

HAL[®] 3625, HAL 3675

Programmable Direct-Angle
Sensors



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Programmable Direct-Angle Sensors

Release Note: Revision bars indicate significant changes to the previous edition.

1. Introduction

The HAL 36xy is a member of a new sensor family using the Micronas 3D HAL technology. This new family has several members. HAL 3625 provides a linear, ratiometric analog output signal with integrated wire-brake detection working with pull-up or pull-down resistor. HAL 3675 features a configurable PWM output with up to 12 bit resolution with frequencies between 0.25 kHz and 2 kHz.

Type	Output Format
HAL 3625	Analog
HAL 3675	PWM

Conventional planar Hall technology is only sensitive to the magnetic field orthogonal to the chip surface. In contrast, the HAL 36xy is sensitive for magnetic fields applied in parallel to the chip surface. This is possible by integrating vertical Hall plates into the standard CMOS process.

With the new vertical Hall technology it is possible to directly measure rotation angles over the entire range from 0° to 360° with simple magnetic circuits. The magnetic field of a small magnet (diametrical magnetization) rotating above the sensor can be measured in a non-contacting way.

The sensor measures both magnetic field components BX and BY. The diametrical magnetization of a rotating magnet generates a flux vector. The vertical Hall elements measure the X- and Y-Component of the magnetic field vector, which normally corresponds to a sine and cosine waveform.

The direct angle information is internally calculated and converted into an analog output voltage. The angle information is proportional to the output voltage.

Due to the measurement method, the sensor provides excellent drift performance over temperature delivering a new class of accuracy.

Additionally to the built-in signal processing, the sensor features an arbitrary programmable linear characteristic for linearization of the output signal (with up to 32 setpoints).

Major characteristics like gain and offset of X- and Y-channel, zero angle position, phase shift between X- and Y-signal, hysteresis, low-pass filter frequency, output slope and offset and clamping levels can be adjusted to the magnetic circuitry by programming the non-volatile memory.

The sensor contains advanced on-board diagnostic features that enhance fail-safe detection. In addition to the standard checks, such as over and undervoltage and wire-break, internal blocks such as ROM and the signal path are monitored during normal operation. The error modes are indicated by forcing the output voltage into error band. For HAL 3675 the error modes are indicated by a change of PWM frequency and duty-cycle.

The HAL 36xy is designed for automotive applications. The devices operates with junction temperatures ranging from -40 °C up to 170 °C.

The sensors are available in a very small four-pin leaded transistor package TO92UP, as well as in a SOIC8 package.

1.1. Major Applications

Due to the sensor's versatile programming characteristics and its high accuracy, the HAL 36xy is the optimal system solution for applications such as:

- Contactless potentiometers
- Rotary position measurement, like
 - Throttle position
 - EGR value position
 - Accelerator paddle position, etc.

1.2. Features

- Angle measurement is extremely robust against temperature and stress influence
- 12 bit ratiometric linear output proportional to the measurement angle for HAL 3625
- 0.25 kHz to 2 kHz (up to 12 bit) PWM output for HAL 3675
- Programmable arbitrary output characteristic with up to 32 setpoints
- 8 kHz sampling frequency
- Operates from 4.5 V up to 5.5 V supply voltage
- Operates from $-40\text{ }^{\circ}\text{C}$ up to $170\text{ }^{\circ}\text{C}$ junction temperature
- On-chip temperature compensation
- Active offset compensation
- Programming via the sensors output pin
- Programmable characteristics in a non-volatile memory (EEPROM) with redundancy and lock function
- Programmable 1st-order low-pass filter
- Programmable hysteresis
- Programmable output slope and offset
- X- and Y-channel gain and offset of signal path programmable
- Phase shift between X- and Y-channel programmable
- Programmable output clamping voltages for error band definition
- Programmable zero angle position
- Programmable magnetic range detection
- 32 bit identification number for customer
- 32 bit identification number with Micronas production information (like X,Y position; wafer number; lot number)
- On-Board diagnostics of different functional blocks of the sensor
- Short-circuit protected push-pull output
- Over- and reverse-voltage protection at V_{SUP}
- Under- and overvoltage detection of V_{SUP}
- Wire-break detection with pull-up or pull-down resistor
- EMC and ESD robust design

2. Ordering Information

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

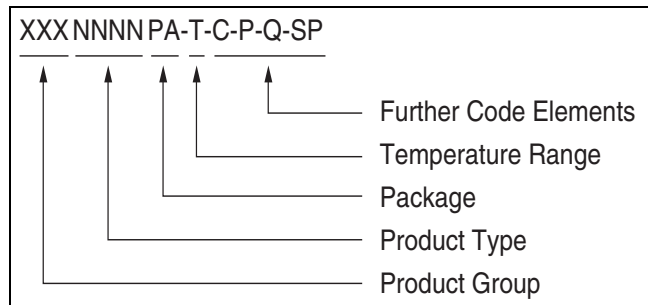


Fig. 2–1: Ordering Code Principle

For a detailed information, please refer to the brochure: “Hall Sensors: Ordering Codes, Packaging, Handling”

2.1. Device-Specific Ordering Codes

The HAL 36xy is available in the following package and temperature variants.

Table 2–1: Available packages

Package Code (PA)	Package Type
DJ	SOIC8-1
UP	TO92UP-1

Table 2–2: Available temperature ranges

Temperature Code (T)	Temperature Range
A	$T_J = -40\text{ °C to }+170\text{ °C}$

The relationship between ambient temperature (T_A) and junction temperature (T_J) is explained in Section 5.1. on page 27.

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
HAL3625DJ-A-[C-P-Q-SP]	3625A
HAL3625UP-A-[C-P-Q-SP]	3625A
HAL3675DJ-A-[C-P-Q-SP]	3675A
HAL3675UP-A-[C-P-Q-SP]	3675A

3. Functional Description

3.1. General Function

The HAL 36xy is a direct angle sensor based on Micronas' 3D HAL technology. The sensor includes two vertical Hall plates for the detection of X and Y magnetic field components, a signal processor for calculation of the angle information, protection devices and a ratiometric linear output or PWM output.

The output signal is proportional to the angle of a rotating magnet target with respect to the sensor. The spinning current offset compensation minimizes the angle error due to supply voltage and temperature variations as well as external package stress.

The sensor can be used for angle measurements in a range between 0° and 360°. The in-system calibration can be utilized by system designer to optimize performance for a specific system. The calibration information is stored in a on chip EEPROM.

The angle measurement is compensated in respect to the flux density variations caused by airgap variations or drifts. Therefore, the sensor enables the development of systems running in harsh electrical and mechanical environments.

The HAL 36xy is programmable by modulation of the output voltage. No additional programming pin is needed.

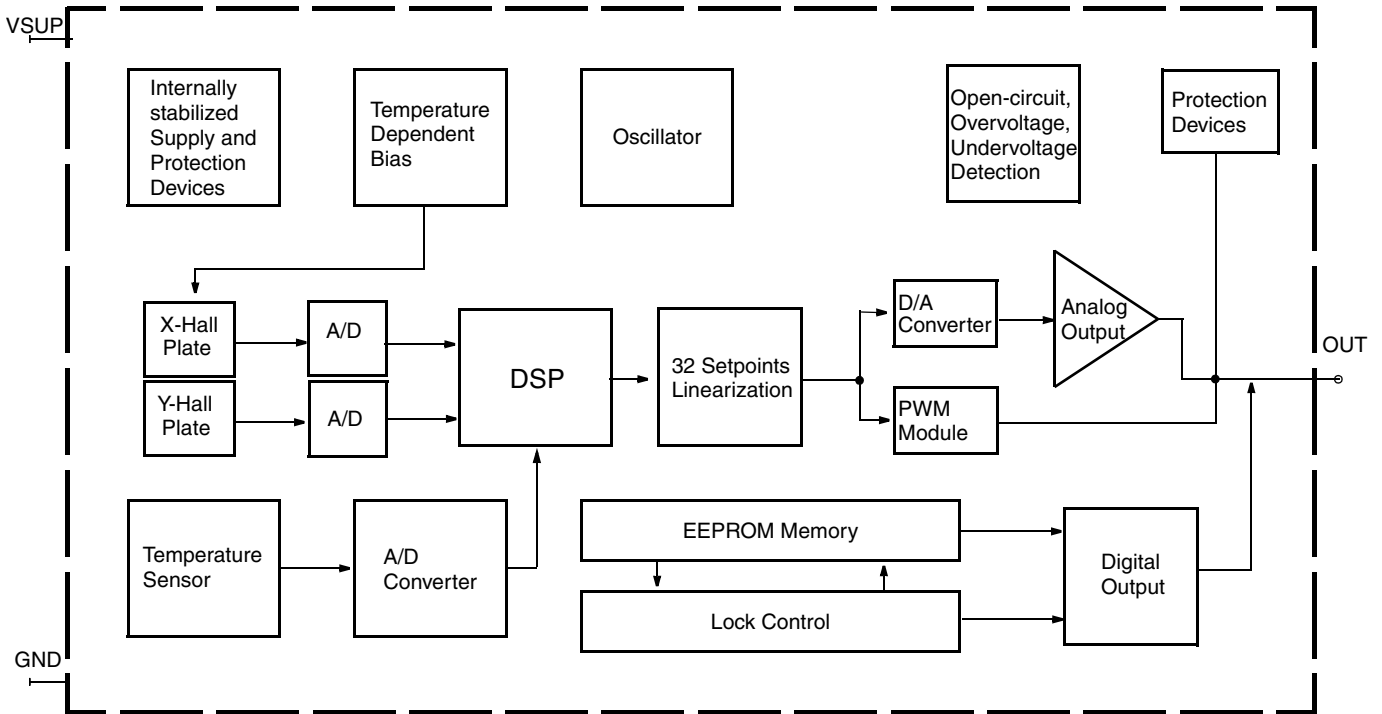


Fig. 3-1: HAL 36xy block diagram

3.2. Signal Path and Register Definition

3.2.1. Signal Path

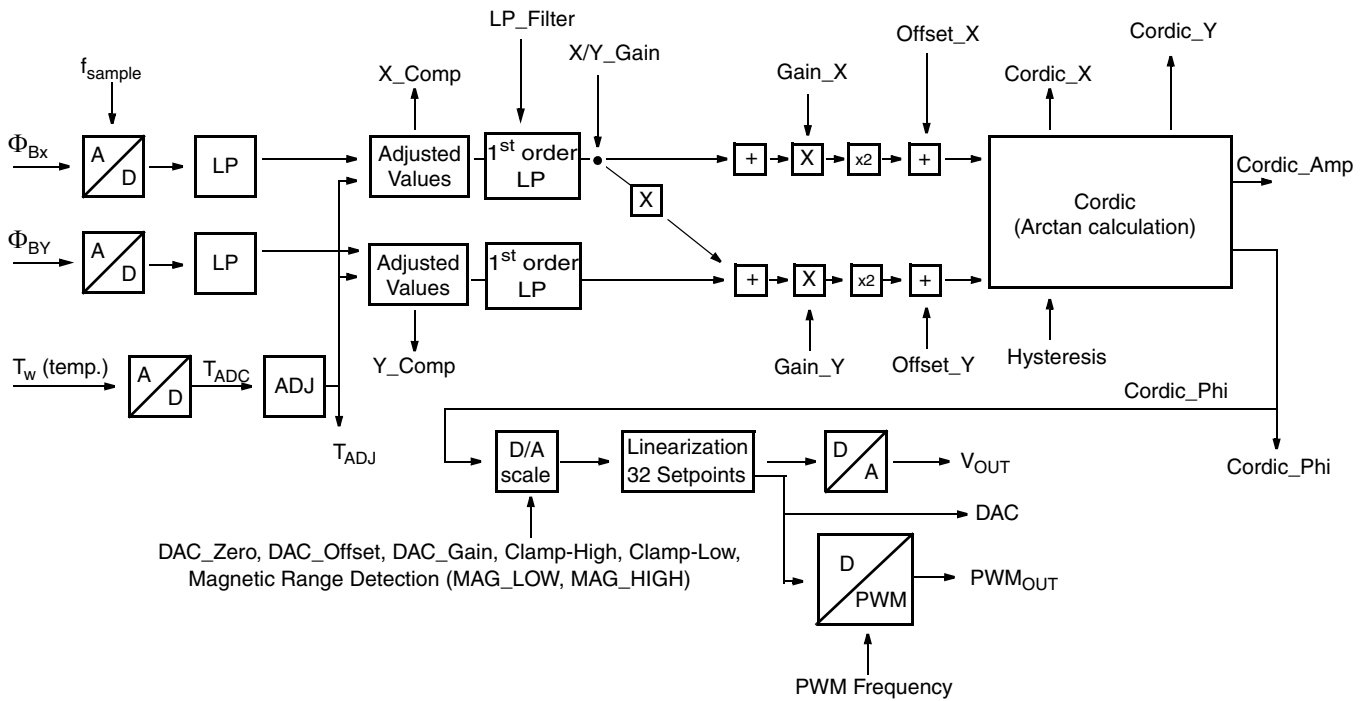


Fig. 3-2: Signal path of HAL 36xy

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. The RAM registers contain measurement data at certain steps of the signal path and the EEPROM registers have influence on the sensors signal processing.

3.2.2.1. RAM Register

TADJ

The TADJ register contains the digital value of the sensor junction temperature. It has a length of 16 bit and is binary coded. From the 16 bit only the range between 0 ... 32767 is used for the temperature information. Typically the temperature sensor is calibrated in the way that at $-40^{\circ}C$ the register value is 100 LSB and at $160^{\circ}C$ it is 12000 LSB.

X_COMP and Y_COMP

X_COMP and Y_COMP register contain the temperature compensated magnetic field information of the X- and Y-channel. Both registers have a length of 16 bit each and are two's-complement coded. Therefore, the register values can vary between $-32768 \dots 32767$.

CORDIC_X and CORDIC_Y

CORDIC_X and CORDIC_Y register contain the compensated magnetic field information of the X- and Y-channel used for the angle calculation based on CORDIC algorithm. These registers include already customer phase-shift, gain and offset correction. Both registers have a length of 16 bit each and are two's-complement coded. Therefore, the register values can vary between $-32768 \dots 32767$.

CORDIC_PHI

The CORDIC_PHI register contains the digital value of the angle calculated by the CORDIC algorithm. It has a length of 16 bit and is binary. From the 16 bit only the range between 0 ... 32767 is used for the angle information.

DAC

The DAC register contains the digital equivalent of the output voltage or PWM output duty-cycle. It has a length of 16 bit and is binary. From the 16 bit only the range between 0 ... 32767 is used for the position information.

CORDIC_AMP

The CORDIC_AMP register contains the digital value of the magnetic field amplitude calculated by the CORDIC algorithm. From mathematical point of view the amplitude can be calculated based on X- and Y-channel amplitude.

$$\text{Amplitude} = \sqrt{X^2 + Y^2}$$

The CORDIC algorithm adds a factor of roughly 1.6 to the equation for the magnetic amplitude. So the equation for the amplitude is defined as follows:

$$\text{CORDIC_AMP} \cong 1.6 \times \sqrt{X^2 + Y^2}$$

DIAGNOSIS

The DIAGNOSIS register enables the customer to identify certain failures detected by the sensor. HAL 36xy 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	Statemachine Self Test	This bit is set to 1 in case that the statemachine (DSP doing the internal signal processing like ArcTan calculation, temperature compensation, etc.) 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	Reserved	
1	MAGHI	This bit is set to 1 in case that the magnetic field is exceeding the MAG-HI register value (magnetic field to high)
0	MAGLO	This bit is set to 1 in case that the magnetic field is below the MAG-LOW register value (magnetic field to low)

Details on the sensor self-tests can be found in Section 3.5. on page 15.

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 check either the status of this register after each write or program command or alternatively the first and second acknowledge. Please check the Programming Guide for HAL 36xy for further details.

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	Programming	These bits are used for programming the memory

3.2.2.2. EEPROM Register

XY_GAIN

XY_GAIN can be used to compensate a phase-shift between X- and Y-channel. The register has a length of 16 bit. It is possible to make a phase shift correction of ±75°. The step size and therefore the smallest possible correction is 0.002°. The register is two's-complement coded and ranges from -32768 to 32767. The register value is sin function based. XY_GAIN is calculated as follows:

$$XY_GAIN = \sin(\text{Phase-shift}) \times 32767$$

Neutral value for this register is zero (no Phase-shift correction).

Note: In case the phase-shift correction is used, then it is necessary to adapt the settings of Gain_Y too. For details see definition of GAIN_Y.

GAIN_X and GAIN_Y

Gain_X and Gain_Y can be used to compensate amplitude mismatches between X- and Y-channel. Micronas delivers pre calibrated sensors with no gain mismatch between X- and Y-channel. Nevertheless it is possible that due to the magnetic circuit a mismatch between X- and Y-channel gain occurs. This can be compensated with Gain_X and Gain_Y.

Both register have a length of 16 bit and are two's-complement coded. Therefore, they can have values between -32768 and 32767 (-1 ... 1). For neutral settings both register values have to be set to 0.5 (register value 16384).

In case that the phase-shift correction is used it is necessary to change also the gain of channel Y (see also XY_GAIN). If phase-shift correction is used the corresponding register has to be set to

$$GAIN_Y = \frac{0.5}{\cos(\text{Phase-shift})} \times 32767$$

Example:

A phase-shift error of 11° between X- and Y-channel should be compensated. XY_GAIN is then set to 6252

$$XY_GAIN = \sin(11^\circ) \times 32767 = 6252.24$$

Then Gain_X must be 0.5 (GAIN_X = 16384) and GAIN_Y must be set to 16690.

$$GAIN_Y = \frac{0.5}{\cos(\text{Phase-shift})} \times 32767 = 16690.14$$

Note: In case Gain_X or Gain_Y exceed the range of -1 ... 1 (-32768 ... 32767), then it is possible to reduce the gain of the opposite channel for compensation.

OFFSET_X and OFFSET_Y

Offset_X and Offset_Y can be used to compensate offset mismatches between X- and Y-channel. Micronas delivers pre calibrated sensors. Nevertheless it is possible that due to the magnetic circuit a mismatch between X- and Y-channel offset occurs. This can be compensated with Offset_X and Offset_Y. Both registers have a length of 16 bit and are two's-complement coded. Therefore, they can have values between -32768 and 32767. For neutral settings both register values have to be set to 0 (register value 0).

DAC_ZERO

DAC_Zero defines the zero degree point on the 360° circle. It can be set to any angle point located on the 360° circle. It is also the starting point/reference for the 32 setpoints. DAC_ZERO has a register length of 16 bit and it is two's-complement coded.

$$DAC_ZERO = 65536 - 2 \times \text{CORDIC_PHI}$$

Note: Before reading CORDIC_PHI it is necessary to set DAC_ZERO to 0.

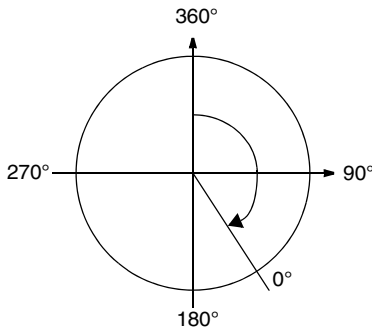


Fig. 3-3: Definition of zero degree point

DAC_GAIN

DAC_Gain defines the gain of the analog or PWM output. The register has a length of 16 bit and is two's-complement coded. DAC_Gain = 1 is neutral setting and leads to a change of the output voltage from 0% to 100% V_{SUP} for an angle change from 0° to 360° (if DAC_OFFSET is set to 0). DAC_Gain can be changed between -64 and 64. The register value is defined by the following equation:

$$DAC_GAIN = 16384 \times \sqrt[5]{0.5 \times DAC_Gain}$$

DAC_OFFSET

DAC_Offset defines the offset of the analog or PWM output. The register has a length of 16 bit and is two's-complementary. DAC_OFFSET = 0 is neutral setting and leads to a change of the output voltage from 0% to 200% of V_{SUP} for an angle change from 0° to 360° (if DAC_GAIN is set to 1). DAC_Offset can be changed between -200% and 200% of V_{SUP}. DAC_OFFSET = 0 leads to a voltage offset of 0% of V_{SUP} and DAC_OFFSET = 32768 leads to a voltage offset of -200% of V_{SUP}.

CLAMP-LOW

CLAMP-LOW defines the minimum output level. The register has a length of 8 bit. Clamp-Low can vary between 0% and 50% of V_{SUP}. The register value can be calculated by the following equation:

$$CLAMP-LOW = 256 - \frac{Clamp-Low}{100\%} \times 128$$

Note: In case calculation of CLAMP-LOW gives 256, then CLAMP-LOW has to be set to 0.

CLAMP-HIGH

CLAMP-HIGH defines the maximum output level. The register has a length of 8 bit. Clamp-High can vary between 50% and 100% of V_{SUP}. The register value is defined by the following equation:

$$CLAMP-HIGH = \frac{100\% - Clamp-High}{100\%} \times 127$$

Magnetic Range Check

The magnetic range check uses the magnitude output and compares it with an upper and lower limit threshold defined by the registers MAG-LOW and MAGHIGH. If either low or high limit is exceeded then the sensor will indicate it with an overflow on the sensors output (output high clamping).

MAG-LOW

MAG-LOW defines the low level for the magnetic field range check function. This register has a length of 8 bit and is a two's complement number.

The overflow bit is set if:

$$CORDIC_AMP < ABS(MAG_LOW \times 256)$$

Example:

MAG_LOW = +30 leads to a detection level of 7680 lsb. As soon as CORDIC_AMP is below 7680 it will be detected as a too low magnetic field and will lead to an error message on the sensors output.

MAG-HIGH

MAG-HIGH defines the high level for the magnetic field range check function. This register has a length of 8 bit and is a two's complement number.

The overflow bit is set if:

$$\text{CORDIC_AMP} > 32767 - \text{MAG_HIGH} \times 256$$

Example:

MAG_HIGH = 30 leads to a detection level of 25087 lsb. As soon as CORDIC_AMP is above 25087 it will be detected as a too high magnetic field and will lead to an error message on the sensors output.

Note: MAG_HIGH is MSB aligned.

Low-Pass Filter

With the LP_Filter register it is possible to select different -3 dB frequencies for HAL 36xy. The low-pass filter is a 1st-order digital filter and the register is 16 bit organized. Various typical filter frequencies between 4 kHz (no filter) and 10 Hz are available.

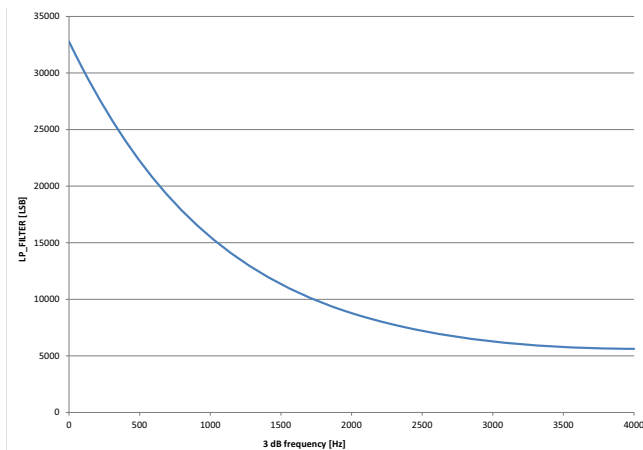


Fig. 3-4: -3db frequency vs. register codes

HYSTERESIS

HYSTERESIS defines the number of digital code uses as an hysteresis in the angle calculation. The purpose of this register is to avoid angle variation on the Cordic_Phi register and finally on the output signal due to noise on the Cordic_X and Cordic_Y signals.

The register has a length of 16 bit and is two's complement number.

It is possible to program a hysteresis between 1 LSB and 16383 LSB. The register value itself is calculated with the following equation:

$$\text{HYSTERESIS} = 65536 - 2 \times \text{hysteresis}$$

Example:

A hysteresis of 50 leads to a HYSTERESIS value of 65436.

PWM Frequency

PWM_FREQ defines the frequency of the PWM output signal. This function is only available in HAL 387x. The PWM frequency is selectable by 2 bits. The following four different frequencies can be used:

Table 3-1: Selectable PWM frequencies for HAL 387x

No.	Frequency	Resolution
0	2 kHz	11 bit
1	1 kHz	12 bit
2	500 Hz	12 bit
3	250 Hz	12 bit

3.3. Output Linearization

In certain applications (e.g. through shaft applications or position measurements) it is required to linearize the output characteristic. This is always the case, when the output of the sensor is not a 100% sine wave. The resulting output characteristic "value vs. angle/position" is not a linear curve as in the ideal case. But it can be linearized by applying an inverse nonlinear compensation curve.

For this purpose the compensation curve will be divided into 32 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.

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, inflection point, or regions where the input is nearly constant. This would require a high density of set points.

To do a linearization the following steps are necessary:

- Measure output characteristics over full range
- Find the inverse (Point-wise mirroring the graph on the bisectrix)
- Do a spline fit on the inverse
- Insert digital value of set point position into spline fit function for each set point (0, 1024, 2048, ..., 32768)
- Resulting values can be directly entered into the EEPROM

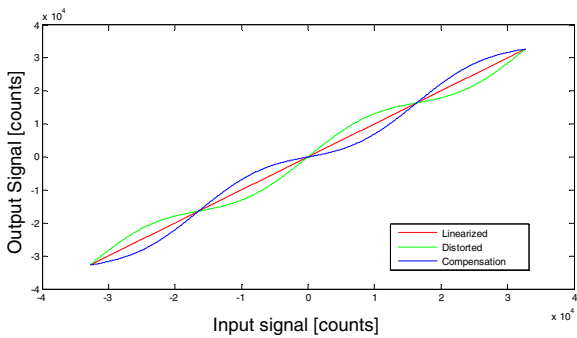


Fig. 3-5: Example for output linearization

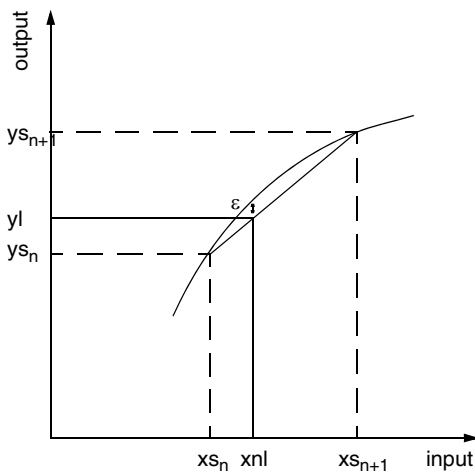


Fig. 3-6: Linearization - Detail

x_{nl} : non linear distorted input value
 y_l : linearized value
 ϵ : remaining error

3.4. NVRAM Registers

Customer Setup

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

Bit no.	Function	Description
15:12	None	Reserved
11:10	PWMFREQ	For HAL 3675 only 0: 1 kHz 1: 500 Hz 2: 250 Hz 3: 2 kHz
9:7	None	Reserved
6	Customer Burn-in Mode	0: Disabled 1: Enabled
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

3.5. On-board Diagnostic features

The HAL 36xy 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:

- EEPROM programming supervision
- EEPROM self-test at power-on
- ROM parity check
- Continuous state machine self-test
- Magnetic range detection
- Overvoltage detection

In case of HAL3625, the sensor indicates a failure by switching the output signal to the upper diagnosis level (max. Vout).

HAL 3675 indicates a failure by changing the PWM frequency. The different errors are then coded in different duty-cycles.

Table 3–2: Failure indication for HAL 387x

Failure Mode	Frequency	Duty-Cycle
EEPROM and state machine self-test	50%	95%
Adder overflow	50%	85%
Magnetic field too low	50%	62.5%
Magnetic field too high	50%	55%
Overvoltage	50%	75%
Undervoltage	50%	100%

Note: In case of an error the sensor changes the selected PWM frequency. Example:
During normal operation the PWM frequency is 1 kHz, in case of an error 500 Hz.

4. Specifications

4.1. Outline Dimensions

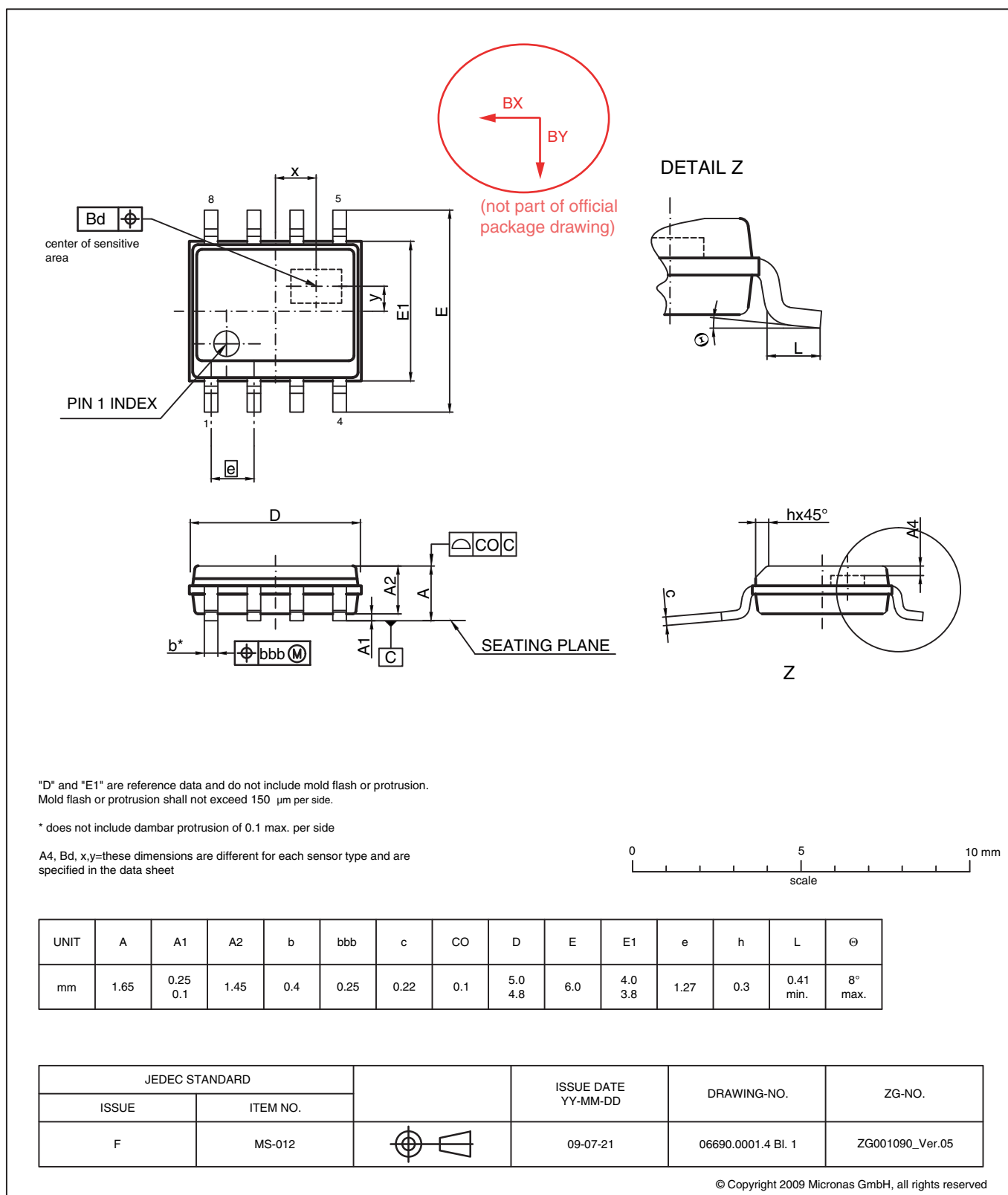


Fig. 4-1:
SOIC8-1: Plastic **S**mall **O**utline **I**C package, 8 leads, gullwing bent, 150 mil
 Ordering code: DJ
 Weight approximately 0.086 g

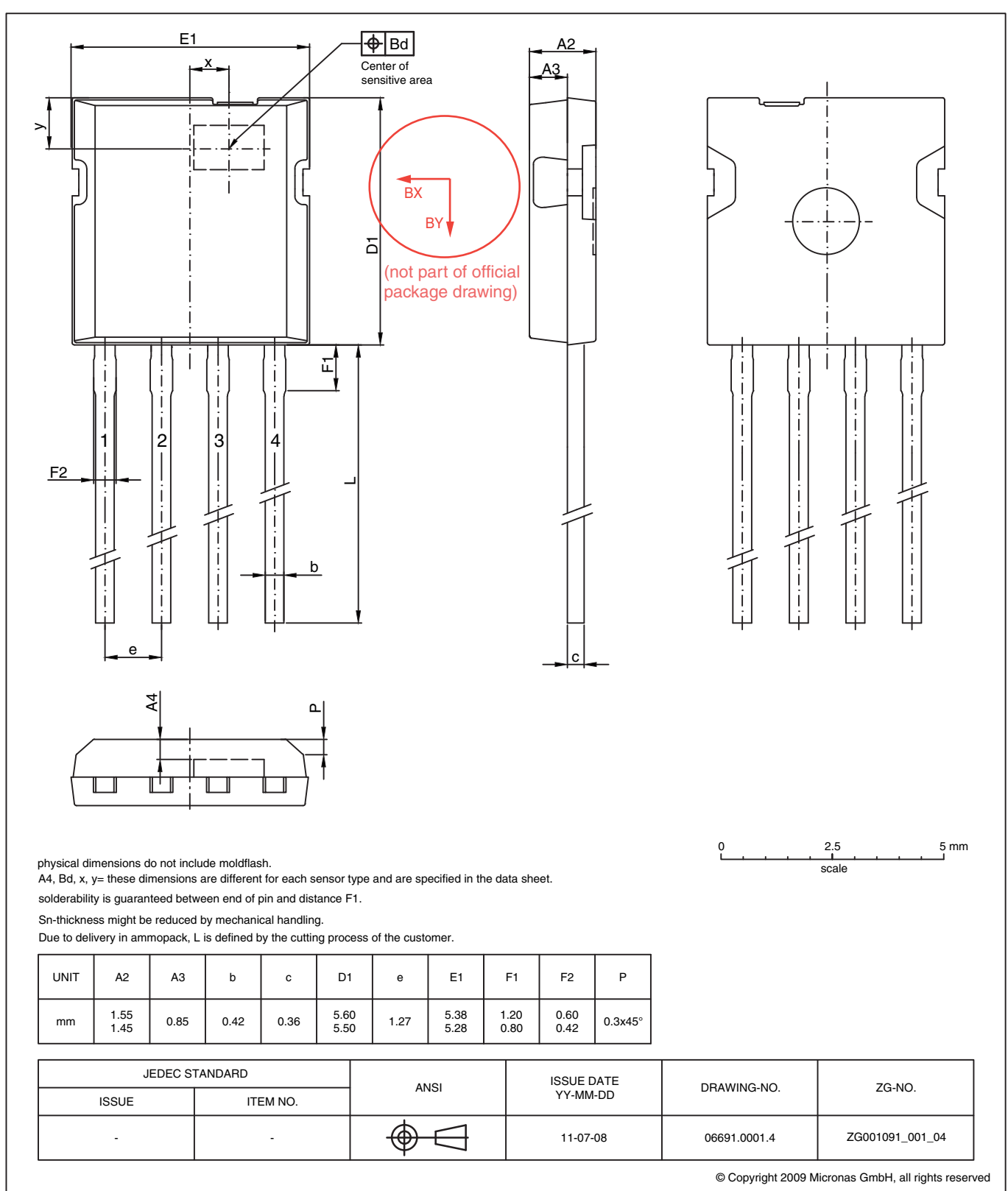
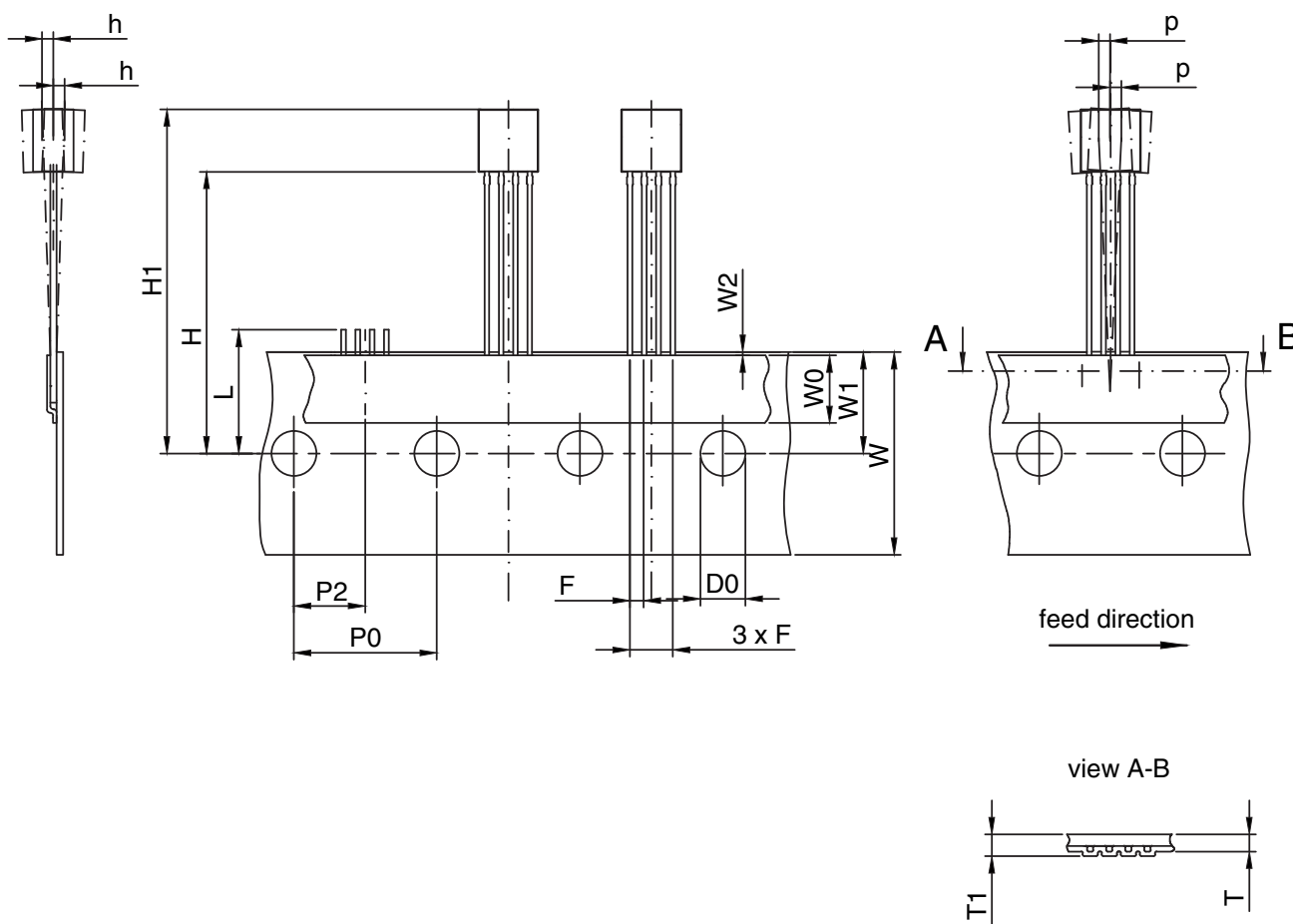


Fig. 4-2:
TO92UP-1: Plastic Transistor Standard UP package, 4 leads
 Weight approximately 0.105 g



all dimensions in mm
 other dimensions see drawing of bulk
 max. allowed tolerance over 20 hole spacings ± 1.0

UNIT	D0	F	H	H1	h	L	P0	P2	Δp	T	T1	W	W0	W1	W2
mm	4.0	1.47 1.07	26 24	30.55	± 1.0	11.0 max	13.2 12.2	7.05 5.65	± 1.0	0.5	0.9	18.0	6.0	9.0	0.3

JEDEC STANDARD		ANSI	ISSUE DATE YY-MM-DD	DRAWING-NO.	ZG-NO.
ISSUE	ITEM NO.				
-	-		10-09-29	06901.4000.1	ZG001095_001_02

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Fig. 4-3:
T092UP: Dimensions ammpack inline, not spread

4.2. Soldering, Welding and Assembly

Please check the Micronas Document "Guidelines for the Assembly of HAL Packages" for further information about solderability, welding, assembly, and second-level packaging. The document is available on the Micronas website or on the service portal.

4.3. Dimensions of Sensitive Area

250 μm x 250 μm

4.4. Package Parameters and Position of Sensitive Areas

	SOIC8-1	TO92UP-1
A4	0.38 mm nominal	0.45 mm nominal
Bd	0.3 mm	0.3 mm
x	0 mm nominal (center of package)	0 mm nominal (center of package)
y	0.13 mm nominal	1.90 mm nominal

4.5. Pin Connections and Short Description

Pin No.	Pin Name	Type	Short Description
1	VSUP	SUPPLY	Supply Voltage Pin
2	GND	GND	Ground
3	TEST	IN	Test
4	OUT	I/O	Push-Pull Output and Programming Pin
5,6,7,8	NC	NC	not connected (only available on SOIC8)

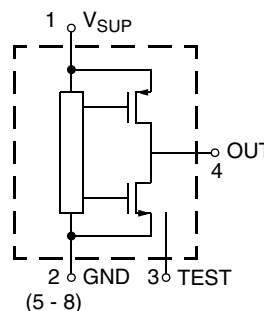


Fig. 4-1: Pin configuration

Note: Pins 3,5,6,7,8 must be connected to GND

4.6. Absolute Maximum Ratings

Stresses beyond those listed in the "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only. Functional operation of the device at these conditions is not implied. Exposure to absolute maximum rating conditions for extended periods will affect device reliability.

This device contains circuitry to protect the inputs and outputs against damage due to high static voltages or electric fields; however, it is advised that normal precautions be taken to avoid application of any voltage higher than absolute maximum-rated voltages to this high-impedance circuit.

All voltages listed are referenced to ground (GND).

Symbol	Parameter	Pin No.	Min.	Max.	Unit	Condition
V _{SUP}	Supply Voltage	VSUP	-18	18	V	t < 1 hr
V _{OUT}	Output Voltage	OUT	-6	18	V	t < 1 hr
V _{OUT} - V _{SUP}	Excess of Output Voltage over Supply Voltage	OUT, VSUP	-	2	V	
I _{OUT}	Continuous Output Current	OUT	-10	10	mA	
T _J	Junction Temperature under bias		-50	190	°C	1)
B _{max}	Magnetic Field	-	-	unlimited	T	
V _{ESD}	ESD Protection	VSUP, GND, TEST, OUT, NC	-4	4	kV	2)

1) For 96 h - Please contact Micronas for other temperature requirements
2) AEC-Q100-002 (100 pF and 1.5 kΩ)

4.6.1. Storage and Shelf Life TO92UP Package

The permissible storage time (shelf life) of the sensors is unlimited, provided the sensors are stored at a maximum of 30°C and a maximum of 85% relative humidity. At these conditions, no Dry Pack is required.

Solderability is guaranteed for two years from the date code on the package.

4.6.2. Storage and Shelf Life SOIC8 Package

SOIC8 Package is a Moisture-sensitive Surface Mount Device. The Moisture Sensitivity Level (MSL) is defined according to JEDEC J-STD-020 (Moisture/Reflow Sensitivity Classification for Nonhermetic Solid State Surface Mount Devices). The device is packed acc. to IPC/JEDEC J-STD-033: Handling, Packing, Shipping and Use of Moisture/Reflow Sensitive Surface Mount Devices. By using these procedures, safe and damage-free reflow can be achieved.

Please follow the instructions printed on each Moisture Barrier Bag. These instructions contain information about the Moisture Sensitivity Level "MSL", the maximum reflow temperature "Peak Package Body Temp." and the time frame "Time for Mounting after opening the MBB". The dry-bag shelf life capability of sealed dry-bags is minimum 12 months starting from the "Bag seal date" printed on each bag.

If moisture-sensitive components have been exposed to ambient air for longer than the specified time according to their MSL, or the humidity indicator card indicates too much moisture after opening a Moisture Barrier Bag (MBB), the components have to be baked prior to the assembly process. Please refer to IPC/JEDEC J-STD-033 for details. Please be aware that packing materials may not withstand higher baking temperatures.

4.7. Recommended Operating Conditions

Functional operation of the device beyond those indicated in the “Recommended Operating Conditions/Characteristics” is not implied and may result in unpredictable behavior, reduce reliability and lifetime of the device.

All voltages listed are referenced to ground (GND).

Symbol	Parameter	Pin No.	Min.	Typ.	Max.	Unit	Remarks
V _{SUP}	Supply Voltage	VSUP	4.5 5.7	5 6	5.5 6.5	V	Normal operation During Programming
I _{OUT}	Continuous Output Current	OUT	-1.2	-	1.2	mA	
R _L	Load Resistor	OUT	5 20	10 -	- -	kΩ	HAL3625 pull-down resistor pull-up resistor
			1	-	-	kΩ	HAL3675 pull-up resistor
C _L	Load Capacitance	OUT	0.33	47	600	nF	HAL3625
			-	1.0	10	nF	HAL3675
N _{PRG}	Number of Memory Programming Cycles ¹⁾	-	-	-	100	cycles	0 °C < T _{amb} < 55 °C
B _{AMP}	Recommended Amplitude of Magnetic Field	-	±30	-	±100	mT	
¹⁾ In the EEPROM, it is not allowed to program only one single address within a 'bank' in the memory. In case of programming one single address the complete bank has to be programmed.							
T _J	Junction Temperature ²⁾	-	-40 -40 -40	- - -	125 150 170	°C	for 8000 h for 2000 h for 1000 h Time values are not additive
¹⁾ In the EEPROM, it is not allowed to program only one single address within a 'bank' in the memory. In case of programming one single address the complete bank has to be programmed. ²⁾ Depends on the temperature profile of the application. Please contact Micronas for life time calculations.							

Note: It is also possible to operate the sensor with magnetic fields down to ±5 mT. Magnetic fields below ±30 mT will lead to an additional angle error.

4.8. Characteristics

at $T_J = -40\text{ }^\circ\text{C}$ to $+170\text{ }^\circ\text{C}$, $V_{SUP} = 4.5\text{ V}$ to 5.5 V , $GND = 0\text{ V}$, after programming and locking of the sensor, at Recommended Operation Conditions if not otherwise specified in the column “Conditions”.

Typical Characteristics for $T_J = 25\text{ }^\circ\text{C}$ and $V_{SUP} = 5\text{ V}$.

Symbol	Parameter	Pin No.	Limit Values			Unit	Test Conditions
			Min.	Typ.	Max.		
I_{SUP}	Supply Current over Temperature Range	VSUP	–	10	15	mA	for HAL 3625 (analog output) and for HAL 3675 (PWM output)
	Resolution ¹⁾	OUT	–	12	–	bit bit	for HAL3625 ratiometric to VSUP for HAL3675 (depends on PWM Period)
$t_{r(O)}$	Response Time of Output ²⁾	OUT	–	0.5	0.6	ms	$C_L = 10\text{ nF}$, time from ideal step to 90% of final output For HAL3675 the response time is defined by the selected PWM period
t_{AVs}	Wake-up time ²⁾	OUT	–	–	1.7	ms	$C_L = 10\text{ nF}$ (see Fig. 4–3 on page 24)
HAL3625 (Analog Output)							
DNL	Differential Non-Linearity of D/A converter	OUT	–3	0	3	LSB	
E_R	Ratiometric Error of Output over temperature (Error in V_{OUT}/V_{SUP})	OUT	–0.2	0	0.2	%	Max of [$V_{OUT5} - V_{OUT4.5}$ and $V_{OUT5.5} - V_{OUT5}$] at $V_{OUT} = 10\%$ and $90\% V_{SUP}$
INL	Non-Linearity of D/A converter	OUT	–0.1	0	0.1	%	% of supply voltage
ΔV_{OFFSET}	D/A converter offset drift over temperature range related to $25\text{ }^\circ\text{C}$ ²⁾	OUT	–0.2	0	0.2	$\%V_{SUP}$	
V_{OUTH}	Output High Voltage ³⁾	OUT	93	–	–	$\%V_{SUP}$	R_L Pull-up = $20\text{ k}\Omega$ R_L Pull-down = $5\text{ k}\Omega$
V_{OUTL}	Output Low Voltage ³⁾	OUT	–	–	7	$\%V_{SUP}$	R_L Pull-up = $20\text{ k}\Omega$ R_L Pull-down = $5\text{ k}\Omega$
ΔV_{OUTCL}	Accuracy of Output Voltage at Clamping Low Voltage over Temperature Range ²⁾	OUT	–30	0	30	mV	R_L Pull-up = $20\text{ k}\Omega$ R_L Pull-down = $5\text{ k}\Omega$ $V_{SUP} = 5\text{ V}$
ΔV_{OUTCH}	Accuracy of Output Voltage at Clamping High Voltage over Temperature Range ²⁾	OUT	–30	0	30	mV	R_L Pull-up = $20\text{ k}\Omega$ R_L Pull-down = $5\text{ k}\Omega$ $V_{SUP} = 5\text{ V}$
OUT_{Noise}	Output Noise RMS ²⁾	OUT	–	4.5 1.5	12 4.0	mV mV	Min. magnetic amplitude = $\pm 30\text{ mT}$ Min. magnetic amplitude = $\pm 100\text{ mT}$ with external capacitor on the output $f_C = 22\text{ kHz}$
R_{OUT}	Output Resistance over Recommended Operating Range	OUT	–	1	10	Ω	$V_{OUTLmax} \leq V_{OUT} \leq V_{OUTHmin}$
¹⁾ Guaranteed by Design ²⁾ Characterized on small sample size, not tested. ³⁾ Signal band area with full accuracy is located between V_{OUTL} and V_{OUTH} . The sensors accuracy is reduced below V_{OUTL} and above V_{OUTH}							

Symbol	Parameter	Pin No.	Limit Values			Unit	Test Conditions
			Min.	Typ.	Max.		
HAL 3675 (PWM Output)							
V _{OUTH}	Output High Voltage	OUT	–	4.9	–	V	VSUP = 5 V, –1 mA < I _{OUT} < 1 mA
V _{OUTL}	Output Low Voltage	OUT	–	0.1	–	V	VSUP = 5 V, –1 mA < I _{OUT} < 1 mA
OUT _{Noise}	Output Noise RMS ²⁾	OUT	–	0.12	0.24	%	Min. magnetic amplitude = ±30 mT Min. magnetic amplitude = ±100 mT with external capacitor on the output Related to 100 % DC
			–	0.02	0.08	%	
f _{PWM}	PWM Frequency	OUT	1.7 0.85 0.425 0.213	2 1 0.5 0.25	2.3 1.15 0.575 0.288	kHz	Customer programmable
J _{PWM}	RMS PWM Jitter ²⁾	OUT	–	1	2	LSB ₁₂	f _{PWM} = 1 kHz
t _{rise}	Rise Time of Digital Output	OUT	–	0.4	–	µs	R _L Pull-up = 1 kΩ, C _L = 10 nF
t _{fall}	Fall Time of Digital Output	OUT	–	0.5	–	µs	R _L Pull-up = 1 kΩ, C _L = 10 nF
ROUT_DIG	On Resistance of Digital Pull-Up Driver	OUT	–	100	200	Ω	Includes 25 Ω series pull-up resistor and 50 Ω pull-down
SOIC8 Package							
R _{thja}	Thermal Resistance Junction to Air	–	–	–	142	K/W	Measured with a 1s0p board
		–	–	–	88	K/W	Measured with a 1s1p board
R _{thjc}	Junction to Case	–	–	–	33	K/W	Measured with a 1s0p board
		–	–	–	22	K/W	Measured with a 1s1p board
TO92UP Package							
R _{thja}	Thermal Resistance Junction to Air	–	–	–	198	K/W	Measured with a 1s0p board
		–	–	–	146	K/W	Measured with a 1s1p board
R _{thjc}	Junction to Case	–	–	–	53	K/W	Measured with a 1s0p board
		–	–	–	38	K/W	Measured with a 1s1p board
²⁾ Characterized on small sample size, not tested.							

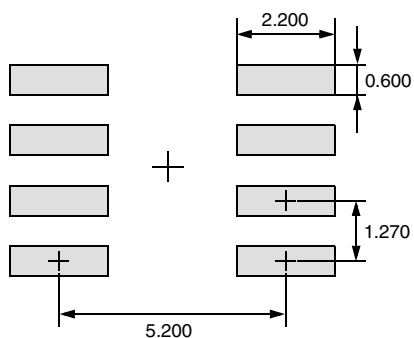


Fig. 4-2: Recommended pad size SOIC8 package (in mm)

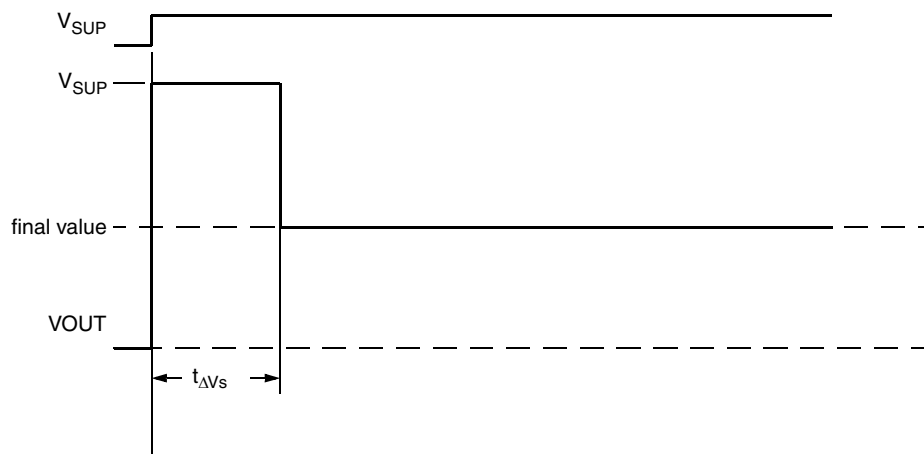


Fig. 4-3: Description of power-on behavior of the sensor

4.9. Magnetic Characteristics

at $T_J = -40\text{ °C}$ to $+170\text{ °C}$, $V_{SUP} = 4.5\text{ V}$ to 5.5 V , $GND = 0\text{ V}$, after programming and locking of the sensor, at Recommended Operation Conditions if not otherwise specified in the column "Conditions".

Typical Characteristics for $T_J = 25\text{ °C}$ and $V_{SUP} = 5\text{ V}$.

Symbol	Parameter	Pin No.	Min.	Typ.	Max.	Unit	Test Conditions
Φ_{RANGE}	Detectable Angle Range ¹⁾	OUT	0	–	360	°	
Φ_{res}	Angle Resolution ¹⁾	OUT	–	–	0.09	°	
$E_{\Phi_{lin}}$	Micro Linearity Error ¹⁾	OUT	–0.2	–	0.2	°/1°	for 120° angle range
			–0.5	–	0.5	°/1°	for 360° angle range
$Sense_{XY}$	Sensitivity of X and Y Hall Plate ²⁾	OUT	138	150	162	LSB/mT	$T_J = 25\text{ °C}$
$\Delta Senses_{XY}$	Sensitivity Drift Factor of Hall Plates over Temperature ²⁾	–	1.25 0.92 0.4	1.4 1.0 0.5	1.5 1.08 0.6		$T_J = -40\text{ °C}$ $T_J = 25\text{ °C}$ $T_J = 170\text{ °C}$
SMm_{XY}	Thermal Sensitivity Mismatch Drift on Raw Signals between X and Y Channel ¹⁾	OUT	–4.0	–	4.0	%	over full temperature range related to 25°C
$Offset_{XY}$	Offset on Raw Signals of X or Y Channel ¹⁾	OUT	–50	0	50	LSB ₁₅	$T_J = 25\text{ °C}$, Can be compensated in customer application (see Section 3.2. on page 8)
$\Delta Offset_{XY}$	Offset Drift on Raw Signals of X or Y Channel ¹⁾	OUT	–100	–	100	LSB ₁₅	over full temperature range related to 25°C
$E_{\Phi_{lin}}$	Resulting Angle Linearity Error (on output of cordic filter) ^{2) 3) 4)}	OUT	–1.3	–	1.3	°	Min. magnetic amplitude = $\pm 30\text{ mT}$ $T_J = 25\text{ °C}$
$\Delta E_{\Phi_{lin}}$	Resulting Angle Linearity Error drift over temperature (on output of cordic filter) ^{2) 3) 4)}	OUT	–1.3	–	1.3	°	Min. magnetic amplitude = $\pm 30\text{ mT}$ Related to $T_J = 25\text{ °C}$
$E_{\Phi_{temp}}$	Temperature Drift Error ⁵⁾	OUT	–0.9 –0.3	–	0.9 0.3	°	for 360° for 120° The error is given due to the temperature drift of the analog output and is linear scaling with the angular range. For HAL 3625 only.
$E_{\Phi_{hys}}$	Hysteresis Error ¹⁾	OUT	–	0	0.03	°	
SMm_{XYLife}	Relative Sensitivity Mismatch Drift on Raw Signals between X and Y Channel over Life Time ⁵⁾	OUT	–	1.0	–	%	after 1000 h HTOL
$\Delta Offset_{XYLife}$	Offset Drift on Raw Signals of X or Y Channel over Lifetime ⁵⁾	OUT	–	30	–	LSB ₁₅	after 1000 h HTOL

¹⁾ Guaranteed by Design

²⁾ Characterized on small sample size, not tested. Specification limit is ± 3 Sigma value

³⁾ In homogeneous magnetic field

⁴⁾ Calculated angular error based on characterization and not on single error summation

⁵⁾ Characterized on small sample size, not tested.

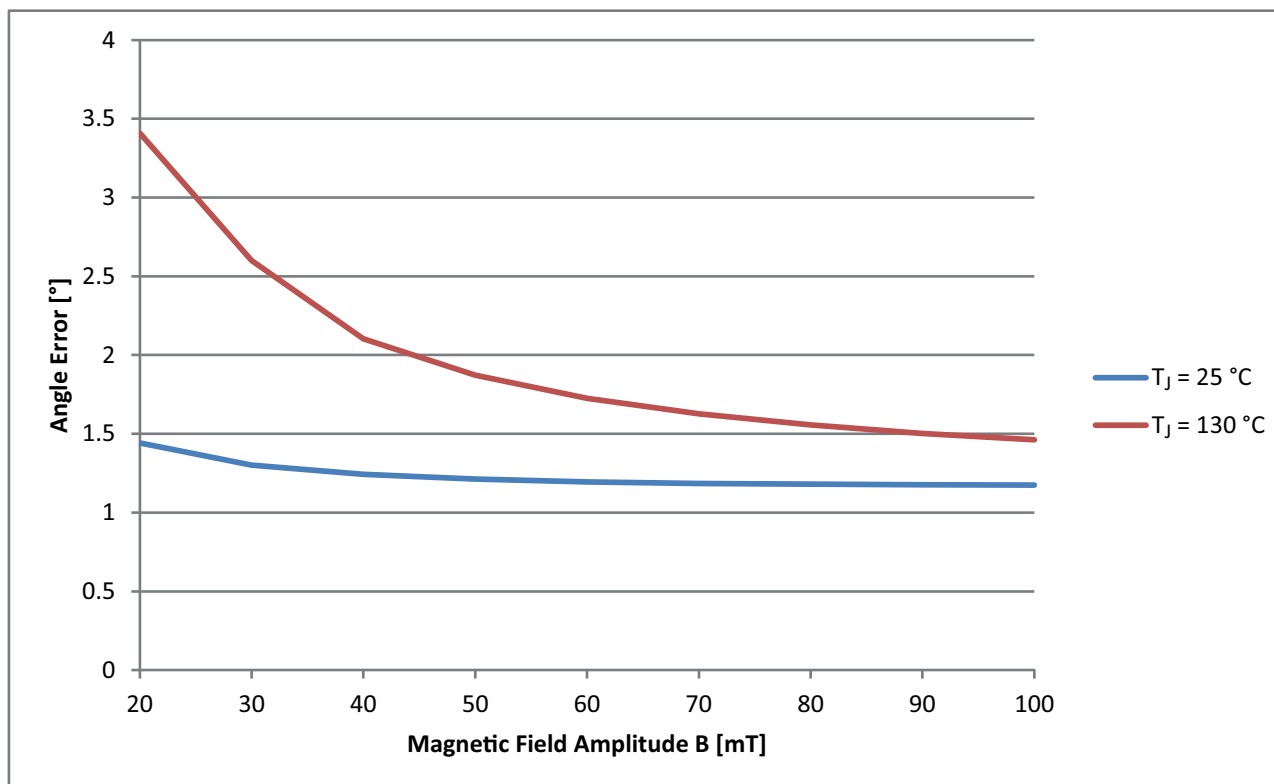


Fig. 4-4: Angular error vs. magnetic field amplitude (3 sigma values)

Note: T_J = 130°C is worst case condition and the temperature with the highest angular error.

4.10. Open-Circuit Detection (only applicable for HAL3625)

at T_J = -40 °C to +170 °C, Typical Characteristics for T_J = 25 °C, after locking the sensor

Symbol	Parameter	Pin No.	Min.	Typ.	Max.	Unit	Comment
V _{OUT}	Output voltage at open V _{SUP} line	OUT	0	0	0.15	V	V _{SUP} = 5 V R _L = 20 kΩ to 200 kΩ
V _{OUT}	Output voltage at open GND line	OUT	4.85	4.9	5.0	V	V _{SUP} = 5 V R _L = 10 kΩ to 200 kΩ
			4.8	4.9	5.0	V	V _{SUP} = 5 V 5 kΩ >= R _L < 10 kΩ

R_L: Can be pull-up or pull-down resistor

4.11. Overvoltage and Undervoltage Detection

at T_J = -40 °C to +170 °C, Typical Characteristics for T_J = 25 °C, after programming and locking

Symbol	Parameter	Pin No.	Min.	Typ.	Max.	Unit
V _{SUP,UV}	Undervoltage Detection Level	VSUP	3.3	3.7	4.4	V
V _{SUP,UVhyst}	Undervoltage Detection Level Hysteresis	VSUP	-	200	-	mV
V _{SUP,OV}	Overvoltage Detection Level	VSUP	5.6	6.2	6.9	V
V _{SUP,OVhyst}	Overvoltage Detection Level Hysteresis	VSUP	-	225	-	mV

5. Application Notes

5.1. Ambient Temperature

Due to the internal power dissipation, the temperature on the silicon chip (junction temperature T_J) is higher than the temperature outside the package (ambient temperature T_A).

$$T_J = T_A + \Delta T$$

At static conditions and continuous operation, the following equation applies:

$$\Delta T = I_{SUP} * V_{SUP} * R_{thjX}$$

The X represents junction to air, case or solder point.

For worst case calculation, use the max. parameters for I_{SUP} and R_{thjX} , and the max. value for V_{SUP} from the application.

The following example for SOIC8 package shows the result for junction to air conditions.

$V_{SUP} = 5.5 \text{ V}$, $R_{thja} = 142 \text{ K/W}$ and $I_{SUP} = 15 \text{ mA}$ the temperature difference $\Delta T = 11.72 \text{ K}$.

The junction temperature T_J is specified. The maximum ambient temperature T_{Amax} can be calculated as:

$$T_{Amax} = T_{Jmax} - \Delta T$$

5.2. EMC and ESD

The HAL36xy is designed for a stabilized 5 V supply. Interferences and disturbances conducted along the 12 V onboard system (product standard ISO 7637 part 1) are not relevant for these applications.

For applications with disturbances by capacitive or inductive coupling on the supply line or radiated disturbances, the application circuits shown in Fig. 5–1 and Fig. 5–2 are recommended. Applications with these arrangements passed the EMC tests according to the product standards ISO 7637 part 3 (Electrical transient transmission by capacitive or inductive coupling) and part 4 (Radiated disturbances).

5.3. Application Circuit for HAL3625

For EMC protection, it is recommended to connect one ceramic 47 nF capacitor each between ground and the supply voltage, respectively the output voltage pin.

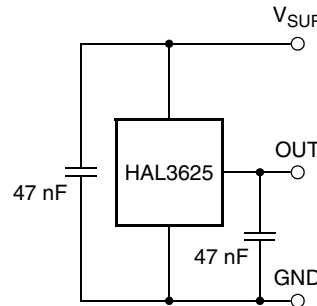


Fig. 5–1: Recommended application circuit for HAL3625

5.4. Application Circuit for HAL3675

For EMC protection, it is recommended to connect one ceramic 47 nF capacitor between ground and the supply voltage and one ceramic 1 nF capacitor between the output pin and ground.

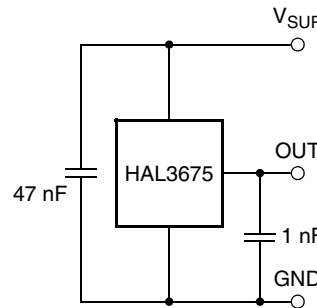


Fig. 5–2: Recommended application circuit for HAL3675

5.5. Measurement of a PWM Output Signal of HAL3675

In case of the PWM output, the magnetic field information is coded in the duty cycle of the PWM signal. The duty cycle is defined as the ratio between the high time “s” and the period “d” of the PWM signal (see Fig. 5–3).

Note: The PWM signal is updated with the rising edge. Hence, for signal evaluation, the trigger-level must be the rising edge of the PWM signal.

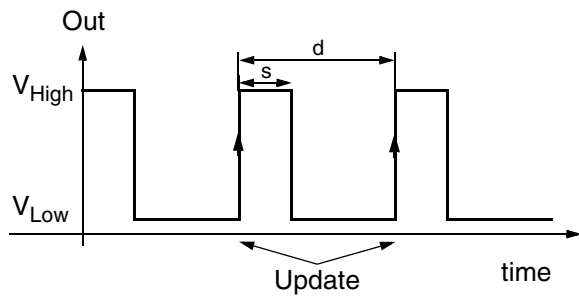


Fig. 5–3: Definition of PWM signal

6. Programming of the Sensor

HAL 36xy features two different customer modes. In **Application Mode** the sensor provides a ratiometric analog output voltage. In **Programming Mode** it is possible to change the register settings of the sensor.

After power-up the sensor is always operating in the **Application Mode**. It is switched to the **Programming Mode** by a pulse on the sensor output pin.

6.1. Programming Interface

In Programming Mode the sensor is addressed by modulating a serial telegram on the sensors output pin. The sensor answers with a modulation of the output voltage.

A logical “0” is coded as no level change within the bit time. A logical “1” is coded as a level change of typically 50% of the bit time. After each bit, a level change occurs (see Fig. 6–1).

The serial telegram is used to transmit the EEPROM content, error codes and digital values of the angle information from and to the sensor.

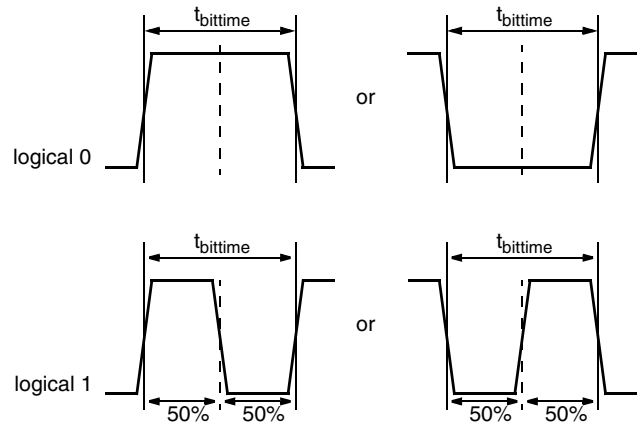


Fig. 6–1: Definition of logical 0 and 1 bit

A description of the communication protocol and the programming of the sensor is available in a separate document (HAL 3625 and HAL 3675 Programming Guide).

Table 6–1: Telegram parameters (All voltages are referenced to GND.)

Symbol	Parameter	Pin No.	Limit Values			Unit	Test Conditions
			Min.	Typ.	Max.		
V _{OUTL}	Voltage for Output Low Level during Programming through Sensor Output Pin	OUT	0	–	0.2*V _{SUP}	V	for V _{SUP} = 5 V
			0		1	V	
V _{OUTH}	Voltage for Output High Level during Programming through Sensor Output Pin	OUT	0.8*V _{SUP}	–	V _{SUP}	V	for V _{SUP} = 5 V
			4	–	5.0	V	
V _{SUPProgram}	V _{SUP} Voltage for EEPROM & NVRAM programming (during Programming)	VSUP	5.7	6.0	6.5	V	Supply voltage for bidirectional communication via output pin as well as for 3-wire communication via supply voltage modulation
t _{bittime}	Biphase Bit Time	OUT	900	1000	1100	µs	T _J = 25°C
	Slew rate	OUT	–	2	–	V/µs	

6.2. Programming Environment and Tools

For the programming of HAL 36xy during product development and also for production purposes a programming tool including hardware and software is available on request. It is recommended to use the Micronas tool kit (HAL-APB V1.x & Lab View Programming Environment) in order to ease the product development. The details of programming sequences are also available on request.

Note: For production HAL-APB V1.5 or higher must be used.

6.3. Programming Information

For production and qualification tests, it is mandatory to set the LOCK bit to one and the POUT bit to zero after final adjustment and programming of HAL 36xy.

The success of the LOCK process should be checked by reading the status of the LOCK bit after locking and/or by an analog check of the sensors output signal.

In order to ensure correct detection of programming errors, the following detailed guidance has to be followed:

- EEPROM: It is mandatory to check the acknowledge (first and second) of the sensor after each write and store sequence to verify that the programming of the EEPROM was successful. To ease debugging of the production line it is recommended to read/check the status of the PROG_DIAGNOSIS register in case of a missing second acknowledge.
- NVRAM: It is mandatory to read/check the status of the PROG_DIAGNOSIS register after programming to verify that the programming of the NVRAM was successful.

In case of programming errors it is possible to reprogram the EEPROM or NVRAM registers as long as the max. number of programming cycles is not exceeded.

Generally, it is recommended to read back all register values to ensure that the intended data is correctly stored in the sensors's memory before locking the sensor. Alternatively, it is also possible to cross-check the sensor output signal with the intended output behavior.

In case of HAL 3675 DAC register values have a direct impact on the programming sequence of the device due to the architecture of the sensor's programming logic. DAC values below 5% and above 25% full-scale potentially increase linearly the number of programming error messages (PUMP error) or respectively missing second acknowledges.

It is recommended to ensure DAC register values between 5% and 25% of Full-Scale. Please contact Micronas in case that DAC register values beyond these limits cannot be avoided during programming of the device.

Electrostatic Discharges (ESD) may disturb the programming pulses. Please take precautions against ESD.

Note: Please check also the "HAL36xy Programming Guide". It contains additional information and instructions about the programming of the devices.

7. Data Sheet History

1. Preliminary Data Sheet: "HAL 3625, HAL3675 Programmable Direct Angle Sensors", July 3, 2012, DSH000208_001EN. First release of the preliminary data sheet.
2. Preliminary Data Sheet: "HAL 3625, HAL3675 Programmable Direct Angle Sensors", March 21, 2013, PD000208_002EN. Second release of the preliminary data sheet.
Major Changes:
 - new package added TO92UP
 - K temperature range removed
 - smaller pull-up resistor specified for HAL3675
3. Data Sheet: "HAL 3625, HAL 3675 Programmable Direct Angle Sensors", Jan. 28, 2015, DSH000166_001EN. First release of the data sheet.
Major Changes:
 - Additional guidance for programming of the sensors
 - Tighter noise specification
 - Update of application circuit for HAL3675
 - Update of package drawings
 - Customer Setup register description updated
 - Characteristics: Output Noise RMS specified