Data Sheet

HAL[®] 880

Programmable Linear
Hall-Effect Sensor

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– HAL

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Contents

Programmable Linear Hall-Effect Sensor

1. Introduction

The HAL880 is a new member of the Micronas family of programmable linear Hall sensors. The HAL880 complements the existing Hall-effect sensor family HAL8xy to the lower end. It is designed to fulfill the requirements of today's state-of-the-art applications for linear and angular measurements that require programmability to compensate system tolerances.

The HAL880 is an universal magnetic field sensor with a linear output based on the Hall effect. The IC can be used for angle or distance measurements if combined with a rotating or moving magnet. The 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.

The HAL880 features a temperature-compensated Hall plate with choppered offset compensation, an A/D converter, digital signal processing, a D/A converter with output driver, an EEPROM memory with redundancy and lock function for the calibration data, an EEPROM for customer serial number, 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 the sensor accuracy.

The HAL880 is programmable by modulating the supply voltage. No additional programming pin is needed. The easy programmability allows a 2-point calibration by adjusting the output voltage directly to the input signal (like mechanical angle, distance, or current). Individual adjustment of each sensor during the customer's 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. This offers a low-cost alternative for all applications that presently need mechanical adjustment or laser trimming for calibrating the system.

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

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

The sensor is designed for hostile industrial and automotive applications and operates with typically 5 V supply voltage in the ambient temperature range from −40 °C up to 125 °C. The HAL880 is available in the very small leaded packages TO92UT-1 and TO92UT-2.

1.1. Major Applications

Due to the sensor's versatile programming characteristics and low temperature drifts, the HAL880 is the optimal system solution for applications such as:

- contactless potentiometer,
- rotary position measurement,
- linear movement,
- current measurements.

1.2. Features

- programmable linear Hall effect sensor with ratiometric output and digital signal processing
- 12-bit analog output
- multiple programmable magnetic characteristics in a non-volatile memory (EEPROM) with redundancy and lock function
- open-circuit (ground and supply line break detection) with 10 kΩ pull-up and pull-down resistor, overvoltage and undervoltage detection
- for programming an individual sensor within several sensors in parallel to the same supply voltage, a selection can be done via the output pin
- temperature characteristics are programmable for matching common magnetic materials
- programmable clamping function
- programming through a modulation of the supply voltage
- operates from −40 °C up to 140 °C junction temperature
- 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 1 kHz
- overvoltage and reverse-voltage protection at all pins
- magnetic characteristics extremely robust against mechanical stress
- short-circuit protected push-pull output
- EMC and ESD optimized design

1.3. Marking Code

The HAL880 has a marking on the package surface (branded side). This marking includes the name of the sensor and the temperature range.

Type	Temperature Range K
HAL880	880K

1.4. Operating Junction Temperature Range (T_J)

The Hall sensors from Micronas are specified to the chip temperature (junction temperature T_J).

K: $T_J = -40\ °C$ to $+140\ °C$

The relationship between ambient temperature (T_A) and junction temperature is explained in Section 4.4. on page 25.

1.5. Hall Sensor Package Codes

HALXXXPA-T

              Temperature Range: K
              Package: UT for TO92UT-1/-2
              Type: 880
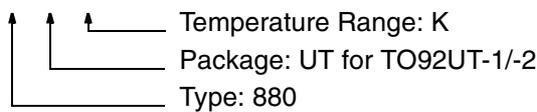
Example: **HAL880UT-K**

$\rightarrow$ Type: 880
$\rightarrow$ Package: TO92UT
$\rightarrow$ Temperature Range: $T_J = -40\ °C$ to $+140\ °C$

Hall sensors are available in a wide variety of packaging versions and quantities. For more detailed information, please refer to the brochure: "Hall Sensors: Ordering Codes, Packaging, Handling".

1.6. Solderability and Welding

Soldering

During soldering reflow processing and manual reworking, a component body temperature of 260 °C should not be exceeded.

Welding

Device terminals should be compatible with laser and resistance welding. Please note, that the success of the welding process is subject to different welding parameters which will vary according to the welding technique used. A very close control of the welding parameters is absolutely necessary in order to reach satisfying results. Micronas, therefore, does not give any implied or express warranty as to the ability to weld the component.

1.7. Pin Connections and Short Descriptions

Pin No.	Pin Name	Type	Short Description
1	V_{DD}	IN	Supply Voltage and Programming Pin
2	GND		Ground
3	OUT	OUT	Push-Pull Output and Selection Pin
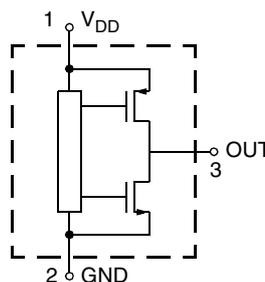
Fig. 1–1: Pin configuration

2. Functional Description

2.1. General Function

The HAL880 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 to an analog voltage with ratiometric behavior, and stabilized by a push-pull output transistor stage. The function and the parameters for the DSP are explained in Section 2.2. on page 8.

The setting of the LOCK register disables the programming of the EEPROM memory for all time. This register cannot be reset.

As long as the LOCK register is not set, the output characteristic can be adjusted by programming the EEPROM registers. The IC is addressed by modulating the supply voltage (see Fig. 2–1). 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_{DD} or GND line is broken. Internal temperature compensation circuitry and the choppered offset compensation enables operation over the full temperature range with minimal changes in accuracy and high offset stability. The circuitry also rejects offset shifts due to mechanical stress from the package. The non-volatile memory consists of redundant and non-redundant EEPROM cells. The non-redundant EEPROM cells are only used to store production information inside the sensor. In addition, the sensor IC is equipped with devices for overvoltage and reverse-voltage protection at all pins.
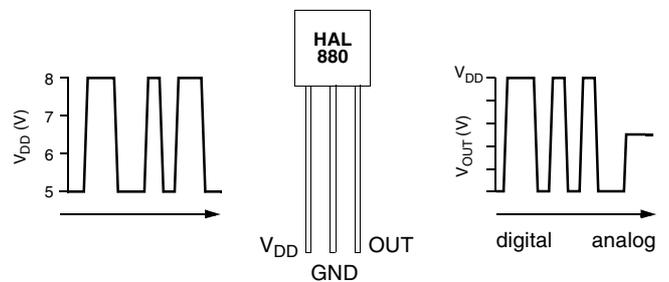
Fig. 2–1: Programming with V_{DD} modulation
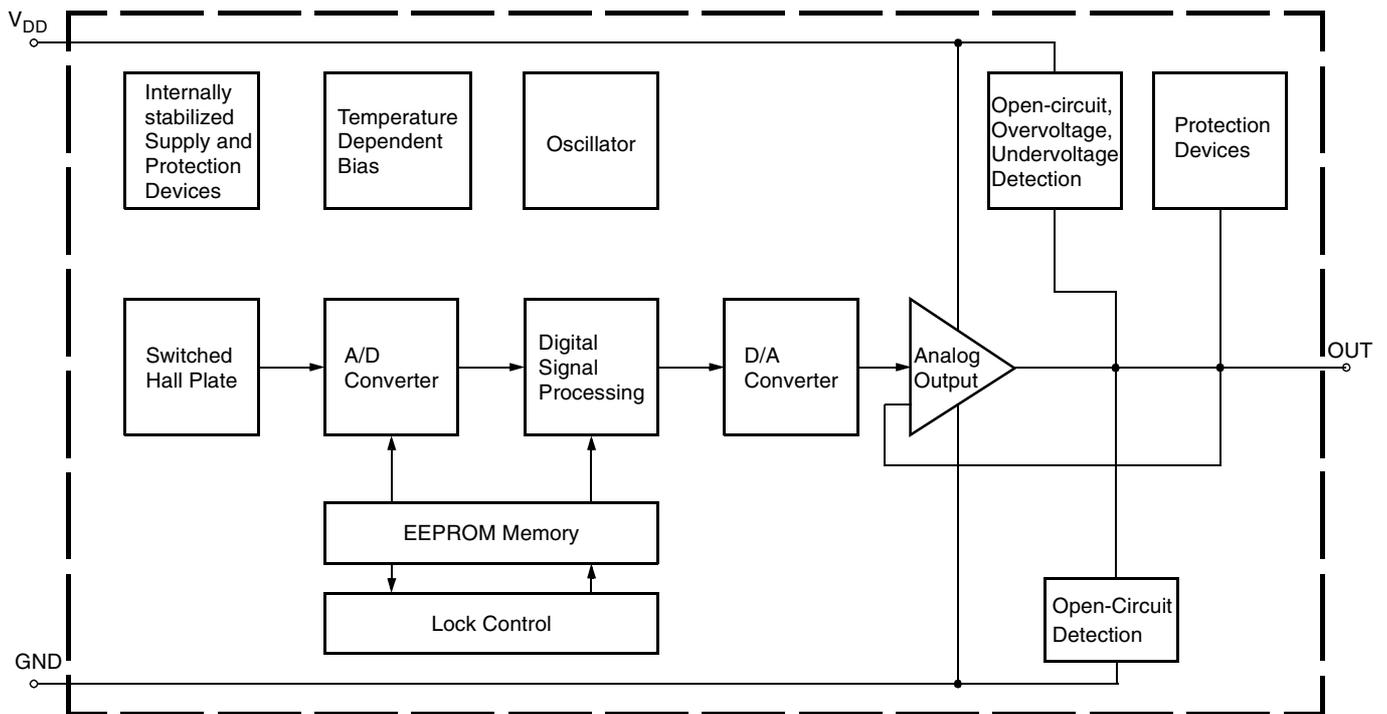
Fig. 2–2: HAL880 block diagram
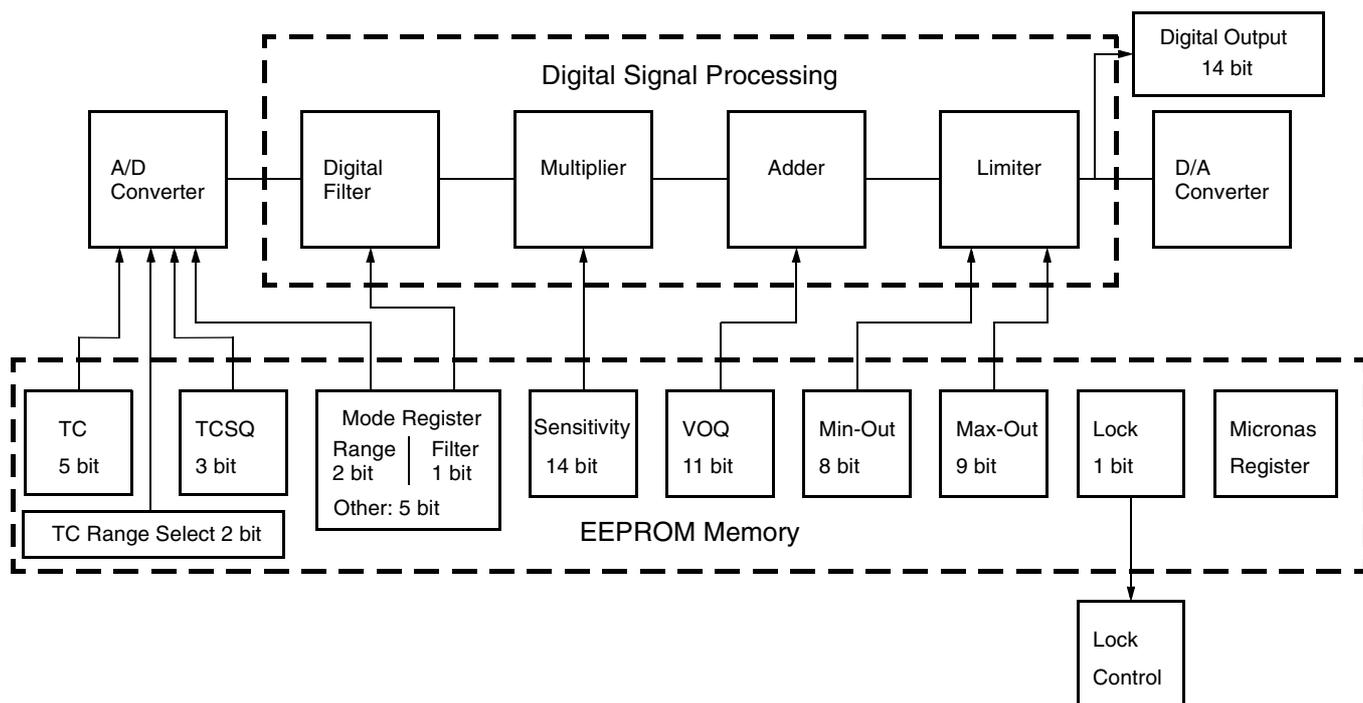
Fig. 2–3: Details of EEPROM and digital signal processing

2.2. Digital Signal Processing and EEPROM

The DSP is the main 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. 2–3 on page 7.

Terminology:

SENSITIVITY: name of the register or register value

Sensitivity: name of the parameter

The EEPROM registers consist of four groups:

Group 1 contains the registers for the adaption of the sensor to the magnetic system: MODE for selecting the magnetic field range and filter frequency, TC, TCSQ and TC-range for the temperature characteristics of the magnetic sensitivity.

Group 2 contains the registers for defining the output characteristics: SENSITIVITY, VOQ, CLAMP-LOW, and CLAMP-HIGH. The output characteristic of the sensor is defined by these 4 parameters.

– The parameter V_{OQ} (Output Quiescent Voltage) corresponds to the output voltage at B = 0 mT.

– The parameter Sensitivity defines the magnetic sensitivity:

$$Sensitivity = \frac{\Delta V_{OUT}}{\Delta B}$$

– The output voltage can be calculated as:

$$V_{OUT} \sim Sensitivity \times B + V_{OQ}$$

The output voltage range can be clamped by setting the registers CLAMP-LOW and CLAMP-HIGH in order to enable failure detection (such as short-circuits to V_{DD} or GND and open connections).

Group 3 contains the general purpose register GP. The GP register can be used to store customer information, like a serial number after manufacturing. Micronas will use this GP REGISTER to store information such as lot number, wafer number, x and y position of the die on the wafer, etc. This information can be readout by the customer and stored in its own data base or it can stay in the sensor as it is.

Group 4 contains the Micronas registers and LOCK for the locking of all registers. The Micronas registers are programmed and locked during production. These registers are used for oscillator frequency trimming,

A/D converter offset compensation, and several other special settings.

An external magnetic field generates a Hall voltage on the Hall plate. The ADC converts the amplified positive or negative Hall voltage (operates with magnetic north and south poles at the branded side of the package) to a digital value. The digital signal is filtered in the internal low-pass filter and manipulated according to the settings stored in the EEPROM. The digital value after signal processing is readable in the D/A-READOUT register. Depending on the programmable magnetic range of the Hall IC, the operating range of the A/D converter is from −30 mT … +30 mT up to −100 mT … +100 mT.

During further processing, the digital signal is multiplied with the sensitivity factor, added to the quiescent output voltage and limited according to the clamping voltage. The result is converted to an analog signal and stabilized by a push-pull output transistor stage.

The D/A-READOUT at any given magnetic field depends on the programmed magnetic field range, the low-pass filter, TC values, CLAMP-LOW and CLAMP-HIGH. The D/A-READOUT range is min. 0 and max. 16383.

Note: During application design, it should be taken into consideration that the maximum and minimum D/A-READOUT should not saturate in the operational range of the specific application.

Range

The RANGE bits are bit 2 and 3 of the MODE register; they define the magnetic field range of the A/D converter.

Magnetic Field Range	RANGE
−30mT...30 mT	0
−60 mT...60 mT	1
−80 mT...80 mT	2
−100 mT...100 mT	3

Filter

The FILTER bit is bit number 4 of the MODE register; it defines the −3 dB frequency of the digital low pass filter.

−3 dB Frequency	FILTER
500 Hz	0
1 kHz	1

Bit Time

The BITTIME bit is bit number 5 of the MODE register; It defines the protocol bit time for the communication between the sensor and the programmer board.

Bit Time	BITTIME
1:64 (Typ. 1.75 ms)	0
1:128 (Typ. 3.5 ms)	1

Output Format

The OUTPUTMODE bits are the bits numbers 6 to 7 of the MODE register.

Output Format	OUTPUTMODE
Analog Output (12 bit)	0

TC Register

The temperature dependence of the magnetic sensitivity can be adapted to different magnetic materials in order to compensate for the change of the magnetic strength with temperature. The adaption is done by programming the TC (Temperature Coefficient) and the TCSQ registers (Quadratic Temperature Coefficient). Thereby, the slope and the curvature of the temperature dependence of the magnetic sensitivity can be matched to the magnet and the sensor assembly. As a result, the output voltage characteristic can be fixed over the full temperature range. The sensor can compensate for linear temperature coefficients ranging from about −3100 ppm/K up to 1000 ppm/K and quadratic coefficients from about −7 ppm/K² to 2 ppm/K². The full TC range is separated in the following four ranges:

TC-Range [ppm/k]	GROUP
−3100 to −1800	0
−1750 to −550	2
−500 to +450 (default value)	1
+450 to +1000	3

TC (5 bit) and TCSQ (3 bit) have to be selected individually within each of the four ranges. For example: 0 ppm/k requires TC-Range = 1, TC = 15 and TCSQ = 1.

Sensitivity

The SENSITIVITY register contains the parameter for the multiplier in the DSP. The Sensitivity is programmable between −4 and 4. For V_{DD} = 5 V, the register can be changed in steps of 0.00049.

For all calculations, the digital value from the magnetic field of the D/A converter is used. This digital information is readable from the D/A-READOUT register.

$$SENSITIVITY = \frac{\Delta V_{out} \times 16384}{2 \times \Delta DA\text{-}Readout \times V_{DD}}$$

VOQ

The VOQ register contains the parameter for the adder in the DSP. V_{OQ} is the output voltage without external magnetic field (B = 0 mT) and programmable from $-V_{DD}$ up to V_{DD}. For V_{DD} = 5 V, the register can be changed in steps of 4.9 mV.

Note: If V_{OQ} is programmed to a negative voltage, the maximum output voltage is limited to:

$$V_{OUTmax} = V_{OQ} + V_{DD}$$

Clamping Voltage

The output voltage range can be clamped in order to detect failures like short circuits to V_{DD} or GND or an open circuit.

The CLAMP-LOW register contains the parameter for the lower limit. The lower clamping voltage is programmable between 0 V and $V_{DD}/2$. For $V_{DD} = 5$ V, the register can be changed in steps of 9.77 mV.

The CLAMP-HIGH register contains the parameter for the upper limit. The upper clamping voltage is programmable between 0 V and V_{DD}. For $V_{DD} = 5$ V, in steps of 9.77 mV.

GP Register

This register can be used to store some information, such as production date or customer serial number. Micronas will store production lot number, wafer number, and x, y coordinates in three blocks of this registers. The total register contains of four blocks with a length of 13 bit each. The customer can read out this information and store it in his own production data base for reference or he can change them and store own production information.

Note: To enable programming of the GP register, bit 0 of the MODE register has to be set to 1. This register is not a guarantee for traceability.

LOCKR

By setting the first bit of this 2-bit register, all registers will be locked and the sensor will no longer respond to any supply voltage modulation. This bit is active after the first power-off and power-on sequence after setting the LOCK bit.

Warning: This register cannot be reset!

D/A-Readout

The 14-bit D/A-READOUT register delivers the actual digital value of the applied magnetic field after the signal processing. This register can be read out and is the basis for the calibration procedure of the sensor in the system environment.

Note: The MSB and LSB are reversed compared with all the other registers. Please reverse this register after readout.

2.3. Calibration Procedure

2.3.1. General Procedure

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 (Programmer Board Version 5.1) and the corresponding software (PC880) for the input of the register values.

For the individual calibration of each sensor in the customer application, a two-point adjustment is recommended. The calibration has be done as follows:

Step 1: Input of the registers which need not be adjusted individually

The magnetic circuit, the magnetic material with its temperature characteristics, the filter frequency, the output mode and the GP register value are given for this application. Therefore, the values of the following registers should be identical for all sensors of the customer application.

- FILTER
  (according to the maximum signal frequency)
- RANGE
  (according to the maximum magnetic field at the sensor position)
- OUTPUTMODE
- TC, TCSQ, and TC-RANGE
  (depends on the material of the magnet and the other temperature dependencies of the application)
- GP
  (if the customer wants to store own production information, it is not necessary to change this register)

As the clamping voltages are given, they have an influence on the D/A-readout value and therefore have to be set after the adjustment process.

Write the appropriate settings into the HAL 880 registers.

Step 2: Initialize DSP

As the D/A-READOUT register value depends on the settings of SENSITIVITY, VOQ, and CLAMP-LOW/HIGH, these registers have first to be initialized with defined values:

- $VOQ_{INITIAL}$ = 2.5 V
- $Sensitivity_{INITIAL}$ = 0.5
- Clamp-Low = 0 V
- Clamp-High = 4.999 V

Step 3: Define Calibration Points

The calibration points 1 and 2 can be set inside the specified range. The corresponding values for V_{OUT1} and V_{OUT2} result from the application requirements.

$$Low\,clamping\,voltage \leq V_{OUT1,2} \leq High\,clamping\,voltage$$

For highest accuracy of the sensor, calibration points near the minimum and maximum input signal are recommended. The difference of the output voltage between calibration point 1 and calibration point 2 should be more than 3.5 V.

Step 4: Calculation of V_{OQ} and Sensitivity

Set the system to calibration point 1 and read the register D/A-READOUT. The result is the value D/A-READOUT1.

Now, set the system to calibration point 2, read the register D/A-READOUT again, and get the value D/A-READOUT2.

With these values, and the target values V_{OUT1} and V_{OUT2}, for the calibration points 1 and 2, respectively, the values for Sensitivity and V_{OQ} are calculated as:

$$Sensitivity = \frac{1}{2} \times \frac{(Vout2 - Vout1)}{D/A\text{-}Readout2 - D/A\text{-}Readout1} \times \frac{16384}{5}$$

$$V_{OQ} = \frac{1}{16} \times \left[\frac{Vout2 \times 16384}{5} - [(D/A\text{-}Readout2 - 8192) \times Sensitivity \times 2] \right] \times \frac{5}{1024}$$

This calculation has to be done individually for each sensor.

Next, write the calculated values for Sensitivity and V_{OQ} into the IC for adjusting the sensor. At that time, it is also possible to store the application specific values for Clamp-Low and Clamp-High into the sensors EEPROM.

The sensor is now calibrated for the customer application. However, the programming can be changed again and again if necessary.

Note: For a recalibration, the calibration procedure has to be started at the beginning (step 1). A new initialization is necessary, as the initial values from step 1 are overwritten in step 4.

Step 5: Locking the Sensor

The last step is activating the LOCK function by programming the LOCK bit. Please note that the LOCK function becomes effective after power-down and power-up of the Hall IC. The sensor is now locked and does not respond to any programming or reading commands.

Warning: This register can not be reset!

3. Specifications

3.1. Outline Dimensions

physical dimensions do not include moldflash.

solderability is guaranteed between end of pin and distance F1.

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

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	4.1 4.0	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.				
-	-	⊕⊏	07-07-02	06609.0001.4	ZG001009_Ver.05

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

physical dimensions do not include moldflash.

solderability is guaranteed between end of pin and distance F1.

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

UNIT	A2	A3	b	c	D1	e	E1	F1	F2	L	Θ
mm	1.55 1.45	0.7	0.42	0.36	4.1 4.0	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.				
-	-		07-07-02	06615.0001.4	ZG001015_Ver.05

Fig. 3–2:
TO92UT-2: Plastic Transistor Standard UT package, 3 leads, not spread
Weight approximately 0.12 g

all dimensions in mm
other dimensions see drawing of bulk
max. allowed tolerance over 20 hole spacings ±1.0
H1 = this dimension is different for each sensor type and is specified in the data sheet

UNIT	D0	F1	F2	H	Δh	L	P0	P2	Δp	T	T1	W	W0	W1	W2
mm	4.0	2.74 2.34	2.74 2.34	20.0 18.0	±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.				
-	ICE 60286-2	⊕ ◁	07-01-18	06632.0001.4	ZG001032_Ver.04

Fig. 3–3:
TO92UT-1: Dimensions ammopack inline, spread

all dimensions in mm
other dimensions see drawing of bulk
max. allowed tolerance over 20 hole spacings ±1.0
H1= this dimension is different for each sensor type and is specified in the data sheet

UNIT	D0	F1	F2	H	Δh	L	P0	P2	Δp	T	T1	W	W0	W1	W2
mm	4.0	1.47 1.07	1.47 1.07	20.0 18.0	±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.				
-	ICE 60286-2		07-01-18	06631.0001.4	ZG001031_Ver.03

Fig. 3–4:
TO92UT-2: Dimensions ammopack inline, not spread

3.2. Dimensions of Sensitive Area

0.25 mm x 0.25 mm

3.3. Positions of Sensitive Areas

	TO92UT-1/-2
y	1.5 mm nominal
A4	0.3 mm nominal
Bd	0.3 mm

3.4. 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 circuit.

All voltages listed are referenced to ground (GND).

Symbol	Parameter	Pin No.	Min.	Max.	Unit
V_{DD}	Supply Voltage	1	−8.5	8.5	V
V_{DD}	Supply Voltage	1	−14.4[1] [2]	14.4[1] [2]	V
$-I_{DD}$	Reverse Supply Current	1	−	50[1]	mA
V_{OUT}	Output Voltage	3	−5[5] −5[5]	8.5[3] 14.4[3] [2]	V
$V_{OUT} - V_{DD}$	Excess of Output Voltage over Supply Voltage	3,1	−	2	V
I_{OUT}	Continuous Output Current	3	−10	10	mA
t_{Sh}	Output Short Circuit Duration	3	−	10	min
T_J	Junction Temperature Range		−40 −40	170[4] 150	°C °C
N_{PROG}	Number of Programming Cycles		−	100	

[1] as long as T_{Jmax} is not exceeded
[2] t < 10 min (V_{DDmin} = −15 V for t < 1 min, V_{DDmax} = 16 V for t < 1 min)
[3] as long as T_{Jmax} is not exceeded, output is not protected to external 14 V-line (or to −14 V)
[4] t < 1000h
[5] internal protection resistor = 50 Ω

3.5. 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
V_{DD}	Supply Voltage	1	4.5	5	5.5	V
I_{OUT}	Continuous Output Current	3	−1	–	1	mA
R_L	Load Resistor	3	5.0	10	–	kΩ
C_L	Load Capacitance	3	0.33	10	1000	nF
R_L: Can be pull-up or pull-down resistor						

3.5.1. Storage and Shelf Life

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 one year from the date code on the package.

3.6. Characteristics

at T_J = −40 °C to +140 °C, V_{DD} = 4.5 V to 5.5 V, GND = 0 V after programming and locking,
at Recommended Operating Conditions if not otherwise specified in the column "Conditions".
Typical Characteristics for T_J = 25 °C and V_{DD} = 5 V.

Symbol	Parameter	Pin No.	Min.	Typ.	Max.	Unit	Conditions
I_{DD}	Supply Current over Temperature Range	1	–	7	10	mA	
V_{DDZ}	Overvoltage Protection at Supply	1	–	17.5	20	V	I_{DD} = 25 mA, T_J = 25 °C, t = 20 ms
V_{OZ}	Overvoltage Protection at Output	3	–	17	19.5	V	I_O = 10 mA, T_J = 25 °C, t = 20 ms
	Resolution	3	–	12	–	bit	ratiometric to V_{DD} [1]
INL	Non-Linearity of Output Voltage over Temperature	3	−1.0	0	1.0	%	% of supply voltage[2] For V_{out} = 0.35 V ... 4.65 V; V_{DD} = 5 V
E_R	Ratiometric Error of Output over Temperature (Error in V_{OUT} / V_{DD})	3	−1.0	0	1.0	%	$\mid V_{OUT1} \text{ - } V_{OUT2} \mid > 2\,V$ during calibration procedure
ES	Error in Magnetic Sensitivity over Temperature Range	3	−6	0	6	%	(see Section 3.6.1. on page 21)
ΔV_{OUTCL}	Accuracy of Output Voltage at Clamping Low Voltage over Temperature Range	3	−45	0	45	mV	R_L = 5 kΩ, V_{DD} = 5 V
ΔV_{OUTCH}	Accuracy of Output Voltage at Clamping High Voltage over Temperature Range	3	−45	0	45	mV	R_L = 5 kΩ, V_{DD} = 5 V
V_{OUTH}	Upper Limit of Signal Band[3]	3	4.65	4.8	–	V	V_{DD} = 5 V, −1 mA ≤ I_{OUT} ≤ 1mA
V_{OUTL}	Lower Limit of Signal Band[3]	3	–	0.2	0.35	V	V_{DD} = 5 V, −1 mA ≤ I_{OUT} ≤ 1mA
f_{ADC}	Internal ADC Frequency over Temperature Range	–	–	128	–	kHz	
$t_{r(O)}$	Step Response Time of Output	3	–	3 2	5 4	ms ms	3 dB Filter frequency = 500 Hz 3 dB Filter frequency = 1 kHz C_L = 10 nF, time from 10% to 90% of final output voltage for a step like signal B_{step} from 0 mT to B_{max}
$t_{d(O)}$	Delay Time of Output	3	–	0.1	0.5	ms	C_L = 10 nF
t_{POD}	Power-Up Time (Time to Reach Stabilized Output Voltage)	–	1.5	1.7	1.9	ms	C_L = 10 nF, 90% of V_{OUT}
BW	Small Signal Bandwidth (−3 dB)	3	–	1	–	kHz	B_{AC} < 10 mT; 3 dB Filter frequency = 1 kHz
V_{OUTn}	Noise Output Voltage$_{pp}$	3	–	6	15	mV	magnetic range = 60 mT[4] 3 dB Filter frequency = 500 Hz Sensitivity ≤ 0.7; C = 4.7 nF (V_{DD} & V_{OUT} to GND)
R_{OUT}	Output Resistance over Recommended Operating Range	3	–	1	10	Ω	$V_{OUTLmax}$ ≤ V_{OUT} ≤ $V_{OUTHmin}$

[1] Output DAC full scale = 5 V ratiometric, Output DAC offset = 0 V, Output DAC LSB = V_{DD}/4096
[2] if more than 50% of the selected magnetic field range is used and the temperature compensation is suitable
[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] peak-to-peak value exceeded: 5%

Symbol	Parameter	Pin No.	Min.	Typ.	Max.	Unit	Conditions
TO92UT Packages							
	Thermal Resistance						
R_{thja}	Junction to Air	–	–	–	235	K/W	Measured with a 1s0p board
R_{thjc}	Junction to Case	–	–	–	61	K/W	Measured with a 1s0p board
R_{thjs}	Junction to Solder Point	–	–	–	128	K/W	Measured with a 1s1p board

3.6.1. Definition of Sensitivity Error ES

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

$$ES \;=\; \max\!\left(\mathrm{abs}\!\left(\frac{\mathrm{meas}}{\mathrm{ideal}} - 1\right)\right)\Bigg|_{[\,T_{min},\,T_{max}\,]}$$

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

$$ES \;=\; \frac{1.001}{0.992} - 1 \;=\; 0.9\%$$

[1] normalized to achieve a least-square-fit straight-line that has a value of 1 at 25 °C

[2] normalized to achieve a value of 1 at 25 °C
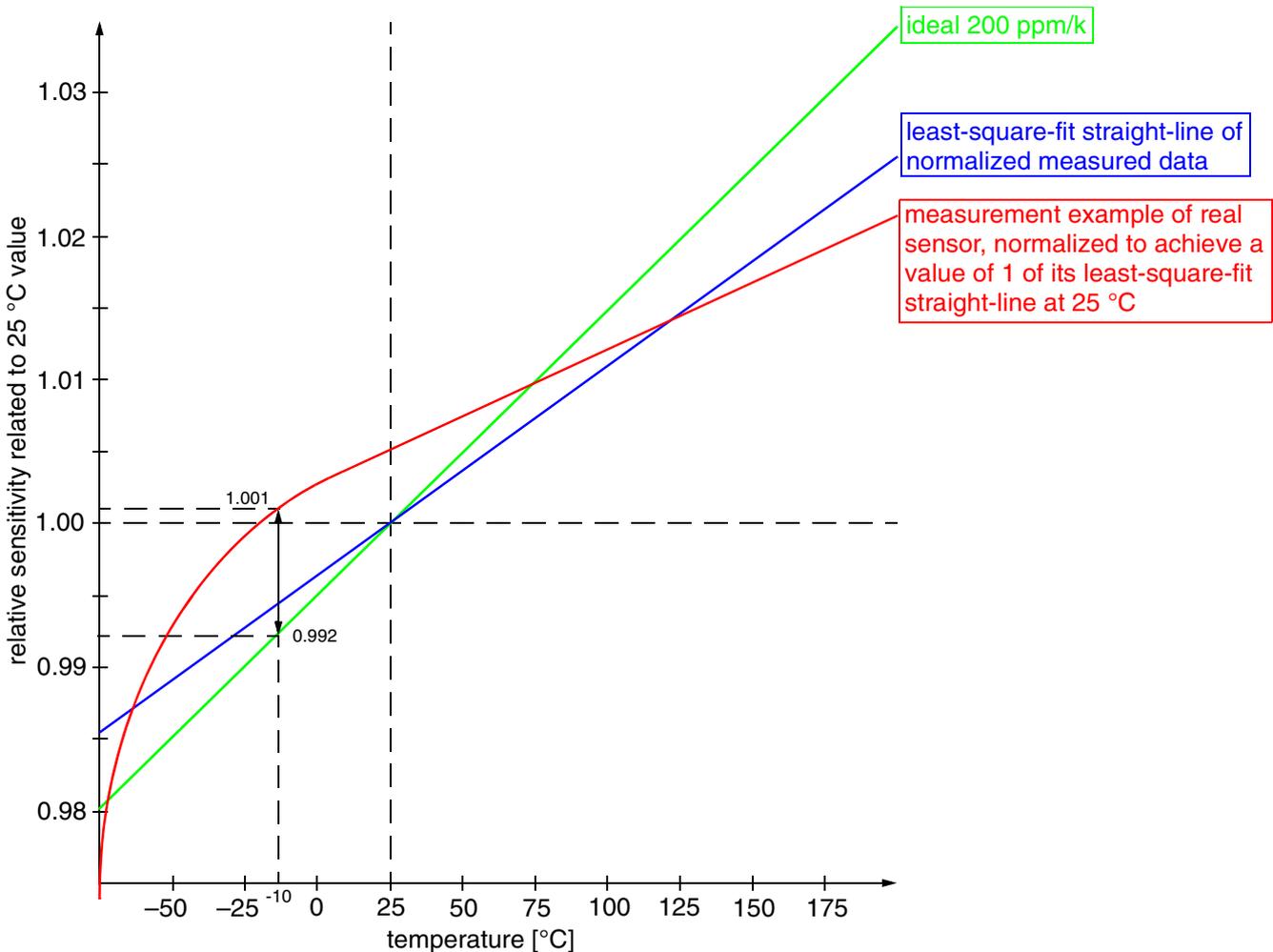
Fig. 3–5: ES definition example

3.7. Open-Circuit Detection

at T_J = −40 °C to +140 °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_{DD} Line	3	0	0	0.15	V	V_{DD} = 5 V R_L = 10 kΩ to 200 kΩ
V_{OUT}	Output Voltage at Open GND Line	3	4.85	4.9	5.0	V	V_{DD} = 5 V 10 kΩ ≥ R_L ≤ 200 kΩ
R_L: can be pull-up or pull-down resistor							

3.8. Power-On Operation

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

Symbol	Parameter	Min.	Typ.	Max.	Unit
POR_{UP}	Power-On Reset Voltage (UP)	–	3.4	–	V
POR_{DOWN}	Power-On Reset Voltage (DOWN)	–	3.0	–	V

3.9. 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	Conditions
$V_{DD,UV}$	Undervoltage Detection Level	1	–	4.2	4.3	V	[1]
$V_{DD,OV}$	Overvoltage Detection Level	1	8.5	8.9	10.0	V	[1]

[1] If the supply voltage drops below $V_{DD,UV}$ or rises above $V_{DD,OV}$, the output voltage is switched to V_{DD} (≥97% of V_{DD} at R_L = 10 kΩ to GND). The CLAMP-LOW register has to be set to a voltage ≥ 200 mV.

Note: The over- and undervoltage detection is activated only **after** locking the sensor!

3.10. Magnetic Characteristics

at T_J = −40 °C to +140 °C, V_{DD} = 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_{DD} = 5 V.

Symbol	Parameter	Pin No.	Min.	Typ.	Max.	Unit	Conditions
B_{Offset}	Magnetic Offset	3	−0.5	0	0.5	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		−15	0	15	µT/K	B = 0 mT, I_{OUT} = 0 mA

4. Application Notes

4.1. Application Circuit

For EMC protection, it is recommended to connect one ceramic 4.7 nF capacitor each between ground and the supply voltage, respectively the output voltage pin. In addition, the input of the controller unit should be pulled-down with a 10 kΩ resistor and a ceramic 4.7 nF capacitor.

Please note that during programming, the sensor will be supplied repeatedly with the programming voltage of 12.5 V for 100 ms. All components connected to the V_{DD} line at this time must be able to resist this voltage.
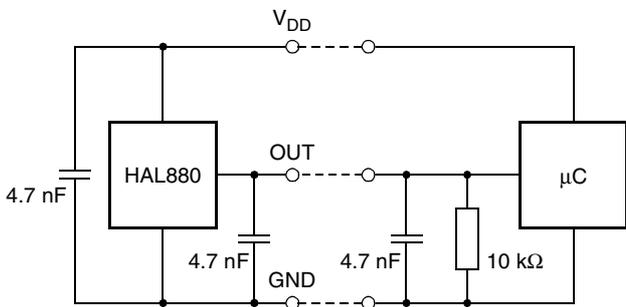
Fig. 4–1: Recommended application circuit

4.2. Use of two HAL880 in Parallel

Two different HAL880 sensors which are operated in parallel to the same supply and ground line can be programmed individually. In order to select the IC which should be programmed, both Hall ICs are inactivated by the "Deactivate" command on the common supply line. Then, the appropriate IC is activated by an "Activate" pulse on its output. Only the activated sensor will react to all following read, write, and program commands. If the second IC has to be programmed, the "Deactivate" command is sent again and the second IC can be selected.

Note: The multi-programming of two sensors works only if the outputs of the two sensors are pulled to GND with a 10 kΩ pull-down resistor.
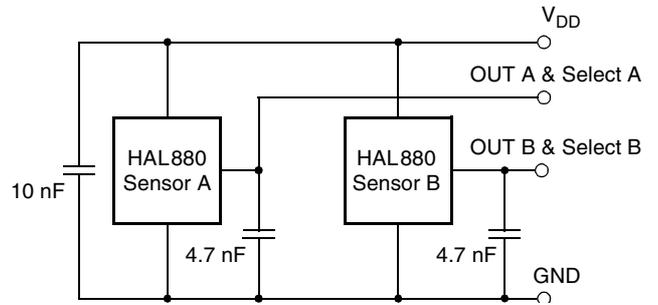
Fig. 4–2: Parallel operation of two HAL880

4.3. Temperature Compensation

The relationship between the temperature coefficient of the magnet and the corresponding TC, TCSQ, and TC-Range codes for linear compensation is given in the following table. In addition to the linear change of the magnetic field with temperature, the curvature can be adjusted as well. For this purpose, other TC, TCSQ, and TC-Range combinations are required which are not shown in the table. Please contact Micronas for more detailed information on this higher order temperature compensation.

Temperature Coefficient of Magnet (ppm/K)	TC-Range	TC	TCSQ
1075	3	31	7
1000	3	28	1
900	3	24	0
750	3	16	2
675	3	12	2
575	3	8	2
450	3	4	2
400	1	31	0
250	1	24	1
150	1	20	1
50	1	16	2
0	1	15	1
−100	1	12	0
−200	1	8	1
−300	1	4	4
−400	1	0	7
−500	1	0	0
−600	2	31	2
−700	2	28	1
−800	2	24	3
−900	2	20	6
−1000	2	16	7
−1100	2	16	2
−1200	2	12	5
−1300	2	12	0

Temperature Coefficient of Magnet (ppm/K)	TC-Range	TC	TCSQ
−1400	2	8	3
−1500	2	4	7
−1600	2	4	1
−1700	2	0	6
−1800	0	31	6
−1900	0	28	7
−2000	0	28	2
−2100	0	24	6
−2200	0	24	1
−2400	0	20	0
−2500	0	16	5
−2600	0	14	5
−2800	0	12	1
−2900	0	8	6
−3000	0	8	3
−3100	0	4	7
−3300	0	4	1
−3500	0	0	4

Note: The above table shows only some approximate values. Micronas recommends to use the TC-Calc software to find optimal settings for temperature coefficients. Please contact Micronas for more detailed information.

4.4. 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:

$$\Delta T = I_{DD} \times V_{DD} \times R_{thJ}$$

For typical values use the typical parameters. For worst case calculation, use the max. parameters for I_{DD} and R_{th}, and the max. value for V_{DD} from the application.

For V_{DD} = 5.5 V, R_{th} = 235 K/W, and I_{DD} = 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:

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

4.5. EMC and ESD

The HAL 880 is designed for a stabilized 5 V supply. Interferences and disturbances conducted along the 12 V on-board 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 by radiated disturbances, the application circuit shown in Fig. 4–1 on page 23 is recommended. Applications with this arrangement should pass the EMC tests according to the product standards ISO 7637 part 3 (electrical transient transmission by capacitive or inductive coupling).

Please contact Micronas for the detailed investigation reports with the EMC and ESD results.

5. Programming of the Sensor

5.1. Definition of Programming Pulses

The sensor is addressed by modulating a serial telegram on the supply voltage. The sensor answers with a serial telegram on the output pin.

The bits in the serial telegram have a different bit time for the V_{DD}-line and the output. The bit time for the V_{DD}-line is defined through the length of the Sync Bit at the beginning of each telegram. The bit time for the output is defined through the Acknowledge Bit.

A logical "0" is coded as no voltage change within the bit time. A logical "1" is coded as a voltage change between 50% and 80% of the bit time. After each bit, a voltage change occurs.

5.2. Definition of the Telegram

Each telegram starts with the Sync Bit (logical 0), 3 bits for the Command (COM), the Command Parity Bit (CP), 4 bits for the Address (ADR), and the Address Parity Bit (AP).

There are 4 kinds of telegrams:

– Write a register (see Fig. 5–2 on page 28)
After the AP Bit follow 14 Data Bits (DAT) and the Data Parity Bit (DP). If the telegram is valid and the command has been processed, the sensor answers with an Acknowledge Bit (logical 0) on the output.

– Read a register (see Fig. 5–3 on page 28)
After evaluating this command, the sensor answers with the Acknowledge Bit, 14 Data Bits, and the Data Parity Bit on the output.

– Programming the EEPROM cells (see Fig. 5–4 on page 28)
After evaluating this command, the sensor answers with the Acknowledge Bit. After the delay time t_w, the supply voltage rises up to the programming voltage.

– Activate a sensor (see Fig. 5–5 on page 28)
If more than one sensor is connected to the supply line, selection can be done by first deactivating all sensors. The output of all sensors will be pulled to ground by the internal 10 kΩ resistors. With an Activate pulse on the appropriate output pin, an individual sensor can be selected. All following commands will only be accepted from the activated sensor.
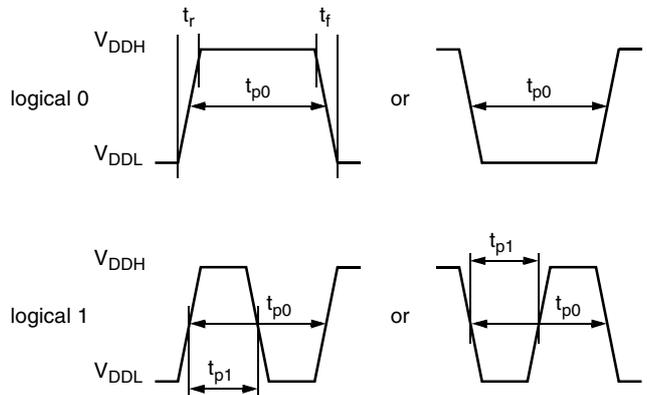

Fig. 5–1: Definition of logical 0 and 1 bit

Table 5–1: Telegram parameters

| Symbol	Parameter	Pin	Min.	Typ.	Max.	Unit	Remarks
V_{DDL}	Supply Voltage for Low Level during Programming	1	5	5.6	6	V	
V_{DDH}	Supply Voltage for High Level during Programming	1	6.8	8.0	8.5	V	
t_r	Rise Time	1	–	–	0.05	ms	
t_f	Fall Time	1	–	–	0.05	ms	
t_{p0}	Bit Time on V_{DD}	1	1.7	1.75	1.8	ms	t_{p0} is defined through the Sync Bit
t_{pOUT}	Bit Time on Output Pin	3	2	3	4	ms	t_{pOUT} is defined through the Acknowledge Bit
t_{p1}	Voltage Change for Logical 1	1, 3	50	65	80	%	% of t_{p0} or t_{pOUT}
V_{DDPROG}	Supply Voltage for Programming the EEPROM	1	12.4	12.5	12.6	V	
t_{PROG}	Programming Time for EEPROM	1	95	100	105	ms	
t_{rp}	Rise Time of Programming Voltage	1	0.2	0.5	1	ms	
t_{fp}	Fall Time of Programming Voltage	1	0	–	1	ms	
t_w	Delay Time of Programming Voltage after Acknowledge	1	0.5	0.7	1	ms	
V_{act}	Voltage for an Activate Pulse	3	3	4	5	V	
t_{act}	Duration of an Activate Pulse	3	0.05	0.1	0.2	ms	
$V_{out,deact}$	Output Voltage after Deactivate Command	3	0	0.1	0.2	V	

WRITE
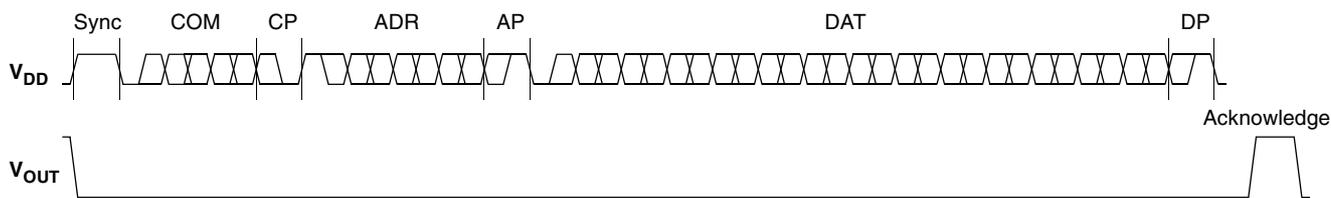
Fig. 5–2: Telegram for coding a Write command

READ
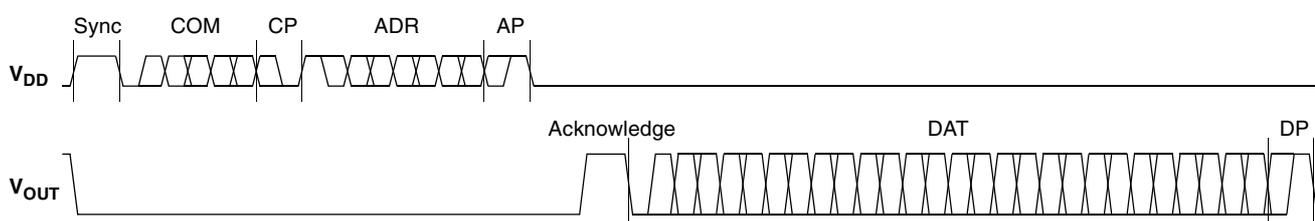
Fig. 5–3: Telegram for coding a Read command

ERASE and PROM
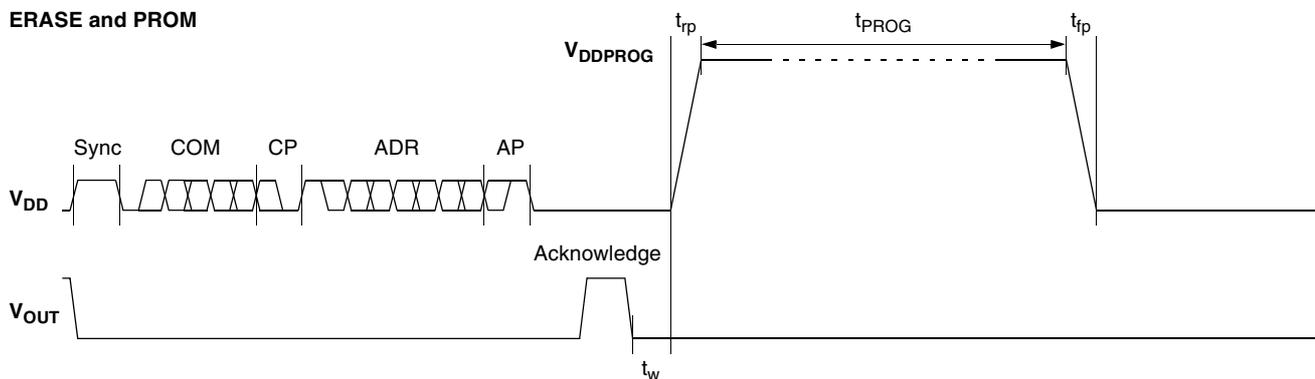
**Fig. 5–4:** Telegram for coding the EEPROM programming
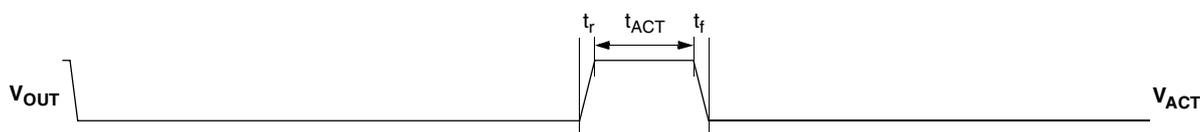
Fig. 5–5: Activate pulse

5.3. Telegram Codes

Sync Bit

Each telegram starts with the Sync Bit. This logical "0" pulse defines the exact timing for t_{p0}.

Command Bits (COM)

The Command code contains 3 bits and is a binary number. Table 5–2 shows the available commands and the corresponding codes for HAL880.

Command Parity Bit (CP)

This parity bit is "1", if the number of zeros within the 3 Command Bits is uneven. The parity bit is "0", if the number of zeros is even.

Address Bits (ADR)

The Address code contains 4 bits and is a binary number. Table 5–3 on page 31 shows the available addresses for the HAL880 registers.

Address Parity Bit (AP)

This parity bit is "1", if the number of zeros within the 4 Address bits is uneven. The parity bit is "0", if the number of zeros is even.

Data Bits (DAT)

The 14 Data Bits contain the register information.

The registers use different number formats for the Data Bits. These formats are explained in Section 5.4. on page 30

In the Write command, the last bits are valid. If, for example, the TC register (10 bits) is written, only the last 10 bits are valid.

In the Read command, the first bits are valid. If, for example, the TC register (10 bits) is read, only the first 10 bits are valid.

Data Parity Bit (DP)

This parity bit is "1", if the number of zeros within the binary number is even. The parity bit is "0", if the number of zeros is uneven.

Acknowledge

After each telegram, the output answers with the Acknowledge signal. This logical "0" pulse defines the exact timing for t_{pOUT}.

Table 5–2: Available commands

Command	Code	Explanation
READ	2	read a register
WRITE	3	write a register
PROM	4	program all nonvolatile registers (except the lock bits)
ERASE	5	erase all nonvolatile registers (except the lock bits)

5.4. Number Formats

Binary number:

The most significant bit is given as first, the least significant bit as last digit.

Example: `101001` represents 41 decimal.

Signed binary number:

The first digit represents the sign of the following binary number (1 for negative, 0 for positive sign).

Example: `0101001` represents +41 decimal
`1101001` represents −41 decimal

Two's complementary number:

The first digit of positive numbers is "0", the rest of the number is a binary number. Negative numbers start with "1". In order to calculate the absolute value of the number, calculate the complement of the remaining digits and add "1".

Example: `0101001` represents +41 decimal
`1010111` represents −41 decimal

5.5. Register Information

CLAMP-LOW

– The register range is from 0 up to 255.

– The register value is calculated by:

$$CLAMP\text{-}LOW = \frac{LowClampingVoltage \times 2}{V_{DD}} \times 255$$

CLAMP-HIGH

– The register range is from 0 up to 511.

– The register value is calculated by:

$$CLAMP\text{-}HIGH = \frac{HighClampingVoltage}{V_{DD}} \times 511$$

VOQ

– The register range is from −1024 up to 1023.

– The register value is calculated by:

$$VOQ = \frac{V_{OQ}}{V_{DD}} \times 1024$$

SENSITIVITY

– The register range is from −8192 up to 8191.

– The register value is calculated by:

$$SENSITIVITY = Sensitivity \times 2048$$

TC

– The TC register range is from 0 up to 1023.

– The register value is calculated by:

$$TC = GROUP \times 256 + TCValue \times 8 + TCSQValue$$

MODE

– The register range is from 0 up to 255 and contains the settings for FILTER and RANGE:

$$MODE = OUTPUTMODE \times 32 + BITRATE \times 16 + FILTER \times 8 + RANGE \times 2 + EnableProgGPRegisters$$

D/A-READOUT

– This register is read only.

– The register range is from 0 up to 16383.

DEACTIVATE

– This register can only be written.

– The register has to be written with 2063 decimal (80F hexadecimal) for the deactivation.

– The sensor can be reset with an Activate pulse on the output pin or by switching off and on the supply voltage.

HAL880

Table 5–3: Available register addresses

Register	Code	Data Bits	Format	Customer	Remark
CLAMP-LOW	1	8	binary	read/write/program	Low-clamping voltage
CLAMP-HIGH	2	9	binary	read/write/program	High-clamping voltage
VOQ	3	11	two's compl. binary	read/write/program	
SENSITIVITY	4	14	signed binary	read/write/program	Range, filter, output mode, interface bit time settings
MODE	5	8	binary	read/write/program	Range and filter settings
LOCKR	6	2	binary	read/write/program	Lock Bit
GP REGISTERS 1...3	8	13	binary	read/write/program	It is only possible to program this register if the mode register bit zero is set to 1.
D/A-READOUT	9	14	binary	read	Bit sequence is reversed during read sequence.
TC	11	10	binary	read/write/program	bit 0 to 2 TCSQ bit 3 to 7 TC bit 7 to 9 TC-RANGE
GP REGISTER 0	12	13	binary	read/write/program	It is only possible to program this register if the mode register bit zero is set to 1.
DEACTIVATE	15	12	binary	write	Deactivate the sensor

Table 5–4: Data formats

Register	Char	\ DAT3				DAT2				DAT1				DAT0			
	Bit	**15**	**14**	**13**	**12**	**11**	**10**	**09**	**08**	**07**	**06**	**05**	**04**	**03**	**02**	**01**	**00**
CLAMP LOW	Write	–	–	–	–	–	–	–	–	V	V	V	V	V	V	V	V
	Read	–	–	V	V	V	V	V	V	V	V	–	–	–	–	–	–
CLAMP HIGH	Write	–	–	–	–	–	–	–	V	V	V	V	V	V	V	V	V
	Read	–	–	V	V	V	V	V	V	V	V	V	–	–	–	–	–
VOQ	Write	–	–	–	–	–	V	V	V	V	V	V	V	V	V	V	V
	Read	–	–	V	V	V	V	V	V	V	V	V	V	V	–	–	–
SENSITIVITY	Write	–	–	V	V	V	V	V	V	V	V	V	V	V	V	V	V
	Read	–	–	V	V	V	V	V	V	V	V	V	V	V	V	V	V
MODE	Write	–	–	–	–	–	–	–	–	V	V	V	V	V	V	V	V
	Read	–	–	V	V	V	V	V	V	V	V	–	–	–	–	–	–
LOCKR	Write	–	–	–	–	–	–	–	–	–	–	–	–	–	–	V	V
	Read	–	–	V	V	–	–	–	–	–	–	–	–	–	–	–	–
GP 1..3 Registers	Write	–	–	–	V	V	V	V	V	V	V	V	V	V	V	V	V
	Read	–	–	V	V	V	V	V	V	V	V	V	V	V	V	V	–
D/A-READOUT	Read	–	–	V	V	V	V	V	V	V	V	V	V	V	V	V	V
TC	Write	–	–	–	–	–	–	V	V	V	V	V	V	V	V	V	V
	Read	–	–	V	V	V	V	V	V	V	V	V	V	–	–	–	–
GP 0 Register	Write	–	–	–	V	V	V	V	V	V	V	V	V	V	V	V	V
	Read	–	–	V	V	V	V	V	V	V	V	V	V	V	V	V	–
DEACTIVATE	Write	–	–	–	–	1	0	0	0	0	0	0	0	1	1	1	1
V: valid, –: ignore, bit order: MSB first																	

5.6. Programming Information

If the content of any register (except the lock registers) is to be changed, the desired value must first be written into the corresponding RAM register. Before reading out the RAM register again, the register value must be permanently stored in the EEPROM.

Permanently storing a value in the EEPROM is done by first sending an ERASE command followed by sending a PROM command. **The address within the ERASE and PROM commands must be zero.** ERASE and PROM act on all registers in parallel.

Note: To store data in the GP register, it is necessary to set bit number 0 of the MODE register to "1", before sending an ERASE and PROM command. Otherwise the data stored in the GP register will not be changed.

If all HAL 880 registers are to be changed, all writing commands can be sent one after the other, followed by sending one ERASE and PROM command at the end.

During all communication sequences, the customer has to check if the communication with the sensor was successful. This means that the acknowledge and the parity bits sent by the sensor have to be checked by the customer. If the Micronas programmer board is used, the customer has to check the error flags sent from the programmer board.

Note: For production and qualification tests, it is mandatory to set the LOCK bit after final adjustment and programming of HAL 880. The LOCK function is active after the next power-up of the sensor. The success of the lock process should be checked by reading at least one sensor register after locking and/or by an analog check of the sensors output signal. Electrostatic discharges (ESD) may disturb the programming pulses. Please take precautions against ESD.

6. Data Sheet History

1. Data Sheet: "HAL880 Programmable Linear Hall-Effect Sensor", Oct. 14, 2008, AI000145_001EN. First release of the advance information.

2. Data Sheet: "HAL880 Programmable Linear Hall-Effect Sensor", Feb. 23, 2009, DSH000152_001EN. Second release of the data sheet. Minor changes:

– small numbering changes (order of chapters).