MICRONAS

Hardware
Documentation

Data Sheet

HAL® 2421

High-Precision Programmable Linear Hall-Effect Sensor

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High-Precision Programmable Linear Hall-Effect Sensor

Release Note: Revision bars indicate significant changes to previous version

1. Introduction

HAL 2421 is a programmable linear Hall-effect sensor. The device is a universal magnetic-field sensor 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 sensor has a ratiometric output characteristic, which means that the output voltage is proportional to the magnetic flux and the supply voltage. It also offers wire-break detection.

The HAL 2421 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-effect Integrated Circuit (IC) can be fit to all common magnetic materials by programming first and second order temperature coefficients of the Hall-effect sensor's 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 kits from TDK-Micronas.

The sensor is designed for industrial and automotive applications and operates with typically 5 V supply voltage in the junction temperature range from –40 °C up to 140 °C. The HAL 2421 is available in TO92UT package.

1.1. Features

– High-precision linear Hall-effect sensor with 12-bit analog output
– 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 up to ±200 mT
– Very low output voltage-drift over temperature
– Active open-circuit (ground and supply line break detection) with 5 kΩ pull-up and pull-down resistor
– Over- 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
– Interpolator - linear interpolation between two successive 8 kHz samples in 32 steps
– Low-pass filter with programmable cut-off frequency
– Active detection of output-short between two sensors
– High immunity against mechanical stress, ESD, EMC
– Operates from T_J = –40 °C up to 140 °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 sensor's versatile programming characteristics and low temperature drifts, the HAL 2421 is the optimal system solution for applications such as:

– Magnetic-field and current measurements,
– Angle sensors (like throttle position, pedal position, and EGR applications),
– Distance and linear movement measurements.

2. Ordering Information

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

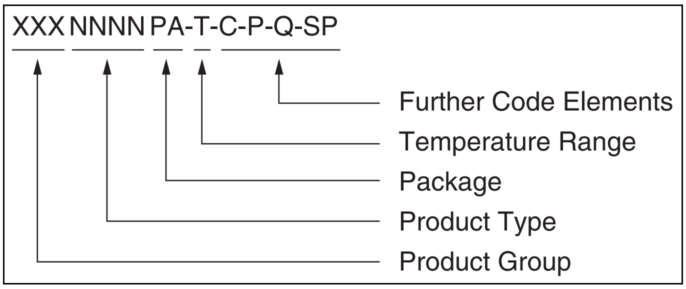


Fig. 2–1: Ordering Code Principle

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

2.1. Device-Specific Ordering Codes

HAL 2421 is available in the following package and temperature variants.

Table 2–1: Available package

Package Code (PA)	Package Type
UT	TO92UT-2

Table 2–2: Available temperature range

Temperature Code (T)	Temperature Range
K	T_J = –40 °C to +140 °C

The relationship between ambient temperature (T_A) and junction temperature (T_J) is explained in Section 5.3. on page 31.

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

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

Available Ordering Code	Package Marking
HAL2421UT-K-[C-P-Q-SP]	2421K

3. Functional Description

3.1. General Function

The HAL 2421 is a monolithic Integrated Circuit (IC) 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-effect 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 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 VSUP 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 sensor. The non-volatile memory consists of redundant EEPROM cells. In addition, this sensor is protected from reverse and overvoltage at all pins.

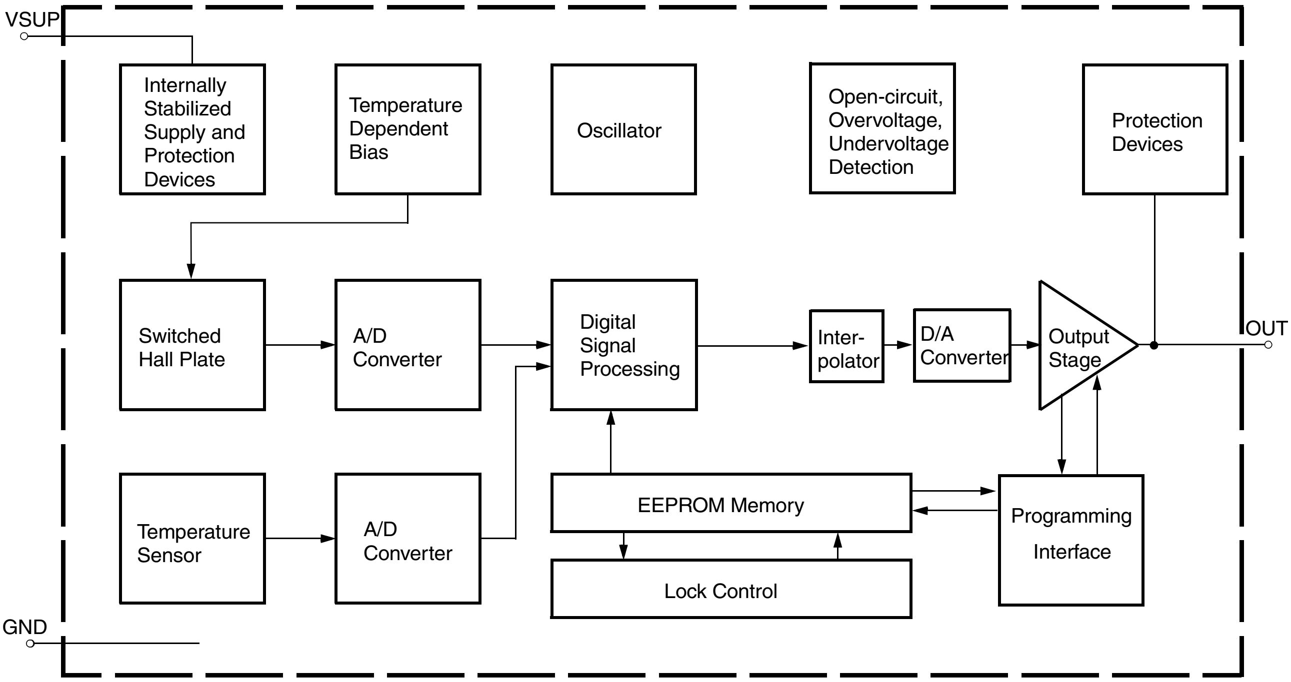


Fig. 3–1: HAL 2421 block diagram

3.2. Signal Path and Register Definition

3.2.1. Signal Path

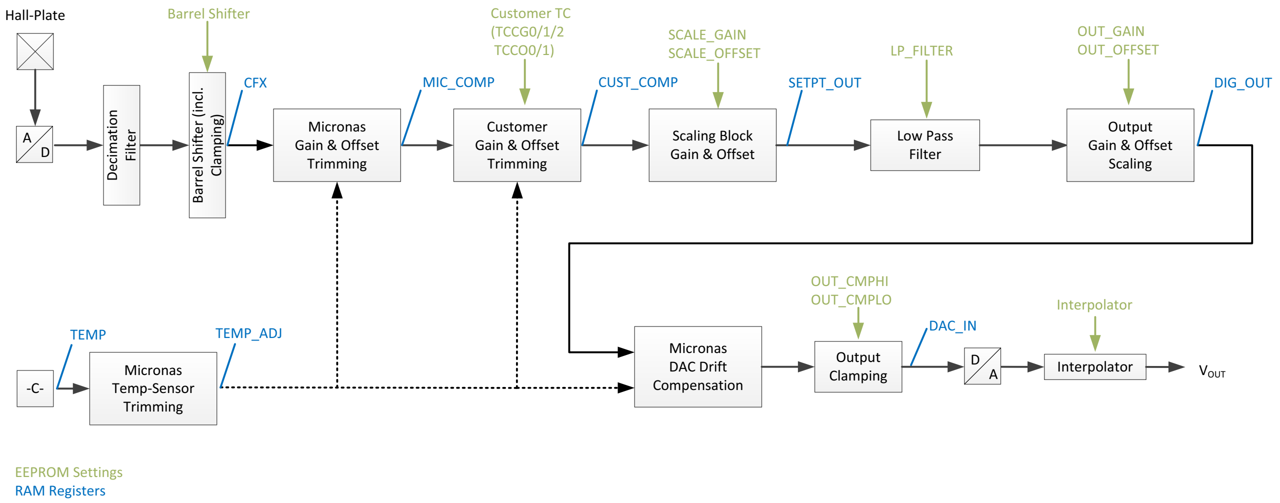


Fig. 3–2: Signal path of HAL 2421

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.

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 bits 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 4.14. on page 28 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 bits and it is two's-complemented coded. Therefore 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 bits 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 2421 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 bits and it is two's-complemented coded. Therefore the register value can vary between –32768 ... 32767.

SETPT_OUT

The SETPT_OUT register offers the possibility to read the magnetic-field information after scaling for the Low Pass Filter block.

This register has a length of 16 bits but the register value is clamped to 0 and 30720.

DIG_OUT

The DIG_OUT register offers the possibility to read the magnetic-field information after the output gain and offset scaling.

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

DAC_IN

The DAC_IN 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 bits and it is two's-complemented coded. Therefor the register value can vary between 0 ... 32767.

MIC_ID1 and MIC_ID2

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

DIAGNOSIS

The DIAGNOSIS register enables the customer to identify certain failures detected by the sensor. HAL 2421 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 machine 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 17.

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/HAR 24xy.

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 too low.
9	Voltage Error during Program/Erase	This bit is set to 1 in case that the internal supply voltage was too 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 HAL/HAR 24xy Programming Guide.

3.2.2.2. EEPROM Register

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 bits each.

Barrel Shifter (Magnetic ranges)

The signal path of HAL 2421 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 bits. The barrel shifter selects 16 bits out of the available 22 bits.

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 length of 16 bits and they are two's-complemented coded. Therefor the register values can vary between –32768 ... 32767.

For calculation of the parameters TCCG and TCCO please refer to the HAL/HAR 24xy User Manual.

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 length of 16 bits and they are two's-complemented coded. Therefor the register values can vary between –32768 ... 32767.

Sensitivity and Offset Scaling before low pass filtering SCALE_GAIN/ SCALE_OFFSET

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

Analog output signal scaling with OUT_GAIN/OUT_OFFSET

The required output voltage range of the analog output is defined by the registers OUT_GAIN (Gain of the output) and OUT_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 length of 16 bits and are two's-complemented coded.

Clamping Levels

The clamping levels OUT_CMPHI and OUT_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 length of 16 bits and are two's-complemented coded. Both clamping levels can have values between 0% and 100% of V_{SUP}.

LP_FILTER

With the LP_FILTER register it is possible to select different –3 dB frequencies for HAL 2421. The low-pass filter is a first-order digital filter and the register is 16-bit organized. Various typical filter frequencies between 4 kHz (no filter) and 100 Hz are available.

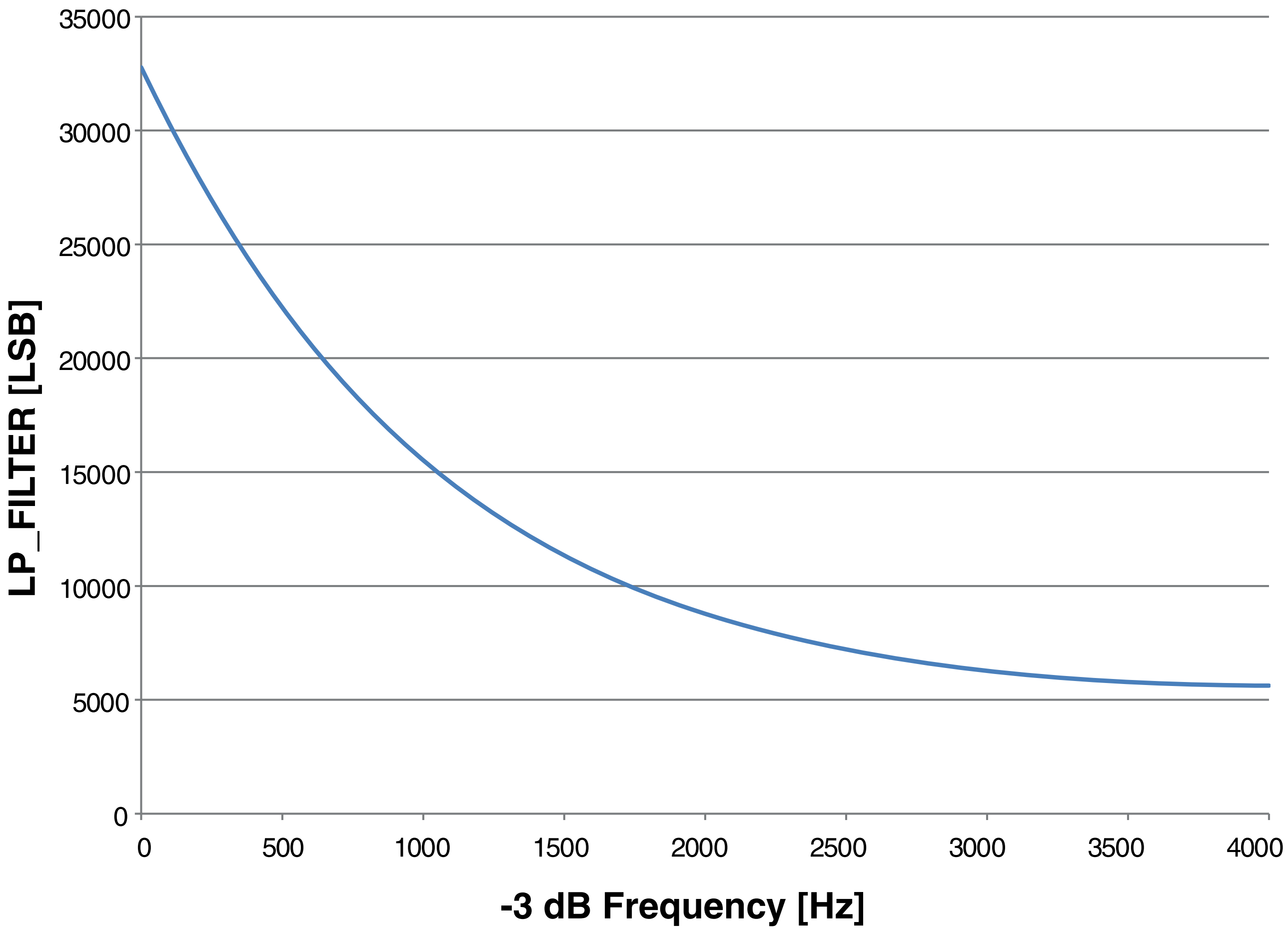


Fig. 3–3: –3db frequency vs. register values

Interpolator

The interpolator provides a linear interpolation between two successive 8 kHz samples, resulting in an increased up-sample rate (32 x 8 kHz) at the DAC side.

The benefit of this block is to reduce amplitude steps by a factor of 32, resulting in a smoothed output and reduced out-of-band noise (>8 kHz).

Please note, that the interpolator does not change the overall signal bandwidth. This is defined by the 8 kHz sampling rate of the ADC.

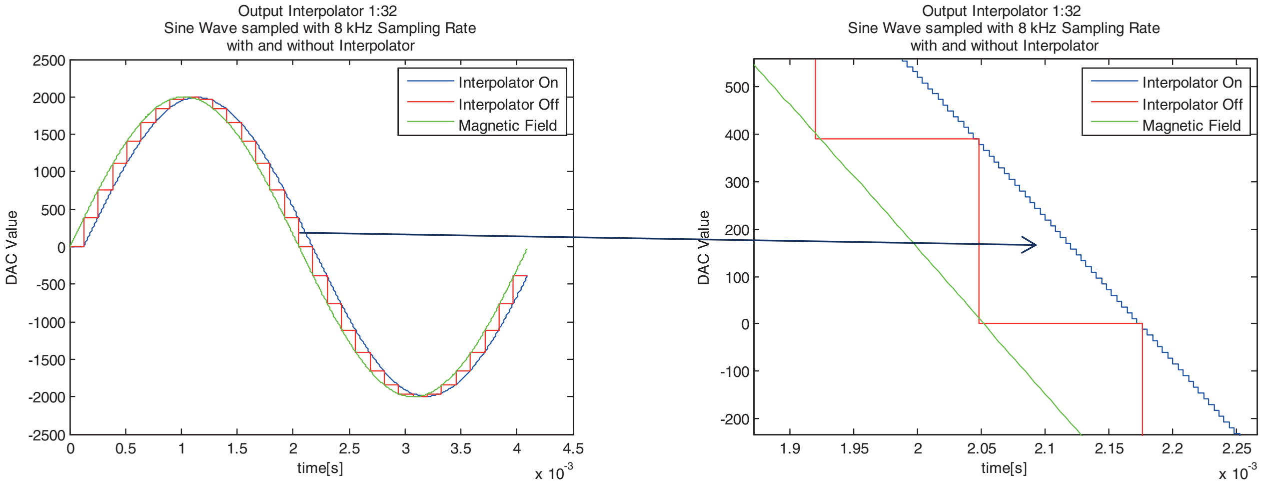


Fig. 3–4: Interpolation of a sine wave output signal

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	Interpolator	Output interpolator 0: Disabled 1: Enabled
14:12	Barrel Shifter	Magnetic range (see Table 3–1 on page 12)
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: High & low side over current detection → OUT = Tristate in error case
7	Error Band	Error band selection for locked devices (Customer Lock bit set). 0: High error band (V_{SUP}) 1: Low error band (GND) The sensor will always go to high error band as long as it is not locked (Customer Lock bit not set) (see Section 4.12. on page 27).
6	Burn-In Mode	0: Disabled 1: Enabled
5	Functionality Mode	1: Normal 0: Extended (see Section 4.13. on page 27)
4	Communication Mode	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 power-on reset (POR)
1	Diagnosis	0: Diagnosis errors force output to error band 1: Diagnosis errors do not force output to error band
0	Lock	Bit must be set to 1 to lock the sensor memory.

3.3. On-Board Diagnostic Features

The HAL 2421 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.

Always Active Diagnostic Features

The following diagnostic features are always active:

– Wire break detection for supply and ground line

– Under voltage detection

– Thermal supervision of output stage

The sensor switches the output to tristate if an over-temperature is detected by the thermal supervision. Additionally the sensor features a wire-break detection circuit. Please see Section 4.12. for further details on the output state in case of a wire break.

Activatable Diagnostic Features

The following diagnostic features can be activated by customer:

– Overvoltage detection

– EEPROM self-test at power-on

– Continuous ROM parity check

– Continuous state machine self-test

– Adder overflow (equivalent to an A/D converter overflow)

– Output-short detection

The sensor indicates a fault immediately by switching the output signal to the selected error band in case that the diagnostic mode is activated by the customer. The customer can select if the output goes to the upper or lower error band by setting bit 7 in the CUST_SETUP register (Table 3–2 on page 16). Further details can be found in Section 3.3. on page 17.

An overcurrent event at the output drives the output to VSUP, GND, or tristate depending on the setting of output-short detection (CUST_SETUP [9:8]).

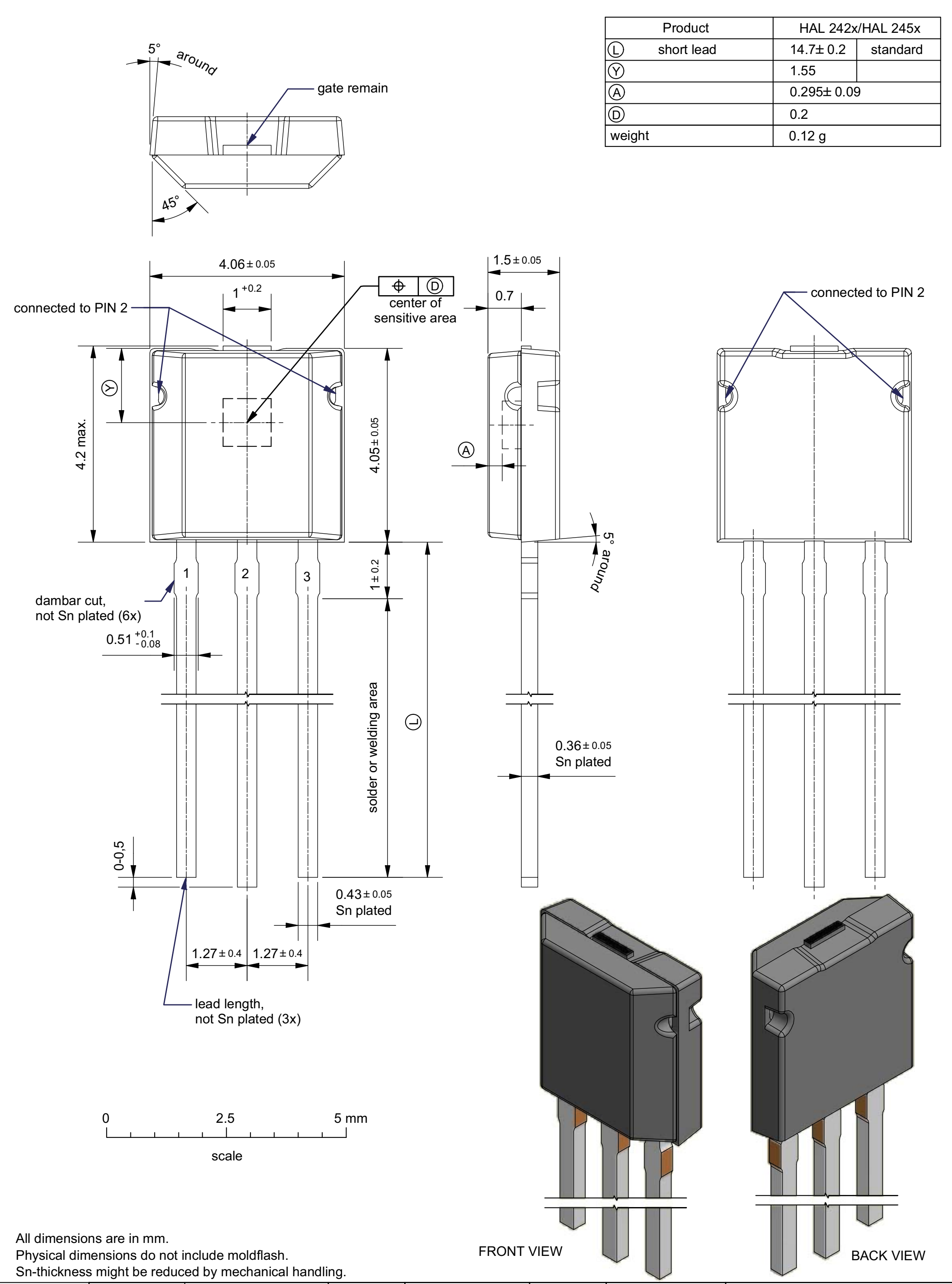
3.4. Calibration of the Sensor

For calibration in the system environment, the application kit from TDK-Micronas is recommended. It contains the hardware for the generation of the serial telegram for programming (TDK-MSP V1.0) 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 24xy Programming Guide”.

4. Specifications

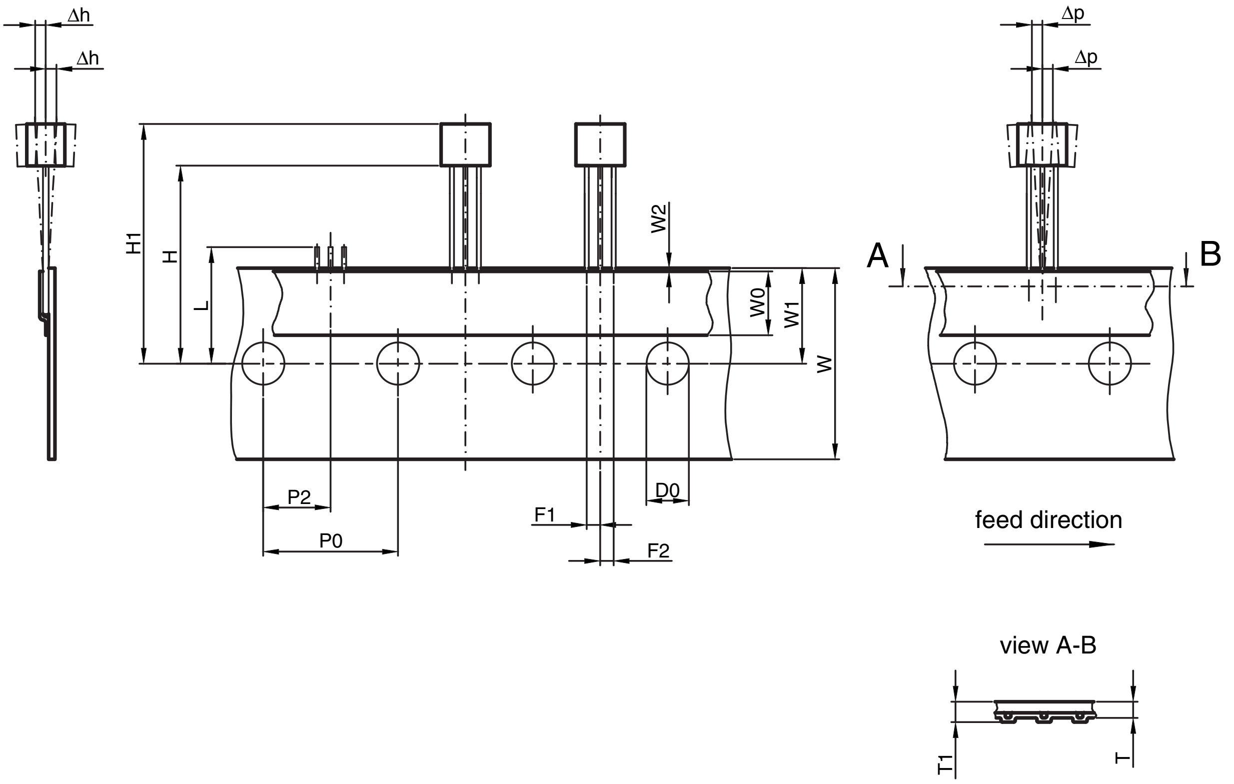
4.1. Outline Dimensions



	Product	HAL 242x/HAL 245x	
(L)	short lead	14.7± 0.2	standard
(Y)		1.55	
(A)		0.295± 0.09	
(D)		0.2	
weight		0.12 g	

PACKAGE	ISSUE DATE (YY-MM-DD)	JEDEC STANDARD		ANSI	REVISION DATE (YY-MM-DD)	REV.NO.	DRAWING-NO.	SPECIFICATION	
		ITEM NO.	ISSUE					TYPE	NO.
TO92UT-2	18-02-22				19-12-05	2	CUTI00032507.1	ZG	2090_Ver.02

Fig. 4–1:
TO92UT-2 Plastic Transistor Standard UT package, 3 leads, non-spread



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

	H	H1	
		TO92UA	TO92UT
Short leads	18 - 20	21 - 23.1	22 - 24.1
Long leads	24 - 26	27 - 29.1	28 - 30.1

UNIT	D0	F1	F2	Δh	L	P0	P2	Δp	T	T1	W	W0	W1	W2
mm	4.0	1.47 1.07	1.47 1.07	±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

STANDARD		ANSI	ISSUE DATE YY-MM-DD	DRAWING-NO.	ZG-NO.
ISSUE	ITEM NO.				
-	IEC 60286-2		16-07-18	06631.0001.4	ZG001031_Ver.05

Fig. 4–2:
TO92UA/UT: Dimensions ammopack inline, not spread

4.2. Solderability, Welding, Assembly

Information related to solderability, welding, assembly, and second-level packaging is included in the document "Guidelines for the Assembly of Micronas Packages".
It is available on the TDK-Micronas website (http://www.micronas.com/en/service-center/downloads) or on the service portal (http://service.micronas.com).

4.3. Pin Connections and Short Descriptions

Pin No.	Pin Name	Type	Short Description
TO92UT Package			
1	VSUP	SUPPLY	Supply voltage
2	GND	GND	Ground
3	OUT	I/O	Output and programming pin

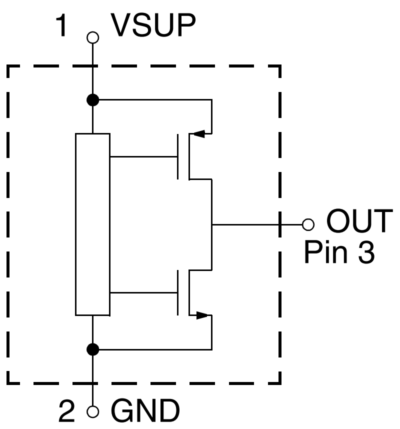


Fig. 4–3: Pin configuration (TO92UT)

4.4. Dimensions of Sensitive Area

250 µm x 250 µm

4.5. 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 must be taken to avoid application of any voltage higher than absolute maximum-rated voltages to this circuit.

All voltages listed are referenced to ground (GND).

Symbol	Parameter	Pin	Min.	Max.	Unit	Condition
V_{SUP}	Supply Voltage	VSUP	–8.5	10	V	t < 96 h [4]
			–18	18	V	t < 1h [4]
V_{OUT}	Output Voltage	OUT	–6[1]	18	V	t < 1h [4]
$V_{OUT} - V_{SUP}$	Excess of Output Voltage over Supply Voltage	OUT, VSUP	–	2	V	
T_J	Junction Temperature Range		–50	190[2]	°C	t < 96h [4]
$T_{STORAGE}$	Transportation/ Short-Term Storage Temperature		–55	150	°C	Device only without packing material.
V_{ESD}	ESD Protection	VSUP, OUT	– 8.0[3]	8.0[3]	kV	

[1] Internal protection resistor = 50 Ω
[2] For 96 h - Please contact TDK-Micronas for other temperature requirements.
[3] AEC-Q-100-002 (100 pF and 1.5 kΩ)
[4] No cumulated stress

4.6. Storage and Shelf Life

Information related to storage conditions of Micronas sensors is included in the document “Guidelines for the Assembly of Micronas Packages”. It gives recommendations linked to moisture sensitivity level and long-term storage.
It is available on the TDK-Micronas website (http://www.micronas.com/en/service-center/downloads) or on the service portal (http://service.micronas.com).

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	Min.	Typ.	Max.	Unit	Comments
V_{SUP}	Supply Voltage	1	4.5 5.7	5 6	5.5 6.5	V V	Normal operation during programming
I_{OUT}	Continuous Output Current	OUT	–1.2	–	1.2	mA	
R_L	Load Resistor	OUT	5.0	10	–	kΩ	Can be pull-up or pull-down resistor
C_L	Load Capacitance	OUT	0.33	47	600	nF	
N_{PRG}	Number of EEPROM Programming Cycles [1)]	–	–	–	100	cycles	0 °C < T_{amb} < 55 °C
N_{PRGNV}	Number of NVRAM Programming Cycles	–	–	–	5	cycles	0 °C < T_{amb} < 55 °C
T_J	Junction Temperature Range [2)]	–	–40 –40	–	125 140	°C	for 8000 h [3)] for 2000 h [3)]

[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 TDK-Micronas for life time calculations.
[3)] Time values are not cumulative.

4.8. Characteristics

at T_J = –40 °C to 140 °C, V_{SUP} = 4.5 V to 5.5 V, GND = 0 V after programming and locking, at Recommended Operation Conditions if not otherwise specified in the column “Conditions”. Typical Characteristics for TJ = 25 °C and VSUP = 5 V.

Symbol	Parameter	Pin	Min.	Typ.	Max.	Unit	Conditions
I_{SUP}	Supply Current over Temperature Range	VSUP	–	7	10.5	mA	
	Resolution[5]	OUT	–	12	–	bit	Ratiometric to V_{SUP} [1]
DNL	Differential Non-Linearity of D/A Converter[4]	OUT	–0.9	0	0.9	LSB	Test limit at 25 °C ambient temperature
INL	Non-Linearity of Output Voltage over Temperature[6]	OUT	–0.3	0	0.3	$\%V_{SUP}$	[2] For V_{out} = 0.35 V ... 4.65 V; V_{SUP} = 5 V; linear setpoint characteristics; T_J = –40 °C to 95 °C
		OUT	–0.3	0	0.3	$\%V_{SUP}$	[2] For V_{out} = 0.35 V ... 4.65 V; V_{SUP} = 5 V; linear setpoint characteristics; T_J = –40 °C to 120 °C
		OUT	–0.5	0	0.5	$\%V_{SUP}$	[2] For V_{out} = 0.35 V ... 4.65 V; V_{SUP} = 5 V; linear setpoint characteristics; T_J = –40 °C to 140 °C
E_R	Ratiometric Error of Output over Temperature (Error in V_{OUT} / V_{SUP})	OUT	–0.25	0	0.25	%	Max of [$V_{OUT5} - V_{OUT4.5}$ and $V_{OUT5.5} - V_{OUT5}$] at V_{OUT} = 10% and 90% V_{SUP}
V_{offset}	Offset Drift over Temperature Range[6] $\lvert V_{OUT}(B = 0\ mT)_{25°C} - V_{OUT}(B = 0\ mT)_{max}\rvert$	OUT	–	–	0.1	$\%V_{SUP}$	V_{SUP} = 5 V ; barrel shifter = 3 (± 50) mT, T_J = –40 °C to 95 °C
		OUT	–	–	0.15	$\%V_{SUP}$	V_{SUP} = 5 V ; barrel shifter = 3 (± 50) mT, T_J = –40 °C to 120 °C
		OUT	–	–	0.2	$\%V_{SUP}$	V_{SUP} = 5 V ; barrel shifter = 3 (± 50) mT, T_J = –40 °C to 140 °C

1) Output DAC full scale = 5 V ratiometric, Output DAC offset = 0 V, Output DAC LSB = V_{SUP}/4096
2) If more than 50% of the selected magnetic-field range is used and the temperature compensation is suitable. INL = V_{OUT} - V_{OUTLSF} with V_{OUTLSF} = Least Square Fit through measured output voltage
3) Signal Band Area with full accuracy is located between V_{OUTL} and V_{OUTH}. The sensor accuracy is reduced below V_{OUTL} and above V_{OUTH}
4) External package stress or overmolding might change this parameter
5) Guaranteed by design
6) Characterized on small sample size, not tested

Symbol	Parameter	Pin	Min.	Typ.	Max.	Unit	Conditions
ΔV_{OUTCL}	Accuracy of Output Voltage at Clamping Low Voltage over Temperature Range[5)]	OUT	–11	0	11	mV	R_L = 5 kΩ, V_{SUP} = 5 V Specification values are derived from resolution of the registers OUT_CMPHI/LO and V_{offset}.
ΔV_{OUTCH}	Accuracy of Output Voltage at Clamping High Voltage over Temperature Range[5)]	OUT	–11	0	11	mV	
V_{OUTH}	Upper Limit of Signal Band[3)]	OUT	93	–	–	$\%V_{SUP}$	V_{SUP} = 5 V; –1 mA ≤ I_{OUT} ≤ 1mA
V_{OUTL}	Lower Limit of Signal Band[3)]	OUT	–	–	7	$\%V_{SUP}$	V_{SUP} = 5 V; –1 mA ≤ I_{OUT} ≤ 1mA
f_{OSC}	Internal Oscillator Frequency over Temperature Range	–	–	4	–	MHz	
$t_{r(O)}$	Step Response Time of Output[6)]	OUT	–	0.6	0.8	ms	C_L = 10 nF; time from 10% to 90% of final output voltage for a step like magnetic signal from 0 mT to B_{max}
t_{POD}	Power-Up Time (Time to Reach Certain Output Accuracy)[6)]	OUT	- - -	- - -	6 3 1.7	ms ms ms	C_L = 10 nF, ±1% of V_{OUT} C_L = 10 nF, ±10% of V_{OUT} C_L = 10 nF, ±20% of V_{OUT}
BW	Small Signal Bandwidth (–3 dB)[6)]	OUT	–	2	–	kHz	
V_{OUTrms}	Output Noise Voltage RMS[6)]	OUT	–	–	0.50	mV	Barrel shifter = 3 Overall gain in signal path = 1 External circuitry according to Fig. 5–1 with low-noise supply T_J = –40 °C to 95 °C
		OUT	–	–	0.70	mV	Barrel shifter=3 Overall gain in signal path =1 External circuitry according to Fig. 5–1 with low-noise supply T_J = –40 °C to 120 °C
		OUT	–	–	0.90	mV	Barrel shifter=3 Overall gain in signal path =1 External circuitry according to Fig. 5–1 with low-noise supply T_J = –40 °C to 140 °C
R_{OUT}	Output Resistance over Recommended Operating Range	OUT	–	1	10	Ω	$V_{OUTLmax}$ ≤ V_{OUT} ≤ $V_{OUTHmin}$
TO92UT Package							
	Thermal Resistance						
R_{thja}	Junction to Air	– –	– –	– –	232 135	K/W K/W	Determined with a 1s0p board Determined with a 2s2p board
R_{thjc}	Junction to Case				33 30	K/W K/W	Determined with a 1s0p board Determined with a 2s2p board

3) Signal Band Area with full accuracy is located between V_{OUTL} and V_{OUTH}. The sensor accuracy is reduced below V_{OUTL} and above V_{OUTH}

4) External package stress or overmolding might change this parameter

5) Guaranteed by design

6) Characterized on small sample size, not tested

4.9. Open-Circuit Detection

at T_J = –40 °C to 140 °C, Typical Characteristics for T_J = 25 °C

Symbol	Parameter	Pin	Min.	Typ.	Max.	Unit	Conditions
V_{OUT}	Output Voltage at Open V_{SUP} Line	OUT	0	0	0.15	V	V_{SUP} = 5 V; R_L [1)] = 10 kΩ to 200 kΩ
			0	0	0.2	V	V_{SUP} = 5 V; R_L [1)] = 5 kΩ to 10 kΩ
V_{OUT}	Output Voltage at Open GND Line	OUT	4.85	4.9	5.0	V	V_{SUP} = 5 V; R_L [1)] = 10 kΩ to 200 kΩ
			4.8	4.9	5.0	V	V_{SUP} = 5 V ;R_L [1)] = 5 kΩ to 10 kΩ

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

4.10. Overvoltage and Undervoltage Detection

at T_J = –40 °C to 140 °C, Typical Characteristics for T_J = 25 °C, after programming and locking

Symbol	Parameter	Pin No.	Min.	Typ.	Max.	Unit	Comments
$V_{SUP,UV}$	Undervoltage Detection Level	1	3.3 3.1	3.9 3.7	4.3 4.1	V V	1) 2)
$V_{SUP,UVhyst}$	Undervoltage Detection Level Hysteresis [3)]	1	–	200	–	mV	
$V_{SUP,OV}$	Overvoltage Detection Level	1	5.6 8.5	6.2 9.5	6.9 10.4	V V	1) 2)
$V_{SUP,OVhyst}$	Overvoltage Detection Level Hysteresis [3)]	1	–	225	–	mV	

1) Customer programmable: EEPROM set to value for normal supply voltage range (Functionality Mode = 1)
2) Customer programmable: EEPROM set to value for extended supply voltage range (Functionality Mode = 0)
3) Characterized on small sample size, not tested

4.11. Output-Short Detection Parameter

at T_J = –40 °C to 140 °C, Typical Characteristics for T_J = 25 °C, after programming and locking

Symbol	Parameter	Pin No.	Min.	Typ.	Max.	Unit	Test Conditions
t_{OCD}	Over Current Detection Time [1)]	3	100	128	150	µs	
$t_{Timeout}$	Time Period without Over Current Detection [1)]	3	200	256	300	ms	
I_{OVC}	Detectable Output-Short Current [1)]	3	5	10	18	mA	

1) Characterized on small sample size, not tested

4.12. Output Voltage in Case of Error Detection

at T_J = –40 °C to 140 °C, Typical Characteristics for T_J = 25 °C, after programming and locking

Symbol	Parameter	Pin No.	Min.	Typ.	Max.	Unit	Test Conditions
$V_{SUP,DIAG}$	Supply Voltage required to get defined Output Voltage Level[1]	1	–	2.4 2.1 1.8	2.9 2.6 2.1	V	T_J = –40 °C T_J = 25 °C T_J = 140 °C
$V_{Error,Low}$	Output Voltage Range of Lower Error Band[1]	3	0	–	4	$\%V_{SUP}$	$V_{SUP} > V_{SUP,DIAG}$; 5 kΩ ≥ R_L ≤ 200 kΩ
$V_{Error,High}$	Output Voltage Range of Upper Error Band[1]	3	96	–	100	$\%V_{SUP}$	$V_{SUP} > V_{SUP,DIAG}$; 5 kΩ ≥ R_L ≤ 200 kΩ

[1] Characterized on small sample size, not tested

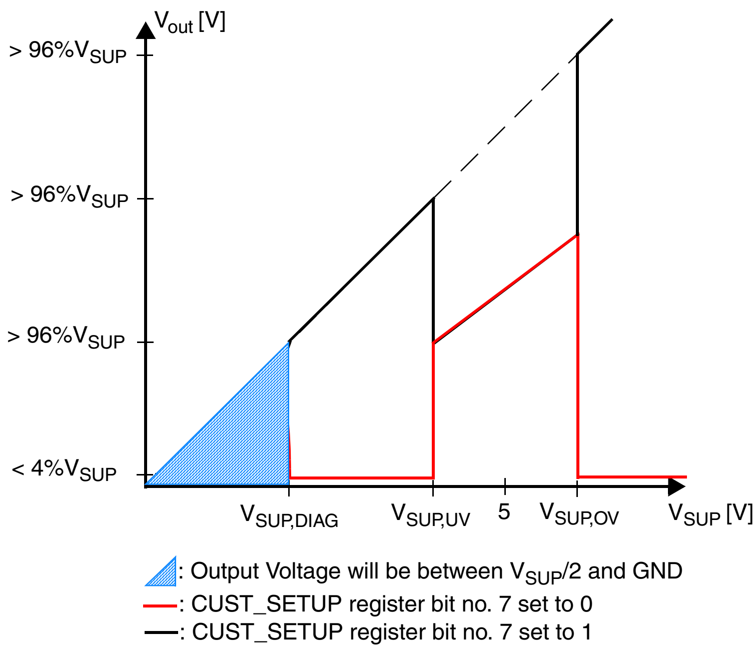


Fig. 4–4: Behavior of HAL 2421 for different V_{SUP}

4.13. Power-On Reset

at T_J = –40 °C to 140 °C, Typical Characteristics for T_J = 25 °C

Symbol	Parameter	Pin No.	Min.	Typ.	Max.	Unit	Conditions
POR_{UP}	Power-on Reset Voltage (up)	1	2.9 2.9		4.3[1] 4.1[2]	V	Min value is V_{SUP_diag} (see Section 4.12.) Max value is V_{SUP_UV} (see Section 4.10.)
POR_{DOWN}	Power-on Reset Voltage (down)	1	2.9 2.9		4.1[1] 3.9[2]	V	Min value is V_{SUP_diag} (see Section 4.12.) Max value is $V_{SUP\_UV} - V_{SUP\_UVhyst}$ (see Section 4.10.)

[1] Customer-programmable EEPROM set to value for normal supply voltage range (Functionality Mode = 1)
[2] Customer-programmable EEPROM set to value for extended supply voltage range (Functionality Mode = 0)

4.14. Magnetic Characteristics

at T_J = –40 °C to 140 °C, V_{SUP} = 4.5 V to 5.5 V, GND = 0 V after programming and locking, at Recommended Operation Conditions if not otherwise specified in the column “Conditions”. Typical Characteristics for T_J = 25 °C and V_{SUP} = 5 V.

Symbol	Parameter	Pin	Min.	Typ.	Max.	Unit	Test Conditions
SENS	Magnetic Sensitivity	$\Delta V_{OUT}/(2xRANGE_{ABS})$				mV/mT	Example: For Barrel_shifter=5 and ΔV_{OUT} = 4 V $RANGE_{ABS}$ = 12 mT Sensitivity=4 V/(2x12mT= 166 mV/mT typ.
$RANGE_{ABS}$	Absolute Range of CFX Register (Magnetic Range)[1)]	–	6	–	200	mT	Programmable: See Table 3–1 for relation between barrel shifter and Magnetic Range.
B_{Offset}	Magnetic Offset[1)]	OUT	–0.4	0	0.4	mT	B = 0 mT, I_{OUT} = 0 mA, T_J = 25 °C, unadjusted sensor
$\Delta B_{Offset}/\Delta T$	Magnetic Offset Change due to T_J[1)]	–	–5	0	5	µT/K	B = 0 mT, I_{OUT} = 0 mA, barrel shifter = 3 (±50) mT
ES	Error in Magnetic Sensitivity[1)]	OUT	–1.0	0	1.0	%	V_{SUP} = 5 V, barrel shifter = 3 (±50) mT, T_J = –40 °C to 95 °C
		OUT	–1.5	0	1.5	%	V_{SUP} = 5 V, barrel shifter = 3 (±50) mT T_J = –40 °C to 120 °C
		OUT	–2.0	0	2.0	%	V_{SUP} = 5 V, barrel shifter = 3 (±50) mT T_J = –40 °C to 140 °C

1) Characterized on small sample size, not tested

4.14.1. Definition of Sensitivity Error ES

ES is the maximum of the absolute value of the quotient of the normalized measured value[1] over the normalized ideal linear[2] value minus 1:

$$ES = \max\left(\text{abs}\left(\frac{\text{meas}}{\text{ideal}} - 1\right)\right)\Bigg|_{[\text{Tmin, Tmax}]}$$

In the example below, the maximum error occurs at –10 °C:

$$ES = \frac{1.001}{0.993} - 1 = 0.8\%$$

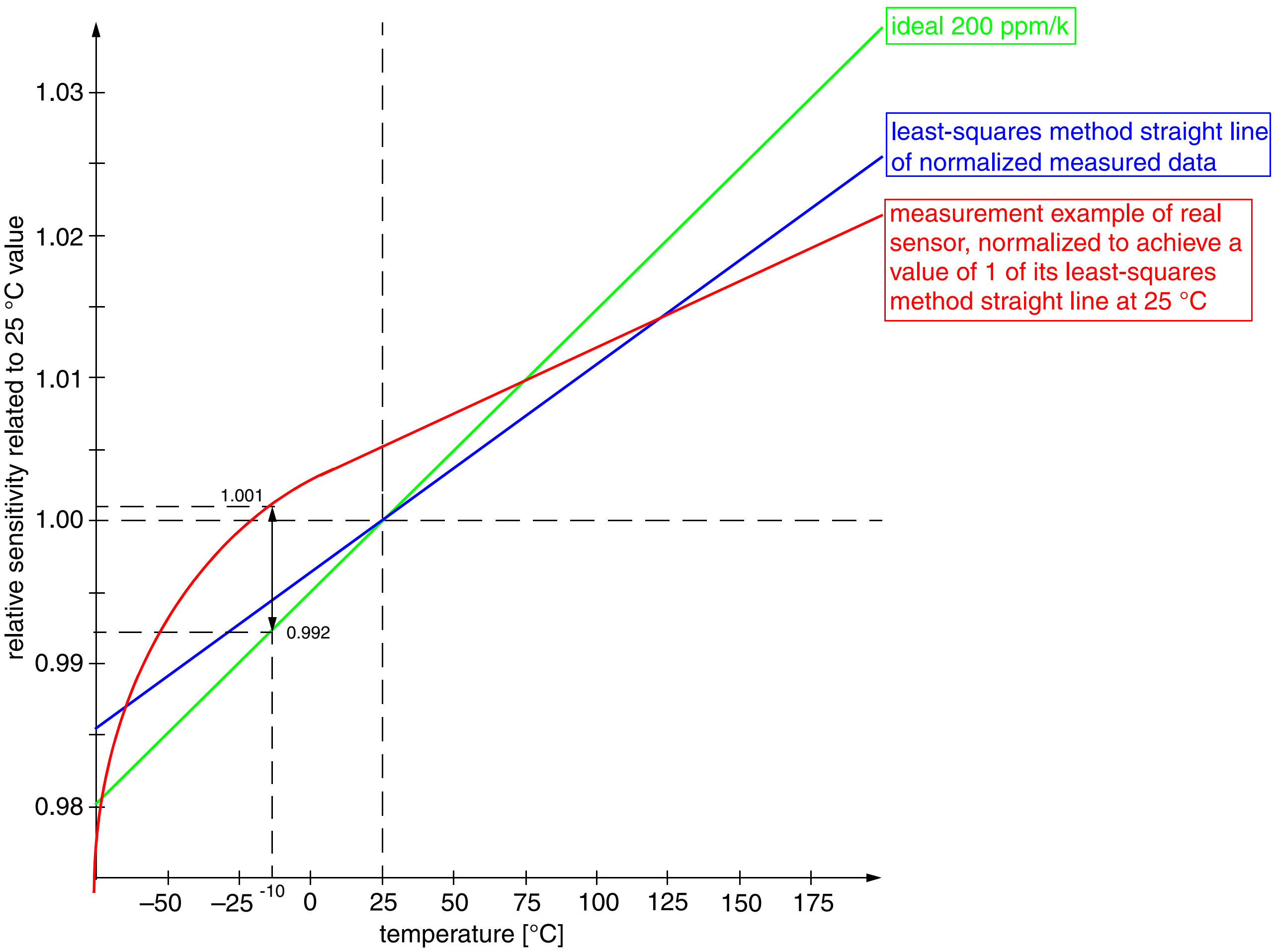


Fig. 4–5: ES definition example

1. Normalized to achieve a least-squares method straight line that has a value of 1 at 25 °C
2. Normalized to achieve a value of 1 at 25 °C

5. Application Notes

5.1. Application Circuit

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.

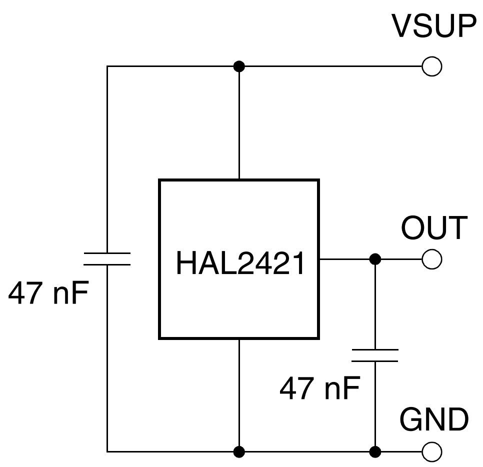


Fig. 5–1: Recommended application circuit

5.2.Use of Two HAL 2421 in Parallel

Two different HAL 2421 sensors which are operated in parallel to the same supply and ground line can be programmed individually as the communication with the sensors is done via their output pins.

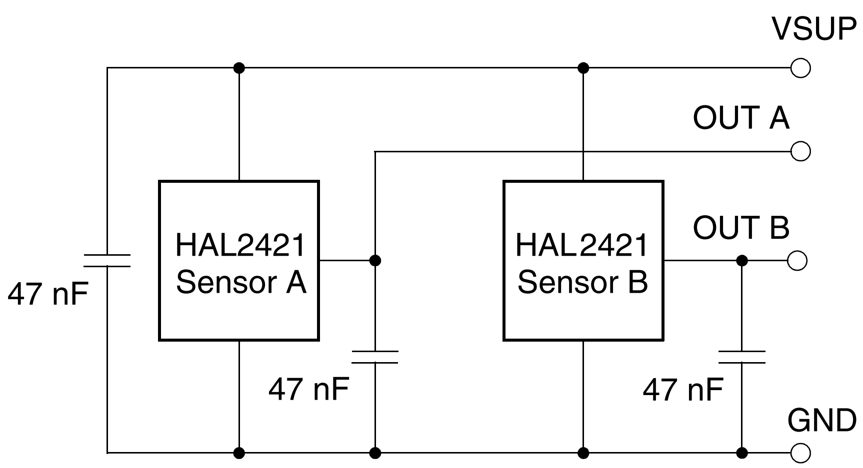


Fig. 5–2: Parallel operation of two HAL 2421

5.3. 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:

$$\Delta T = I_{SUP} \times V_{SUP} \times R_{thjx}$$

For typical values, use the typical parameters. For worst case calculation, use the max. parameters for I_{SUP} and R_{thjx} (x is representing the different R_{th} value, like junction to ambient R_{thja}), and the max. value for V_{SUP} from the application.

For V_{SUP} = 5.5 V, R_{th} = 235 K/W, and I_{SUP} = 10 mA, the temperature difference ΔT = 12.93 K.

For all sensors, the junction temperature T_J is specified. The maximum ambient temperature T_{Amax} can be calculated as:

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

Note The calculated self-heating of the devices is only valid for the R_{th} test boards. Depending on the application setup, the final results in an application environment might deviate from these values.

6. Programming of the Sensor

HAL 2421 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.

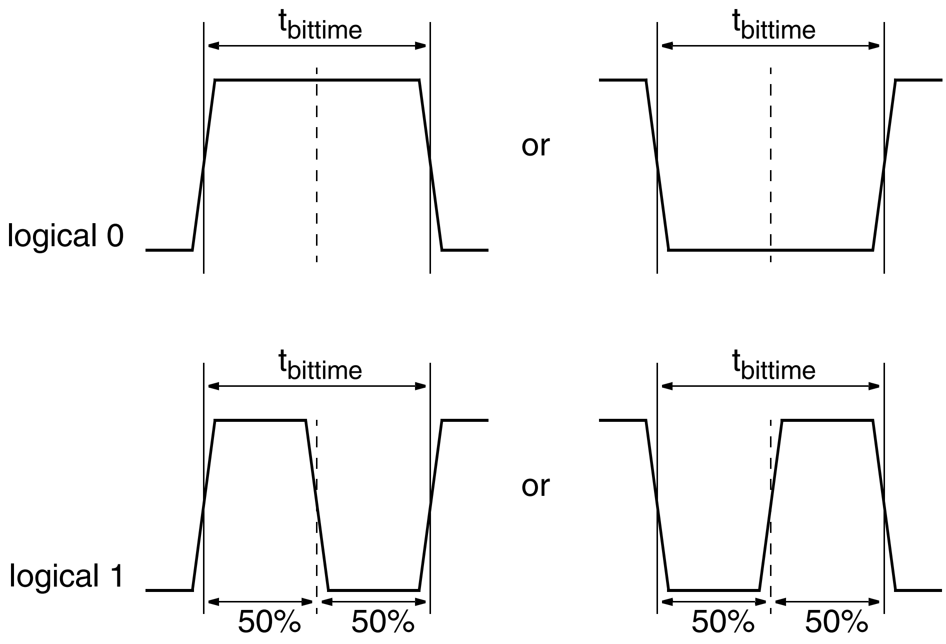


Fig. 6–1: Definition of logical 0 and 1 bit

A description of the communication protocol and the programming of the sensor is available in a separate document (Application Note "HAL/HAR 24xy Programming Guide").

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

Symbol	Parameter	Pin	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	
			0	–	1.0	V	for V_{SUP} = 5 V
V_{OUTH}	Voltage for Output High Level during Programming through Sensor Output Pin	OUT	$0.8{*}V_{SUP}$	–	V_{SUP}	V	
			4.0	–	5.0	V	for V_{SUP} = 5 V
$V_{SUP\text{-}Program}$	V_{SUP} Voltage for Programming	VSUP	5.7	6.0	6.5	V	
$t_{bittime}$	Biphase Bit Time	OUT	900	1000	1100	µs	
SR	Slew Rate[1)]	OUT	–	2.0	–	V/µs	
1) Depending on output load. Characterized on small sample size.							

6.2. Programming Environment and Tools

For the programming of HAL 2421 during product development a programming tool including hardware and software is available on request. It is recommended to use TDK-Micronas' USB kit and TDK's Magnetic Sensor Programmer (TDK-MSP V1.0x) with LabVIEW^{TM} Programming Environment in order to ease the product development. The details of programming sequences are also available on request.

6.3. Programming Information

For reliability in service, it is mandatory to set the LOCK bit to one and the POUT bit to zero after final adjustment and programming of HAL 2421.

The success of the LOCK process must be checked by reading the status of the LOCK bit after locking and by a negative communication test after a power on reset.

It is also mandatory to check the acknowledge (first and second) of the sensor or to read/check the status of the PROG_DIAGNOSIS register after each write and store sequence to verify if the programming of the sensor was successful. Please check HAL 24xy Programming Guide for further details.

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

7. Document History

1. Advance Information: "HAL 2421 High-Precision Programmable Linear Hall-Effect Sensor", Sept. 9, 2019, AI000214_001EN. First release of the advance information.

2. Data Sheet: "HAL 2421 High-Precision Programmable Linear Hall-Effect Sensor", Dec. 9, 2019, DSH000205_001EN. First release of the data sheet.

   Major changes:
   - Package drawing updated
   - Characteristics: values for V_{OUTrms} changed
   - Magnetic Characteristics: values for SENS and $Range_{ABS}$ changed

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