µs	$t_{2\_1}=T - t_{1\_1}$ [2]
Time difference between Programmer low and high level	t_4	–	–	–	µs	$t_4 = 2 * \|t_{1\_x} - t_{2\_x}\|$ [2]
Programmer low pulse after PWM bit	t_3	$0.1*t_4$	–	$0.3*t_4$	µs	$t_4 = 2 * \|t_{1\_x} - t_{2\_x}\|$ [2][3]
Interface reset time	T_{Res}	1.7	–	5	ms	[2][4]
Input signal low level	$V_{low, in}$	–	–	$0.3*V_{DD}$	V	[2]
Input signal high level	$V_{high, in}$	$0.7*V_{DD}$	–	–	V	[2]
Output signal low level	$V_{low, out}$	–	–	$0.1*V_{DD}$	V	For $I_{out} \leq 3.4$ mA, defined only for $V_{pullup} = V_{DD} = 4.5V-5.5V$ [2]
SICI line pull-up resistor	R_{pu}	1		10	kΩ	[2]

1) Achievable transmission rate (minimum Programmer PWM period) depends on parasitic capacities in external circuitry.
2) Verified by design/characterization.
3) Rise/fall times due to parasitic capacitances on the line have to be added.
4) Maximum time for reset calculated for worst case interruption of SICI transmission.

2.2.2 Programming protocol

One data frame of the SICI interface consists of 1 control bit, 16 data bits arranged MSB first and 1 parity bit (odd parity). The SICI communication is started by the programmer sending an "activate programming mode" command directly after power-up of the sensor. The sensor remains silent until the correct password is received. The control bit is "1" for command frames" and "0" for data frames. The sensor is ready for programming 300 µs after receiving the "activate programming mode" command.

After entering programming mode, the programmer can start transmitting one or multiple frames. Between two frames, the programmer has to pause for at least t_{pause}.

As described in **Chapter 2.2.1**, the SICI interface is bit-synchronous, so every bit sent by the programmer is immediately responded by one bit from the sensor.

To read data content from the sensors registers, the programmer can send a "read" command including the register address to read from. As the SICI interface is bit-synchronous, the "read" command from the programmer has to be followed by one or multiple "empty" data frames, that is frames containing all 0's.The

sensor responds the read command by replying the last valid command that it received.

In case the last valid command was "activate programming mode" command the sensor will reply with an "1" at the parity bit, otherwise the sensor responds by repeating every bit of the last valid command it received. Then, it responds the empty data frame by sending the content of the addressed register.

Multiple consecutive registers can be read with one read command by sending more than one empty frame after the "read" command. The sensor then automatically increments the register address with every received empty frame and responds by sending the content of the consecutive registers (see **Figure 6**).

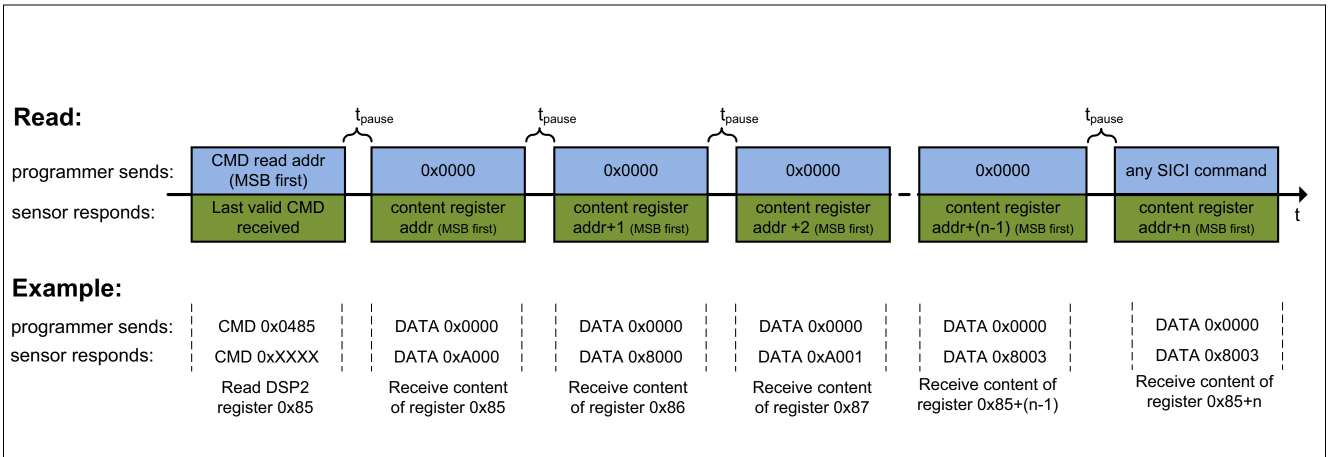

Figure 6 Frame order for read commands

To write data to registers, the programmer can send a "write" command including the register address to write to, followed by a data frame containing the data which shall be written to the addressed register. The sensor responds to the write command by showing last valid command that it received, in case the last valid command was "activate programming mode" command the sensor will then reply with an "1" at the parity bit.

Otherwise the sensor responds by repeating every bit of the last valid command it received, and it responds to the data frame by repeating the write command again.

Multiple consecutive registers can be written with one command by sending more than one data frame after the "write" command. The sensor automatically increments the address, so the content of the sent data frames from the programmer is written into consecutive registers. The sensor responds every data frame by repeating the write command including the (incremental) address that is written to (see **Figure 7**).

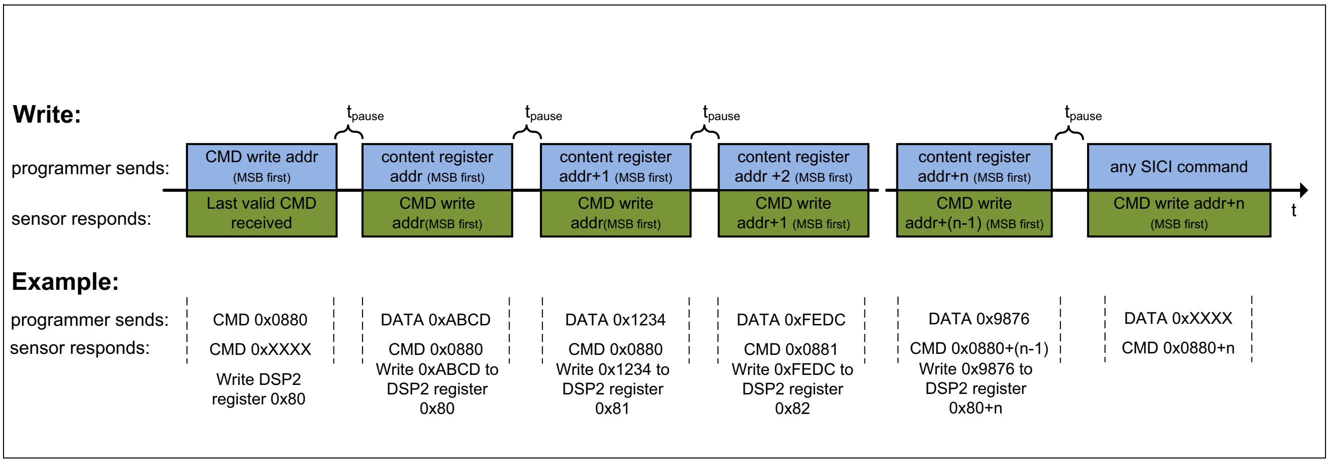

Figure 7 Frame order for write commands

The possible commands that can be sent by the programmer are listed in **Table 2**. The two signal processing units of the TLE4999C, DSP1 and DSP2, have separate sets of working registers. Read and write access to these registers is done via the corresponding read and write commands for DSP1 and DSP2, respectively.

Note: Wrong SICI commands (that is any bit patterns not covered by ***Table 2****), are ignored by the sensor.*

Table 2 SICI commands

Command	Bits (MSB...LSB)	Description
Activate programming mode with SPC ID 0	$E478_H$	After receiving this command, the sensor enters programming mode. Can be exited by an external supply voltage reset or with the corresponding interface command ($AB00_H$). *Note: Activate programming mode commands are only valid for programmed SPC ID of the sub channel.* *Note: password $E478_H$ is valid for synchronous mode and SPC ID 0.*
Activate programming mode with SPC ID 1	$E479_H$	
Activate programming mode with SPC ID 2	$E47A_H$	
Activate programming mode with SPC ID 3	$E47B_H$	
Exit programming mode	$AB00_H$	After receiving this command, the sensor leaves programming mode.
DSP1 Read	$01xx_H$	Read data frame(s) from DSP1 register address xx_H
DSP1 Write	$02xx_H$	Write data frame(s) to DSP1 register address xx_H
DSP2 Read	$04xx_H$	Read data frame(s) from DSP2 register address xx_H
DSP2 Write	$08xx_H$	Write data frame(s) to DSP2 register address xx_H
EEP Refresh Page	$D0xx_H$	Refresh EEPROM page; This can be specified by the lower byte of the SICI command which has the following function: Bit 3:0 define the data page to be refreshed Bit 4 defines if the configuration page should be updated (no update of the data page if this bit is 1) Bit 7:5 define the delay after which the refresh should start. The resolution is 1024 µs per LSB.
EEP Program	$43xx_H$	Start programming sequence for EEPROM page xx_H

Table 2 SICI commands

Command	Bits (MSB...LSB)	Description
EEP Automatic Margin Check	$86xx_H$	Perform automatic margin check for all EEPROM pages at once, xx specifies a delay for activation of the auto margin check (32µs steps).
EEP Lock	$0D00_H$	Lock entire EEPROM

Table 3 summarizes the timings for programming mode.

Table 3 Timing specification for frame pause and programming mode activation

Parameter	Symbol	Values			Unit	Note or Test Condition
		Min.	Typ.	Max.		
Pause between frames	t_{pause}	30	–	–	µs	gap between frames to ensure correct processing
Pause after programming mode activation	t_{act_pause}	300			µs	
Time window for activation of programming interface	$t_{activate}$	2	–	5	ms	time after power-up of the sensor during which the "activate programming mode" command is accepted by the sensor
Pause after programming pulse	t_{prog_pause}	1	–	–	ms	

2.2.3 DSP registers

The following registers of the TLE4999C's signal processing units, DSP1 and DSP2, can be accessed with the corresponding "DSP1/2 Read/Write" commands:

Table 4 DSP1 Registers

Address	Symbol	Function	R/W
00_H	HW_STATUS_main	Hardware Status main	read only
10_H	HCAL_main	16bit internal calibrated main Hall ADC value (signed)	read only
14_H	TINT_main	16bit internal calibrated main temperature value (signed)	read only
16_H	SCAL_main	16bit internal calibrated main stress value (signed)	read only
21_H	OUT_main	16bit main Hall SPC output value (unsigned)	read only

Table 5 DSP2 Registers

Address	Symbol	Function	R/W
00_H	HW_STATUS_sub	Hardware Status sub	read only
$0B_H$	HCAL_sub	16bit internal calibrated sub Hall ADC value (signed)	read only
$0F_H$	TINT_sub	16bit internal calibrated sub temperature value (signed)	read only
12_H	SCAL_sub	16bit internal calibrated sub stress value (signed)	read only
$1C_H$	OUT_sub	16bit sub Hall SPC output value (unsigned)	read only
$4C_H$	HW_ID	Hardware ID	read only
$7F_H$	EEP_STAT	EEPROM Status	read only
$E8_H$	EEP_WORD0	EEPROM mapping register - line 0	read/write
$E9_H$	EEP_WORD1	EEPROM mapping register - line 1	read/write
EA_H	EEP_WORD2	EEPROM mapping register - line 2	read/write
EB_H	EEP_WORD3	EEPROM mapping register - line 3	read/write
EC_H	EEP_WORD4	EEPROM mapping register - line 4	read/write
ED_H	EEP_WORD5	EEPROM mapping register - line 5	read/write
EE_H	EEP_WORD6	EEPROM mapping register - line 6	read/write
EF_H	EEP_WORD7	EEPROM mapping register - line 7	read/write

The registers HCAL_main/sub, TINT_main/sub, and SCAL_main/sub provide a readout of the main and sub path Hall, temperature, and stress measurements during programming interface access. They are employed for the user calibration procedure described in **Chapter 3**.

The register HW_ID contains the hardware ID of the TLE4999C, which can be found in the **Table 6**

Table 6 Hardware ID

HW_ID	Design step
0000_B	A1
0001_B	A2
0010_B	A3

The registers EEP_WORD0 to EEP_WORD7 are mapping registers for read and write access to the EEPROM. After receiving an "EEP Refresh Page" command D0xx$_H$, the sensor maps the content of EEPROM page xx$_H$ to these registers.

2.2.3.1 HW_STATUS_sub

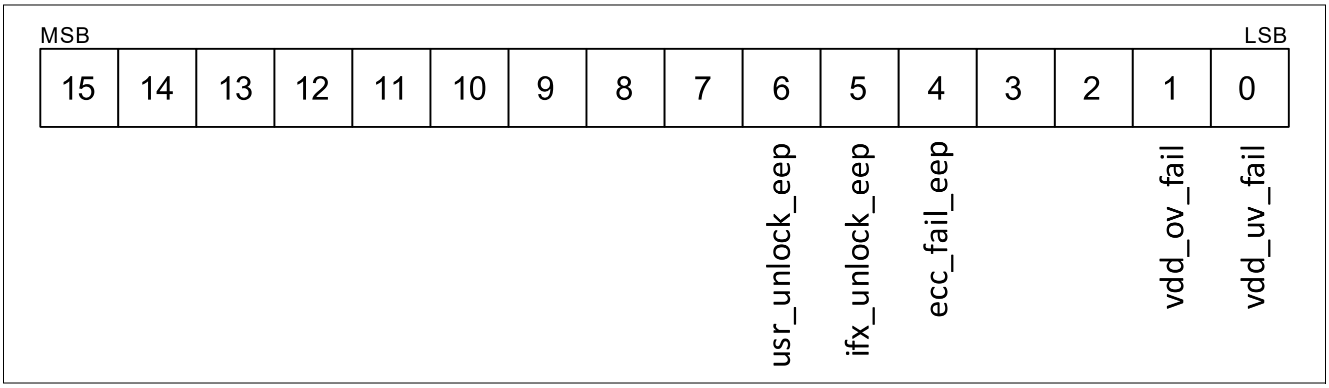

Figure 8 Hardware Status Register

- vdd_uv_fail is "1" in case an external supply under voltage is detected.
- vdd_ov_fail is "1" in case an external supply over voltage is detected.
- ecc_fail_eep is "1" if at least one multi-bit error was detected by the ECC.
- ifx_unlock_eep is "1" if the lock to the Infineon area of the EEPROM is not applied.
- usr_unlock_eep is "1" if the lock to the user area of the EEPROM is not applied.

2.2.3.2 EEP_STAT

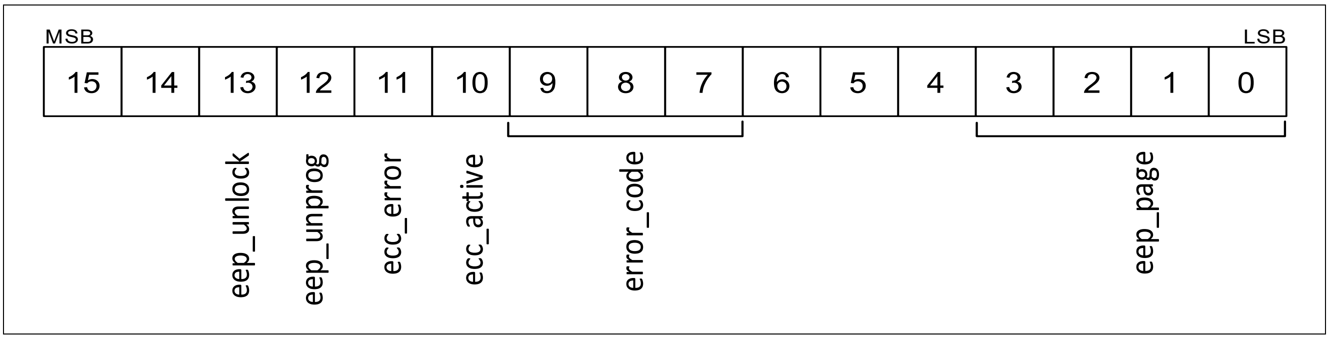

Figure 9 EEPROM Status Register

- eep_page contains the active EEPROM page address which has been selected with the last "EEPROM Refresh Page" command.
- error_code contains the error code of a detected EEPROM error. If no error is present, this field can be either "000$_B$" or "111$_B$".
- ecc_active is "1" if at least one single-bit error was detected and automatically corrected by the ECC (error correction code) mechanism.
- ecc_error is "1" if at least one multi-bit error was detected by the ECC.
- eep_unprog is "1" in case the EEPROM configuration was not programmed. In this case, the SPC output remains disabled.
- eep_unlock is "1" as long as the EEPROM is unlocked. After locking, it is "0".

2.3 SPC Checksum calculation

Depending on the selected output protocol the checksum nibble can be a 4 bit, 6 bit or 8 bit CRC of the data nibbles that can include the status nibble (feature selectable see **Table 16**).

The 4 bit CRC is calculated using a polynomial $x^4+x^3+x^2+1$ with a seed value of 0101_B. The remainder after the last data nibble is transmitted as CRC. The 6 bit checksum is calculated using a polynomial $(x^6 + x + 1)$ with a seed value of 010101_B and the 8 bit checksum is calculated using a polynomial $(x^8 + x^5 + x^3 + x^2 + x + 1)$ with a seed value of 01010101_B.

The CRC calculation method is based on the recommended implementation in the SENT standard 2016.

For this recommended implementation, the CRC is calculated based on the input data which is then augmented with four extra zero bits (protocol A, B and C), six extra zero bits (protocol E) or eight extra zeros bit (protocol D) and an additional CRC calculation step.

Simple C implementation for the SPC 4 bit CRC calculation:

```
char *MakeCRC(char *BitString)
   {
   static char Res[5];                                 // CRC Result
   char CRC[4];
   int  i;
   char DoInvert;

   for (i=0; i<4; ++i)  CRC[i] = 0;                    // Init before calculation

   for (i=0; i<strlen(BitString); ++i)
      {
      DoInvert = ('1'==BitString[i]) ^ CRC[3];         // XOR required?

      CRC[3] = CRC[2] ^ DoInvert;
      CRC[2] = CRC[1] ^ DoInvert;
      CRC[1] = CRC[0];
      CRC[0] = DoInvert;
      }

   for (i=0; i<4; ++i)  Res[3-i] = CRC[i] ? '1' : '0'; // Convert binary to ASCII
   Res[4] = 0;                                         // Set string terminator

   return(Res);
   }
```

2.4 EEPROM

2.4.1 EEPROM Map

The EEPROM contains data for configuration, calibration and temperature compensation. It is organized in different pages, each page consists of 8 lines with 16 data bits per line. It is only possible to access one EEPROM page at a time for read / write operation. An overview of the user configurable range of the EEPROM is shown in **Figure 10**.
Each EEPROM line is protected by 6 additional ECC bits which provide detection and correction of flipped bits. The ECC can detect and automatically correct one flipped bit within a data line during operation of the sensor. If two bits within a data line flip, the ECC detects an error but cannot automatically correct it. In this case, the sensor indicates an error by disabling the sensor's SPC interface. The ECC bits are handled by the EEPROM controller internally and cannot be accessed manually.

In the EEPROM, the Infineon lock and user lock sections are on separate pages. The Infineon lock section is already locked at delivery and cannot be changed in the user programming. The user lock area shall be locked after the user calibration and configuration is complete.

		MSB															LSB
page	word	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	W0	User ID1 (15…0)															
0	W1	Clamping low main (15…0) - CLM															
0	W2	Clamping high main (15…0) - CHM															
0	W3	reserved		LPM (3…0)				Linear temperature coefficient main (9…0) -TC1M									
0	W4	Reference temperature main (6…0) - T0M							Quadratic temperature coefficient main (8…0) -TC2M								
0	W5	Gain main (13…0) - GM														reserved	
0	W6	Zero point main (15…0)															
0	W7	3V3 EN	RM	reserved				MPC version main (2…0) MPCM			SPC ID main (1…0) SPC IDM		CRC config main	SSM EN	SPC Protocol main (2…0) - SPCM		
1	W0	RS	CRC config sub	LPS (3…0)				Linear temperature coefficient sub (9…0) -TC1S									
1	W1	Reference temperature sub (6…0) - T0S							Quadratic temperature coefficient main (8…0) -TC2S								
1	W2	Gain sub (13…0) - GS														reserved	
1	W3	Zero point sub (15…0)															
1	W4	User ID2 (15…0)															
1	W5	Clamping low sub (15…0) - CLS															
1	W6	Clamping high sub (15…0) - CHS															
1	W7	MPC version sub (2..0) MPS			SPC Protocol sub (2…0) - SPS			FH ID (1…0)		SPC ID sub (1…0) SPC IDS		VT	BM	Unit time (3…0) - UT			
2	W0	Multi point calibration main 1 (15…0) - MPCM1															
2	W1	Multi point calibration main 2 (15…0) - MPCM2															
2	W2	Multi point calibration main 3 (15…0) - MPCM3															
2	W3	Multi point calibration main 4 (15…0) - MPCM4															
2	W4	Multi point calibration main 5 (15…0) - MPCM5															
2	W5	Multi point calibration main 6 (15…0) - MPCM6															
2	W6	Multi point calibration main 7 (15…0) - MPCM7															
2	W7	reserved								Block CRC main (7…0)							
3	W0	Multi point calibration sub 5 (15…0) - MPCS5															
3	W1	Multi point calibration sub 6 (15…0) - MPCS6															
3	W2	Multi point calibration sub 7 (15…0) - MPCS7															
3	W3	Multi point calibration sub 1 (15…0) - MPCS1															
3	W4	Multi point calibration sub 2 (15…0) - MPCS2															
3	W5	Multi point calibration sub 3 (15…0) - MPCS3															
3	W6	Multi point calibration sub 4 (15…0) - MPCS4															
3	W7	reserved								Block CRC sub (7…0)							

Figure 10 Page structure and addressing scheme of the user range of the EEPROM

2.4.2 EEPROM Block CRC

Both pages of the EEPROM user lock section are protected by separate 8 bit block CRCs (cyclic redundancy checks). The block checksum are calculated from lines 00 to the first 8 bits of line 07 of the corresponding page (page 0 & 2 for main and page 1 & 3 for sub) using the following polynomial: $x^8 + x^4 + x^3 + x^2 + 1$

and the seed value: 10101010_B.

When changing the content of an EEPROM page, the block checksum has to be re-calculated from the new page content and written into the corresponding CRC field.

In case the checksum value stored in the CRC field does not match the page content, the TLE4999C detects a CRC error and disables the SPC output.

2.4.3 EEPROM configuration parameters

2.4.3.1 Magnetic field range - RM, RS

The range parameters RM (range main channel) and RS (range sub channel) can be configured independently.

Depending on the working range of the magnetic field the range setting of the A/D converter can be selected between fine or regular. It is always symmetrical around the zero field point.

Any two points in the magnetic field range can be selected to be the end points of the output value (clamping high and clamping low). The output value is represented within the range between the two points.

In the case of fields higher than the range limits, the output signal may be distorted, or the internal safety mechanism "Hall range check" is activated. Furthermore the data bits of affected channel will be set to '0', plus the corresponding error bit in the Status nibble will be set to '1' (see **TLE4999C Safety Manual**).

Table 7 Range setting main/sub

Parameter RM, RS	Range	Nominal Range in mT
1	Fine	±25
0	Regular	±50 (default)

2.4.3.2 Gain setting - GM, GS

The gain parameters Gain_main and Gain_sub can be configured independently.

The overall sensitivity of each measurement channel is defined by the range and the gain setting. The compensated Hall measurement value is multiplied by the Gain value. The multiplication factor is given by:

$$\mathrm{Gain}_{\mathrm{main}} = \frac{\mathrm{GM}}{1079} \tag{2.1}$$

$$\mathrm{Gain}_{\mathrm{sub}} = \frac{\mathrm{GS}}{1079} \tag{2.2}$$

Table 8 Gain setting main/sub

Parameter GM,GS	Value	Description
Range	-8192...8191	corresponds to gain factor -7.59 ... 7.59
Quantization step	926 ppm	
Default[1)]	1079	corresponds to gain factor 1.0

1) In 50mT range, a gain factor of +1.0 corresponds to a nominal sensitivity of 36.875 LSB_{12}/mT.

Note: The main and sub channel of the TLE4999C show by default (both Gain settings 1.0) inverse output slopes.

2.4.3.3 Zero point setting - ZM, ZS

The zero point values correspond to the channel output values with zero magnetic field at the sensor. They can be configured independently for main and sub channel.

Table 9 Zero point setting main/sub

Parameter GM,GS	Value	Description
Range	0 ... 65536	corresponds to zero point at 0 LSB_{16}... 65536 LSB_{16}
Quantization step	1 LSB_{16}	
Default	32767	corresponds to nominal zero point[1)] at 65536 LSB_{16} (= 50% of full output range)

1) Subject to specified initial zero point specification.

2.4.3.4 Low pass filter setting - LPM, LPS

Configurable digital low pass filters are implemented in the signal paths of the main and sub channels. The possible settings, together with the corresponding phase and step response delays are shown in **Table 10**. **Figure 11** shows a Bode plot of the filter settings, and **Figure 11** illustrates the phase delay and step response.

The filter setting can be configured independently for main and sub channel.

Table 10 Low pass filter setting main/sub

Parameter LP	Nominal cutoff frequency in Hz (-3 dB point)	Nominal Phase Delay of 100 Hz Signal in µs	Nominal Step-Response (90%) Time in µs
0	Off[1)]	122	244
1	80	1530	4770
2	160	992	2430
3	200	838	1970
4	240	726	1630
5	320	576	1280
6	400	481	1002
7	470	416	864
8	500	391	800
9	650	319	618
10	870	250	480

Table 10 Low pass filter setting main/sub

Parameter LP	Nominal cutoff frequency in Hz (-3 dB point)	Nominal Phase Delay of 100 Hz Signal in µs	Nominal Step-Response (90%) Time in µs
11	980	226	416
12	1070	207	384
13	1270	177	320
14	1380	161	288
15	1530	144	256

1) Set programmable low pass filter off, inherent filter of ADC stays on

Note: The delays given in ***Table 10*** *are internal delays. In order to calculate the total latency in a specific configuration, the SPC interface transmission time has to be added.*

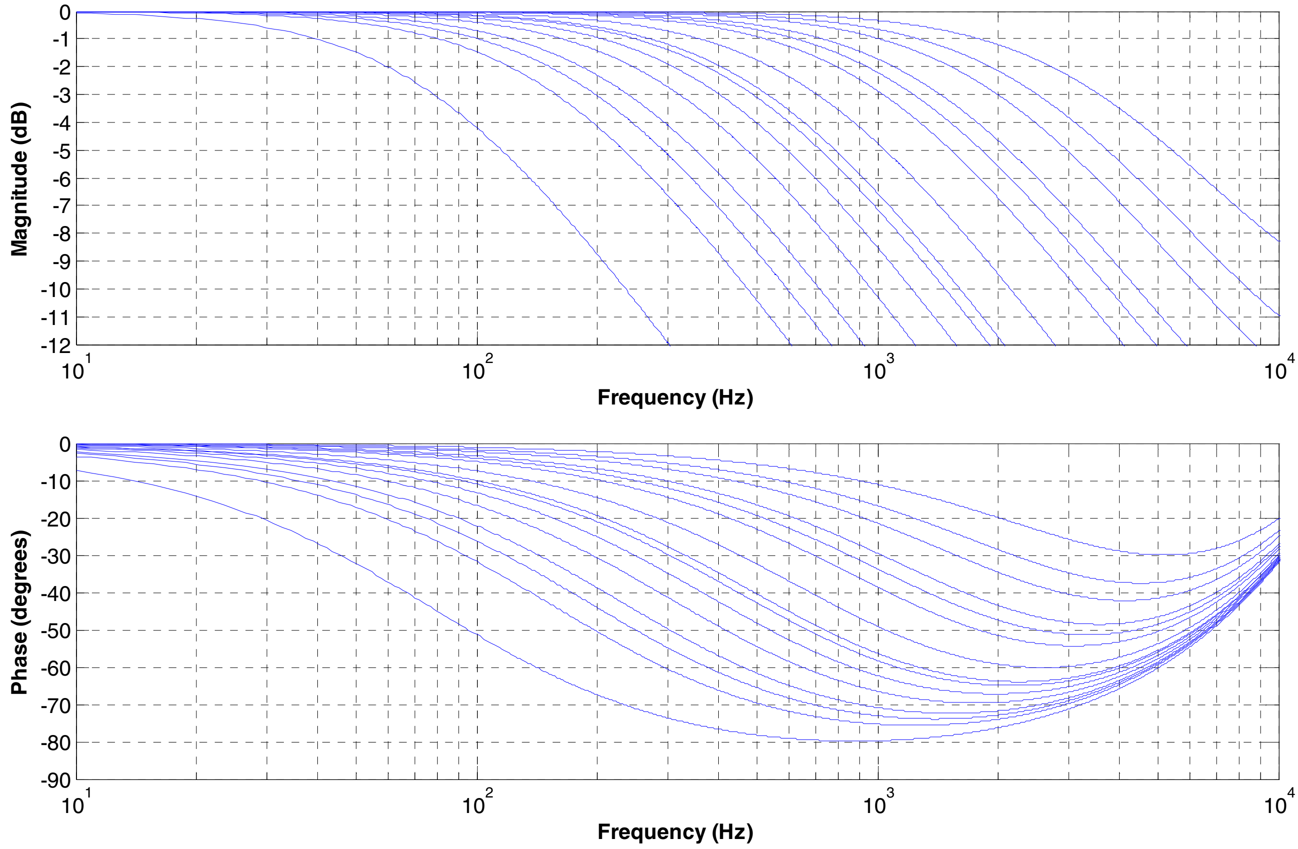

Figure 11 Bode Plot of TLE4999C Low pass filter settings 80 Hz to 1530 Hz (bottom to top graph).

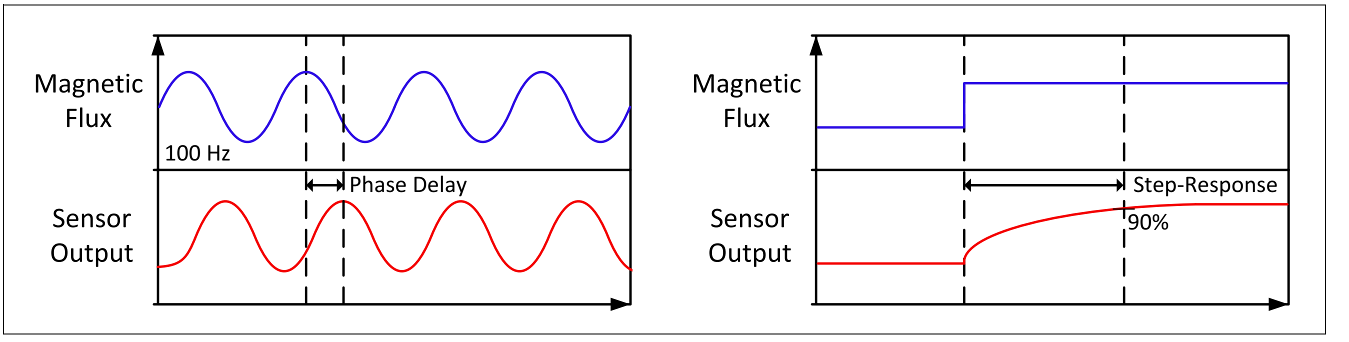

Figure 12 Illustration of phase delay and step response.

2.4.3.5 Clamping - CHM, CLM, CHS, CLS

The clamping function is useful for separating the output range into an operating range and error ranges. If the magnetic field is exceeding the selected measurement range, the output value is limited to the clamping values. Any value in the error range has to be interpreted has an error by the receiver.

The high and low clamping levels can be configured independently for main and sub channel.

Figure 13 shows the default output curve in which the magnetic field range between -50mT and 50mT is mapped from 5% to 95% of the full 16 bit output range.

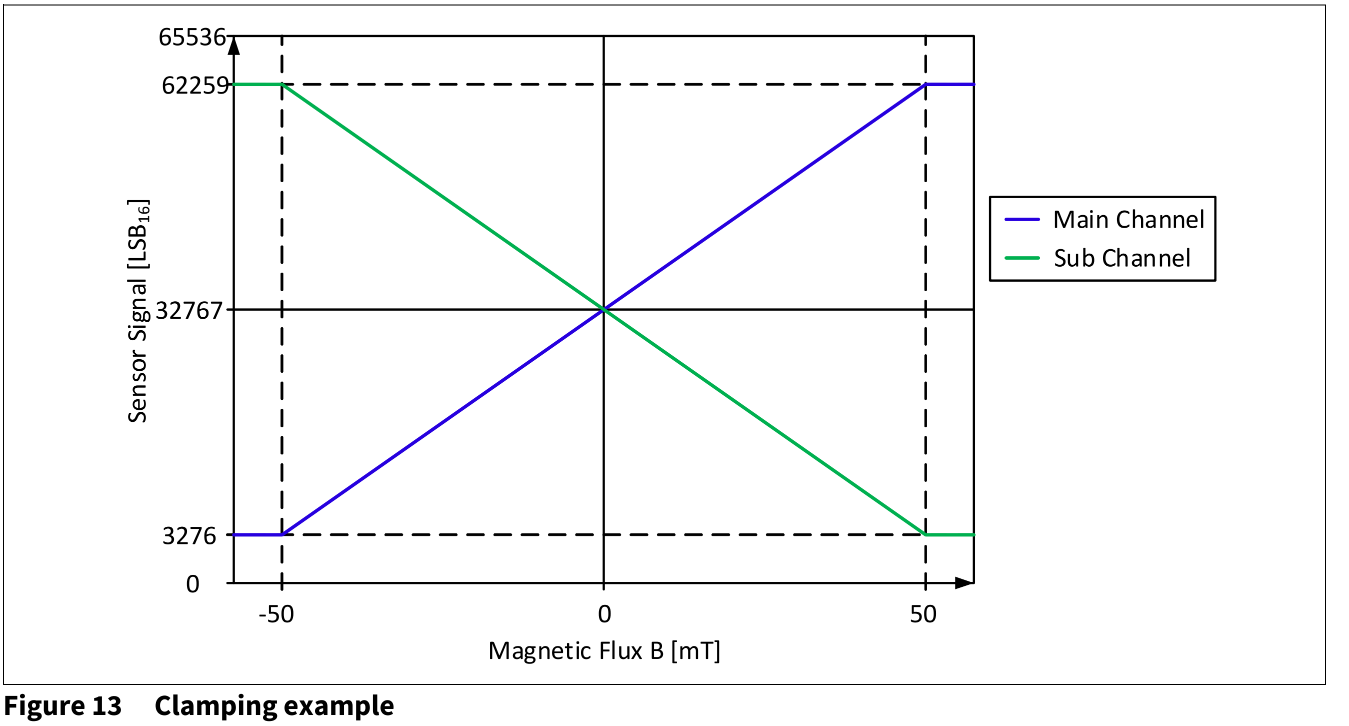

Figure 13 Clamping example

Table 11 Clamping high/low settings for main/sub

Parameter CHM,CLM,CHS,CLS	Value	Description
Range	0 ... 65536	corresponds to upper/lower clamping at 0 LSB_{16} ... 65536 LSB_{16}
Quantization step	1 LSB_{16}	
Default	CLM, CLS: 3276 CHM, CHS: 62259	corresponds to clamping at 5% and 95% of full 16bit output range

2.4.3.6 Temperature compensation - T0M, T0S, TC1M, TC1S, TC2M, TC2S

Both channels of the TLE4999C have a user-configurable second-order temperature compensation, which can be used to compensate the thermal reduction of the magnetic flux of a permanent magnet.

Three parameters are used for the application temperature compensation:

- Reference temperature T_0
- A linear coefficient (1^{st} order) TC_1
- A quadratic coefficient (2^{nd} order) TC_2

The temperature compensation parameters for main and sub channel are stored in separate pages in the EEPROM.

The detailed procedure to derive the optimum TC1 and TC2 parameters for a a given magnet characteristic is described in **Chapter 3.1**.

Table 12 Reference temperature setting main/sub

Parameter T0M, T0S	Value	Description
Range	0...127	corresponds to 0...127°C
Quantization step	1°C	
Default	25	25°C

Table 13 Linear temperature coefficient main/sub

Parameter TC1M, TC1S	Value	Description
Range	0...1023	corresponds to -2400...5400 ppm/°C
Quantization step	7.629 ppm/°C	
Default	315	corresponds to 0 ppm/°C

Table 14 Quadratic temperature coefficient setting main/sub

Parameter TC2M, TC2S	Value	Description
Range	0...511	corresponds to -30...30 ppm/°C^2
Quantization step	0.119 ppm/°C^2	
Default	256	corresponds to 0 ppm/°C^2

Attention: ***Even though the TLE4999C has separate T0, TC1, and TC2 EEPROM registers for main and sub channel, these registers shall be programmed to exactly the same values for both channels.***

2.4.3.7 SPC protocol identification - SPC ID

The SPC protocol of the TLE4999C has an ID bit included. This bit allows the identification of up to four individual TLE4999C sensors implemented in one system. The value of this ID bit in the protocol is given by the setting of the ID bit in the TLE4999C's EEPROM.

The SPC ID can be set programming the correspondent EEPROM register.

Table 15 SPC ID main/sub

Parameter SPC: SPC IDM, SPC IDS	Value
SPC ID 0	00_B (default)
SPC ID 1	01_B
SPC ID 2	10_B
SPC ID 3	11_B

Attention: ***Even though the TLE4999C has separate SPC ID EEPROM registers for main and sub channel, these registers shall be programmed to exactly the same values for both channels.***

2.4.3.8 User ID1, ID2

The fields user ID1 and user ID2 in the TLE4999C's EEPROM per default contain the specific production lot information of the sensor, but they are free for use by the system integrator to store their own production specific information. They are not used in any way by the TLE4999C's internal signal processing.

2.4.3.9 CRC configuration - CRC Config

It is possible to configure the SPC protocol to include the status nibble in the CRC calculation of the TLE4999C's SPC interface:

Table 16 CRC configuration

Parameter CRC config	Value	Description
CRC config	1	status nibble included in the CRC (default)
CRC config	0	status nibble not included in the CRC

2.4.3.10 Short serial message - SSM EN

A short serial message format can be implemented. It follows the SENT 2016 standard definition but is updated to a common numbering scheme for software and hardware developers (bit numbering starting with highest MSB number down to 0 for the LSB).

If selected, the serial data is transmitted (bit by bit) in the status and communication nibble of consecutive messages from the transmitter. The serial data will be communicated in a 16-bit sequence as shown in **Figure 14**.

The starting bit of a serial message is indicated by a "1" in bit 1 of the status and communication nibble for the SPC protocol. The next 15 received frames must contain a value of "0" in this same bit position. All 16 frames must be successfully received (no errors, calibration pulse variation, data nibble CRC error, etc.) for the serial value to be received by the ECU.

The 16-bit message consists of a 4 bit message ID nibble, 2 nibbles (1 byte) of data, and a CRC checksum nibble. The CRC checksum is derived for the message ID and 2 data nibbles and is the same checksum algorithm as used to calculate the SPC CRC nibble. The message ID is used to identify the type of data being communicated in the data byte. Actual serial data message IDs and data values are application specific.

All data transmitted in the serial data bit in bit 0 of the status and communication nibble for the SPC protocol is sent in the order "most significant bit" (MSB, bit no. 15) down to "least significant bit" (LSB, bit no. 0).

The short serial messages of TLE4999C will contain 5 messages which will be sent out in the sequence shown in **Figure 14**: SSM message sequence. After the last message (Message ID 4) is sent, the next message will be the first again (Message ID 0).

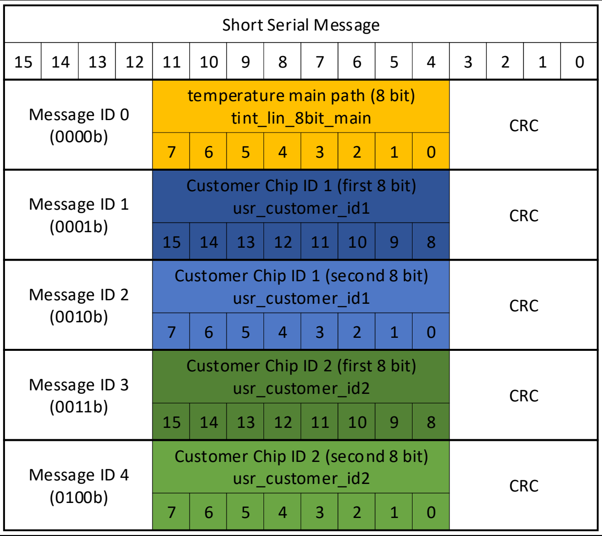

Figure 14 Short serial message structure

Table 17 Sort serial message

Parameter SSM EN	Value	Description
SSM EN	0	Short serial message disabled (default)
SSM EN	1	short serial message enabled

2.4.3.11 3.3V Bus capability - 3.3V EN

The SPC output of the TLE4999C is also capable of working on 3.3V buses.

To achieve good emissions performance, both signal edges are controlled by a control loop which operates the output driver in push-pull mode. By setting the EEPROM bit (see **Table 18**), the user can select if a 3.3V bus is used or the bus voltage is at 5V. In the case of 3.3V on the bus line, a comparator monitors this voltage and stops the ramp at 3V such that the output signal level is not pushed up to 5V and to cause unwanted peaks in the output signal.

Table 18 3.3V Bus capability

Parameter 3.3V EN	Value	Description
3.3V EN	0	3.3V Bus capability disabled (default)
3.3V EN	1	3.3V Bus capability enabled[1)]

1) This feature shall only be used for UT ≥ 1µs

2.4.3.12 SPC output protocol - SPCM; SPCS

The TLE4999C has 5 selectable SPC output protocols, for further details see **TLE4999C Data sheet.** The different protocols can be selected in the EEPROM using the following configurations.

Table 19 SPC output protocol Main/Sub

Parameter SPCM, SPCS	Value
Protocol A (2x 12 bit Hall + 4 bit CRC)	000_B (default)
Protocol B (2x 16 bit Hall +4 bit CRC)	001_B
Protocol C (2x 12 bit Hall + 8 bit temperature + 4 bit CRC)	010_B
Protocol D (2 x14 bit Hall + 2x2 bit RC + 8 bit CRC)	011_B
Protocol E (2 x 12 bit Hall +2 bit RC +6 bit CRC)	100_B

Attention: ***Even though the TLE4999C has separate SPC output EEPROM registers for main and sub channel, these registers shall be programmed to exactly the same values for the two channels.***

2.4.3.13 Frameholder - FH

The frameholder functionality allows the user to operate multiple sensors in a bus configuration with synchronized sampling of the measurement value. This is achieved by having (apart from the SPC Bus ID) a separate frameholder ID for each chip on the bus which is used as a common signal trigger.

Generally, when the frameholder ID is triggered, all sensors on the bus start converting and processing a measurement value. For the sensor, which has frameholder ID = SPC Bus ID, the sensor has to prepare the output data values immediately after the trigger on the bus (synchronization pulse and data nibbles). The other sensors keep their converted value in the internal registers which have to be polled separately by the master with an addressing trigger pulse.

To activate this feature the frameholder ID must be different than the SPC ID.

In the below bus configuration example, sensor 1 has SPC ID=0 and a frameholder ID= 0 (frameholder disabled) and the sensor 2 has SPC ID=1 and frameholder ID= 0 (frameholder enabled), see **Figure 15**

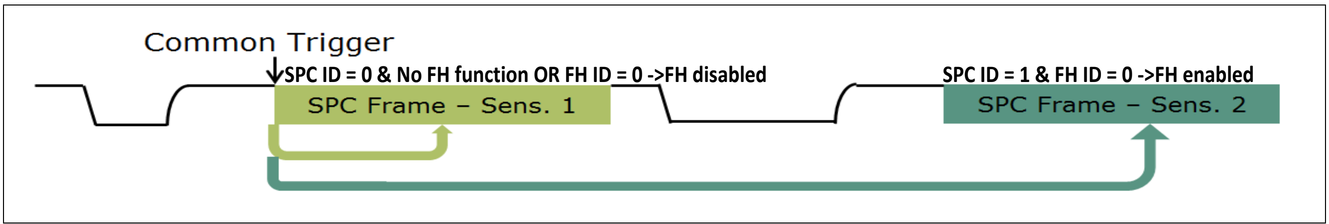

Figure 15 Frameholder

When the ECU triggers ID0, sensor 1 will answer with his data and sensor 2 will prepare the internal data measurement, once the ECU triggers ID1, sensor 2 it will answer back with the data it measured when ID0 was triggered. The advantage is that the measured data is taken at the same time.

The frameholder ID can be set by programming the correspondent EEPROM register bits, see **Table 20**

Table 20 Frameholder ID

Parameter FH ID	Value
FH ID 0	00_B
FH ID 1	01_B
FH ID 2	10_B
FH ID 3	11_B

Attention: ***If the frameholder ID is identical to the SPC ID the frameholder feature is disabled (default).***

2.4.3.14 Variable trigger - VT

Two options are available for the total trigger length. It can be a constant trigger value with a length of 90 UT or variable trigger value. The variable trigger length is $t_{mlow,min}$ + 12 UT and depends on the trigger low time $t_{mlow,min}$. Both settings can be used in a bus configuration as the address of the sensor is defined by the low time $t_{mlow,min}$ only.

The advantage of the variable trigger length is that the total frame length can be reduced.

Table 21 Variable trigger

Parameter VT	Value	Description
VT	0	Variable trigger option disabled (default)
VT	1	Variable trigger option enabled

2.4.3.15 Bus mode - BM

The TLE4999C can be configured to work in synchronous mode (bus off) or in bus mode, by setting the following EEPROM register bit.

Table 22 Bus mode

Parameter BM	Value	Description
BM	0	Bus mode disabled (default)
BM	1	Bus mode enabled

Attention: ***Infineon recommends that when using very fast unit times (UT ≤ 1 µs) the sensor is operated in bus mode with variable trigger option activated and address 0, instead of the conventional synchronous mode even if the sensor is not used in a bus configuration.***

2.4.3.16 Unit time - UT

Different SPC unit times can be programmed. See **Table 23**

Table 23 Unit time

Parameter UT	value
0.5 µs	0001_B
0.75 µs	0010_B
1 µs	0011_B
1.25 µs	0100_B

Table 23 Unit time

Parameter UT	value
1.5 µs	0101_B
2.0 µs	0110_B
2.5 µs	0111_B
3.0 µs	1000_B (default)

2.4.3.17 Multipoint linearization - MPCM; MPCS

Several options are available for the linearization points that are configurable in the EEPROM. The user can correct the linear characteristic by selecting different multi point calibration versions, for further details see **Chapter 3.2.1**.

For the different EEPROM registers related to this feature see **Table 24**,

Table 24 Multipoint calibration version main/sub

Parameter MPCM, MPCS	Value
MPC off	000_B (default)
MPC equally spaced	001_B
Version A	010_B
Version B	011_B
Version C	100_B
Version D	101_B

2.5 Programming Flow

The programming flow of the TLE4999C EEPROM is shown in **Figure 16** and **Figure 17**. To program the EEPROM, the sensor is brought into programming mode by sending the "Activate programming mode" command within the time window $t_{activate}$ after power-on. Write the data to be programmed to the sensor. The desired page to write to is then selected by using the "Program Page" command. All the data to be written into the desired page is sent to the sensor, followed by the "Program Page" command and the application of a programming pulse. The procedure is repeated for all pages that need to be programmed.

After programming of all desired pages, the written data shall be read back by the programmer to ensure that the correct values are programmed.

Then a margin check shall be executed by sending the "EEP Automatic Margin Check" command and applying a programming pulse (see also **Chapter 2.5.3**). The margin check ensures the reliable data retention of the programmed EEPROM cells.

Finally, the EEPROM shall be locked by sending the "EEPROM Lock" command and applying a programming pulse.

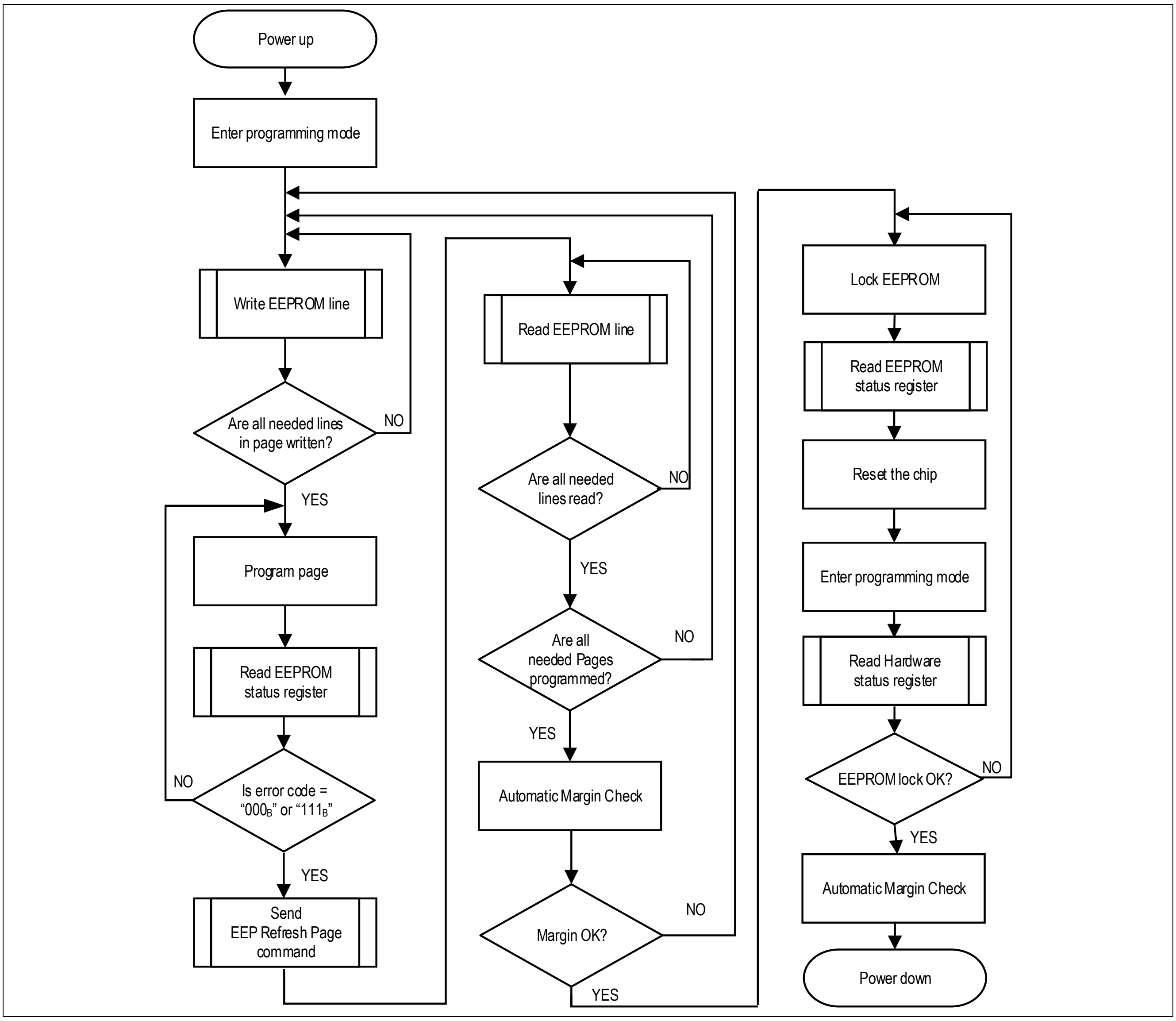

Figure 16 Overview EEPROM Programming

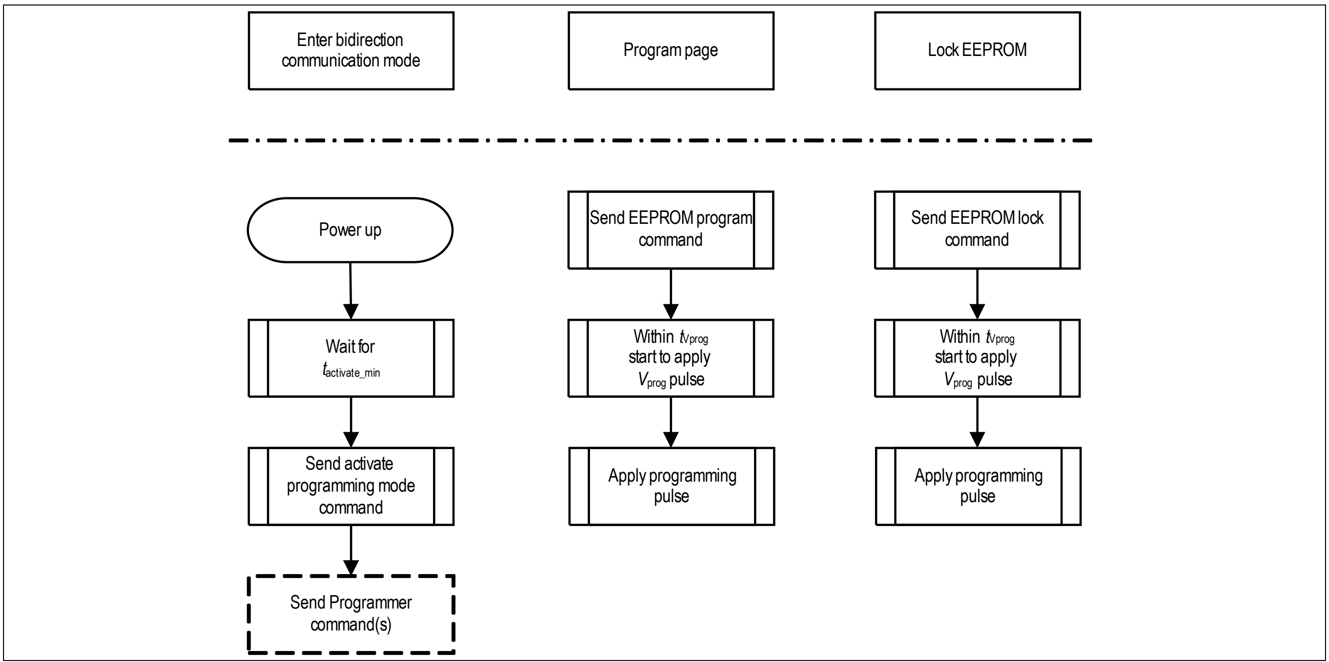

Figure 17 Subroutines of the EEPROM Programming

2.5.1 Defining the content of the EEPROM

The EEPROM access of the TLE4999C in programming mode is handled by the DSP2. To program an EEPROM page, the corresponding page address is mapped to the EEP registers of DSP2 using the "Program Page" command. This command also loads the content of the registers into the EEPROM page. Therefore, all the lines will be overwritten.

The desired content is written to the EEPROM registers by the "DSP2 Write" command. After the desired lines of the selected page are written, the content of the EEP registers is transferred into the selected EEPROM page using the "EEPROM program" command, followed by the application of a programming pulse that burns the data into the EEPROM cells. After the programming pulse, the programmer has to wait at least t_{prog_pause} before sending the next SICI frame. **Table 25** shows the specification of the programming pulse.

The EEPROM status register will indicate that the intelligent programming routine finished correctly. To verify that the correct content is written to the EEPROM cells, it is recommended to check this by reading back all EEPROM lines of the active page.

After all pages are programmed and checked, it is recommended to lock the EEPROM using the "EEP Lock" command. It is also recommended to verify the correct locking by reading back the EEPROM status register after the locking operation.

The programming mode is then exited by the "Exit programming mode" command.

Table 25 Timing and electrical characteristics for programming pulse

Parameter	Symbol	Values			Unit	Note or Test Condition
		Min.	Typ.	Max.		
Programming pulse voltage	V_{prog}	15.8	–	16.4	V	valid for EEPROM page programming, and EEPROM lock
Margin test pulse voltage	–	15.8	–	16.4	V	valid for EEPROM margin test
Duration of programming pulse for EEPROM page programming	t_{prog}	400	–	–	ms	measured after Vprog,min is reached

Table 25 Timing and electrical characteristics for programming pulse (cont'd)

Parameter	Symbol	Values			Unit	Note or Test Condition
		Min.	Typ.	Max.		
Duration of rising/falling edge of programming pulse	t_{prog_rise} t_{prog_fall}	–	–	400	µs	influence of cable and external circuitry has to be taken into account
Duration of programming pulse for EEPROM margin test	t_{prog_MT}	7	–	–	ms	measured after Vprog,min is reached
Duration of programming pulse for EEPROM lock	t_{prog_lock}	135	–	–	ms	measured after Vprog,min is reached
Programming cycles per EEPROM page	n_{prog}	–	–	10		a programming cycle is defined as applying the programming pulse once in order to change the state of at least one EEPROM cell. each page can be programmed n_{prog} times
Programming temperature	T_{prog}	10	–	60	°C	
Time window to start the programming pulse	t_{Vprog}	0	–	20	ms	measured from reaching the low level after the last SICI frame

2.5.2 Memory Lock

It is recommended to lock the EEPROM after the programming is finished. This is done by sending the EEPROM lock command and applying the programming pulse for a time t_{prog_lock}. The same voltage level and start time window as used for a normal EEPROM programming operation are valid (V_{prog_min} and t_{Vprog}).

The EEPROM is separated in two areas. The first area is the customer lock area (EEPROM pages 0 and 1). The second area is the Infineon lock area. The Infineon lock area is already locked at delivery so that it cannot be changed anymore.

The correctness of the locking operation can be verified by reading the EEPROM status register. Once the EEPROM is locked there is no possibility to rewrite the EEPROM again.

2.5.3 Margin Check

After programming, a margin check is necessary to get confirmation about the stored charge inside the EEPROM cells and therewith check the quality of the EEPROM programming. The TLE4999C uses intelligent programming, which continuously monitors the actual margin voltage while the programming voltage is applied and stops programming automatically when the optimum charge state is reached.

The EEPROM stores the data inverted, a programmed "0" will have a high voltage level (V_{MARGIN_0}) and the margin voltage can be directly verified. The cells with a programmed "1" will have a low voltage level (V_{MARGIN_1}) and their margin voltage might be slightly negative. For these cells, it can be only checked that the margin voltage is below the low voltage level (V_{MARGIN_1}) maximum.

Figure 18 shows the two ranges for a programmed "1" and "0" and **Table 26** gives the specification for the margin voltage levels.

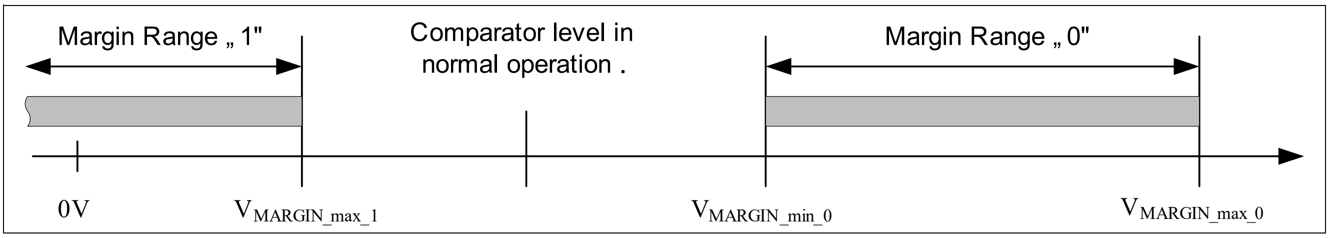

Figure 18 Margin Range

The TLE4999C offers an automatic margin check mechanism, which shall be implemented in the programming procedure to ensure the reliability of the EEPROM programming.

Table 26 Margin voltages

Parameter	Symbol	Values			Unit	Note or Test Condition
		Min.	Typ.	Max.		
Margin voltage "1"	V_{MARGIN_1}	–	0	0.25	V	
Margin voltage "0"	V_{MARGIN_0}	2	–	5	V	

The automatic margin check gives a fast confirmation whether the margin voltages of all EEPROM cells are within the target levels. This check is executed by issuing the "EEP Automatic Margin Check" command and applying the programming pulse for a time t_{prog_MT}.

In order to support a more robust test procedure it is possible to specify a certain delay for the test to start (within the command). For this purpose the auto margin command is issued by the Test-Interface and the margin test can be applied within the specified delay. Therefore it is possible to accurately raise the voltage to margin test level before the test starts. The auto margin command supports a 8 bit delay with 32µs steps (0ms to ~8ms delay). The same voltage level and start time window as used for an EEPROM programming operation are valid (V_{prog} and t_{Vprog}).

After the supply voltage has returned to normal, the EEPROM assembly buffer data registers (Address: $E8_H$ and $E9_H$) contain the following information:

- Address $E8_H$, bits[5:0]: value for the weakest programmed '0'
- Address $E8_H$, bits[11:6]: value for the strongest programmed '0'
- Address $E9_H$, bits[5:0]: value for the weakest programmed '1'
- Address $E9_H$, bits[11:6]: value for the strongest programmed '1'

All readout values can be interpreted as follow:

- All values are 6 bit and each LSB represents 100mV, giving a range of 0.0V – 6.3V.
- All values are rounded up (e.g. if the margin voltage is 4.23V, the returned value will be 4.3V)
- If the programmed '1's have negative margin voltage, the values will be clamped to 0.0V.

3 Calibration of TLE4999C

3.1 Temperature compensation

A temperature compensation mechanism is implemented in the TLE4999C to account for thermal drift of the Hall probe sensitivity and thermal reduction of the magnetization of a permanent magnet. Initially, the TLE4999C is pre-configured by Infineon to have a constant magnetic sensitivity over temperature.

In case the TLE4999C is used to measure an absolute magnetic field, for example in a current sensing application, then no additional adaptation of the temperature compensation by the user is required.

If the TLE4999C is used in a position sensing application where it measures the magnetic field generated by a moving permanent magnet, then it is typically desired that the output signal of the TLE4999C depends only on the magnet position. In this case, a user adaptation of the temperature compensation parameters TC1 and TC2 for main and sub channel is required to account for thermal reduction of the magnet's remanence. Therefore, the TLE4999C has to be configured to increase its sensitivity accordingly with increasing temperature to compensate the thermal reduction of the remanence.

This temperature coefficient of the remanence depends on the chosen magnet material, so the temperature compensation of the TLE4999C has to be adapted to the permanent magnet used in the application.

3.1.1 Magnet temperature compensation polynomial

The user temperature compensation of the TLE4999C uses a diverse second order polynomials for main and sub channel. **Equation (3.1)** shows the calculation for the main channel, which shall be used for the derivation of the user temperature coefficients TC1 and TC2. The same TC1 and TC2 values shall be used also for the sub channel.

$$S(TINT) = 1 + (TINT - 32 \cdot T_0) \cdot \left(\frac{TC1 - 315}{2^{22}} + \frac{TC2 - 256}{2^{20}} \cdot \frac{TINT - 32 \cdot T_0}{2^{13}}\right) \tag{3.1}$$

with:

$$TINT = 32 \cdot T_J[°C] \tag{3.2}$$

T_J is the junction temperature in °C. The coefficients TC1, and TC2 are the linear and quadratic temperature compensation coefficients, respectively. They are stored in the EEPROM and pre-configured by Infineon for a constant magnetic sensitivity over temperature (see **Chapter 2.4.3.6**).

The reference temperature T_0 is the temperature where the polynomial has the value "1" and is thus the temperature where the absolute magnetic sensitivity matches the configured gain value. T_0 can be chosen freely in the application. It is recommended to leave it at default setting.

3.1.2 Determination of compensation parameters from measurement

For the determination of the coefficients for the application sensitivity polynomial (**Equation (3.1)**) a measurement of the temperature behavior of the sensor output in the application is recommended. A basic example for a position sensing application using the TLE4999C and a moveable permanent magnet is shown in **Figure 19**.

In a setup that uses a permanent magnet, the magnetic field has a temperature dependency due to the thermal reduction of the remanence. In order to determine the optimum sensitivity compensation behavior of the sensor to cancel this temperature dependency, the sensor's output value shall be measured at different temperatures, with the permanent magnet in a fixed position.

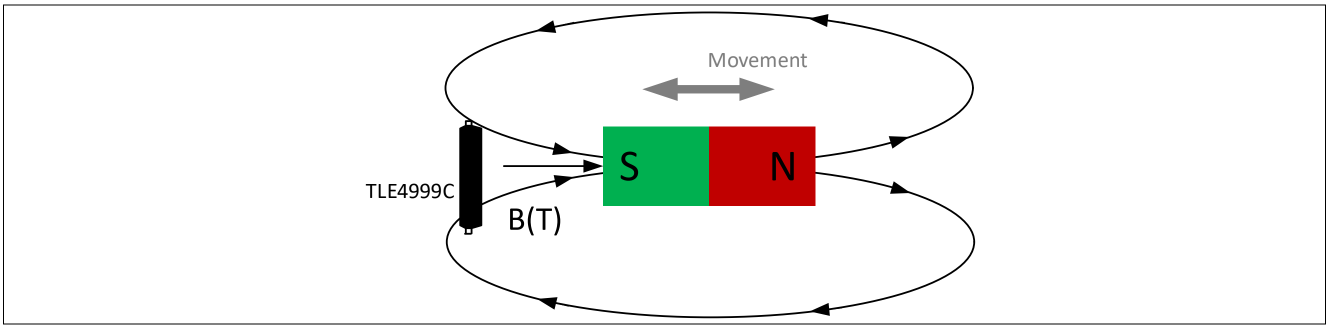

Figure 19 Example position sensing application

The thermal reduction of the remanence depends mainly on the magnetic material used and has typically only minor variations from sample to sample.

Therefore a reference measurement on a (small) number of application samples is typically sufficient to determine a reference polynomial for the application in general and can be used for production.

It is typically not required to perform the described measurement over temperature for every individual sample.

With the described setup, the following procedure is used to obtain the coefficients of the application sensitivity polynomial:

- Measure the sensor output for at least three different temperatures at a defined, fixed magnet position. The magnetic flux density at the sensor shall be non-zero at this given magnet position. It is recommended for best accuracy of the calibration procedure to use a magnet position that leads to the highest possible magnetic flux at the sensor, while still being inside the allowed magnetic flux operating range.
- For each data point, read the junction temperature $T_J^{(i)}$, and the $OUT^{(i)}$ value via the programming interface.
- For each data point, calculate the compensation sensitivity value $S^{(i)}$ from the $OUT^{(i)}$ value and the output value at zero field OUT_0, using **Equation (3.3)**

$$S^{(i)} = \frac{OUT_0}{OUT^{(i)} - OUT_0} \tag{3.3}$$

- Plot $S^{(i)}$ as a function of $T_J^{(i)}$ and apply a quadratic fit ($cx^2 + bx + a$) which yields coefficients a, b and c (see **Figure 20**).
- Derive the coefficients of the application sensitivity polynomial from the parameters a, b, and c obtained from the quadratic fit using **Equation (3.4)** and **Equation (3.5)**.

$$TC_1 = \frac{b + 2 \cdot c \cdot T_0}{a + b \cdot T_0 + c \cdot T_0^2} \tag{3.4}$$

$$TC_2 = \frac{c}{a + b \cdot T_0 + c \cdot T_0^2} \tag{3.5}$$

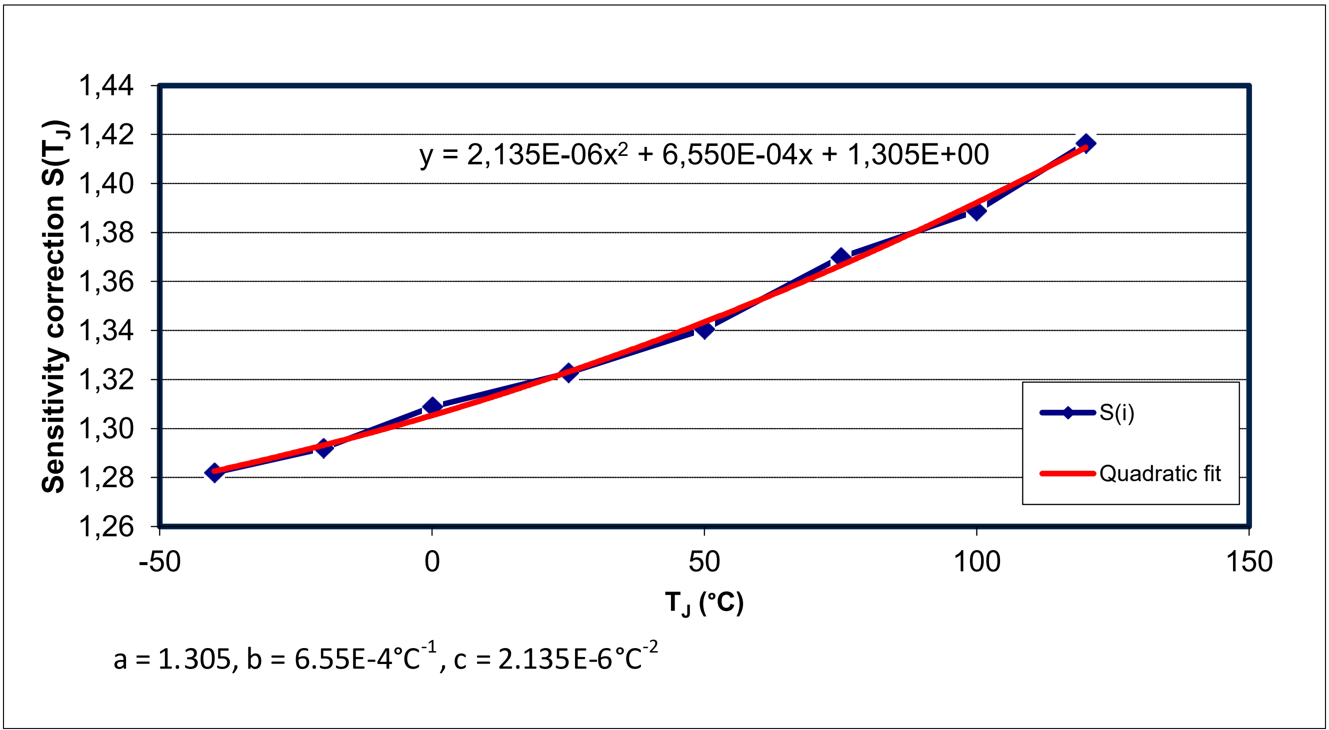

Figure 20 Example polynomial fit procedure.

3.2 Output calibration

In a position sensing application, the maximum and minimum magnetic field sensed by the TLE4999C depends on the used permanent magnet and the movement range covered by the application. To achieve the maximum possible accuracy in such applications, it is recommended to adapt the output characteristic of the TLE4999C to the application. Therefore the possible digital output range is matched to the magnetic input range that is available in the application.

3.2.1 Multipoint calibration

The linear characteristic of the TLE4999C can be re-adjusted by programming 9 points in the EEPROM (where 2 are fixed and 7 points are available to program in the EEPROM).

The linearization applied is a piece wise linearization which can be described as in **Figure 21**.

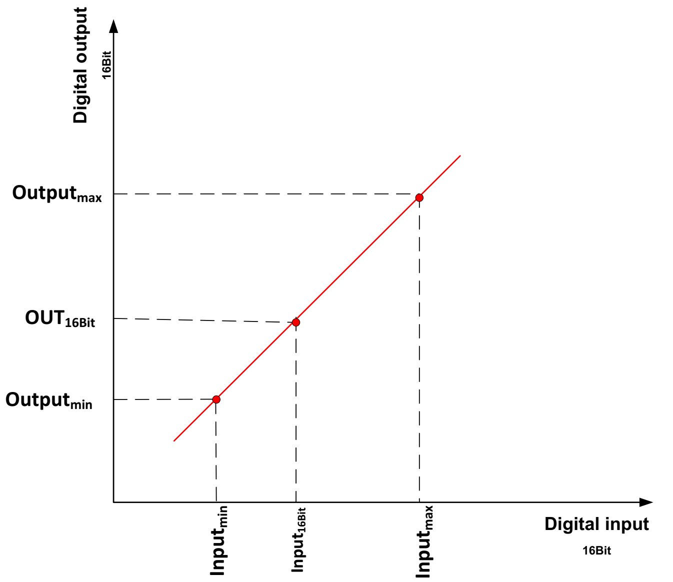

Figure 21 General linearization element for piece wise linearization.

The input, which represents the magnetic field value (stress and temperature compensated value with user gain applied), is computed in the signal processing chain.

This value is within a linearization element which is defined by the two values $Input_{min}$ and $Input_{max}$.

With respect to the two programmed values $Output_{min}$ and $Output_{max}$, a slope is computed which represents the compensation slope for this magnetic field segment.

This calculation can be performed according to **Equation (3.6)**

$$OUT_{16Bit} = \frac{(Input_{16Bit} - Input_{min}) \times (Input_{max} - Input_{min})}{(Input_{max} - Input_{min})} + Input_{min} \tag{3.6}$$

Note: $Input_{min}$ and $Input_{max}$ are 16 bit signed integer values ranging from -32768 to 32767. OUT_{16Bit} is a 16bit unsigned integer value ranging from 0 to 65536.

The internal signal processing of the TL4999C is done with 16 bit values.

So in order to extend the calibration to 9 input points, the chip internally maps and assigns the input values to the possible output values for a 16 bit scale, independent of the selected SPC output protocol, which can be 12, 14, or 16 bit.

For the MAIN channel, the EEPROM parameters eep_usr_mpc_main_1... eep_usr_mpc_main_7 are available.

Similarly for the SUB channel, the parameters eep_usr_mpc_sub_1... eep_usr_mpc_sub_7 are available.

Figure 22 shows the arrangement of the points for equally spaced linearization points, which are valid for both the Main and Sub channel.

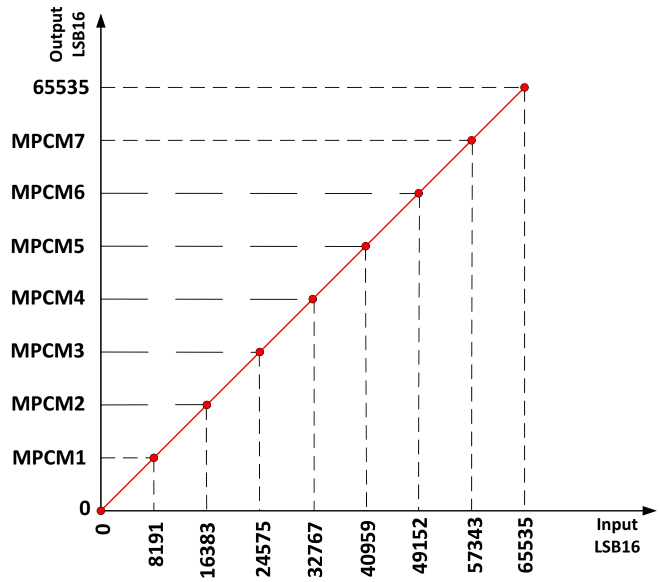

Figure 22 Multipoint linearization equidistant example

3.2.1.1 Finer granularity linearization for position determination

As shown in **Chapter 3.2.1**, the linearization can be equally spaced over the whole signal values range.

Beside this, the TLE4999C offers 4 other linearization options to adapt the signal processing to the input signal to get an optimal output signal.

For the alignment of the linearization points, 5 different options are available meaning that the points are on fixed, predefined positions depending on the option selected by the user.

The alignment of the points is shown in **Figure 23**

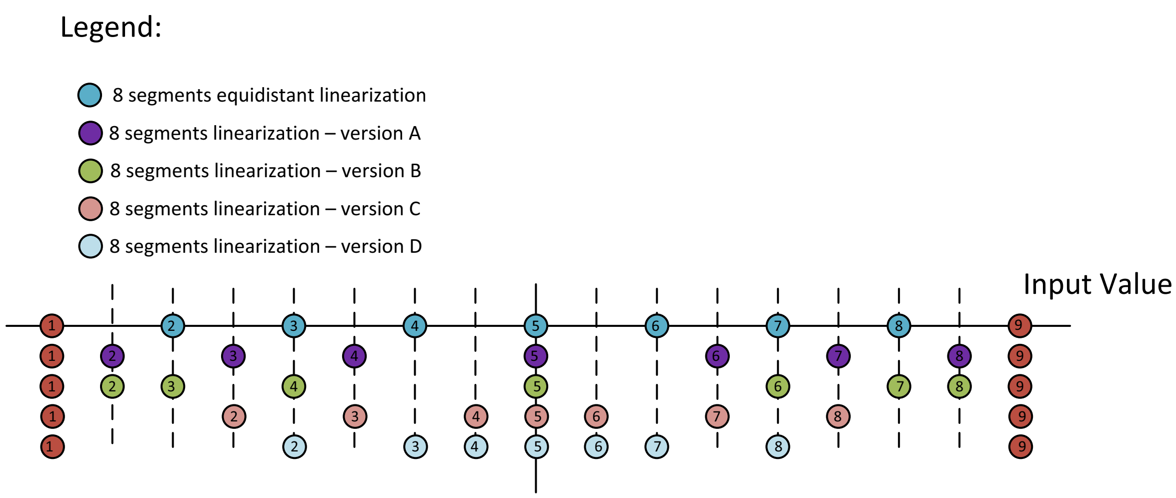

Figure 23 Linearization versions

The selectable options for the user are (see **Table 24**):

- Enable/disable the feature
- 8 segments equidistant linearization
- 8 segments version A
- 8 segments version B
- 8 segments version C
- 8 segments version D

Depending on the non-linear behavior of the measurement problem, the user can select the concentration of linearization points in a finer granularity either at the corners, i. e. at high magnetic fields (Version A and Version B) or at low magnetic fields (Version C and Version D).

The alignment of the input values (as shown above for the equidistant linearization) is as follows:

Table 27 Multipoint calibration alignment main channel

	0	**MPCM1**	**MPCM2**	**MPCM3**	**MPCM4**	**MPCM5**	**MPCM6**	**MPCM7**	**65535**
Equidistant	0	8191	16383	24575	32767	40959	49151	57343	65535
Version A	0	4095	12287	20479	32767	45055	53247	61439	65535
Version B	0	4095	8191	16383	32767	49151	57343	61439	65535
Version C	0	12287	20479	28671	32767	36863	45055	53247	65535
Version D	0	16383	24575	28671	32767	36863	40959	49151	65535

With these 5 schemes, additional position applications can be covered and scenarios where non-linearities around the center or corners can be compensated.

As an example the **Figure 24** shows the arrangement of the points for the 8 segments version A

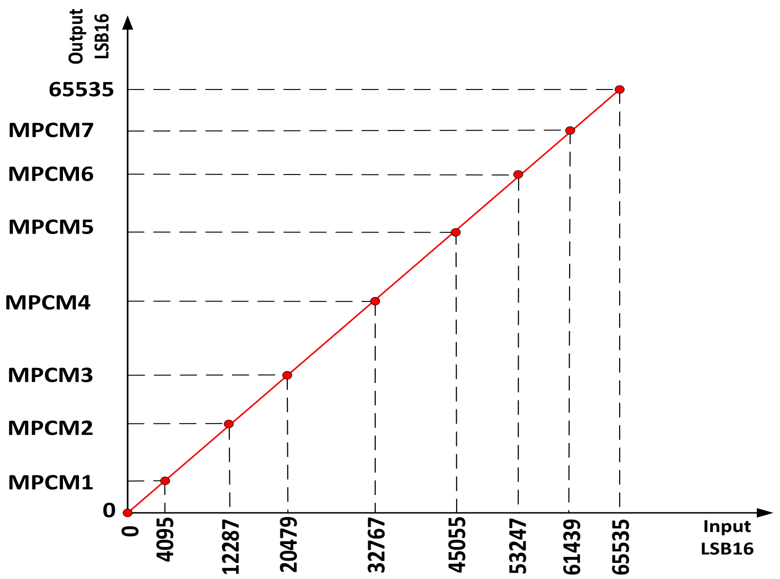

Figure 24 Multipoint linearization version A example

3.2.2 Multipoint calibration procedure

For the multipoint calibration, the following procedure is used for main and sub channel separately:

- Analyze the application movement range in the application module and check its non linearity.
- Depending on the non linearity of the output, select 7 points inside the range to be corrected, like the below example in **Figure 25**.
- Program the obtained digital value in the correspondent EEPROM register.
- Depending on the non linearity of the output, select one of the available MPC options, as shown in **Chapter 3.2.1.1**.
- The TLE4999C internally calculates and assigns the programmed value to the correspondent position, depending on the selected MPC mode.

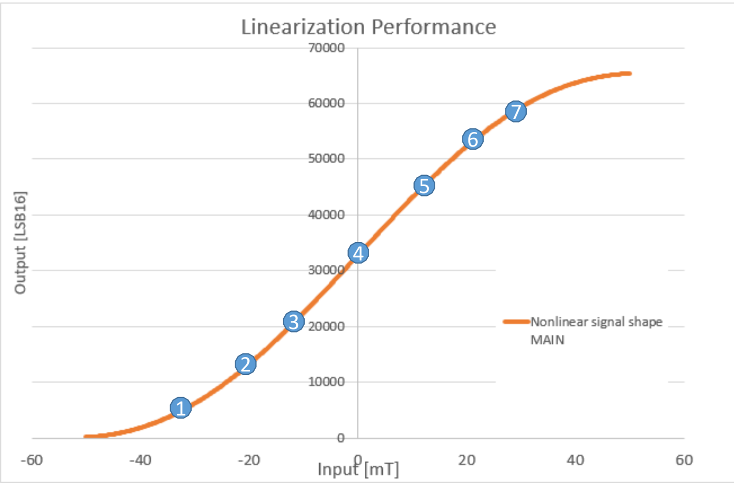

Figure 25 Non linear output

On below **Figure 26**, the result when applying the equally spaced version and version A, to the input from the example on **Figure 25** is shown:

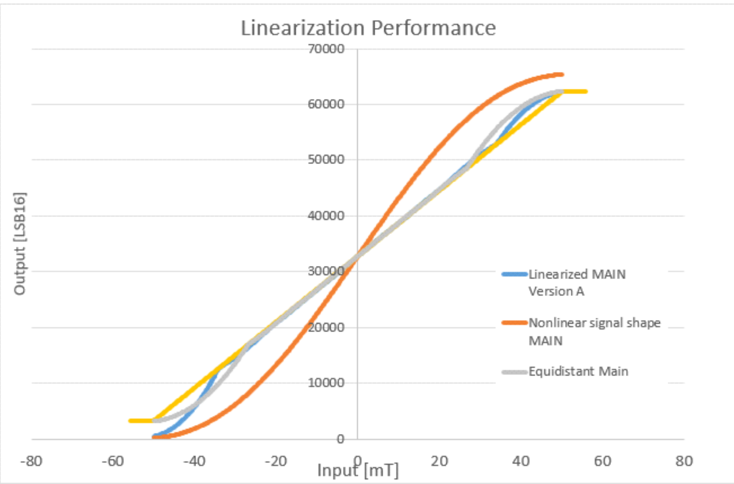

Figure 26 MPC example for equidistant linearization and version A

In order to simplify procedure, Infineon can provide an Excel file that can help the user to select the MPC mode that best fits the application needs, please contact your Infineon sales representative.

Terminology

D	
DSP	Digital Signal Processing unit
E	
ECC	Error correction code to protect EEPROM content
EEPROM (abbrev. EEP)	Electrically erasable and programmable read only memory - programmable memory for sensor calibration and configuration data
G	
GND	Electrical ground of the sensor
L	
LSB	Least significant bit
M	
MPC	Multipoint calibration
MSB	Most significant bit
MVS	Margin voltage selector
O	
OUT	Digital output pin of the sensor
P	
PDL	Peripheral Data Line - combined supply and data input/output line of a SPC sensor
PWM	Pulse Width Modulation
S	
SPC	Short PWM code
SICI	Serial Inspection and Configuration Interface - Programming interface of the TLE4999C

4 Revision History

Revision	Date	Changes
01_00	2020-11-27	initial release.

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