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MICRONAS

Hardware Documentation

Data Sheet

HAL® 242x

High-Precision Programmable Linear Hall-Effect Sensor with Arbitrary Output Characteristics

Edition April 15, 2016
DSH000174_001EN

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Contents

High-Precision Programmable Linear Hall-Effect Sensor with Arbitrary Output Characteristics

Note Revision bars indicate significant changes to the previous edition.

1. Introduction

HAL 242x is a family of programmable linear Hall-effect sensors consisting of two members: the HAL 2420 and the HAL 2425.

Both devices are universal magnetic field sensors with a linear output based on the Hall effect. Major characteristics like magnetic field range, sensitivity, output quiescent voltage (output voltage at B=0 mT), and output voltage range are programmable in a non-volatile memory. The sensors have a ratiometric output characteristic, which means that the output voltage is proportional to the magnetic flux and the supply voltage. Additionally, both sensors offer wire-break detection.

The HAL 2425 offers 16 setpoints to change the output characteristics from linear to arbitrary or vice versa.

Table 1–1: HAL 242x family members

Device	Key Function
HAL 2420	2 Setpoints (calibration points)
HAL 2425	16 Setpoints

The HAL 242x features a temperature-compensated Hall plate with chopper offset compensation, an A/D converter, digital signal processing, a D/A converter with output driver, an EEPROM with redundancy and lock function for the calibration data, a serial interface for programming the EEPROM, and protection devices at all pins. The internal digital signal processing is of great benefit because analog offsets, temperature shifts, and mechanical stress do not degrade digital signals.

The easy programmability allows a 2-point calibration by adjusting the output signal directly to the input signal (like mechanical angle, distance, or current). Individual adjustment of each sensor during the final manufacturing process is possible. With this calibration procedure, the tolerances of the sensor, the magnet, and the mechanical positioning can be compensated in the final assembly.

In addition, the temperature compensation of the Hall IC can be fit to all common magnetic materials by programming first and second order temperature coefficients of the Hall sensor sensitivity.

It is also possible to compensate offset drift over temperature generated by the customer application with a first order temperature coefficient for the sensor offset. This enables operation over the full temperature range with high accuracy.

The calculation of the individual sensor characteristics and the programming of the EEPROM can easily be done with a PC and the application kit from Micronas.

The sensors are designed for hostile industrial and automotive applications and operate with typically 5 V supply voltage in the junction temperature range from –40 °C up to 170 °C. The HAL 242x is available in the very small leaded package TO92UT-1/-2 and in the SOIC8-1 package.

1.1. Features

– High-precision linear Hall-effect sensors with 12-bit analog output

– 16 setpoints for various output signal shapes (HAL 2425)

– Multiple customer programmable magnetic characteristics in a non-volatile memory with redundancy and lock function

– Programmable temperature compensation for sensitivity and offset

– Magnetic field measurements in the range of ±200 mT

– Low output voltage drifts over temperature

– Active open-circuit (ground and supply line break detection) with 5 kΩ pull-up and pull-down resistor, overvoltage and undervoltage detection

– Programmable clamping function

– Digital readout of temperature and magnetic field information in calibration mode

– Programming and operation of multiple sensors at the same supply line

– Active detection of output short between two sensors

– High immunity against mechanical stress, ESD, EMC

– Operates from T_J = –40 °C up to 170 °C

– Operates from 4.5 V up to 5.5 V supply voltage in specification and functions up to 8.5 V

– Operates with static magnetic fields and dynamic magnetic fields up to 2 kHz

– Overvoltage and reverse-voltage protection at all pins

– Short-circuit protected push-pull output

– Qualified according to AEC-Q100

1.2. Major Applications

Due to the sensors' versatile programming characteristics and low temperature drifts, the HAL 242x is the optimal system solution for applications such as:

– Contactless potentiometers,

– Angle sensors (like throttle position, pedal position and EGR applications),

– Distance and linear movement measurements,

– Magnetic field and current measurement.

2. Ordering Information

A Micronas device is available in a variety of delivery forms. They are distinguished by a specific ordering code:

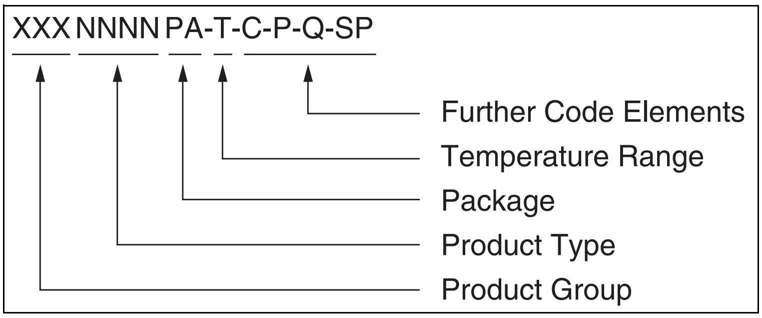


Fig. 2–1: Ordering Code Principle

For a detailed information, please refer to the brochure: "Micronas Sensors and Controllers: Ordering Codes, Packaging, Handling".

2.1. Device-Specific Ordering Codes

HAL 242x is available in the following package and temperature variants.

Table 2–1: Available packages

Package Code (PA)	Package Type
UT	TO92UT-1/-2
DJ	SOIC8-1

Table 2–2: Available temperature ranges

Temperature Code (T)	Temperature Range
A	T_J = –40 °C to +170 °C

The relationship between ambient temperature (T_A) and junction temperature (T_J) is explained in Section 5.4. on page 29.

For available variants for Configuration (C), Packaging (P), Quantity (Q), and Special Procedure (SP) please contact Micronas.

Table 2–3: Available ordering codes and corresponding package marking

Available Ordering Codes	Package Marking
HAL2420UT-A-[C-P-Q-SP]	2420A
HAL2420DJ-A-[C-P-Q-SP]	2420A
HAL2425UT-A-[C-P-Q-SP]	2425A
HAL2425DJ-A-[C-P-Q-SP]	2425A

3. Functional Description

3.1. General Function

The HAL 242x is a monolithic integrated circuit which provides an output voltage proportional to the magnetic flux through the Hall plate and proportional to the supply voltage (ratiometric behavior).

The external magnetic field component perpendicular to the branded side of the package generates a Hall voltage. The Hall IC is sensitive to magnetic north and south polarity. This voltage is converted to a digital value, processed in the Digital Signal Processing Unit (DSP) according to the settings of the EEPROM registers, converted back to an analog voltage with ratiometric behavior, and buffered by a push-pull output transistor stage.

The setting of a LOCK bit disables the programming of the EEPROM memory for all time. This bit cannot be reset by the customer.

As long as the LOCK bit is not set, the output characteristic can be adjusted by programming the EEPROM registers. The IC is addressed by modulating the output voltage.

In the supply voltage range from 4.5 V up to 5.5 V, the sensor generates an analog output voltage. After detecting a command, the sensor reads or writes the memory and answers with a digital signal on the output pin. The analog output is switched off during the communication. Several sensors in parallel to the same supply and ground line can be programmed individually. The selection of each sensor is done via its output pin.

The open-circuit detection provides a defined output voltage if the V_{SUP} or GND line is broken.

Internal temperature compensation circuitry and the spinning-current offset compensation enables operation over the full temperature range with minimal changes in accuracy and high offset stability. The circuitry also reduces offset shifts due to mechanical stress from the package. The non-volatile memory consists of redundant EEPROM cells. In addition, the sensor IC is equipped with devices for overvoltage and reverse-voltage protection at all pins.

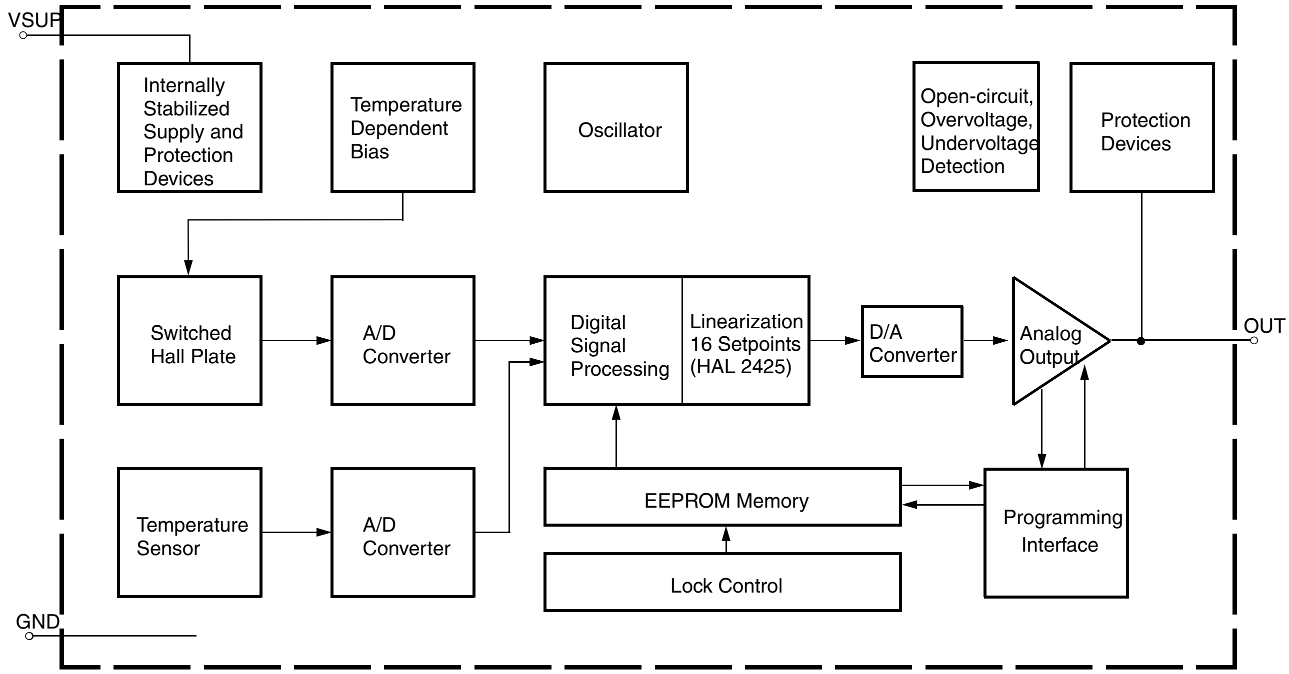


Fig. 3–1: HAL 242x block diagram

3.2. Signal path and Register Definition

3.2.1. Signal path

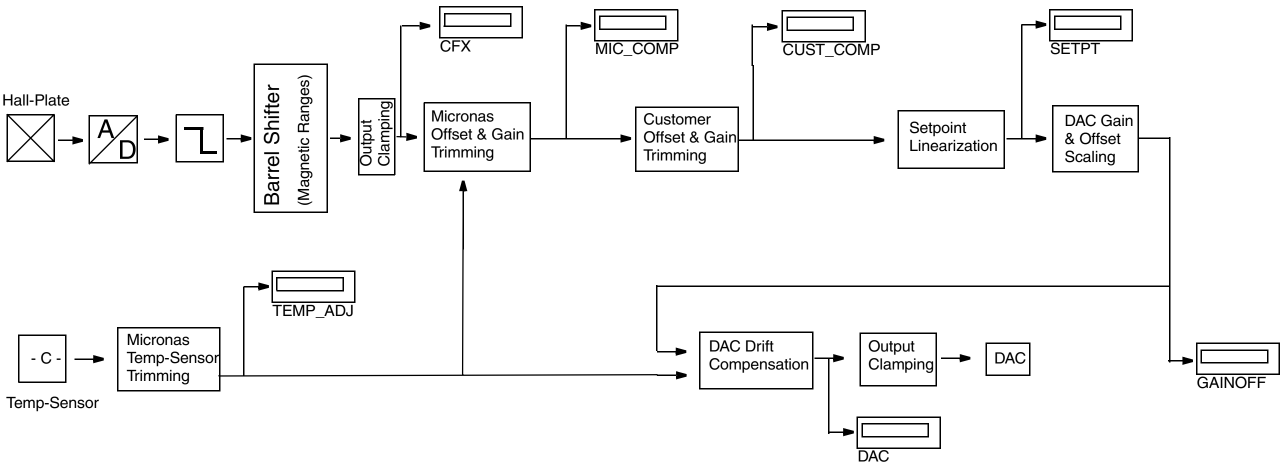


Fig. 3–2: Signal path of HAL 242x

3.2.2. Register Definition

The DSP is the major part of this sensor and performs the signal conditioning. The parameters for the DSP are stored in the EEPROM registers. The details are shown in Fig. 3–2.

Terminology:

GAIN: Name of the register or register value

Gain: Name of the parameter

The sensors signal path contains two kinds of registers. Registers that are readout only (RAM) and programmable registers (EEPROM & NVRAM). The RAM registers contain measurement data at certain positions of the signal path and the EEPROM registers have influence on the sensors signal processing.

3.2.2.1.RAM registers

TEMP_ADJ

The TEMP_ADJ register contains the calibrated temperature sensor information. TEMP_ADJ can be used for the sensor calibration over temperature. This register has a length of 16 bit and it is two's-complemented coded. Therefor the register value can vary between –32768 ... 32767.

CFX

The CFX register represents the magnetic field information directly after A/D conversion, decimation filter and magnetic range (barrel shifter) selection. The register content is not temperature compensated. The temperature variation of this register is specified in Section 4.11. on page 35 by the parameter $RANGE_{ABS}$.

Note During application design, it must be taken into consideration that CFX should never overflow in the operational range of the specific application and especially over the full temperature range. In case of a potential overflow the barrels shifter should be switched to the next higher range.

This register has a length of 16 bit and it is two's-complemented coded. Therefor the register value can vary between –32768 ... 32767. CFX register values will increase for positive magnetic fields (south pole) on the branded side of the package (positive CFX values) and it will decrease with negative magnetic field polarity.

MIC_COMP

The MIC_COMP register is representing the magnetic field information directly after the Micronas temperature trimming. The register content is temperature compensated and has a typical gain drift over temperature of 0 ppm/k. Also the offset and its drift over temperature is typically zero. The register has a length of 16 bit and it is two's-complemented coded. Therefor the register value can vary between –32768 ... 32767.

CUST_COMP

The CUST_COMP register is representing the magnetic field information after the customer temperature trimming. For HAL 242x it is possible to set a customer specific gain of second order over temperature as well as a customer specific offset of first order over temperature. The customer gain and offset can be set with the EEPROM registers TCCO0, TCCO1 for offset and TCCG0 ... TCCG2 for gain. Details of these registers are described on the following pages.

The register has a length of 16 bit and it is two's-complemented coded. Therefor the register value can vary between –32768 ... 32767.

SETPT

The SETPT register offers the possibility to read the magnetic field information after the linearization of the magnetic field information with 16 setpoints. This information is also required for the correct setting of the sensors DAC GAIN and OFFSET in the following block.

The register has a length of 16 bit and it is two's-complemented coded. Therefor the register value can vary between –32768 ... 32767.

GAINOFF

The GAINOFF register offers the possibility to read the magnetic field information after the DAC GAIN and OFFSET scaling.

This register has a length of 16 bit and it is two's-complemented coded. Therefor the register value can vary between –32768 ... 32767.

DAC

The DAC register offers the possibility to read the magnetic field information at the end of the complete signal path. The value of this register is then converted into an analog output voltage.

The register has a length of 16 bit and it is two's-complemented coded. Therefor the register value can vary between –32768 ... 32767.

MIC_ID1 and MIC_ID2

The two registers MIC_ID1 and MIC_ID2 are used by Micronas to store production information like, wafer number, die position on wafer, production lot, etc. Both registers have a length of 16 bit each and are readout only.

DIAGNOSIS

The DIAGNOSIS register enables the customer to identify certain failures detected by the sensor. HAL 242x performs certain self tests during power-up of the sensor and also during normal operation. The result of these self tests is stored in the DIAGNOSIS register. DIAGNOSIS register is a 16 bit register.

Bit No.	Function	Description
15:6	None	Reserved
5	State Machine (DSP) Self-test	This bit is set to 1 in case that the state maschine self-test fails. (continuously running)
4	EEPROM Self-test	This bit is set to 1 in case that the EEPROM self-test fails. (Performed during power-up only)
3	ROM Check	This bit is set to 1 in case that ROM parity check fails. (continuously running)
2	Adder overflow	This bit is set to 1 in case that an overflow occurs during calculation of the Micronas temperature compensation
1:0	None	Reserved

Details on the sensor self-tests can be found in Section 3.3. on page 21.

PROG_DIAGNOSIS

The PROG_DIAGNOSIS register enables the customer to identify errors occurring during programming and writing of the EEPROM or NVRAM memory. The customer must either check the status of this register after each write or program command or alternatively the second acknowledge. Please check the Programming Guide for HAL 242x.

The PROG_DIAGNOSIS register is a 16 bit register. The following table shows the different bits indicating certain errors possibilities.

Bit No.	Function	Description
15:11	None	Reserved
10	Charge Pump Error	This bit is set to 1 in case that the internal programming voltage was to low
9	Voltage Error during Program/Erase	This bit is set to 1 in case that the internal supply voltage was to low during program or erase
8	NVRAM Error	This bit is set to 1 in case that the programming of the NVRAM failed
7:0	Memory Programming	For further information please refer to the Programming Guide for HAL 242x

3.2.2.2.EEPROM register

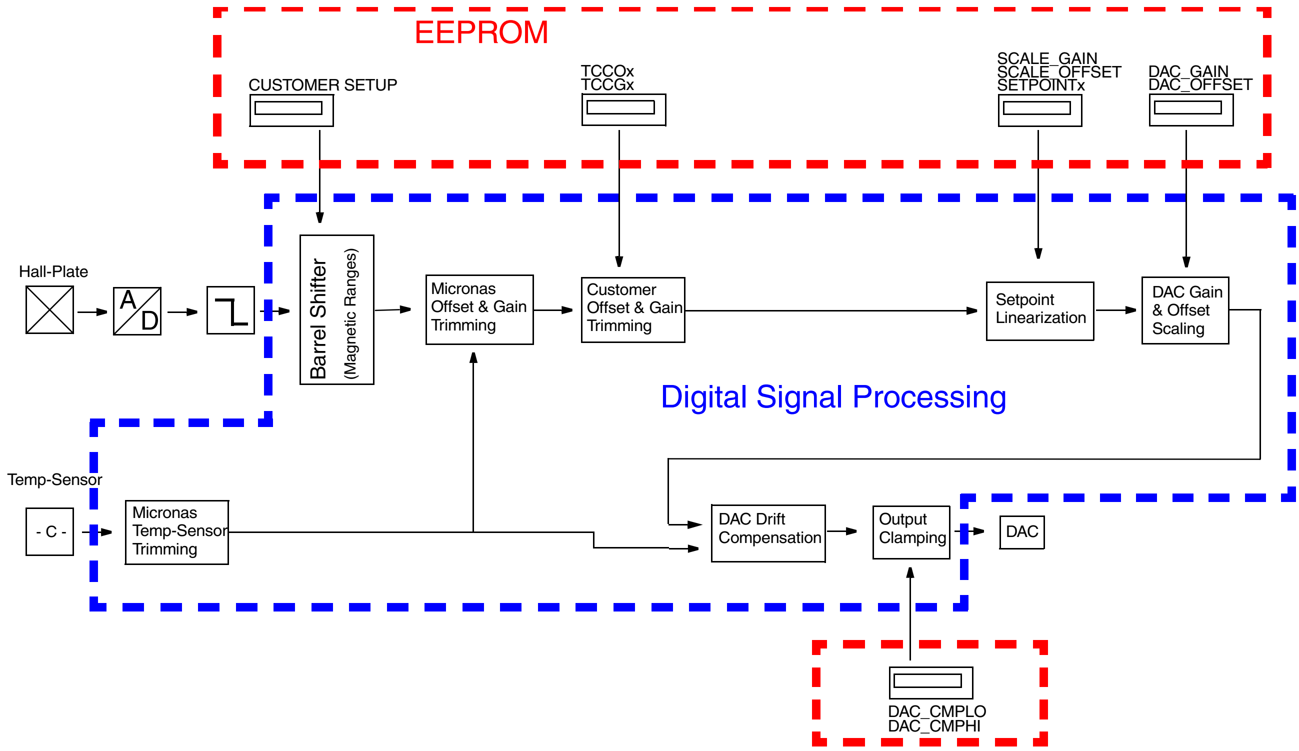


Fig. 3–3: Details of EEPROM and Digital Signal Processing

CUST_ID1 and CUST_ID2

The two registers CUST_ID1 and CUST_ID2 can be used to store customer information. Both registers have a length of 16 bit each.

Barrel Shifter (Magnetic ranges)

The signal path of HAL 242x contains a Barrel Shifter to emulate magnetic ranges. The customer can select between different magnetic ranges by changing the Barrel shifter setting. After decimation filter the signal path has a word length of 22 bit. The Barrel Shifter selects 16 bit out of the available 22 bit.

Note In case that the external field exceeds the magnetic field range the CFX register will be clamped either to –32768 or 32767 depending on the sign of the magnetic field.

Table 3–1: Relation between Barrel Shifter setting and emulated magnetic range

BARREL SHIFTER	Used bits	Typ. magnetic range
0	22...7	not used
1	21...6	± 200 mT
2	20...5	± 100 mT
3	19...4	± 50 mT
4	18...3	± 25 mT
5	17...2	± 12 mT
6	16...1	± 6 mT

The Barrel Shifter bits are part of the CUSTOMER SETUP register (bits 14...12). The CUSTOMER SETUP register is described on the following pages.

Magnetic Sensitivity TCCG

The TCCG (Sensitivity) registers (TCCG0 ... TCCG2) contain the customer setting for the multiplier in the DSP. The multiplication factor is a second order polynomial of the temperature.

All three polynomial coefficients have a bit length of 16 bit and they are two's-complemented coded. Therefor the register values can vary between –32768 ... 32767. In case that the target polynomial is based on normalized values, then each coefficient can vary between –1 ... +1. To store each coefficient into the EEPROM it is necessary to multiply the normalized coefficients with 32768.

Example:

– Tccg0 = 0.5102 => TCCG0 = 16719

– Tccg1 = –0.0163 => TCCG1 = –536

– Tccg2 = 0.0144 => TCCG2 = 471

In case that the polynomial was calculated based on not normalized values of TEMP_ADJ and MIC_COMP, then it is not necessary to multiply the polynomial coefficients with a factor of 32768.

Magnetic Sensitivity TCCO

The TCCO (Offset) registers (TCCO0 and TCCO1) contain the parameters for the adder in the DSP of the sensor. The added value is a first order polynomial of the temperature.

Both polynomial coefficients have a bit length of 16 bit and they are two's-complemented coded. Therefor the register values can vary between –32768 ... 32767.
In case that the target polynomial is based on normalized values, then each coefficient can vary between –1 ... +1. To store each coefficient into the EEPROM it is necessary to multiply the normalized coefficients with 32768.

In case that the polynomial was calculated based on not normalized values of TEMP_ADJ and MIC_COMP, then it is not necessary to multiply the polynomial coef-
SETPOINTS

HAL 2425 features a linearization function based on 16 setpoints. The setpoint linearization in general allows to linearize a given output characteristic by applying the inverse compensation curve.

Each of the 16 setpoints (SETPT) registers have a length of 16 bit. The setpoints have to be computed and stored in a differential way. This means that if all setpoints are set to 0, then the linearization is set to neutral and a linear curve is used.

Sensitivity and Offset Scaling before setpoint linearization SCALE_GAIN/ SCALE_OFFSET

The setpoint linearization uses the full 16 bit number range 0...32767 (only positive values possible). So the signal path should be properly scaled for optimal usage of all 16 setpoints.

For optimum usage of the number range an additional scaling stage is added in front of the set point algorithm. The setpoint algorithm allows positive input numbers only.

The input scaling for the linearization stage is done with the EEPROM registers SCALE_GAIN and SCALE_OFFSET. The register content is calculated based on the calibration angles. Both registers have a bit length of 16 bit and are two's-complemented coded.

Analog output signal scaling with DAC_GAIN/DAC_OFFSET

The required output voltage range of the analog output is defined by the registers DAC_GAIN (Gain of the output) and DAC_OFFSET (Offset of the output signal). Both register values can be calculated based on the angular range and the required output voltage range. They have a bit length of 16 bit and are two's-complemented coded.

Clamping Levels

The clamping levels DAC_CMPHI and DAC_CMPLO define the maximum and minimum output voltage of the analog output. The clamping levels can be used to define the diagnosis band for the sensor output. Both registers have a bit length of 16 bit and are two's-complemented coded. Both clamping levels can have values between 0% and 100% of V_{SUP}.

3.2.2.3. NVRAM Registers

Customer Setup

The CUST_SETUP register is a 16 bit register that enables the customer to activate various functions of the sensor like, customer burn-in mode, diagnosis modes, functionality mode, customer lock, etc.

Table 3–2: Functions in CUST_SETUP register

Bit No.	Function	Description
15	None	Reserved
14:12	Barrel Shifter	Magnetic Range (see Section Table 3–1: on page 16)
11:10	None	Reserved
9:8	Output Short Detection	0: Disabled 1: High & low side over current detection -> OUT = V_{SUP} in error case 2: High & low side over current detection -> OUT = GND in error case 3: Low side over current detection -> OUT = Tristate in error case
7:6	None	Reserved
5	Functionality Mode	1: Normal
4	Communication Mode (POUT)	Communication via output pin 0: Disabled 1: Enabled
3	Overvoltage Detection	0: Overvoltage detection active 1: Overvoltage detection disabled
2	Diagnosis Latch	Latching of diagnosis bits 0: No latching 1: Latched till next POR (power-on reset)
1	Diagnosis	0: Diagnosis errors force output to error band (V_{SUP}) 1: Diagnosis errors do not force output to error band (V_{SUP})
0	Customer Lock	Bit must be set to 1 to lock the sensor memory

3.2.2.4.Setpoint linearization accuracy

The set point linearization in general allows to linearize a given output characteristic by applying the inverse compensation curve.

For this purpose the compensation curve will be divided into 16 segments with equal distance. Each segment is defined by two setpoints, which are stored in EEPROM. Within the interval, the output is calculated by linear interpolation according to the position within the interval.

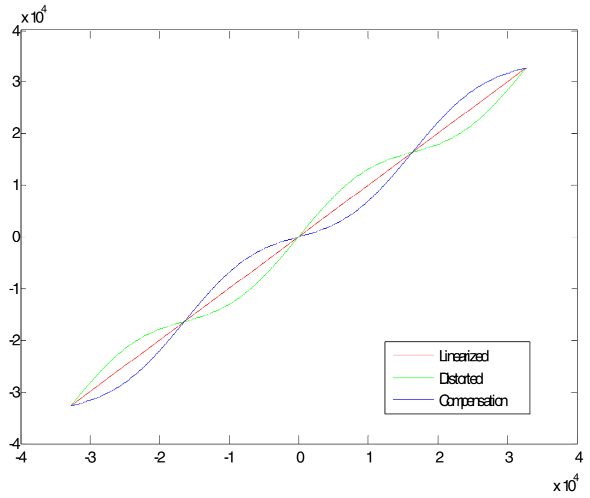


Fig. 3–4: Linearization - Principle

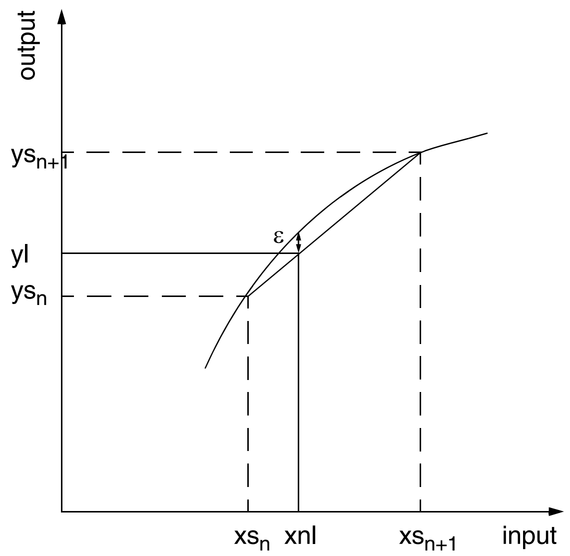


Fig. 3–5: Linearization - Detail

xnl: non linear distorted input value
yl: linearized value
ε: remaining error

The constraint of the linearization is that the input characteristic has to be a monotonic function. In addition to that it is recommended that the input does not have a saddle point or inflection point, i.e. regions where the input is nearly constant. This would require a high density of set points

3.3. On-board Diagnostic features

The HAL 242x features two groups of diagnostic functions. The first group contains basic functions that are always active. The second group can be activated by the customer and contains supervision and self-tests related to the signal path and sensor memory.

Diagnostic features that are always active:

– Wire break detection for supply and ground line

– Undervoltage detection

– Thermal supervision of output stage (overcurrent, short circuit, etc.)

Diagnostic features that can be activated by customer:

– Overvoltage detection

– EEPROM self-test at power-on

– Continuous ROM parity check

– Continuous state machine self-test

– Adder overflow

The sensor indicates a fault immediately by switching the output signal to the upper diagnosis level (max. Vout) in case that the diagnostic mode is activated by the customer. The sensor switches the output to tristate if an over temperature is detected by the thermal supervision. The sensor switches the output to ground in case of a V_{SUP} wire break.

3.4. Calibration of the sensor

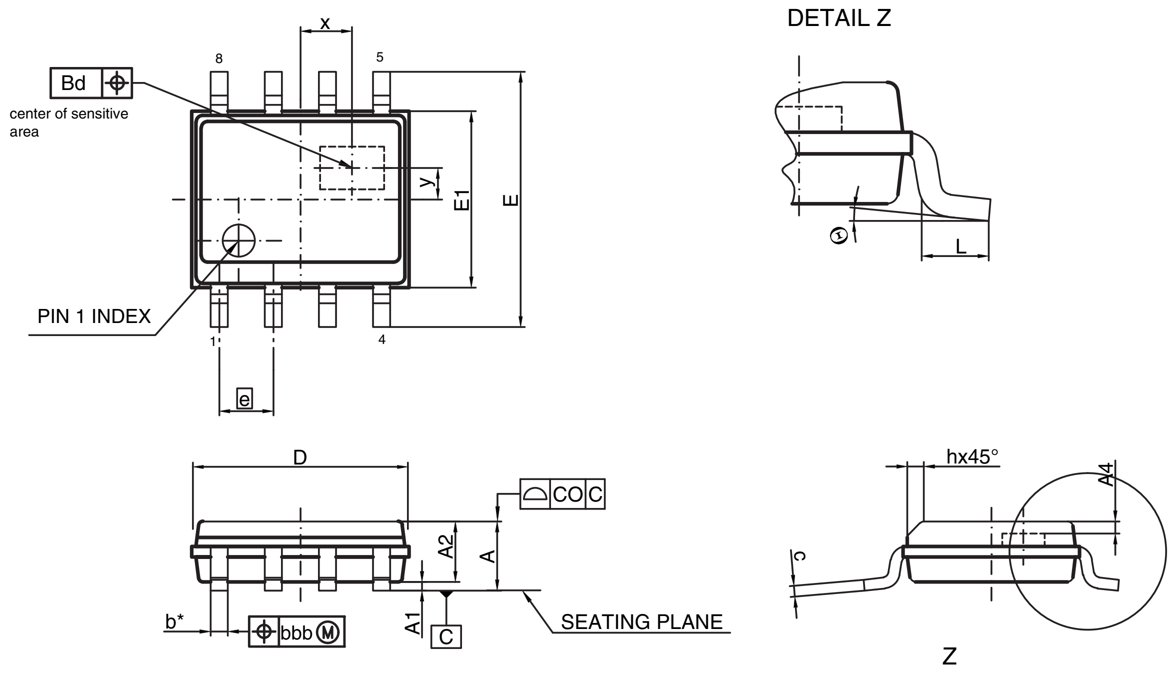
For calibration in the system environment, the application kit from Micronas is recommended. It contains the hardware for the generation of the serial telegram for programming (HAL-APB V1.5) and the corresponding LabView based programming environment for the input of the register values.

For the individual calibration of each sensor in the customer application, a two point calibration is recommended.

A detailed description of the calibration software, calibration algorithm, programming sequences and register value calculation can be found in the Application Note “HAL 242x Programming Guide”.

4. Specifications

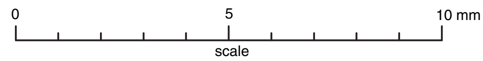
4.1. Outline Dimensions



"D" and "E1" are reference data and do not include mold flash or protrusion.
Mold flash or protrusion shall not exceed 150 µm per side.

* does not include dambar protrusion of 0.1 max. per side

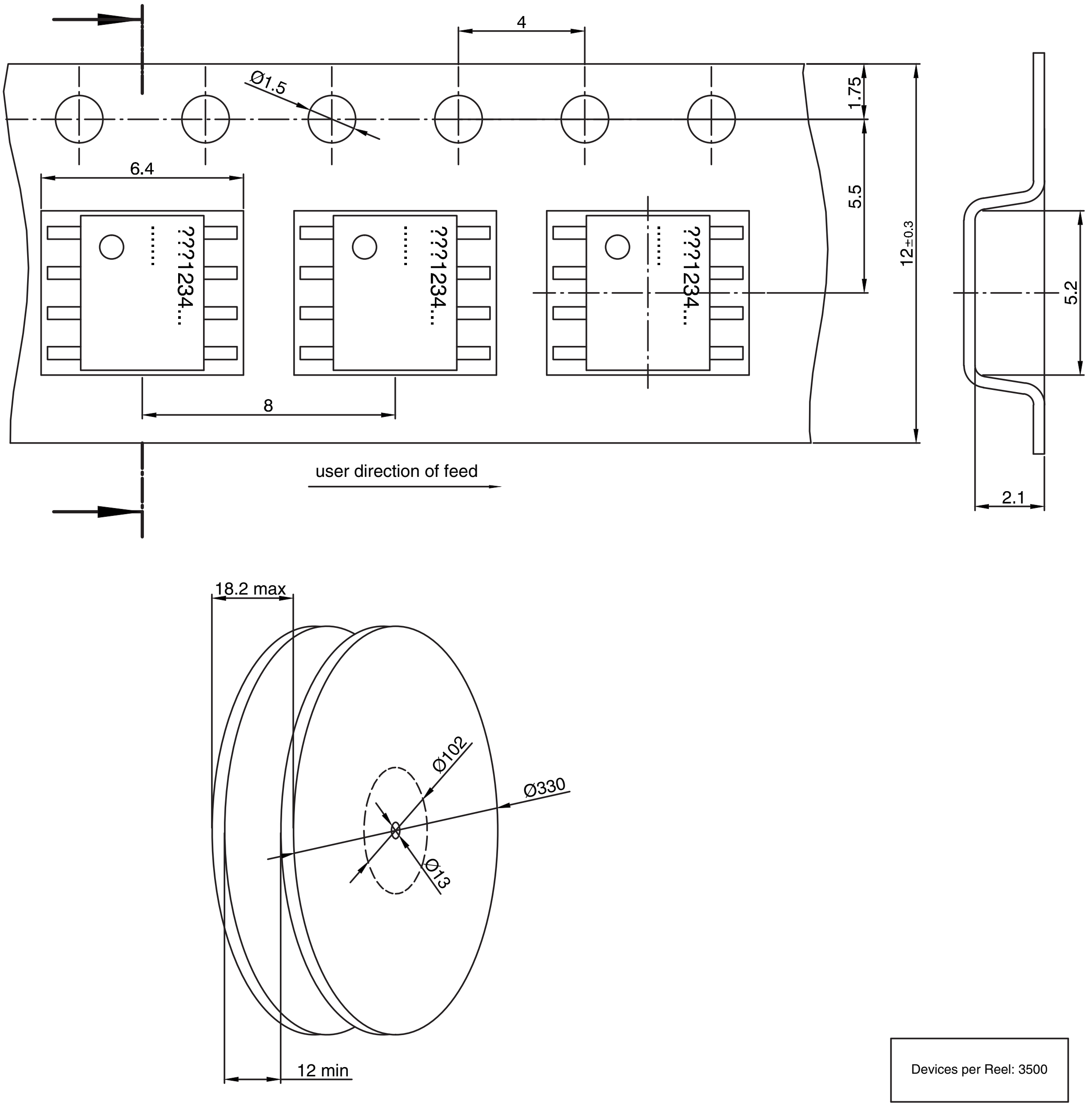
A4, Bd, x,y=these dimensions are different for each sensor type and are specified in the data sheet



UNIT	A	A1	A2	b	bbb	c	CO	D	E	E1	e	h	L	Θ
mm	1.65	0.25 0.1	1.45	0.4	0.25	0.22	0.1	5.0 4.8	6.0	4.0 3.8	1.27	0.3	0.41 min.	8° max.

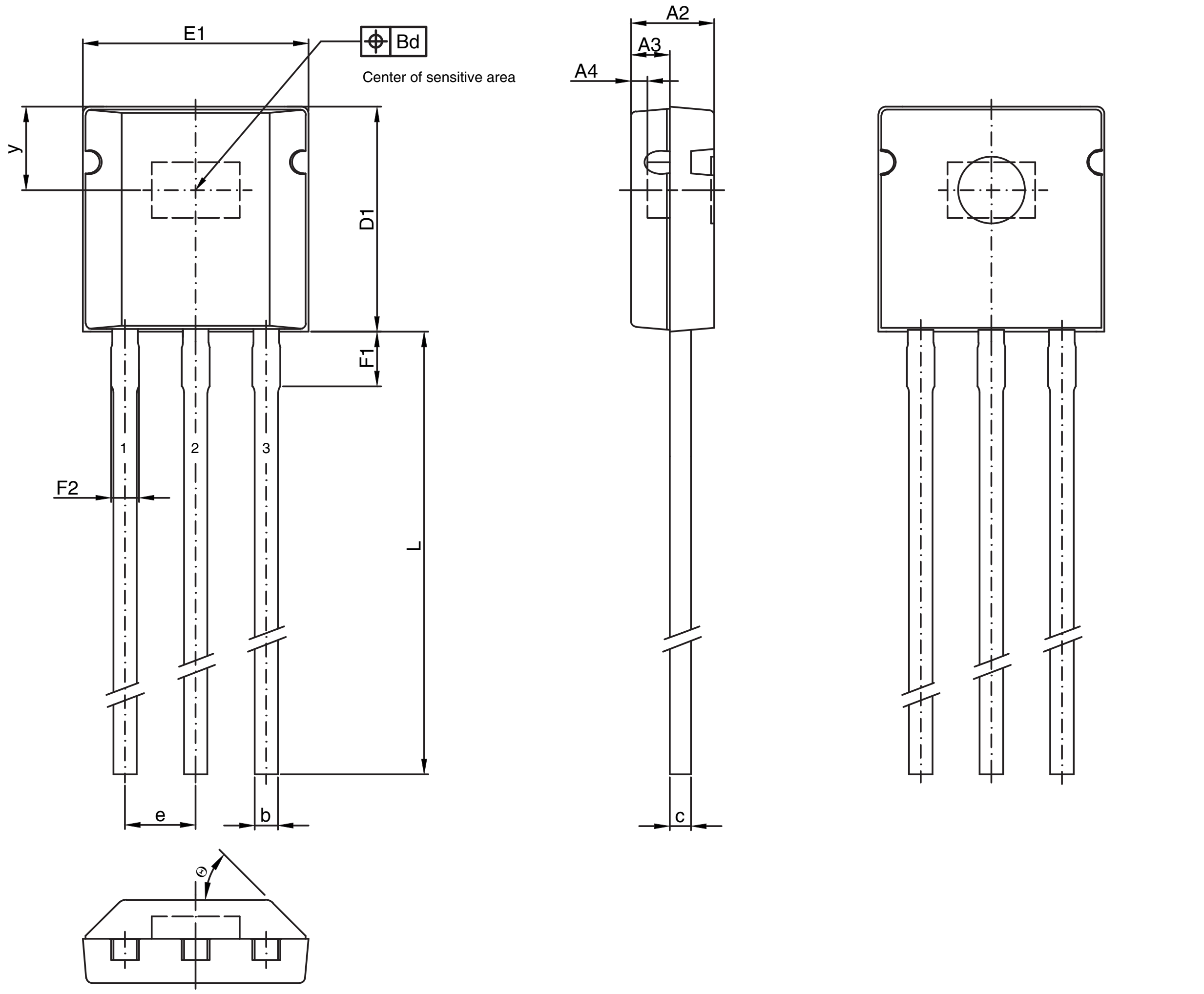
JEDEC STANDARD			ISSUE DATE YY-MM-DD	DRAWING-NO.	ZG-NO.
ISSUE	ITEM NO.				
F	MS-012		09-07-21	06690.0001.4 Bl. 1	ZG001090_Ver.05

Fig. 4–1:
SOIC8-1: Plastic **S**mall **O**utline **IC** package, 8 leads, gullwing bent, 150 mil
Ordering code: DJ
Weight approximately 0.086 g



IEC STANDARD		ANSI	ISSUE DATE YY-MM-DD	DRAWING-NO.	ZG-NO.
ISSUE	ITEM NO.				
4th	60286-3		12-01-31	06836.0001.4	ZG002036_001_01

Fig. 4–2:
SOIC8: Tape and Reel Finishing



physical dimensions do not include moldflash.

solderability is guaranteed between end of pin and distance F1.

Sn-thickness might be reduced by mechanical handling.

A4, Bd, y= these dimensions are different for each sensor type and are specified in the data sheet.

min/max of D1 are specified in the datasheet.

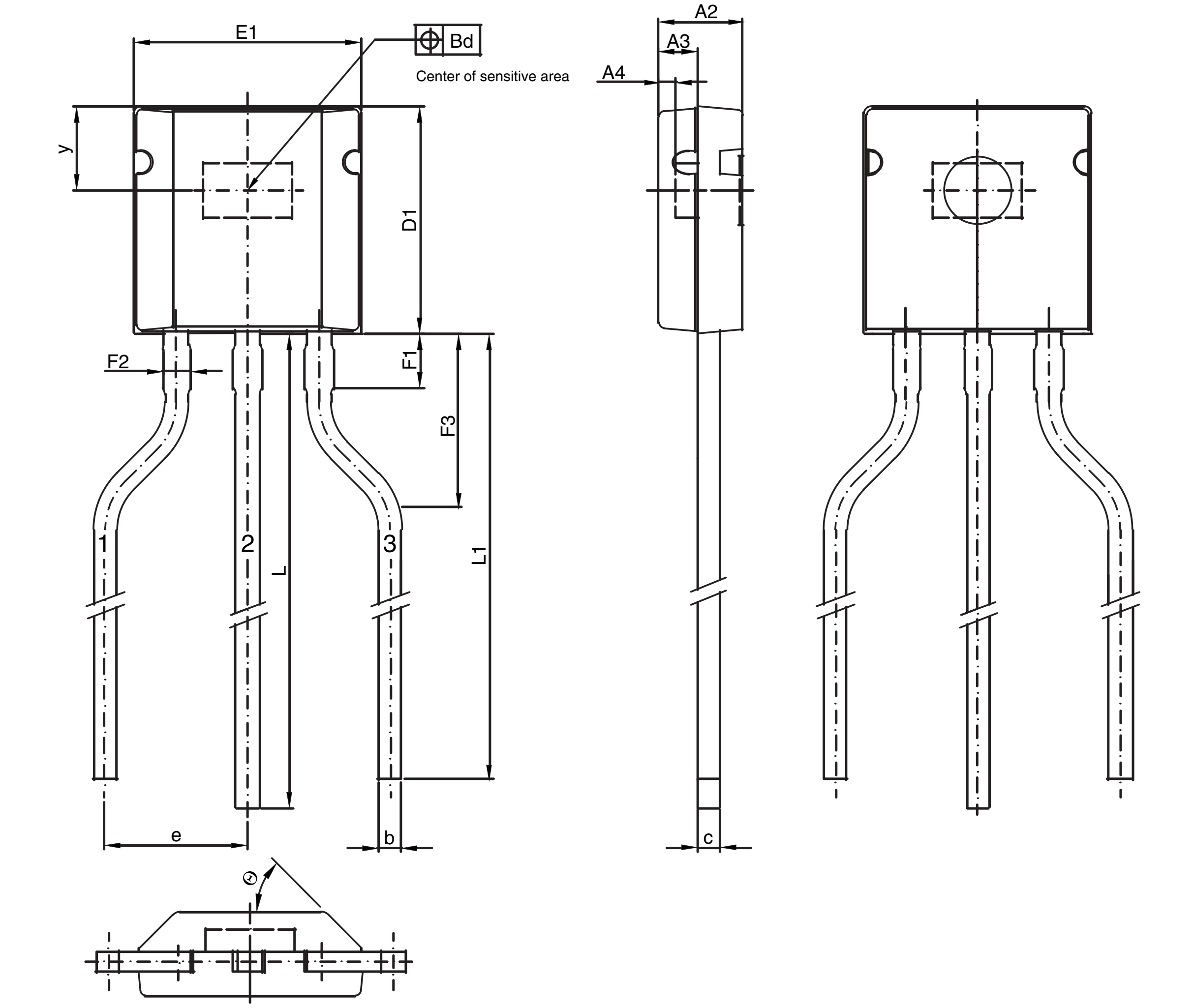
0 2.5 5 mm

scale

UNIT	A2	A3	b	c	D1	e	E1	F1	F2	L	Θ
mm	1.55 1.45	0.7	0.42	0.36	4.05	1.27	4.11 4.01	1.2 0.8	0.60 0.42	14.5 min	45°

JEDEC STANDARD		ANSI	ISSUE DATE YY-MM-DD	DRAWING-NO.	ZG-NO.
ISSUE	ITEM NO.				
-	-		15-01-09	06615.0001.4 Bl. 1	ZG001015_Ver.08

Fig. 4–3:
TO92UT-2 Plastic Transistor Standard UT package, 3 pins
Weight approximately 0.12 g



physical dimensions do not include moldflash.
solderability is guaranteed between end of pin and distance F1.
Sn-thickness might be reduced by mechanical handling.
A4, Bd, y= these dimensions are different for each sensor type and are specified in the data sheet.
min/max of D1 are specified in the datasheet.

UNIT	A2	A3	b	c	D1	e	E1	F1	F2	F3	L	L1	Θ
mm	1.55 1.45	0.7	0.42	0.36	4.05	2.54	4.11 4.01	1.2 0.8	0.60 0.42	4.0 2.0	14.5 min	14.0 min	45°

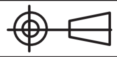
JEDEC STANDARD		ANSI	ISSUE DATE YY-MM-DD	DRAWING-NO.	ZG-NO.
ISSUE	ITEM NO.				
-	-		10-04-29	06609.0001.4	ZG001009_Ver.07

Fig. 4–4:
TO92UT-1 Plastic Transistor Standard UT package, 3 leads, spread
Weight approximately 0.12 g