AUTOMOTIVE CURRENT TRANSDUCER FLUXGATE TECHNOLOGY

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

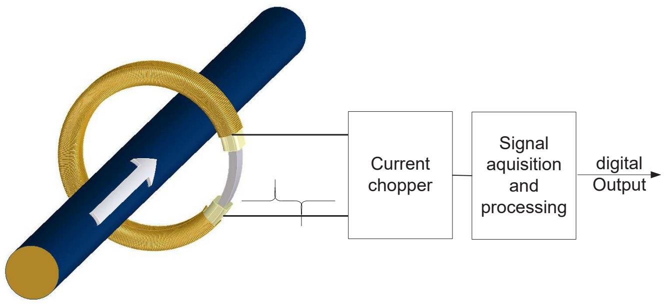
  0.5 % error over temperature range: −40 °C to +85 °C
- Full galvanic separation.

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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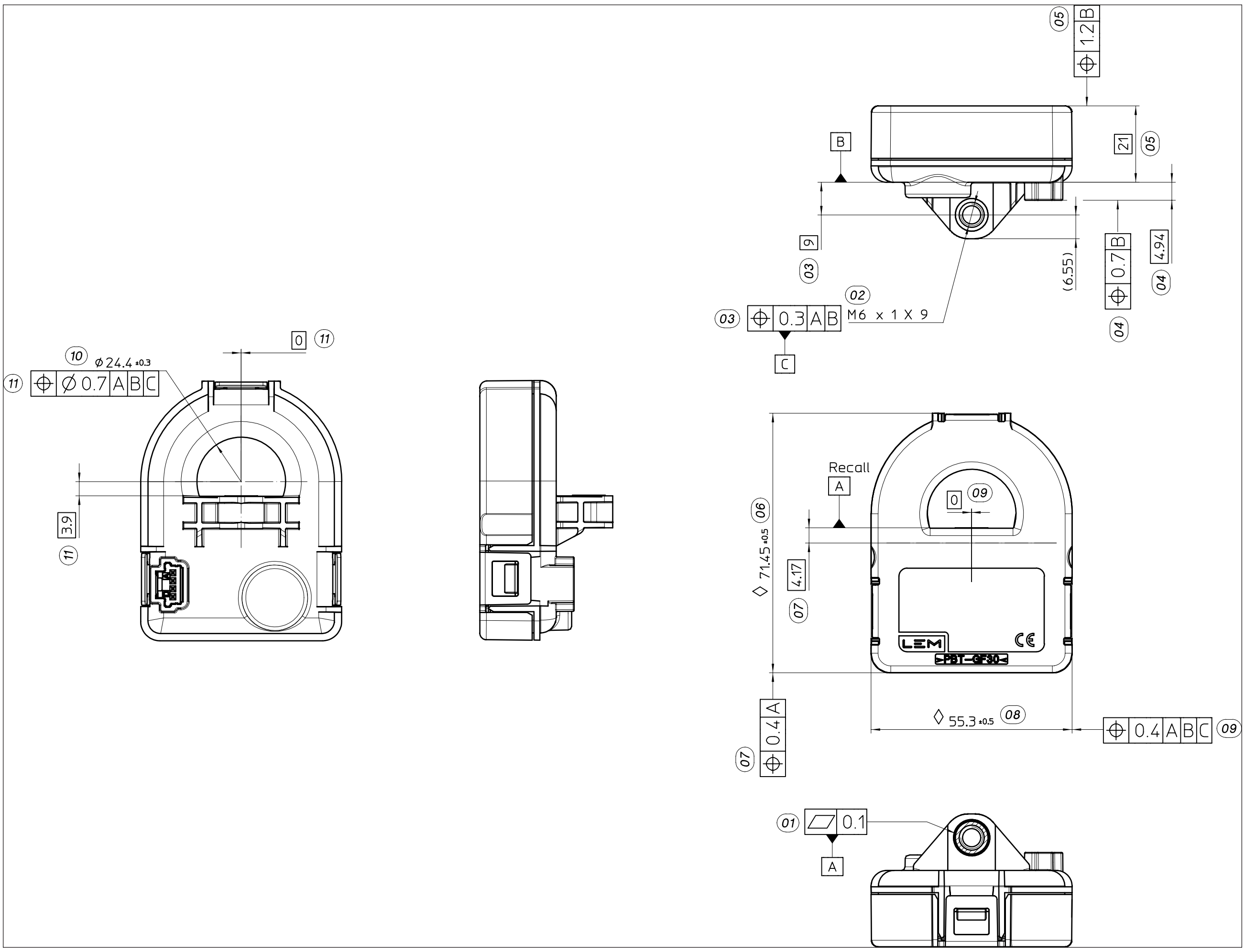
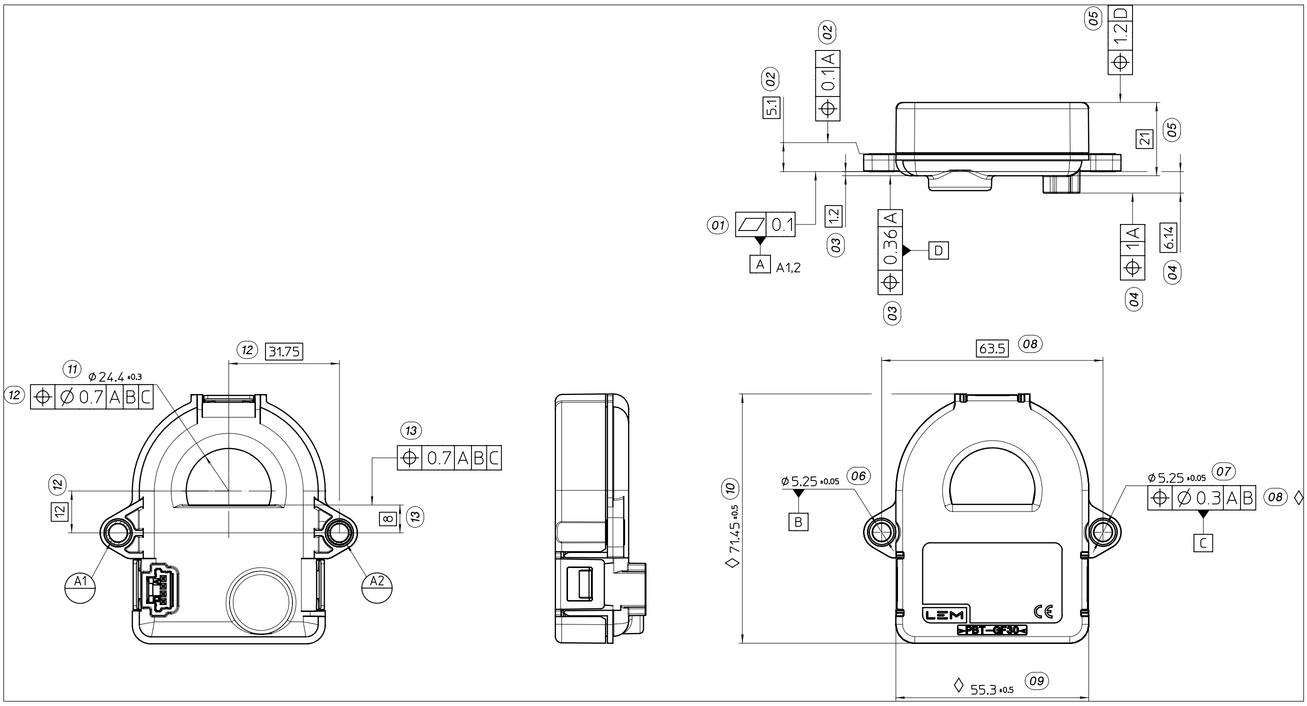
Dimensions (in mm)

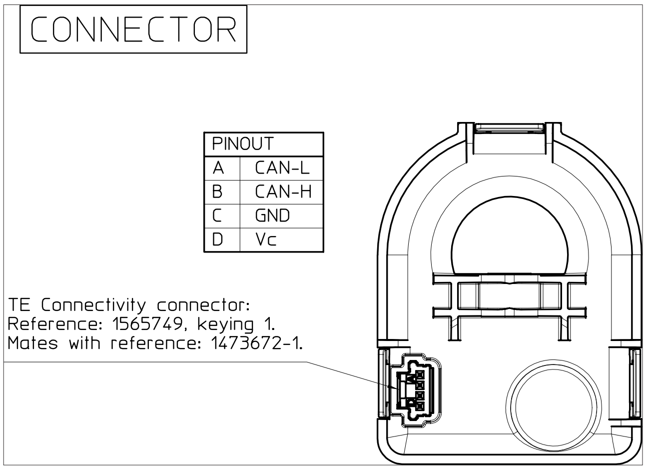
Busbar version



Panel mounting version



Connector pin out



Weight and Recommended screwing torque instruction

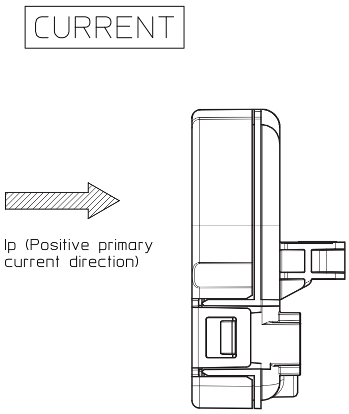
Busbar Version

- 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

Primary current direction as below:



Absolute ratings (not operating)

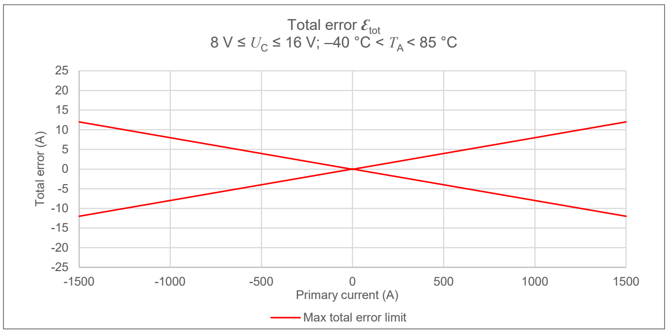
Parameter	Symbol	Unit	Specification	Conditions
Over-voltage	U_C	V	24	1 minute
Reverse polarity	U_C	V	−18	1 minute
Minimum supply voltage	$U_{C\ min}$	V	6	continuous
Maximum supply voltage	$U_{C\ max}$	V	18	continuous
Ambient storage temperature	$T_{A\ st}$	°C	−40 /+105	
Creepage distance	d_{Cp}	mm	12.5	
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	

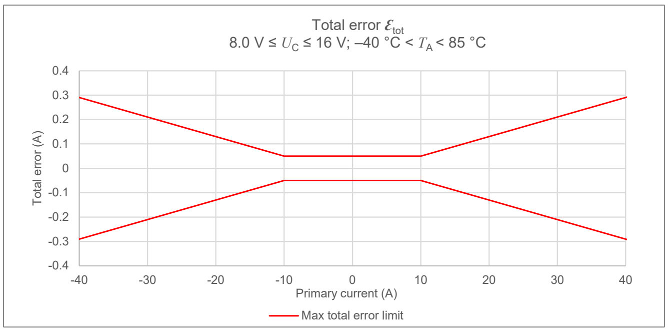
Characteristics in nominal range

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	ε_L	%		±0.1		At room temperature
Total error: [−1500 A, +1500 A]	ε_{tot}	%	−0.5		+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	ε_{tot}	%		±7		With a minimum of ±2 A Typical value after ageing Performances are considered with average value over 20 CAN frames (200 ms)

Total Error Graph

Analog Channel - Total 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 @ 3sigma	
(A)	(A)	(%)
−1500	±7.5	±0.5
−10	±0.05	-
0	±0.05	-
10	±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

The CAB-SF 1500 might be disturbed by current ripple produced by inverter and electric machine. When the frequency of the current ripple gets close to the fluxgate coil's frequency then the coil's frequency might get locked to the ripple current frequency. The CAB-SF 1500 embeds a software strategy that detects this behavior. As soon as the strategy detects coil's frequency locking then the strategy turns off the fluxgate to unlock the coil's frequency out of the current ripple's one.
This strategy has been validated to a mission profile defined internally. Nevertheless, to prevent any issue in relation with current ripple mission profile, LEM must be contacted to check that your current ripple profile fits with our software strategy.

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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
- Two versions of CAN resistor termination are available: 120 Ohms or 4800 Ohms.

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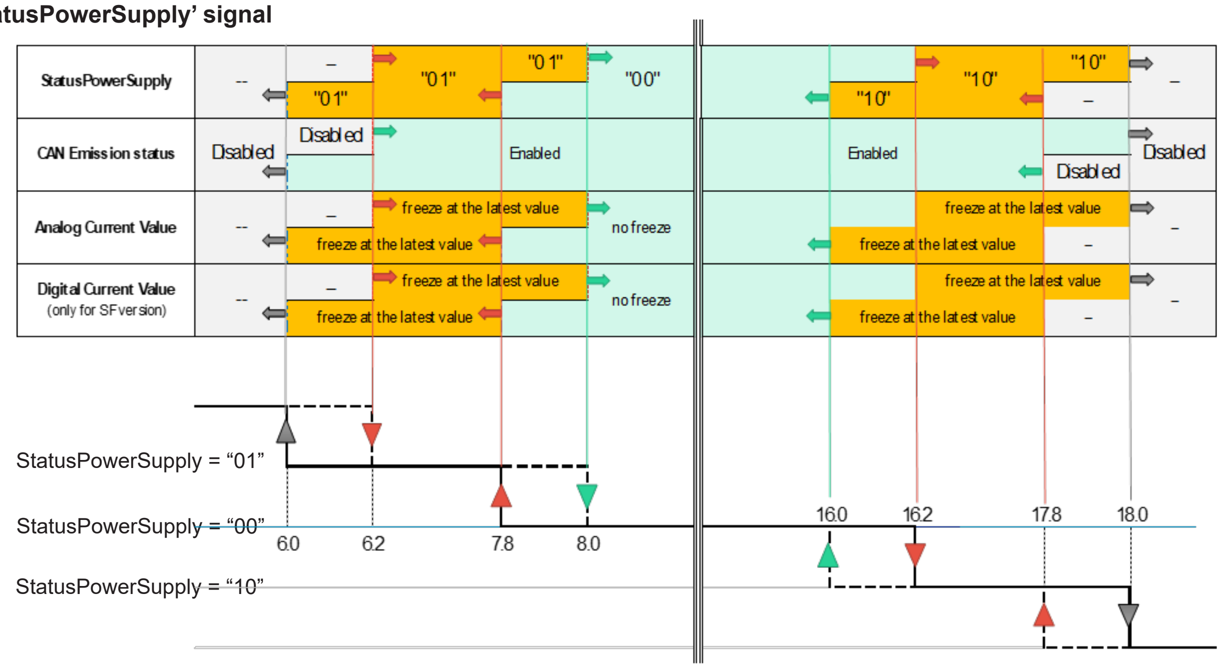
• **'SequenceCounterI_P' signal**
- Initialized with 0 and incremented by 1 for every subsequent send request
- When the counter reaches the value 15 (0xF), then restart with 1 for the next send request

• **'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"

Note:
At sensor start-up, if supply voltage < 7.8 V or > 16.2 V, no CAN frame emission.

• **'Status Internal Error' signal**
- This flag is set to 1 to inform the BMS about two use cases:

1. Internal hardware error (reference voltage, DAC errors)
2. 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 SafetyGoalViolation = 1

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

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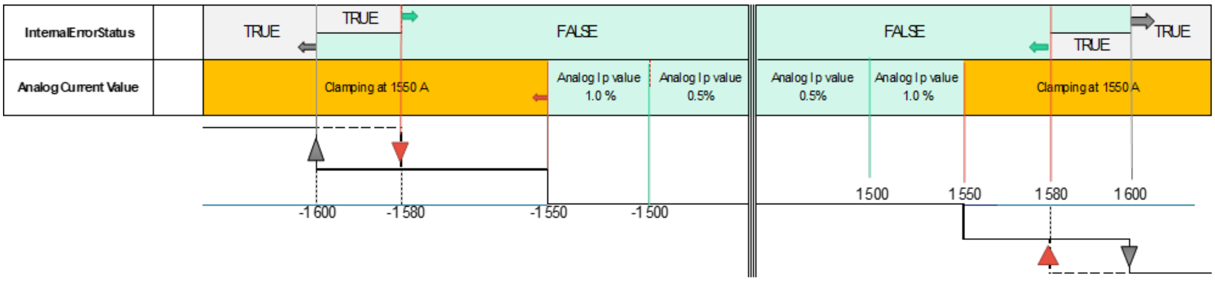
• **'Analog Current' signal**

Analog measurement of the primary current

$-1500 \le I_P \le +1500$. '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

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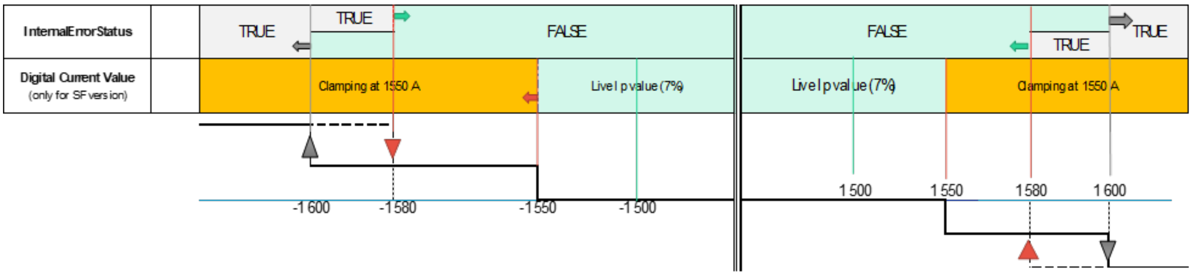
• 'Digital Current' signal

$\hat{I}_{P\,max} \leq I_P < -1550$. 'Digital Current' signal is clamped at −1550 A. Error = NA
$+1550 < I_P \leq \hat{I}_{P\,max}$. '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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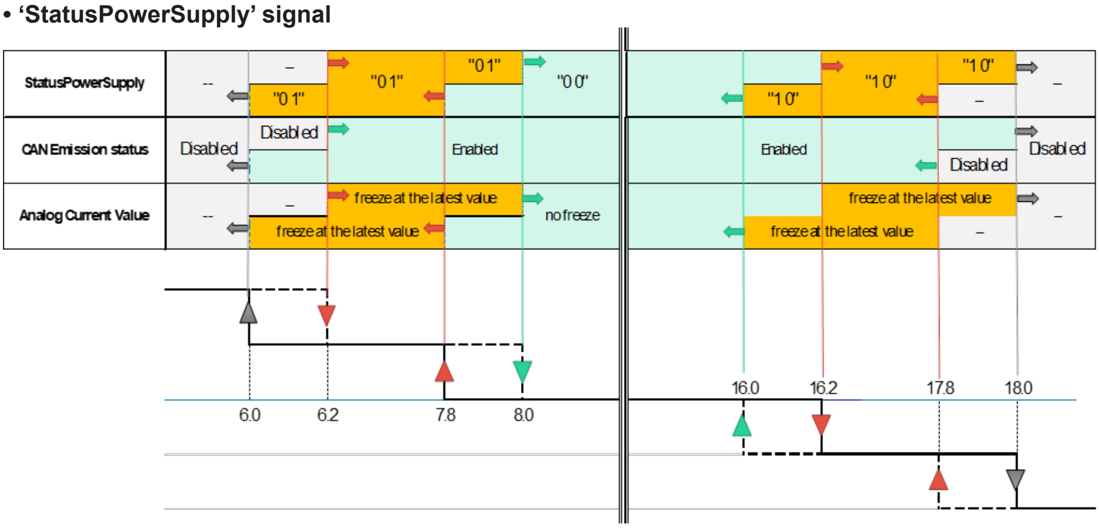
CAB 1500 CAN message table

- 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

- **'SequenceCounterI_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**



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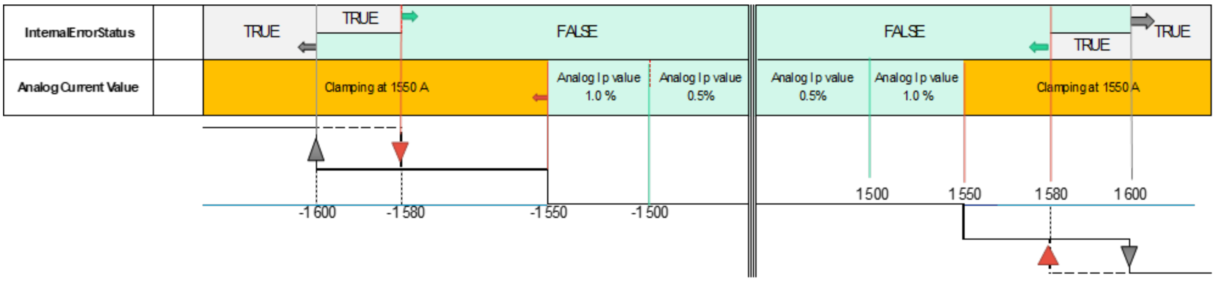
CAN Frame Content								
	7	6	5	4	3	2	1	0
BYTE 0	Sequence Counter I_P				Status Power Supply		Status Internal Error	Safety Goal Violation
	MSB			LSB	MSB	LSB		

When Power Supply voltage measurement is not available, then ‘Status Power Supply’ = “1 1”
At sensor start-up :
If supply voltage < 7.8 V or > 16.2 V, no CAN frame emission

- **‘Status Internal Error’ signal**
  Internal hardware error (reference voltage, DAC errors).

- **‘Analog Current’ signal**
  Analog measurement of the primary current
  $-1500 \leq I_P \leq +1500$. ‘Analog Current’ signal = I_P. Accuracy = 0.5 %
  $-1550 \leq I_P < -1500$. ‘Analog Current’ signal = I_P. Accuracy = 1 %
  $+1500 < I_P \leq +1550$. ‘Analog Current’ signal = I_P. Accuracy = 1 %



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

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		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		
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Functional Safety (ASIL C compliant)	ISO 26262 (11/2018)	1 DOCUMENT 1.1 Applicable documents 1.2 Reference documents 2 GLOSSARY 3 Introduction 4 Assumption 5 Product overview 5.1 Purpose 5.2 Type of Current Sensor 5.3 Safety Element out of Context (SEooC) 5.4 Functional Block Diagram 5.5 Mission Profile 6 Safety Measures 6.1 Safety Goal allocated to the sensor 6.2 Safety Concept 6.3 Description of the maintenance activities expected from the customer 6.4 Description of the maintenance activities expected from the customer in the case of a failure indicated by the warning and degradation concept 7 Hardware Requirements on System Level 7.1 Datasheet Compliance 8 Software Requirements on System Level 8.1 DTC Monitoring 9 Failure Rates and FMEDA 9.1 FMEDA Reference Document 9.2 FMEDA Applicable Standard 9.3 Failure Mode Distribution 9.4 FMEDA Results 10 Provisions Against Dependent Failures 10.1 External Parasitic Magnetic Fields 10.2 Environmental constraints 11 Measures to Prevent Systematic Failures 11.1 Parasitic Magnetic Fields due to Bus Bar design 11.2 Current Ripple Influences 11.3 CAB-SF 1500-C Fastening 12 Diagnostic 12.1 Diagnostic Trouble Codes Monitoring 12.2 Diagnostic Mode / Maintenance Operation 13 Safety-related content of the instructions for operation, service and decommissioning 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 Sensor not supply Check After stab. @ 25 °C (End test)
Low temperature storage	ISO 16750-4 § 5.1.1.2 (04/2010)	T °C = −40 °C Duration = 24 h; Power off, no monitoring Check After stab. @ 25 °C (End test)
High temperature storage	ISO 16750-4 § 5.1.2.2 (04/2010)	T °C = 85 °C Duration = 96 h; Power off, no monitoring 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 Duration = 30 cycles; 1 cycle = 8 h Total duration = 10 days U_C = 13.5 V (≡ connected); I_P = 0 A; no monitoring 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 Duration = 300 cycles according to the climatc code (defined table 4); Exposure time : 30 min. U_C = NO power supply (≡ unconnected) and No wiring harness Check After stab. @ 25 °C (End test)
Random Vibration	ISO 16750-3 § 4.1.2.4 (12/2012)	Random; −40 °C /+85 °C during 8 hours; 8 h for each axie and each DUT; RMS acceleration 27.1 m/s² Torque measurement before and after. Connected but not supply. No monitoring
Mechanical Shocks	ISO 16750-3 § 4.2 (12/2012)	Temperature: Ambient temperature. Default § 4.2.2 Operating mode: 3.2 Pulse shape: half sine, 50 G, 6 ms 10 shocks per direction (total 60) & Meas. torque Bef. and After Offset before and after; Parts not connected Check After stab. @ 25 °C (End test)
Free Fall	ISO 16750-3 § 4.3 (12/2012)	Number of devices: 3 Falls/DUT: 2 Height = 1 m on Concrete floor 3 axes; 2 directions by axis; 1 sample by axis Operating mode: 1.1 Temperature: 25 °C if not specified 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) Class 2

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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 By default: case 2; Duration : 60 s; 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; At T_{max}, apply 18 V for 60 min to all inputs; At room temperature, apply 24 V for 60 s
Superimposed alternating voltage	ISO 16750-2 § 4.4 (12/2012)	12 V system serverity1: U_{pp} = 1 V triangular, logaritymic 5 times sweep continuously
Slow dicrease and increase of supply voltage	ISO 16750-2 § 4.5 (12/2012)	Test performed at room temperature $U_{C\ min}$ = 8.5 V Dicrease from $U_{C\ min}$ to 0 V and increase from 0 V to $U_{C\ min}$; Change rate: 0.5 V/min
Momentary drop in supply voltage	ISO 16750-2 § 4.6.1 (12/2012)	Test performed at room temperature $U_{C\ min}$ = 8.5 V $U_{C\ min}$ to 4.5 V See Fig 4 or 5 according to the nominal system voltage
Reset behaviour at voltage drop	ISO 16750-2 § 4.6.2 (12/2012)	Test performed at room temperature See Fig 6
Load dump	ISO 16750-2 § 4.6.4 (12/2012)	Test performed at room temperature Pulse B, Pulse described in tables 5 & 6 'System with 12V nominal voltage Class C U_A = 14 V, U_S* = 35 V, U_S = 80 V, R_i = 1 ohm T_d = 400 ms, 5 pulses at 1 min intervals
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. 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 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. U_C = NO power supply (≡ unconnected) Criteria B
Immunity to Radiated disturbances (ALSE)	ISO 11452-2 (11/2004)	Test level II and Test level IV · CW and AM in the [200 MHz – 800 MHz] frequency band. · CW, AM and PM1 in the [800 MHz – 1 GHz] frequency band. · CW and PM1 in the [1 GHz – 1.2 GHz] frequency band. · CW and PM2 in the [1.2 GHz – 1.4 GHz] frequency band. · CW and PM1 in the [1.4 GHz – 2.7 GHz] frequency band. · CW and PM2 in the [2.7 GHz – 3.2 GHz] frequency band. Acceptance, Criteria B / Level 1 for level II Acceptance, Criteria B / Level 2 for level IV
Transient Disturbances Conducted along Supply Lines	ISO 7637-2 (03/2008)	test pulse : 1 : −100 V t_1 = 5 s (0.2 to 5 s) 2a : 50 V t_1 = 0.2 to 5 s 2b : 10 V t_d = 2 s 3a : U -150 V 3b : U 100 V 4 : U_S = 5 to 6.5 V t_7 = 50 ms t_8 = 10 s t_r = 100 ms
Transient Disturbances Conducted along I/O or Sensor Lines	ISO 7637-3 (07/2007)	12 V nominal supply voltage Fast a : CCC –150 V 10 min Fast b : CCC +100 V 10 min slow pulse positive: ICC +20 V 20 min slow pulse negative: ICC –20 V 20 min
Immunity to Conducted disturbances (BCI)	ISO 11452-4 (12/2011)	Table E.1 Test level I, 1 MHz to 3 MHz : 60 mA * F(MHz) /3 | 3 to 400 MHz : 60 mA Test level II, 1 MHz to 3 MHz : 100 mA * F(MHz) /3 | 3 to 400 MHz : 100 mA Test level IV, 1 MHz to 3 MHz : 200 mA * F(MHz) /3 | 3 to 400 MHz : 200 mA Acceptance, Criteria B / Level 2
Conducted emission - Voltage method	CISPR 25 (2016) § 6.3	Table 5, Class 3, BROADCAST and MOBILE SERVICES 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 radiating loop method Test requirement see TableA.1(Internal filed) Test level I FPSC Status I

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