# AUTOMOTIVE CURRENT TRANSDUCER FLUXGATE TECHNOLOGY

## CAB-SF 1500-000, CAB-SF 1500-001, CAB-SF 1500-003, CAB-SF 1500-004, CAB-SF 1500-006, CAB 1500-000, CAB 1500-001

## Introduction

The CAB sensor family has been specially designed for the current measurement of the battery packs found in electric and hybrid vehicles. The CAB-SF 1500 sensor is equipped with electronic mechanisms and software that guarantee a level of reliability that is required by the security concepts of battery management systems.

## Features

- Fluxgate transducer technology
- Busbar mounting or panel mounting
- Unipolar +12 V battery power supply
- Output signal: High speed CAN (500 kpbs).

| | CAN Resistor Termination | Casing Version | Other Comments |
|---|---|---|---|
| CAB-SF 1500-000 | 4800 Ω | Bus bar | |
| CAB-SF 1500-001 | 4800 Ω | Panel mounting | |
| CAB-SF 1500-003 | 120 Ω | Bus bar | |
| CAB-SF 1500-004 | 4800 Ω | Bus bar | Inverted $I_P$ sig |
| CAB-SF 1500-006 | 120 Ω | Bus bar | |
| CAB 1500-000 | 4800 Ω | Bus bar | |
| CAB 1500-001 | 4800 Ω | Panel mounting | |

## Special features

- Connector type: Tyco AMP 1473672-1
- Configurable CAN speed
- Configurable CAN ID.

## Advantages

- Low offset
- Total error before ageing

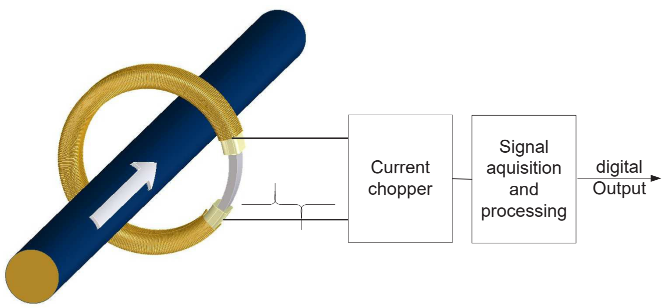
  0.5 %  error over temperature range: −40 °C to +85 °C
- Full galvanic separation.
- Compatible with 800 V applications following ISO60664-1 standard.

## Automotive applications

The CAB-SF 1500 is designed to run in a vehicle battery pack or in a battery disconnect unit and cannot be used in an environment exposed to water projections and gravel projections. The CAB-SF 1500 is compliant with Functional Safety standard ISO 26262.
The test plan used to validate the product is described at the end of the document.

## Principle of Fluxgate Transducers

A low-frequency fluxgate transducer is made of a wound core which saturates under low induction.
A current chopper switches the winding's current to saturate the magnetic core alternatively at ±Bmax with a fixed frequency.
Fluxgate transducers use the change of the saturation's point symmetry to measure the primary current.
Due to the principle of switching the current, all offsets (electric and magnetic) are cancelled.



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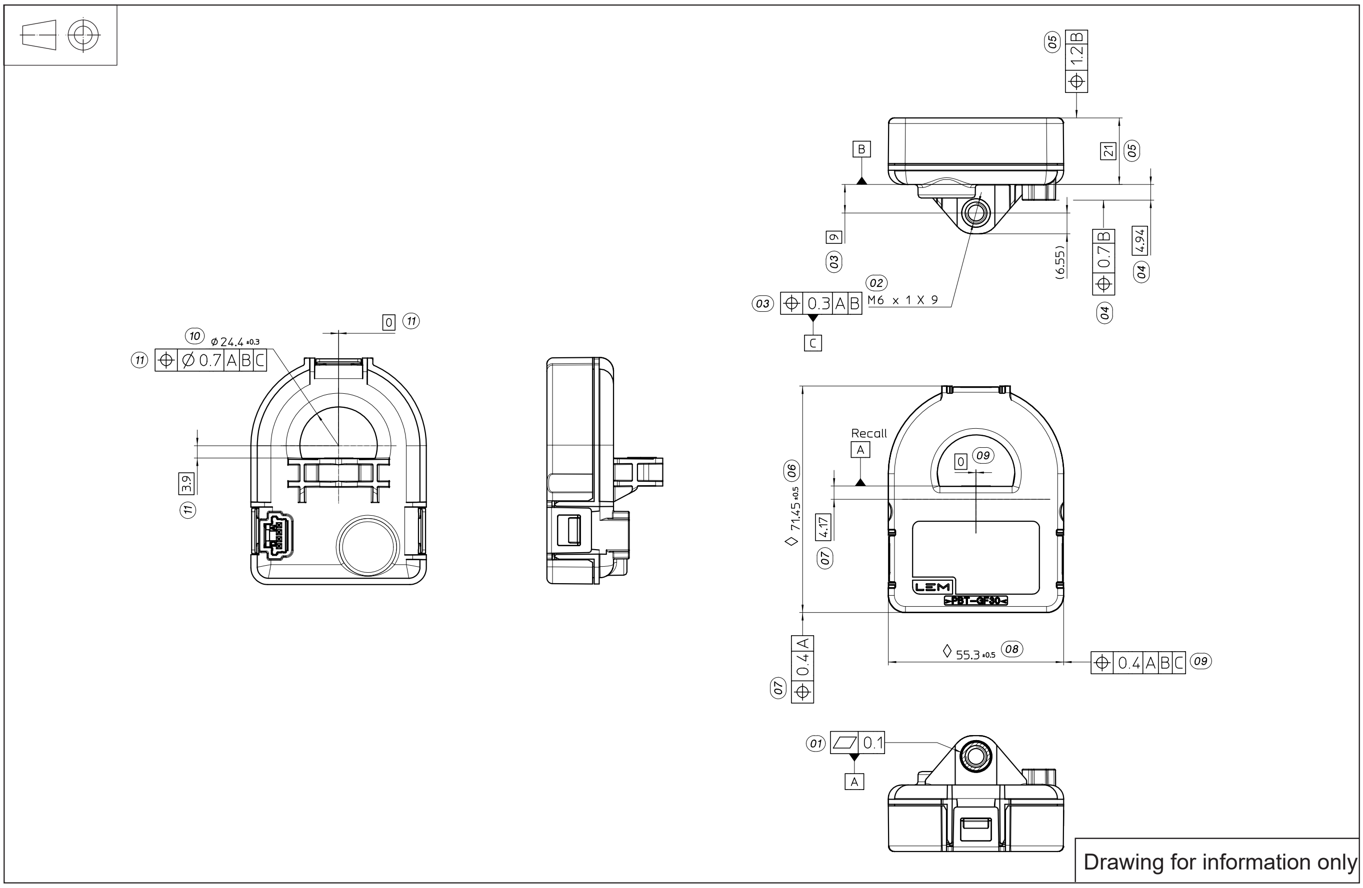
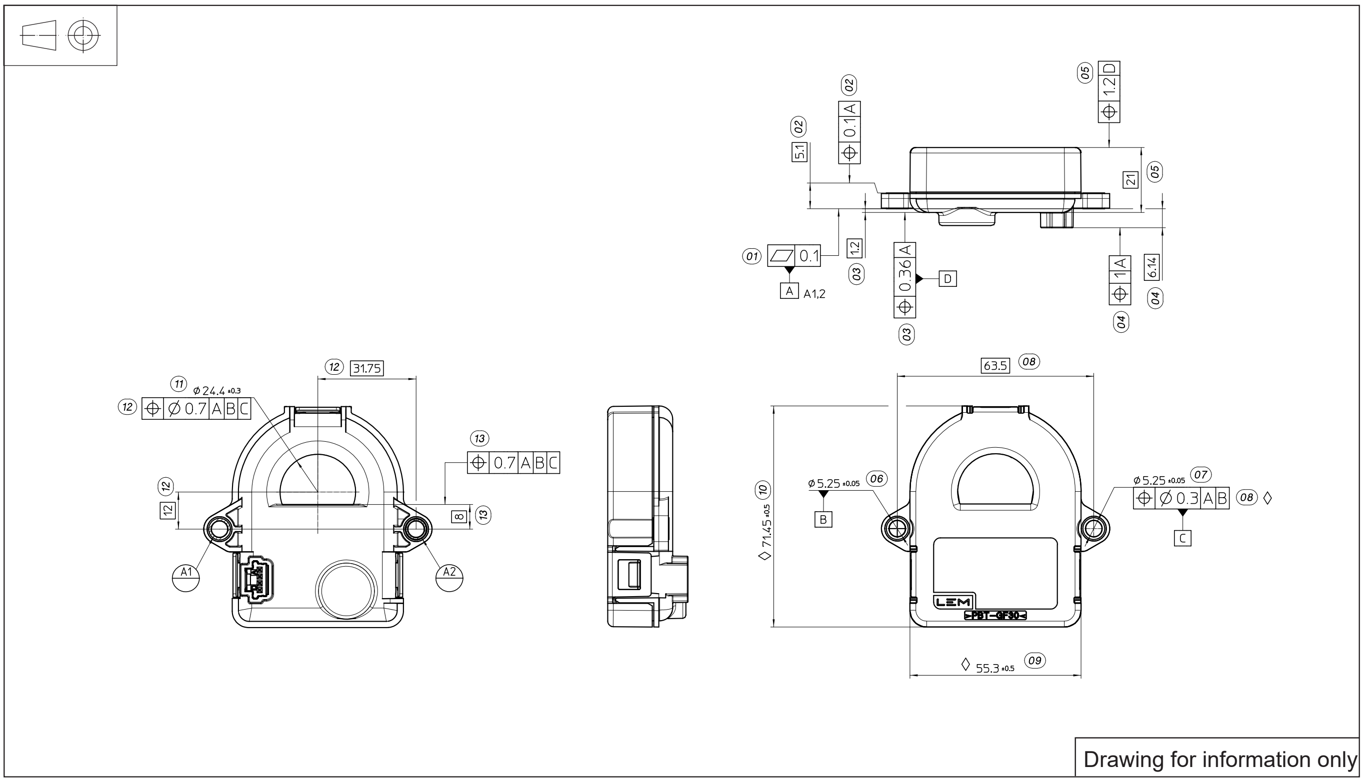
# **Dimensions** (in mm)

## Busbar version




## Panel mounting version





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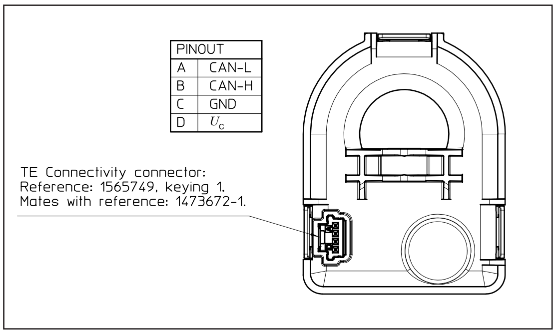
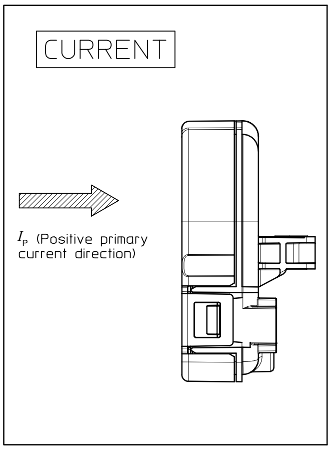
## Connector pin out




## Primary current direction as below:




## Weight and Recommended screwing torque instruction

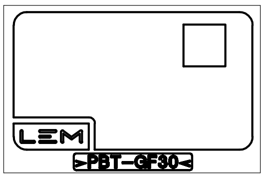
### Busbar Version

- Weight: 94 g ±5 %
- Recommended screwing torque instruction:
  - sensor shall be fixed with M6 fastener
  - tightening torque:
    - screw grade 6.8: 6.6 Nm
    - screw grade 8.8: 7.7 Nm

### Bracket Version

- Weight: 91 g ±5 %
- Recommended screwing torque instruction:
  - sensor shall be fixed with 2 M5 fastener
  - tightening torque:
    - screw grade 6.8: 3.8 Nm
    - screw grade 8.8: 4.4 Nm

## Laser Marking

| Designation | Datacode | 2D matrix content | Text marking area |
|---|---|---|---|
| CAB-SF 1500-000 | P = Production center ID<br>YY = Last two digit of the year<br>DDD = Day number of the year<br>CC = Machine ID<br>HH = Hour<br>MM = Minute<br>SS = Second<br>J = Machine jig ID | PYYDDDCCHHMMSSJ90.D9.65.000.0 |   |
| CAB-SF 1500-001 | | PYYDDDCCHHMMSSJ90.D9.65.001.0 | |
| CAB-SF 1500-002 | | PYYDDDCCHHMMSSJ90.D9.65.002.0 | |
| CAB-SF 1500-003 | | PYYDDDCCHHMMSSJ90.D9.65.003.0 | |
| CAB-SF 1500-004 | | PYYDDDCCHHMMSSJ90.D9.65.004.0 | |
| CAB-SF 1500-005 | | PYYDDDCCHHMMSSJ90.D9.65.005.0 | |
| CAB-SF 1500-006 | | PYYDDDCCHHMMSSJ90.D9.65.006.0 | |
| CAB 1500-000 | | PYYDDDCCHHMMSSJ90.H5.65.000.0 | |
| CAB 1500-001 | | PYYDDDCCHHMMSSJ90.H5.65.001.0 | |
| CAB 1500-002 | | PYYDDDCCHHMMSSJ90.H5.65.002.0 | |
| CAB 1500-004 | | PYYDDDCCHHMMSSJ90.H5.65.004.0 | |



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## Absolute ratings (not operating)

| Parameter | Symbol | Unit | Specification | Conditions |
|---|---|---|---|---|
| Over-voltage | $U_C$ | V | 24 | 1 min |
| Reverse polarity | $U_C$ | V | −18 | 1 min |
| Minimum supply voltage | $U_{C\ min}$ | V | 6 | continuous |
| Maximum supply voltage | $U_{C\ max}$ | V | 18 | continuous |
| Ambient storage temperature | $T_{A\ st}$ | °C | −40 /+105 | |
| Creepage distance | $d_{Cp}$ | mm | 12.5 | |
| Clearance | $d_{Cl}$ | mm | 12.5 | |
| RMS voltage for AC insulation test | $U_d$ | kV | 2.5 | 50 Hz,1 min |
| Insulation resistance | $R_{INS}$ | MΩ | 500 | 500 V - ISO 16750-2 |
| IP Level | | | IP41 | |

## Characteristics in nominal range

| Parameter | Symbol | Unit | Specification | | | Conditions |
|---|---|---|---|---|---|---|
| | | | Min | Typical | Max | |
| **Electrical Data** | | | | | | |
| Supply voltage | $U_C$ | V | 8 | 13.5 | 16 | no continuous operation at [8 V - 10 V], [75 °C - 85 °C] if > 1000 A $I_P$ current |
| Current consumption @ $I_P$ = 0 A | $I_C$ | mA | 50 | 70 | 100 | 8 V < $U_C$ < 16 V, CAN acknowledge |
| Current consumption @ ±$I_P$ = 1500 A | $I_C$ | mA | 430 | 500 | 1300 | 8 V < $U_C$ < 16 V, CAN acknowledge |
| Ambient operating temperature | $T_A$ | °C | −40 | | +85 | |
| **Performance Data** | | | | | | |
| Primary nominal DC or RMS current | $I_{P\ N}$ | A | −1500 | | 1500 | |
| CAN signal 'CSM_BAT_CURRENT' clamping value | | A | −1550 | | 1550 | For $I_P$ between ±1550 A and over current value |
| Primary withstand peak current (maximum) | $\hat{I}_{P\ max}$ | A | −1700 | | 1700 | |
| Overload recovery time | $t_s$ | ms | | 10 | | When $I_P$ goes back under 1550 A |
| Frequency bandwidth | $BW$ | Hz | | 20 | | With Periodic CAN message @ 10 ms |
| Start-up time | $t_{start}$ | ms | | 170 | | |
| **Analog measurement Channel** | | | | | | |
| Linearity error | $\varepsilon_L$ | % | | ±0.1 | | At room temperature |
| Total error: [−1500 A, +1500 A] | $\varepsilon_{tot}$ | % | | ±0.5 | | Over full temperature range Performances are considered with average value over 20 CAN frames (200 ms) |
| Output noise | | mA | | ±50 | | With Periodic CAN message @ 10 ms. Peak to peak value. No averaging |
| **Digital measurement channel** | | | | | | |
| Total error | $\varepsilon_{tot}$ | % | | ±7 | | With a minimum of ±2 A Typical value after ageing Performances are considered with average value over 20 CAN frames (200 ms) |



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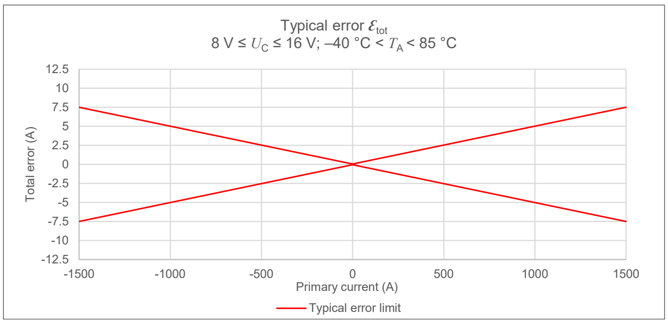
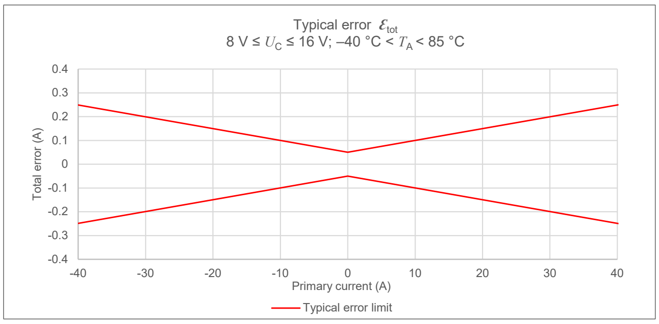
## Typical Error Graph

Analog Channel - Typical error from −40 °C to 85 °C:
Performances are considered with average value over 20 CAN frames (200 ms)




| $I_P$ | Total error (8 V ≤ $U_C$ ≤ 16 V; −40 °C < $T_A$ < 85 °C) | |
|---|---|---|
| | Max error @ 3 sigma | |
| (A) | (A) | (%) |
| −1500 | ±7.5 | ±0.5 |
| 0 | ±0.05 | - |
| 1500 | ±7.5 | ±0.5 |





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## External Magnetic Field Influences

The CAB-SF 1500 delivers an accurate current level measurement. However, to ensure its proper functioning and to ensure the current level accuracy, it is necessary to comply with rules for setting up in the BMS environment. Thus, some conditions must be respected during the design of the environment of the sensor:

- Primary busbar centering
- Busbar shape
- Contactors position

LEM's recommendations can be found in the application notes available on request. Please contact LEM support team to ensure that your busbars design fits with LEM's design guideline.

## Current Ripple Influences

Current ripples on the high voltage DC lines could be induced during power conversion from devices like DC/DC, inverter, on-board charger, and so on.

Current ripples not only negatively impact on the health of li-ion batteries, but also could cause malfunctions of the CAB sensor. The failure mode can manifest itself as a disturbed current measurement due to aliasing effect, leading to internal error when the threshold is exceeded. The malfunctions can be automatically recovered when the ripple current is absent.

Normally the ripple current should be measured and minimized during vehicle system design and development. For proper function of the CAB sensor, the acceptable maximum value of the ripple current should be checked. Please contact LEM support team on the reference values, LEM's recommendations can be found in the application notes available on request.



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## CAN output specification

- CAN protocol 2.0B
- Bit order: big endian (Motorola)
- CAN oscillator tolerance: 0.27 %
- No sleep mode capability
- 120 ohm termination resistor to be added externally (except CAB-SF 1500-003, CAB-SF 1500-006), internal CAN impedance = 4800 ohm
- CAB-SF 1500-003 and CAB-SF 1500-006 integrates 120 ohm termination resistor inside sensor
- User guide for CAN modification can be found in the application notes available on request.

## CAB-SF 1500 CAN message table

- CAB1500_$I_P$ message overview.
  Default frame ID: 0x3C2; transmit period: 10 ms.

| CAN Frame Content | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| BYTE 0 | Sequence Counter $I_P$ | | | | Status Power Supply | | Status Internal Error | Safety Goal Violation |
| | MSB | | | LSB | MSB | LSB | | |
| BYTE 1 | Analog Current | | | | | | | |
| | MSB | | | | | | | |
| BYTE 2 | Analog Current | | | | | | | |
| | | | | | | | | |
| BYTE 3 | Analog Current | | | | | | | |
| | | | | | | | | LSB |
| BYTE 4 | Digital Curent | | | | | | | |
| | MSB | | | | | | | |
| BYTE 5 | Digital Curent | | | | | | | |
| | | | | | | | | LSB |
| BYTE 6 | Reserved | | | | | | | |
| | MSB | | | | | | | LSB |
| BYTE 7 | CRC_ $I_P$ | | | | | | | |
| | MSB | | | | | | | LSB |



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- **'SequenceCounter$I_P$' signal**
  - Initialized with 0 and incremented by 1 for every subsequent send request
  - When the counter reaches the value 15 (0xF), then restart with 1 for the next send request.

- **'StatusPowerSupply' signal**

| CAN Frame Content | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| BYTE 0 | Sequence Counter $I_P$ | | | | Status Power Supply | | Status Internal Error | Safety Goal Violation |
| | MSB | | | LSB | MSB | LSB | | |

When Power Supply voltage measurement is not available, then 'StatusPowerSupply' = "1 1"

Notes:
- At sensor start-up, if supply voltage < 7.8 V or > 16.2 V, no CAN frame emission
- Status details can be found in the application notes available on request.

- **'Status Internal Error' signal**

This flag is set to 1 to inform the BMS about two use cases:
- Internal hardware error (reference voltage, DAC errors)
- Over current detected in the busbar - current above 1600 A. In this use case, the Status Internal Error flag is set to 1 (see details on the next page in 'AnalogCurrent' signal section)

- **'Safety Goal Violation' signal [SG1: Current Sensing Error]**

within the current range of [ −1500 A; −220 A [ and ] +220 A; +1500 A ], if there more than 20% of difference between analog current level and digital current level --> then Safety Goal Violation = 1

within the current range of [ −220 A; 220 A ], if there is a gap above 44 A between analog current level and digital current level --> then Safety Goal Violation = 1

Safe State: To provide Safety Goal violation flag, keep providing data measurement
FTTI: 500 ms


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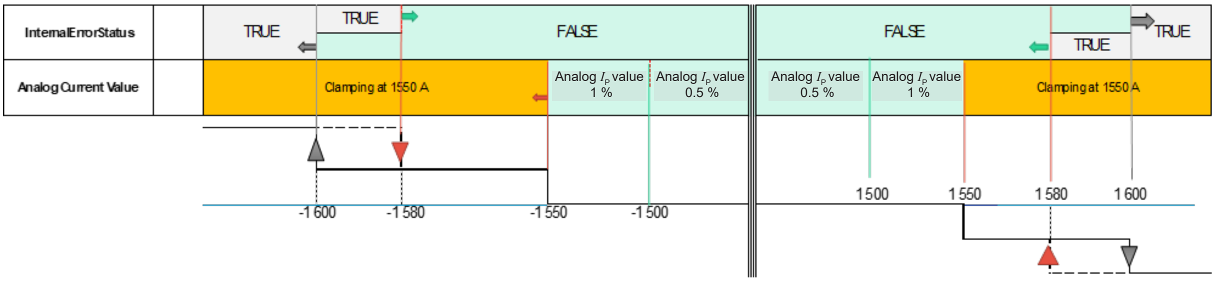
• **'Analog Current' signal**

Analog measurement of the primary current
−1500 ≤ $I_P$ ≤ +1500. 'Analog Current' signal = $I_P$. Error = 0.5 %
−1550 ≤ $I_P$ < −1500. 'Analog Current' signal = $I_P$. Error = 1 %
+1500 < $I_P$ ≤ +1550. 'Analog Current' signal = $I_P$. Error = 1 %




Here below the values for Byte 1, 2 and 3:

| $I_P$ | Hex value | MSB | | LSB |
|---|---|---|---|---|
| | | Byte 1 | Byte 2 | Byte 3 |
| 1550.000 | 97A6B0 | 97 | A6 | B0 |
| 1500.000 | 96E360 | 96 | E3 | 60 |
| 0.001 | 800001 | 80 | 00 | 01 |
| 0.000 | 800000 | 80 | 00 | 00 |
| −0.001 | 7FFFFF | 7F | FF | FF |
| −1500.000 | 691CA0 | 69 | 1C | A0 |
| −1550.000 | 685950 | 68 | 59 | 50 |



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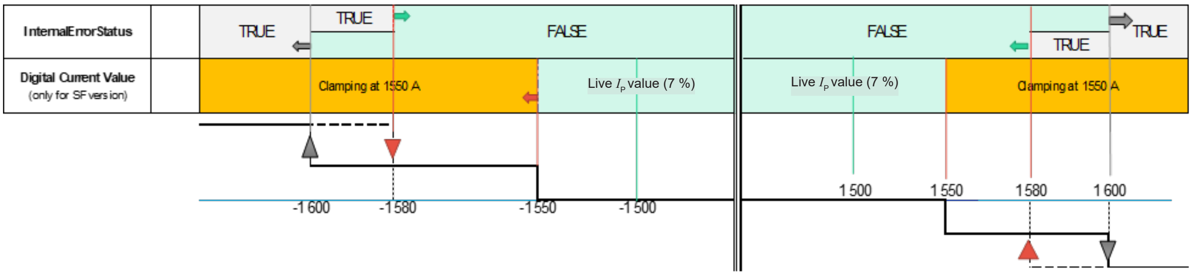
• 'Digital Current' signal

$\hat{I}_{P\,max} \le I_P < -1550$. 'Digital Current' signal is clamped at −1550 A. Error = NA
$+1550 < I_P \le \hat{I}_{P\,max}$. 'Digital Current' signal is clamped at +1550 A. Error = NA




Digital measurement of the primary current, Byte 4 and 5:

| $I_P$ | Hex value | MSB | LSB |
|---|---|---|---|
| | | Byte 4 | Byte 5 |
| 1550 | 860E | 86 | 0E |
| 1500 | 85DC | 85 | DC |
| 1 | 8001 | 80 | 01 |
| 0 | 8000 | 80 | 00 |
| −1 | 7FFF | 7F | FF |
| −1500 | 7A24 | 7A | 24 |
| −1550 | 79F2 | 79 | F2 |

**• 'CRC_ $I_P$' signal**

8-bit SAE J1850 CRC calculation of the first seven bytes.

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## CAB 1500 CAN message table

● CAB1500_$I_P$ message overview.

Default frame ID: 0x3C2; transmit period: 10 ms.

| CAN Frame Content | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| BYTE 0 | Sequence Counter $I_P$ | | | | Status Power Supply | | Status Internal Error | Reserved |
| | MSB | | | LSB | MSB | LSB | | |
| BYTE 1 | Analog Current | | | | | | | |
| | MSB | | | | | | | |
| BYTE 2 | Analog Current | | | | | | | |
| | | | | | | | | |
| BYTE 3 | Analog Current | | | | | | | |
| | | | | | | | | LSB |
| BYTE 4 | Reserved | | | | | | | |
| | | | | | | | | |
| BYTE 5 | Reserved | | | | | | | |
| | | | | | | | | |
| BYTE 6 | Reserved | | | | | | | |
| | | | | | | | | |
| BYTE 7 | CRC_ $I_P$ | | | | | | | |
| | MSB | | | | | | | LSB |

• **'SequenceCounter$I_P$' signal**

- Initialized with 0 and incremented by 1 for every subsequent send request
- When the counter reaches the value 15 (0xF), then restart with 1 for the next send request

• **'StatusPowerSupply' signal**

| CAN Frame Content | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| BYTE 0 | Sequence Counter $I_P$ | | | | Status Power Supply | | Status Internal Error | Reserved |
| | MSB | | | LSB | MSB | LSB | | |

When Power Supply voltage measurement is not available, then 'Status Power Supply' = "1 1"

Notes:
• At sensor start-up, if supply voltage < 7.8 V or > 16.2 V, no CAN frame emission
• Status details can be found in the application notes available on request.





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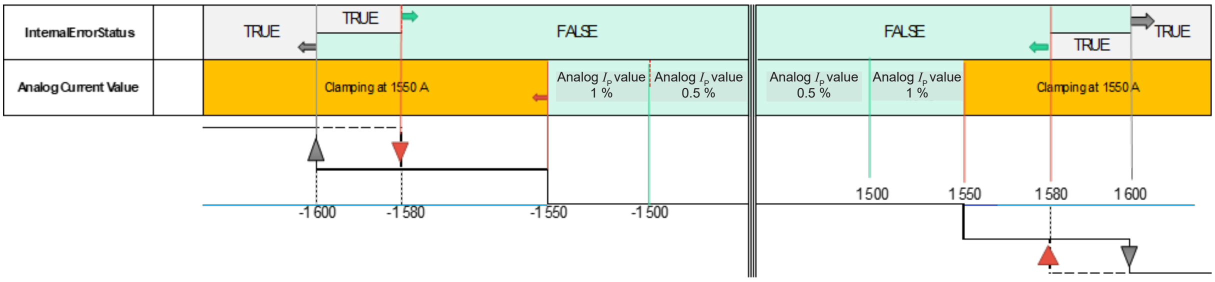
**• 'Status Internal Error' signal**

Internal hardware error (reference voltage, DAC errors).

**• 'Analog Current' signal**

Analog measurement of the primary current
$-1500 \le I_P \le +1500$. 'Analog Current' signal = $I_P$. Error = 0.5 %
$-1550 \le I_P < -1500$. 'Analog Current' signal = $I_P$. Error = 1 %
$+1500 < I_P \le +1550$. 'Analog Current' signal = $I_P$. Error = 1 %




Here below the values for Byte 1, 2 and 3:

| $I_P$ | Hex value | MSB | | LSB |
|---|---|---|---|---|
| | | Byte 1 | Byte 2 | Byte 3 |
| 1550.000 | 97A6B0 | 97 | A6 | B0 |
| 1500.000 | 96E360 | 96 | E3 | 60 |
| 0.001 | 800001 | 80 | 00 | 01 |
| 0.000 | 800000 | 80 | 00 | 00 |
| −0.001 | 7FFFFF | 7F | FF | FF |
| −1500.000 | 691CA0 | 69 | 1C | A0 |
| −1550.000 | 685950 | 68 | 59 | 50 |

**• 'CRC_ $I_P$' signal**

8-bit SAE J1850 CRC calculation of the first seven bytes.



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## Applicable standards - Functional Safety - CAB-SF 1500

| Safety | | |
|---|---|---|
| | | Safety Manual Table of Contents |
| Functional Safety<br>(ASIL C compliant) | ISO 26262<br>(11/2018) | 1 DOCUMENT<br>1.1 Applicable documents<br>1.2 Reference documents<br>2 GLOSSARY<br>3 Introduction<br>4 Assumption<br>5 Product overview<br>5.1 Purpose<br>5.2 Type of Current Sensor<br>5.3 Safety Element out of Context (SEooC)<br>5.4 Functional Block Diagram<br>5.5 Mission Profile<br>6 Safety Measures<br>6.1 Safety Goal allocated to the sensor<br>6.2 Safety Concept<br>6.3 Description of the maintenance activities expected from the customer<br>6.4 Description of the maintenance activities expected from the customer in the case of a failure indicated by the warning and degradation concept<br>7 Hardware Requirements on System Level<br>7.1 Datasheet Compliance<br>8 Software Requirements on System Level<br>8.1 DTC Monitoring<br>9 Failure Rates and FMEDA<br>9.1 FMEDA Reference Document<br>9.2 FMEDA Applicable Standard<br>9.3 Failure Mode Distribution<br>9.4 FMEDA Results<br>10 Provisions Against Dependent Failures<br>10.1 External Parasitic Magnetic Fields<br>10.2 Environmental constraints<br>11 Measures to Prevent Systematic Failures<br>11.1 Parasitic Magnetic Fields due to Bus Bar design<br>11.2 Current Ripple Influences<br>11.3 CAB-SF 1500-C Fastening<br>12 Diagnostic<br>12.1 Diagnostic Trouble Codes Monitoring<br>12.2 Diagnostic Mode / Maintenance Operation<br>13 Safety-related content of the instructions for operation, service and decommissioning<br>14 Field Monitoring |

*Safety Manual availability after NDA and assurance of business signed.



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## Applicable standards - PV tests performed - CAB-SF 1500

| Test | Standard | Procedure |
|---|---|---|
| CHARACTERIZATION AT 25 °C (Initial and final) | LEM CO.60.09.014.0 | Sensitivity; Total error; Offset; Linearity error; Current Consumption |
| CHARACTERIZATION IN TEMPERATURE RANGE (Initial and final) | LEM CO.60.09.014.0 | Sensitivity; Total error; Offset; Linearity error; Current Consumption |
| **Environmental test** | | |
| Ageing 85 °C /85 % $RH$ | JESD 22-A101 (03/2009) | $T$ °C = 85 °C; $RH$ = 85 %; Duration = 1000 h<br>Sensor not supply<br>Check After stab. @ 25 °C (End test)<br>Performance after test, from −40 °C to 85 °C:<br>$I_O \leq 50$ mA, $\varepsilon_{tot} \leq 1$ % |
| Low temperature storage | ISO 16750-4 § 5.1.1.2 (04/2010) | $T$ °C = −40 °C<br>Duration = 24 h; Power off, no monitoring<br>Check After stab. @ 25 °C (End test) |
| High temperature storage | ISO 16750-4 § 5.1.2.2 (04/2010) | $T$ °C = 85 °C<br>Duration = 96 h; Power off, no monitoring<br>Check After stab. @ 25 °C (End test) |
| Temperature cycle with specified change rate | ISO 16750-4 § 5.3.1 (04/2010) | $T$ °C = −40 °C & +85 °C, see Fig. 2 of ISO 16750-4<br>Duration = 30 cycles; 1 cycle = 8 h<br>Total duration = 10 days<br>$U_C$ = 13.5 V (≡ connected); $I_P$ = 0 A; no monitoring<br>Check After stab. @ 25 °C (End test) |
| Thermal shock | ISO 16750-4 § 5.3.2 (04/2010) | $T$ °C = "$T$ °C Operating min & max" −40 to +85 °C<br>Duration = 300 cycles according to the climatc code (defined table 4);<br>Exposure time : 30 min.<br>$U_C$ = NO power supply (≡ unconnected) and No wiring harness<br>Check After stab. @ 25 °C (End test) |
| Random Vibration | ISO 16750-3 § 4.1.2.4 (12/2012) | Random;<br>−40 °C /+85 °C during 8 hours;<br>8 h for each axie and each DUT; RMS acceleration 27.1 m/s²<br>Torque measurement before and after. Connected but not supply.<br>No monitoring |
| Mechanical Shocks | ISO 16750-3 § 4.2 (12/2012) | Temperature: Ambient temperature.<br>Default § 4.2.2<br>Operating mode: 3.2<br>Pulse shape: half sine, 50 G, 6 ms<br>10 shocks per direction (total 60)<br>& Meas. torque Bef. and After<br>Offset before and after; Parts not connected<br>Check After stab. @ 25 °C (End test) |
| Free Fall | ISO 16750-3 § 4.3 (12/2012) | Number of devices: 3<br>Falls/DUT: 2<br>Height = 1 m on Concrete floor<br>3 axes; 2 directions by axis; 1 sample by axis<br>Operating mode: 1.1<br>Temperature: 25 °C if not specified<br>Check after test at 25 °C and visual inspection |
| Cross section checking on PCBA | IPC-A-610G: 2017 Class 3 | IPC-TM-650 2.1.1F:2015 |
| Cross section checking on solderless connections | GB/T 18290.5-2015 | IPC-TM-650 2.1.1F:2015 |
| Whisker checking on PCBA | Refer to JESD201-A (04/2010) | Refer to JESD22-A121A (04/2010)<br>Class 2 |
| Insulation high voltage | ISO 16750-2 § 4.12 (12/2012)<br>IEC 60664-1 | 3.5 KV AC 50 Hz 60 s<br>1000 V DC for 60 s<br>Resistance criteria: > 1000 Mohm |

## Applicable standards - PV tests performed - CAB-SF 1500

| Test | Standard | Procedure |
|---|---|---|
| | **Electrical test** | |
| Reverse voltage | ISO 16750-2 § 4.7 (12/2012) | Test performed at room temperature<br>By default: case 2;<br>Duration : 60 s;<br>Level defined in table 7 according to the nominal system voltage |
| Overvoltage (for 12 V nominal voltage) | ISO 16750-2 § 4.3.1 (12/2012) | $T$ °C = $T_{max}$ - 20 °C and room temperature;<br>At $T_{max}$, apply 18 V for 60 min to all inputs;<br>At room temperature, apply 24 V for 60 s |
| Superimposed alternating voltage | ISO 16750-2 § 4.4 (12/2012) | 12 V system<br>severity1: 1 V peak to peak according to Fig. 2<br>triangular, logaritymic<br>5 times sweep continuously |
| Slow decrease and increase of supply voltage | ISO 16750-2 § 4.5 (12/2012) | Test performed at room temperature<br>$U_{S\ min}$ = 8.5 V<br>Decrease from $U_{S\ min}$ to 0 V and increase from 0 V to $U_{S\ min}$;<br>Change rate: 0.5 V/min |
| Momentary drop in supply voltage | ISO 16750-2 § 4.6.1 (12/2012) | Test performed at room temperature<br>$U_{C\ min}$ = 8.5 V<br>$U_{C\ min}$ to 4.5 V<br>See Fig. 4 |
| Reset behaviour at voltage drop | ISO 16750-2 § 4.6.2 (12/2012) | Test performed at room temperature<br>See Fig. 6 |
| Load dump | ISO 16750-2 § 4.6.4 (12/2012) | Test performed at room temperature<br>Pulse B, Pulse described in tables 6<br>'System with 12 V nominal voltage Class C<br>$U_A$ = 14 V, $U_S$* = 35 V, $U_S$ = 80 V, $R_i$ = 1 ohm $T_d$ = 400 ms,<br>5 pulses at 1 min intervals See Fig. 9 |
| Ground reference and supply voltage | ISO 16750-2 § 4.8 (12/2012) | Test performed at room temperature and test method defined at § 4.8.2 |
| Signal line interruption | ISO 16750-2 § 4.9.1 (12/2012) | Operating the sensor and open the circuit line after line.<br>Opening duration for each line: 10 s |
| Short circuit protection-Signals circuits | ISO 16750-2 § 4.10.2 (12/2012) | Connect all inputs and outputs to $U_{S\ max}$ = 16 V and to GND for a duration of 60 s |
| Insulation test | ISO 16750-2 § 4.11 (12/2012) | Remaining time: 0.5 h<br>$U$ = 500 V, 50 Hz for 60 s |



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| Test | Standard | Procedure |
|---|---|---|
| **EMC test** | | |
| Immunity to Electrostatic Discharges (Handling of devices) | ISO 10605 (07/2008) | Contact discharges: ±8 kV; Air discharges: ±15 kV.<br>$U_C$ = NO power supply (≡ unconnected)<br>Criteria B |
| Immunity to Radiated disturbances (ALSE) | ISO 11452-2 (11/2004) | Test level II and Test level IV<br>· CW and AM in the [200 MHz – 800 MHz] frequency band.<br>· CW, AM and PM1 in the [800 MHz – 1 GHz] frequency band.<br>· CW and PM1 in the [1 GHz – 1.2 GHz] frequency band.<br>· CW and PM2 in the [1.2 GHz – 1.4 GHz] frequency band.<br>· CW and PM1 in the [1.4 GHz – 2.7 GHz] frequency band.<br>· CW and PM2 in the [2.7 GHz – 3.2 GHz] frequency band.<br>Acceptance, Criteria B / Level 1 for level II<br>Acceptance, Criteria B / Level 2 for level IV |
| Transient Disturbances Conducted along Supply Lines | ISO 7637-2 (03/2008) | test pulse :<br>1 : −100 V $t_1$ = 5 s (0.2 to 5 s)<br>2a : 50 V $t_1$ = 0.2 to 5 s<br>2b : 10 V $t_d$ = 2 s<br>3a : $U$ -150 V<br>3b : $U$ 100 V |
| Transient Disturbances Conducted along I/O or Sensor Lines | ISO 7637-3 (07/2007) | 12 V nominal supply voltage<br>Fast a : CCC –150 V 10 min<br>Fast b : CCC +100 V 10 min<br>slow pulse positive: ICC +20 V 20 min<br>slow pulse negative: ICC –20 V 20 min |
| Immunity to Conducted disturbances (BCI) | ISO 11452-4 (12/2011) | Table E.1<br>Test level I, 1 MHz to 3 MHz : 60 mA * F(MHz) /3 \| 3 to 400 MHz : 60 mA<br>Test level II, 1 MHz to 3 MHz : 100 mA * F(MHz) /3 \| 3 to 400 MHz : 100 mA<br>Test level IV, 1 MHz to 3 MHz : 200 mA * F(MHz) /3 \| 3 to 400 MHz : 200 mA<br>Acceptance, Criteria B / Level 2 |
| Conducted emission - Voltage method | CISPR 25 (2016) § 6.3 | Table 5, Class 3, BROADCAST and MOBILE SERVICES<br>Freq = 0.15 MHz to 108 MHz |
| Radiated emission - ALSE | CISPR 25 (2016) § 6.5 | Table 7, Class 3, BROADCAST and MOBILE SERVICES |
| Immunity to magnetic fileds | ISO 11452-8 (2015 E) | 12 V Nominal supply voltage<br>radiating loop method<br>Test requirement see TableA.1(Internal filed) Test level I<br>FPSC Status I |



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