| VACUUMSCHMELZE | # Specification | **Item no.: T60404-N4641-X836** |
|---|---|---|
| K-No.:30626 | **Differential Current Sensor for EV-charging acc. to the partly combined standards IEC62955-1:2018 and UL2231-2 Ed.2** | Date: 06.10.2023 |
| Customer: Standard type | |  |

## Description
- Fluxgate current sensor with toroidal core
- PCB mounting

## Characteristics
- Excellent accuracy
- Switching open-collector outputs
- Compact design

Patents: EP2571128 / US9397494 / CN103001175 // EP2813856

## Applications
Mainly used for stationary and mobile applications:
- Wallbox
- Personnel Protection Systems for EV acc. to UL2231

## Electrical data – Ratings

| | | min. | typ. | max. | Unit |
|---|---|---|---|---|---|
| $I_P$ | Primary nominal RMS current (1phase / 3phase) | | | 80 / 40 | A |
| $I_{\Delta N1}$ | Rated residual operating current 1 | | 6 | | mA dc |
| $I_{\Delta N2}$ | Rated residual operating current 2 | | 20 | | mA rms |
| $I_{\Delta N1,\ tolerance}$ | Trip tolerance 1 | 4 | 5 | 6 | mA dc |
| $I_{\Delta N2,\ tolerance}$ | Trip tolerance 2 | 15 | | 20(1) / 70(2) | mA rms |
| $I_{\Delta Rl,\mathbf{1}}$ (Fig.3) | Recovery Current level for $I_{\Delta N1}$ (absolute value DC) | | 2.5 | | mA |
| $I_{\Delta Rl,\mathbf{2}}$ (Fig.3) | Recovery Current level for $I_{\Delta N2}$ (absolute value rms) | | 10 | | mA |

(1) f = 50/60 Hz (2) f = DC to 2kHz

## Accuracy – Dynamic performance data

| | | min. | typ. | max. | Unit |
|---|---|---|---|---|---|
| $I_{\Delta N,max}$ | Max. measuring range (peak) | -300 | | +300 | mA |
| X | Resolution (@ $I_{\Delta N}$, $\Theta_A$ = 25°C) | | < 0.2 | | mA |
| $t_r$ | Response time(3) | | | see Fig.2 | |
| $f_{BW}$ (Fig.5) | Frequency range | DC | | 2 | kHz |

## General data

| | | min. | typ. | max. | Unit |
|---|---|---|---|---|---|
| $\vartheta_A$ | Ambient operation temperature | -40 | | 85 | °C |
| $\vartheta_{Storage}$ | Ambient storage temperature | -40 | | 85 | °C |
| m | Mass | | 21 | | g |
| $V_{CC}$ | Supply voltage | 4.8 | 5 | 5.2 | $V_{DC}$ |
| $I_{CC}$ | Supply current | | 33 | | mA rms |
| $S_{clear,\ pp}$ | Clearance (primary to secondary)(4) | | 8mm | | |
| $S_{creep,\ pp}$ | Creepage (primary to secondary)(4) | | 8mm | | |
| FIT | EN/IEC 61709 / SN 29500(5) | | < 2200 | | fit |

(3) **Switching time of a relay (IEC: t = 20ms / UL: t = 10ms) is considered.**

(4) **Constructed, manufactured and tested in accordance with IEC60664-1:2020**
**Isolated wires are preferred to fulfill the insulation coordination acc. to IEC 62955:2018, it is necessary to use insulated primary conductors that meet the requirements of the basic insulation for the rated voltage. If isolated primary conductors are used, the isolation coordination is acc. to: Reinforced insulation, Insulation material group 1, Pollution degree 2 and overvoltage category III.**

(5) **The results are valid under following conditions: 55°C mean component ambient temperature by continuous operation (8760h per year); Environment condition: ground mobile, no dust or harmful substances, according to IEC61709; Fit equals one failure per 10^9 component hours**

## General description of sensor function:

The Sensor is sensitive to AC and DC current and can be used for fault current detection in EV-charging applications. The Sensor detects DC fault currents according to IEC62955:2018 and AC/DC fault currents according to UL2231-2 Ed.2. In the event of a 6mAdc fault current, PIN 7 will change its state from a low level (GND) to high impedance state. In the event of a 20mArms fault current, PIN 6 will change state from a low level (GND) to a high impedance state. Pin 7 only fulfills the switch-off characteristic of the IEC62955 standard (monitoring the dc fault current). An additional driver-circuit must be used for driving a load switch or circuit breaker as defined in IEC62955 / UL2231 as applicable.

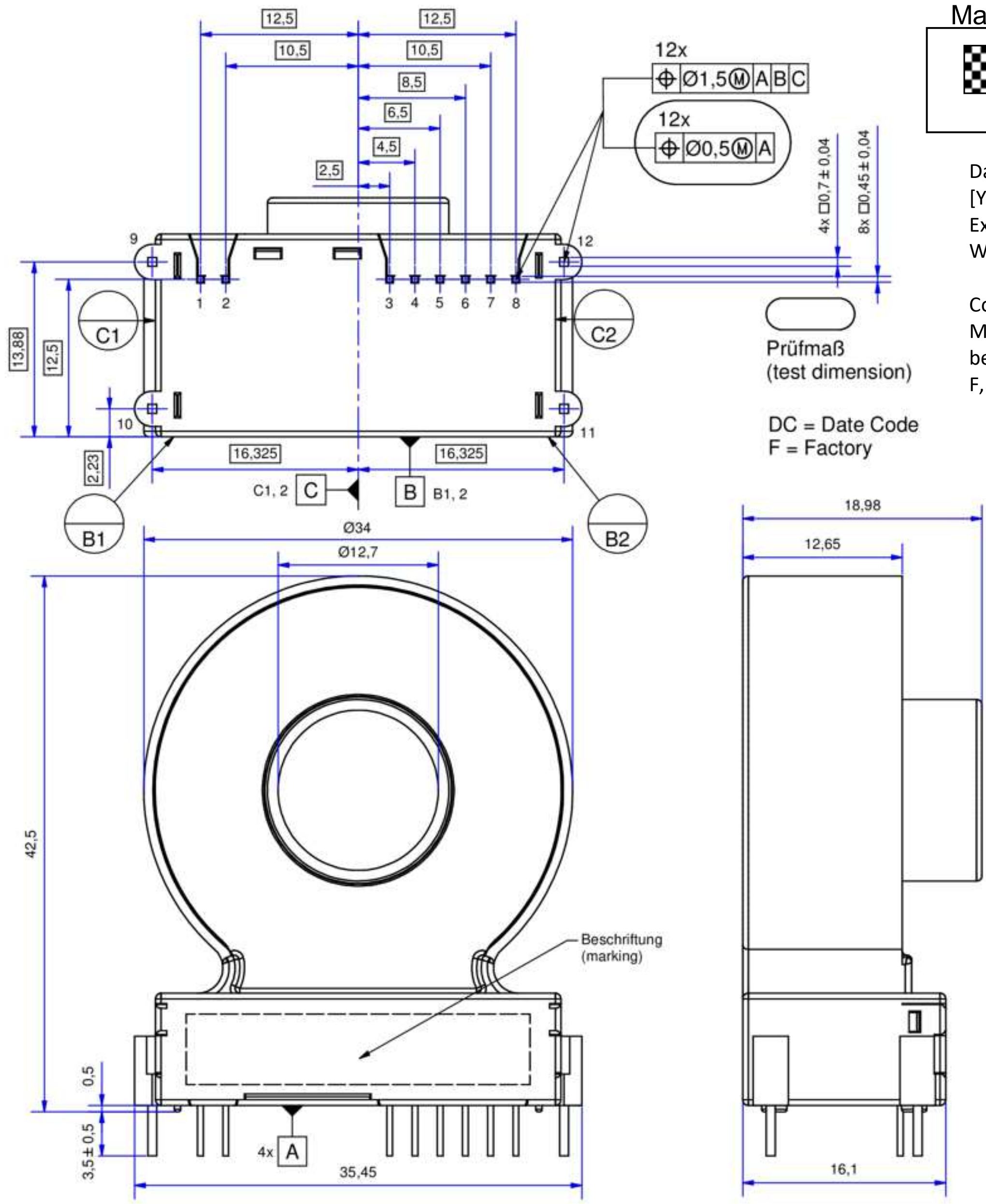
| Datum | Name | Index | Änderung |
|---|---|---|---|
| | | 81 | |
| | | | |

| Editor: R&D-PD NPI D | Designer: SF | | MC-PM: ZB | | | Released by: SB |
|---|---|---|---|---|---|---|

**Mechanical outline (mm):** General tolerances DIN ISO 2768-c

Connections:

PIN no. 1-8: 0.46mm x 0.46mm
PIN no. 9-12: 0.7mm x 0.7mm




Marking:

benvac
4641-X836
F DC

Datecode Format:
[YWW]
Example: J04: 2017, Week 4

Content of Data-Matrix-Code is:
benvac, 4641-X836, F, DC

| Editor: R&D-PD NPI D | Designer: SF | | MC-PM: ZB | | | Released by: SB |
|---|---|---|---|---|---|---|



## PIN description:

| **PIN no.** | **Description** |
|---|---|
| PIN 1 → VCC | Positive supply voltage |
| PIN 2 → GND | Ground connection |
| PIN 3 → TxD | UART Interface Transmit Data (see Chapter "Serial Data Interface (UART)" for more information) |
| PIN 4 → RxD-T | UART Interface Receive Data<br>2nd function (Test via internal microcontroller): A function test including an offset measurement is activated if this PIN is connected to GND for a period of 40ms to 1.2s. If the PIN is set to GND less than 40ms or more than 1.2s, no function test will be performed, see timing diagram (fig. 3).<br>**Attention:** During the functional test and offset measurement, no differential current may flow. UART interface is a diagnostic interface and is not suitable for activating protective measures against electric shock (disconnection of the monitored circuit).<br>To ensure high accuracy of the sensor this test should be activated at regular intervals (e.g. at startup, before measuring…).<br>If a push-pull switch is used, the voltage range must be 0V…5V.<br>(see Chapter "Serial Data Interface (UART)" for more information) |
| Pin 5 → DE | Drive Enable for Serial communication transceivers.<br>For Typical Application it is left open. |
| PIN 6 → X20-OUT (open collector output) | X20 switches in acc. to UL2231 (CCID20 requirements) and no system fault occurs the output on PIN 6 is a low level (GND). In any other case PIN 6 is in a high impedance state (see tab. 1). |
| PIN 7 → X6-OUT (open collector output) | X6 switches in acc. to IEC62955 requirements and no system fault occurs the output on PIN 7 is a low level (GND). In any other case PIN 7 is in a high impedance state. (see tab. 1). |
| PIN 8 → T-W | Test winding N=25 (max. ratings → 5 mA) Test winding is internally connected to VCC. (see fig. 1) |

**Typical application diagram:**

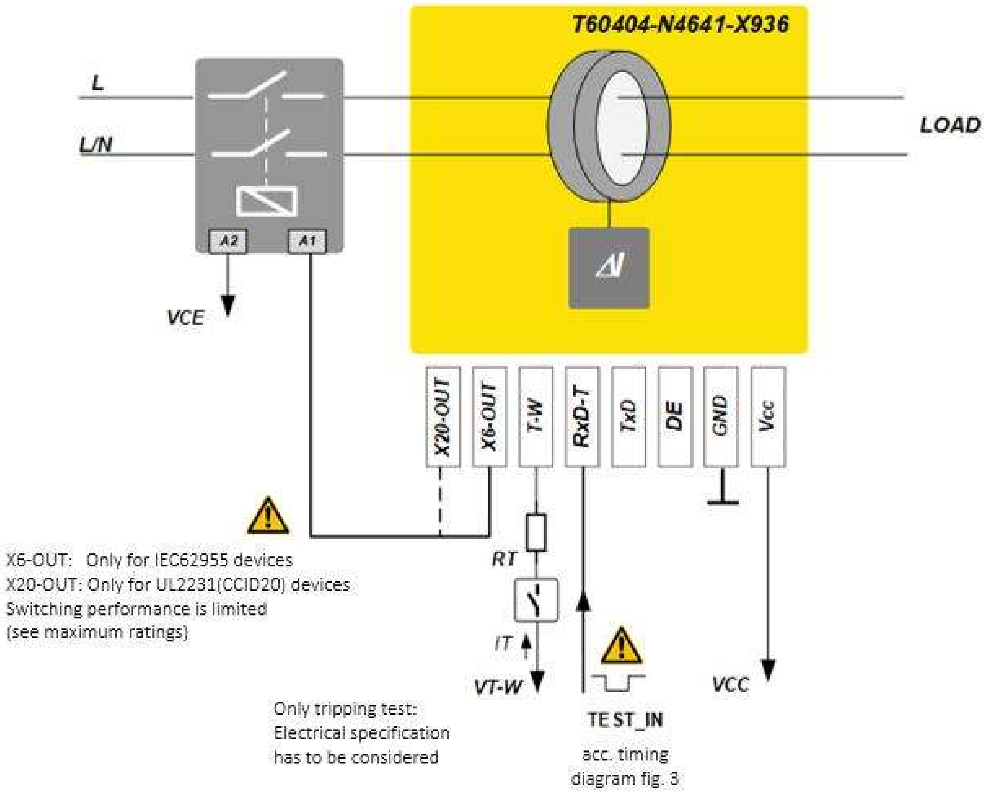
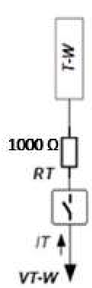



***Fig. 1: Single sensor configuration without using UART***

The sensor can be used without UART Interface. In this case a functional test is carried out by a LOW level signal on terminal RxD-T (acc. timing diagram fig. 3). It is essential to perform a sensor test regularly for proofability of the sensors function correctly.
Figure 3 explains the timing of the functional test via terminal RxD-T. The sensor generates a suitable internal test current to test the tripping levels for the output X6-OUT and X20-OUT (acc. timing diagram fig. 3).

The function of the sensor can also be tested using the test winding. Internally, the test winding is connected to Vcc. With an external switch to pin T-W the test current can be applied, a resistor (RT) in series to the switch and T-W limits the current to the test winding. If the RT resistor is not installed, a short circuit occurs across the test winding, which destroys the sensor. To keep the max ratings of 5 mA a 1k Ohm resistor should be installed. The test current of 125 mA is then obtained through the turns ratio of N = 25.




Current can calculated by: $IT = \frac{V_{cc}}{RT} = \frac{5\,V}{1000\,\Omega} = 5\,mA$

| **Absolute maximung ratings[6]:** | | **Min.** | **Typ.** | **Max.** | **Unit** |
|---|---|---|---|---|---|
| $V_{CEO}$ | Collector-Emitter voltage (PINs 6 and 7) | | | 40 | V |
| $I_{CC,MAX}$ | Collector current (PINs 6 and 7) | | | 50 | mA |
| $V_{CC}$ | Maximum supply voltage (without function) | -0.3 | | 6 | V |
| $U_{Max}$ | Maximum rated insulation voltage | | | 250 | V |
| $V_{TEST-IN, low}$ | TEST-IN Input Voltage, low level | 0 | | 0.6 | V |
| $V_{TEST-IN, high}$ | TEST-IN Input Voltage, high level | 2.5 | | 5 | V |

**(6)Stresses above these ratings may cause permanent damage.**
**Exposure to these conditions for extended periods may degrade device reliability.**
**Functional operation of the device at these or any other conditions beyond those specified is not supported. The values described here refer only to the basisinsulation**

**Final Tests:** (Measurements after temperature balance of the samples at room temperature, SC=significant characteristic)

| | | **Min.** | **Max.** | **Unit** |
|---|---|---|---|---|
| HV | HV-test | 1500 | 0 | V |
| Vcc | Supply voltage | 4.9 | 5.1 | $V_{DC}$ |
| Status & Calib | Calib. Via UART | | | |
| Icc | Supply current | 16 | 28 | mA |
| RxD_Vcc | RxD-T voltage | 2.8 | 3.4 | V |
| X6-OUT (normal) | X6-OUT voltage | 0 | 0.6 | V |
| X20-OUT (normal) | X20-OUT voltage | 0 | 0.6 | V |
| X6-OUT (activated) | X6-OUT voltage activated @5V, 1kΩ (pull-up) | 4.9 | 5.1 | V |
| X20-OUT (activated) | X20-OUT voltage activated @5V, 1kΩ (pull-up)* | 4.9 | 5.1 | V |
| TC1 (SC) | Trip current_1 - X6-OUT +6mA DC / 80A@50Hz | 4.5 | 5.4 | mA |
| TC2 | Trip current_2 - X6-OUT -6mA DC | -5.4 | -4.5 | mA |
| TC3 | Trip current_3 - X20-OUT 20mA@60Hz | 14 | 20 | mA |
| TC4 | Trip current_4 – X20-OUT 130mA@1000Hz | 105 | 149 | mA |
| LV1 | Limit values of break time - X6-OUT@6mA DC | 0 | 700 | ms |
| LV2 | Limit values of break time – X20-OUT@20mA, 60Hz | 0 | 1000 | ms |
| EXT1 | Externally winding test – X6 act | 4.9 | 5.1 | V |
| EXT2 | Externally winding test – X20 act. | 4.9 | 5.1 | V |

**Product Tests:** (more EMC test's can be shown if required)

| | | | |
|---|---|---|---|
| ESD | Acc. to VAC sheet M3238<br>Air- and contact discharge;<br>U=±2000V, R=1500Ω, C=100pF<br>Acc. to Human Body Model JESD22-A114 | tbd<br>±2.0 | kV |

**Requalification Tests:** (replicated every year, Precondition acc. to M3238)

| | | | | |
|---|---|---|---|---|
| $\hat{U}_{W, prim-sec}$ | M3064 | Impulse test (1.2µs/50µs waveform)<br>PIN 1-8 vs. primary wire<br>5 pulse ➔ polarity +, 5 pulse ➔ polarity - | 5.5 | kV |
| $U_d$ | M3014 | Test voltage, 60s<br>PIN 1-8 vs. primary wire | 1.5 | kV rms |
| $U_{PDE}$ | M3024 | Partial discharge voltage (extinction)<br>PIN 1-8 vs. primary wire<br>*acc. to table 24 IEC 61800-5-1:2007 | 1.2 | kV rms |
| $U_{PD}$ x 1.875 | M3024 | Partial discharge voltage (extinction)<br>PIN 1-8 vs. primary wire<br>*acc. to table 24 IEC 61800-5-1:2007 | 1.5 | kV rms |

**Other instructions:**

- Temperature of the primary conductor should not exceed 105°C.
- Housing and bobbin material UL-listed, flammability class 94V-0.
- UL certification is still pending
- ~~Further standards UL 2231 E-file No. 488116, category FFUQ2 / FFUQ8~~
- ⚠ The UART-interface is not suitable to use the alarm message for safety measure

**Requirements to be fulfilled by the customer application**

- Vcc during Test-IN function test must be at least 4.8V
- Fall- and rise-time of Vcc: t > 20µs/V

**Figures:**

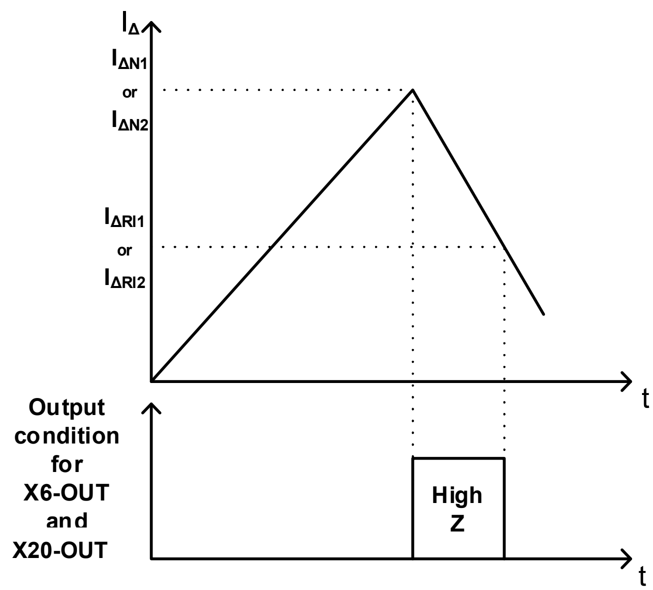
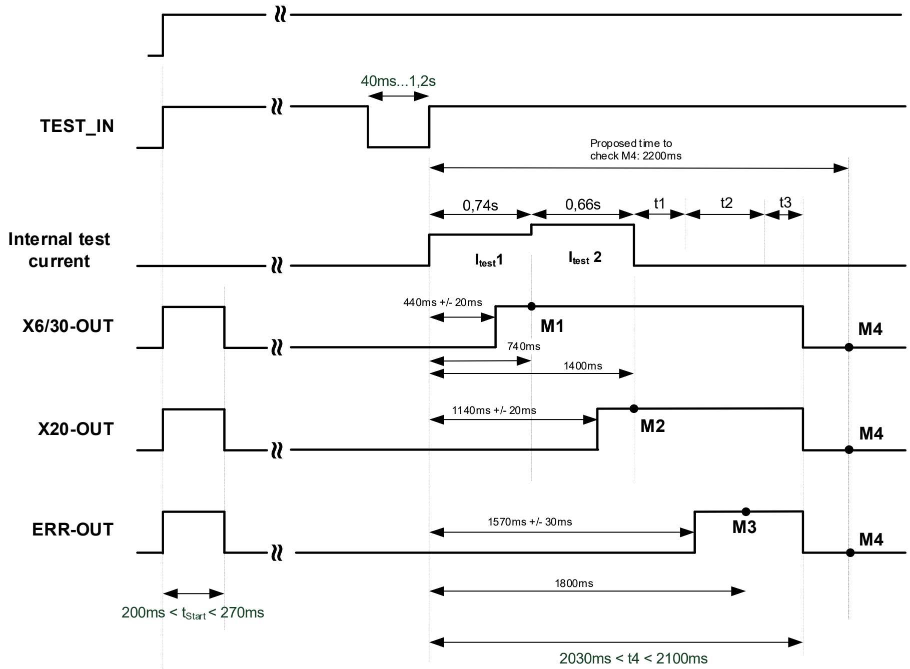



***Fig. 2: Meaning of switching recovery level***

If the trip-level $I_{\Delta N1}$ is reached the outputs X6-OUT and X20-OUT will change it state from low-level (GND) to high impedance. Depending on the presence of the differential curent $I_\Delta$, the outputs X6-OUT and X20-OUT will remain in this state until $I_\Delta$ falls below recovery threshold $I_{\Delta RI1}$.




| | | |
|---|---|---|
| **t1 = 120ms** | | **Check for welded contacts.** |
| **t2 = 500ms** | | **Time for offset calibration.** |
| **t3 =10ms to 80ms** | | **Time required to store the offset calibration value. Depends on the difference to the value already stored in memory.** |
| **M1...M4** | | **points in time to check output levels** |

***Fig. 3: Power-Up timing diagram***

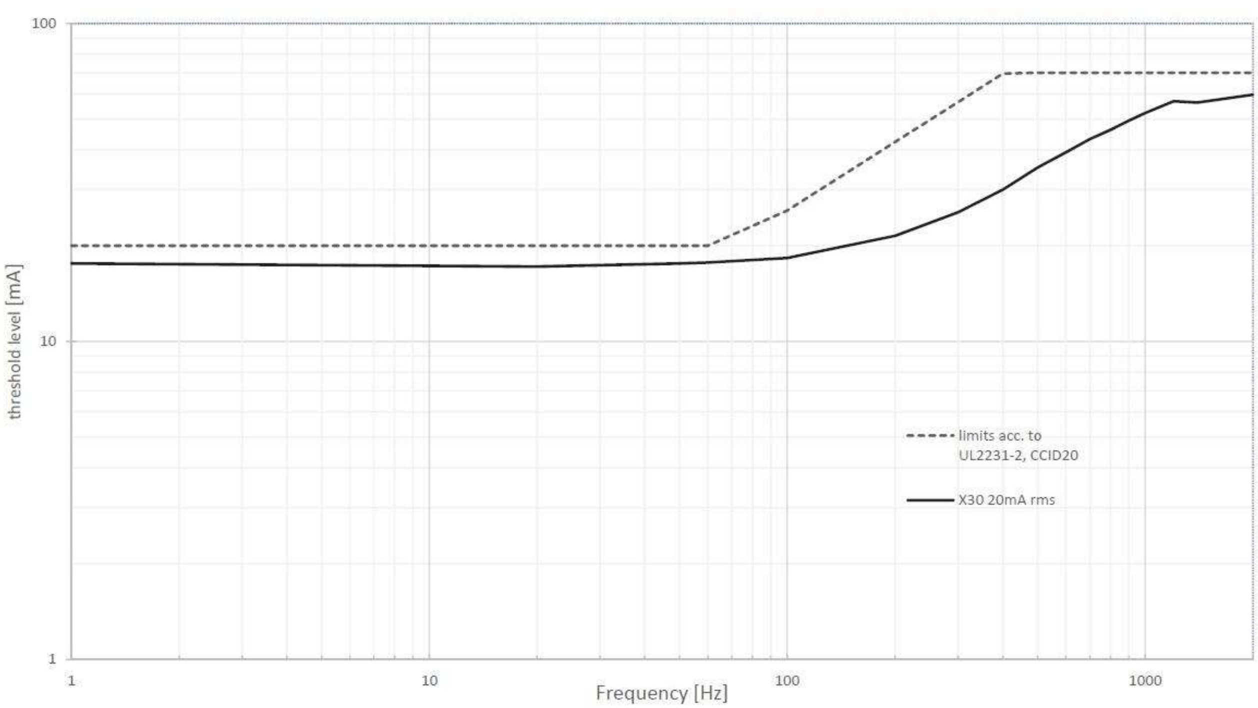



***Fig. 5:UL2231 response value over frequency***

| X6-OUT | X20-OUT | State |
|---|---|---|
| GND | GND | Normal condition |
| High impedance | GND | $I_{\Delta N1} \geq$ DC6mA |
| GND | High impedance | $I_{\Delta N2} \geq$ AC20mA |
| High impedance | High impedance | $I_{\Delta N2} \geq$ DC20mA<br>or<br>Error, system fault |
| All other conditions not mentioned in the table are not possible. If these conditions occur, the sensor is an unknown state and describes an Error. | | |

***Tab. 1: Possible output states***

| | 6mA | 60mA | 200mA |
|---|---|---|---|
| Standard values acc. to IEC62955:2018 | 10s | 0.3s | 0.1s |
| Typical values of sensor | 0.45s | 0.06s | 0.035s |

***Tab. 2: Maximum and typical values of break time for residual direct currents***

## Typical application diagram using UART-interface:

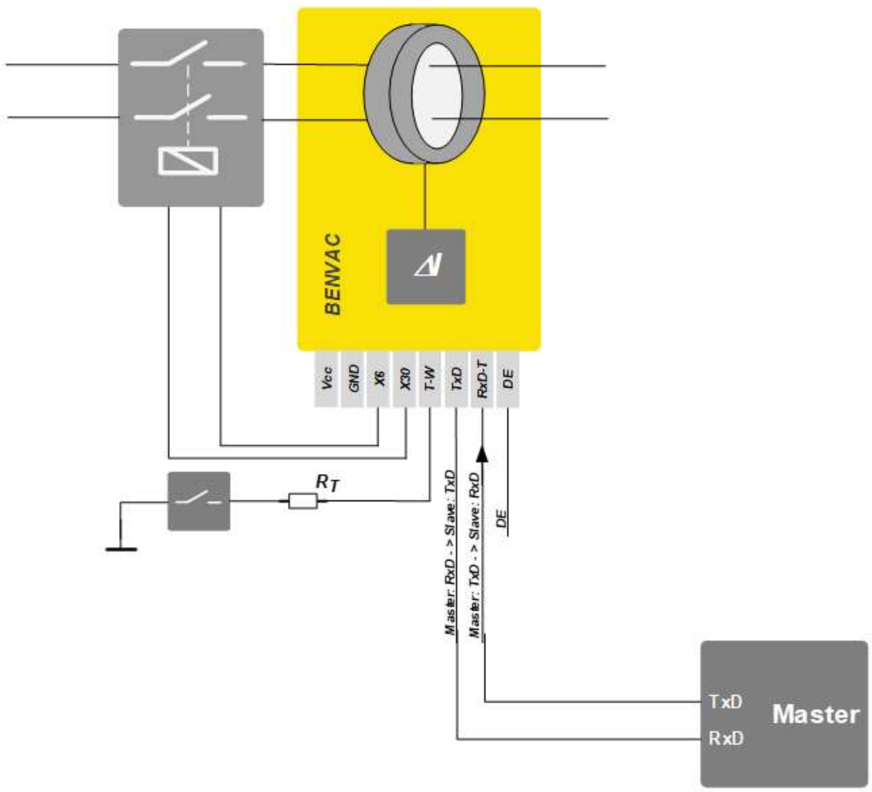



***Fig 6: UART Typical Application with Master***

Figure 6 explains the typical application for the sensor with additional Master to interface the sensor. In this system, the interface-signals TxD and RxD are cross connected (Master TxD -> Sensor RxD; Master RxD -> Sensor TxD). The master addresses a sensor by sending a message acc. to the protocol described in chapter “Serial Data Interface (UART)”.
The sensor monitors and trips via the switching outputs X6-OUT/X20-OUT if the leakage current exceeds the response value.
A functional test can be started by the master using the “start functional test”-message (see chapter “Serial Data Interface (UART)”).
The master has access to measured values via the interface by using the “get measurement and status”-message according to chapter “Serial Data Interface (UART)”.

## Serial Data Interface (UART)

| Parameter | Specification | Description |
|---|---|---|
| Address range | 1…255 (0x01 – 0xFF) | Factory setting: 0x64 = 100d |
| Configuration | 10 bit | 1 startbit<br>8 data bits<br>1 stop bit<br>No parity<br>LSB first |
| Message format | Address<br>Message code<br>Message length<br>Message data<br>Checksum: 2 Byte | Adress:0x01..0xFF, default address: 0X64<br>Specification: acc. section “General message format” |
| Data Direction (DE-PIN) | LOW: Receive data<br>HIGH: transmit data | |
| TxD voltage signal‘s | High-signal: 2,7V…3,5V<br>Low-signal: 0,0…0,5V | |
| RxD voltage signal‘s | High-signal: 2,4…3,6V<br>Low-signal: 0…0,40V | |
| Transmission distance | ≤200mm | from the sensor pins to a master or interface driver |
| TxD Output-Resistance | 100Ω | |
| TxD Short circuit behavior | protected | |
| Data transmitting rate | 19200 baud | |
| Cycle time T1 | 1/ 19200 (s) | |
| Falling/rising time T2/T3 | < 200ns | |

***Tab. 3: Serial Data Interface (UART)***

## Data frame

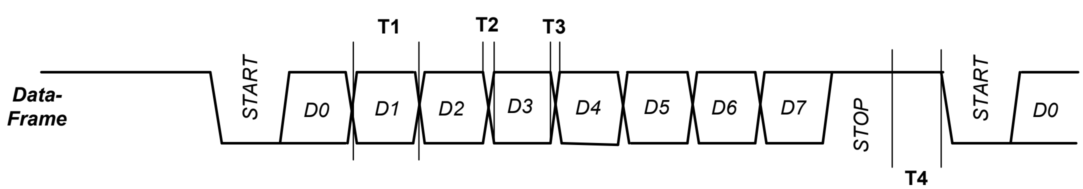



***Fig. 7: Data format UART-protocol***

## Timing

An idle time of more than 2 bytetimes between 2 bytes is interpreted as end of the message.
The slave starts to send an answer (begin of startbit) by no later than 20ms after reception of the stopbit of the last message byte.
Between 2 requests to a slave, the master shall wait a minimum time of 50ms until the next request. This is to avoid influence on the residual current measurement because of high traffic loads generated by a master.

## Error handling

Each message transmitted has a 16-Bit checksum in the last two bytes transmitted to check the message integrity.
The crc is calculated byte by byte incorporating the complete message and then the two crc bytes are appended on the end of the message.
The crc-polynom used is 0x18005 (x^16 + x^15 + x^2 + 1).
If a slave detects a crc-error, it does not answer that request. The master shall repeat the message up to 2 times and if the slave still does not answer, the slave shall be considered to be defective.

## General message format

| Sensor-address | Message-Code | Message-Length | Message-Data[ ] | CRC high byte | CRC low byte |
|---|---|---|---|---|---|

*Tab. 4: General message format*

The sensor address (1 byte) is the slave address in the range of 1..255. Address 0 is the broadcast address.
The message-code (1 byte) contains the coding instruction of the following bytes.
The message-length (1 byte) contains the length of the optionally following message-data field. 0 means no message-data field follows.
The message-data-field contains the data for the message.
The crc (2 bytes) is calculated from sensor-address up to the last byte of the message-data field.
Numbers larger than 1 byte are transmitted most significant byte first.
Integer numbers are represented in two´s complement.

## Messages Overview

| Message | Message-Code | Description |
|---|---|---|
| Get measurement and status | 0x01 | Retrieve dc and rms value of the differential current.<br>Get info about operational state, fault state and hardware coded configuration state |
| Start functional test | 0x04 | Start a functional test to determine correct switching ability of the sensor hardware |

*Tab. 5: Message-Code*

## Start functional test

| Master request | | Slave answer | |
|---|---|---|---|
| Adr. | address 1..255 | Adr. | Slave address |
| MsgCode | 0x04 | MsgCode | 0x04 |
| MsgLength | 0x00 | MsgLength | 0x01 |
| CRC | crc highbyte | MsgData[0] | Infobyte |
| CRC | crc lowbyte | CRC | crc highbyte |
| | | CRC | crc lowbyte |

*Tab. 6: functional test*

A functional test is started with this command.

Infobyte:
- 0x00 General problem, request cannot be executed.
- 0x01: Request accepted and will be executed
- 0x02: Request cannot be executed because a test or reset is just active.
- 0x03..0xff: reserved

During the functional test an offset measurement is conducted. Offset measurement takes place during the last max. 600ms before the end of the functional test sequence.

## Get measurement and status

| Master request | | Slave answer | |
|---|---|---|---|
| Adr. | address 1..255 | Adr. | Slave address |
| MsgCode | 0x01 | MsgCode | 0x01 |
| MsgLength | 0x00 | MsgLength | 0x07 |
| CRC | crc highbyte | MsgData[0..1] | $dI_{RMS}$, Highbyte in MsgData[0] |
| CRC | crc lowbyte | MsgData[2..3] | $dI_{DC}$, Highbyte in MsgData[2] |
| | | MsgData[4] | Statusbyte 1 (Operational state) |
| | | MsgData[5] | Statusbyte 2 (Fault state) |
| | | MsgData[6] | Statusbyte 3 (Configuration state) |
| | | CRC | crc highbyte |
| | | CRC | crc lowbyte |

***Tab. 7: Master Slave communication***

The measurement values of residual current rms and dc are represented in 0.1 mA resolution.
MsgData[0…1] contains the rms value of the residual current.
The range is 0.0 mA … 100.0 mA

MsgData[2…3] contains the magnitude of the direct component of the residual current.
The range is 0.0 mA … 300.0 mA

| Bit | meaning | |
|---|---|---|
| Bit 7 | General fault | 1 = fault |
| Bit 6 | reserved | |
| Bit 5 | Testmode | 1 = functional test active<br>0 = normal measurement |
| Bit 4 | reserved | |
| Bit 3 | reserved | |
| Bit 2 | state of X6 | 1=on, enabled, not tripped<br>0=off, disabled, tripped |
| Bit 1 | state of X20 | 1=on, enabled, not tripped<br>0=off, disabled, tripped |
| Bit 0 | state of internal ERROR | 1 = no error, enabled<br>0 = error, disabled |

***Tab. 8: Statusbyte 1***

| Bit | meaning | |
|---|---|---|
| Bit 7 | reserved | |
| Bit 6 | reserved | |
| Bit 5 | Asic fault | 1 = fault |
| Bit 4 | Asic gain fault | 1 = fault |
| Bit 3 | Asic offset fault | 1 = fault |
| Bit 2 | Feedback fault | 1 = fault |
| Bit 1 | reserved | |
| Bit 0 | Configuration fault | 1 = fault |

***Tab. 9: Statusbyte 2***

| Bit | meaning |
|---|---|
| Bit 7 | reserved |
| Bit 6 | reserved |
| Bit 5 | reserved |
| Bit 4 | reserved |
| Bit 3 | reserved |
| Bit 2 | reserved |
| Bit 1 | Unused always 0 |
| Bit 0 | reserved |

***Tab. 10: Statusbyte 3***