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CAB 1500 APPLICATION NOTES

INFORMATION IN THIS DOCUMENT SHOULD BE USED AS REFERENCE, THEY ARE NOT GUARANTEED VALUES

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1 Revision history

Rev	Date	Who	Change and updates
0	2/Jun/2023	hjc	Creation

2 CLARIFICATION

- Information in this document should be used as reference, they are not guaranteed values.

3 Reference

Document	Version
ISO 15765-2:2011Road vehicles —Diagnostic communication over Controller AreaNetwork (DoCAN) Part 2: Transport protocol and network layer services	2011-10-15
ISO 14229-1:2013Road vehicles —Unified diagnostic services (UDS) Part 1: Specification and requirements	2013-03-15

4 Abbreviation

- CAN: Controller Area Network
- UDS: Unified Diagnostic Services
- CRC: Cyclic Redundancy Check
- ECU: Electronic Control Unit

5 E2E CRC

5.1 Aim

- Aim to clarify CAB1500 Series E2E Protection Instruction.

5.2 Reference

- Refer to 'AutoSAR_PRS_E2EProtocal' profile 1

5.3 CAB 1500 SERIES EXCEPT CAB-SF 1500-002

5.3.1 Data layout

- CRC is the 7th byte in the signal group
- Alive counter locates in highest 4 bits of 0th byte

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

5.3.2 Counter

- Initialized with 0 for the first CAN frame transmission
- Incremented by 1 for every subsequent send request
- When the counter reaches the value 15, then it shall restart with 1 for the next send request

5.3.3 DataID

- E2E_P01_DATAID_LOW: only the low byte is included, and high byte is never used.
- DataId configurable
- Default value: 0xFFFF (DataId is not included in CRC calculation)

5.3.4 CRC calculation

5.3.4.1 CRC calculation data

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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		
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

crcData

Byte0	Byte1	Byte2	Byte3	Byte4	Byte5	Byte6

5.3.4.2 Calculation algorithm

```
nCRC = 0xFF;
for ( i=0U ; i<7 ; i++ )
{
   nCRC ^= crcData[i];
   for ( bit=0U ; bit<8 ; bit++ )
   {
      if ( (nCRC & 0x80) != 0 )
      {
         nCRC <<= 1;
         nCRC ^= 0x1D;
      }
      else
      {
         nCRC <<= 1;
      }
   }
}
result = nCRC ^ 0xFF
```

crcDataSize

CRC-8-SAE J1850 for CRC calculation.
Initial value :0xFF
XOR value :0xFF

5.4 CAB-SF 1500-002

5.4.1 Data layout

- CRC is the 0th byte in the signal group.

- Alive counter locates in lowest 4 bits of 1st byte.

CAN Frame Content

	7	6	5	4	3	2	1	0
BYTE 0	CRC_I_P							
BYTE 1	StatusPowerSupply		Analog Channel FAILED	Digital Channel FAILED	Sequence Counter I_P			
					MSB			
BYTE 2	AnalogCurrent							
	MSB							
BYTE 3	AnalogCurrent							
BYTE 4	AnalogCurrent							
								LSB
BYTE 5	DigitalCurent							
	MSB							
BYTE 6	DigitalCurent							
								LSB
BYTE 7	Unused			Temperature Status		OverCurrer Status	SafetyGoal Violation	OtherHard' are Error

5.4.2 Counter

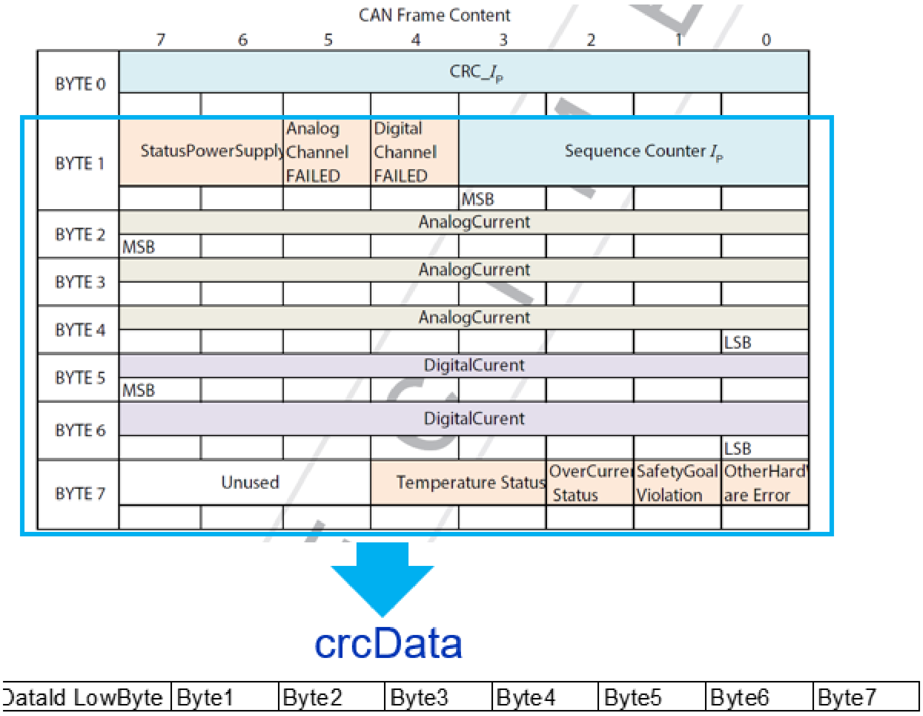
- Initialized with 0 for the first CAN frame transmission
- Incremented by 1 for every subsequent send request
- When the counter reaches the value 15, then it shall restart with 1 for the next send request

5.4.3 Danaids

- E2E_P01_DATAID_LOW: only the low byte is included, and high byte is never used.
- DataID configurable
  DataID = 0x0080

5.4.4 CRC calculation

5.4.4.1 CRC calculation data



5.4.4.2 Calculation algorithm

```
nCRC = 0;
for ( i=0U ; i<8 ; i++ )
{
   nCRC ^= crcData[i];
   for ( bit=0U ; bit<8 ; bit++ )
   {
      if ( (nCRC & 0x80) != 0 )
      {
         nCRC <<= 1;
         nCRC ^= 0x1D;
      }
      else
      {
         nCRC <<= 1;
      }
   }
}
result = nCRC ^ 0
```

crcDataSize

CRC-8-SAE J1850 for CRC calculation.

Initial value: 0x00

XOR value: 0x00

E2E Profile 1 uses CRC-8-SAE J1850 but using different initial and XOR values.

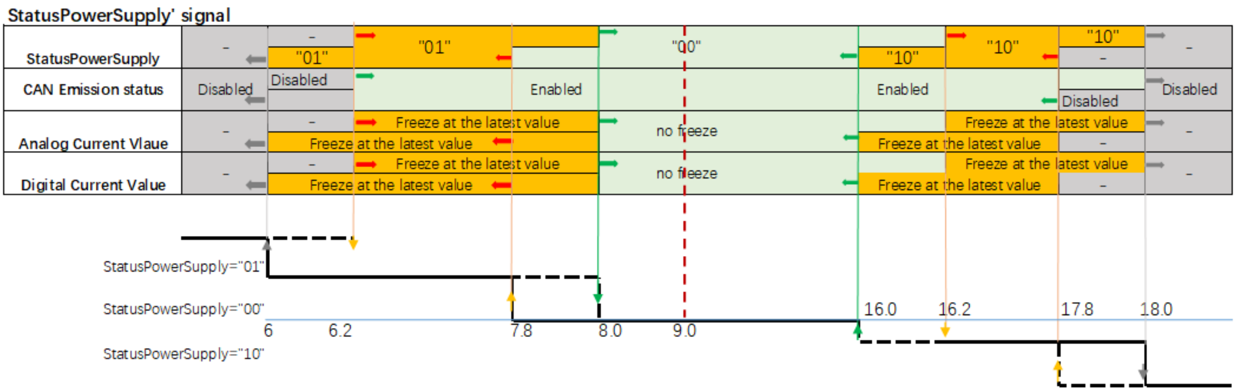
6 Power supply instruction

6.1 Aim

- Aim is to clarify power status indication.
- Aim is to present power consumption under different working conditions including primary current and temperature.
- Aim is to provide power information for CAB power design system.

6.2 StatusPowerSupply

- The ‘StatusPowerSupply’ signal goal is to protect the CAB sensor from working under unsafe operating areas, aim for CAB power supply setup instruction
- LEM recommends power supply range [9V-16V] (9V and 16V included).
  [8V-9V] (9V excluded) ripple voltage should be lower than 400mVpp.



CAN Frame Content								
	7	6	5	4	3	2	1	0
BYTE0	Sequence Counter Ip				StatusPowerSupply		Status internal error	Safety Goal violation
	MSB			LSB	MSB	LSB		

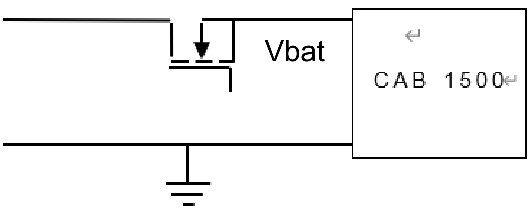
- Power Supply range

1) In above StatusPowerSupply signal illustration, all the setting values for power status are typical values, the actual threshold voltages may deviate from the setting values due to hardware consistency and mesurement tolerance, with deviation range±0.3V.
   Below data is for customer information as long as power status is concerned.

Threshold name	Power status bits	Min.(V)	Typ. (V)	Max. (V)
Threshold Low voltage	00->01	7.5	7.8	8.1
Threshold High voltage	00->10	15.9	16.2	16.5
Hysteresis	01→00 or10→00		0.2	

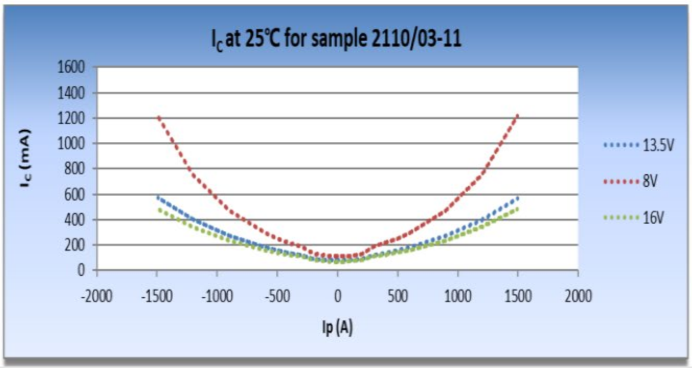
Note:Test condition ,room tempertuare, IP=0A, voltage measurement position CAB supply pin side. Different application may lead slightly difference with the result.

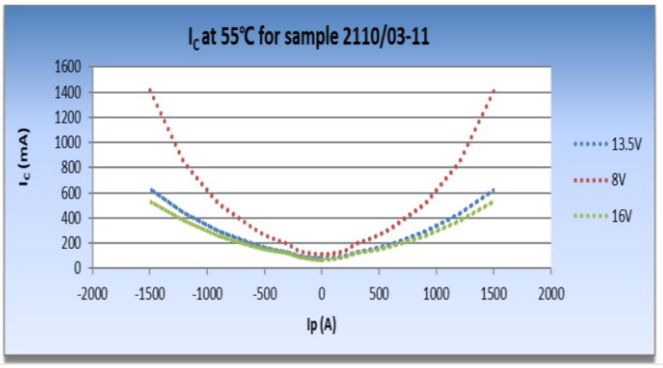
2) When Power Supply voltage measurement is not available, then ‘StatusPowerSupply’ = “1 1”
   At sensor start-up, if supply voltage < 7.8 V or > 16.2 V, no CAN frame emission
3) The Vbat voltage mentioned above is the real voltage supplied on CAB terminals
   Suggestion: if there is a MOSFET or transistor applied before CAB supply voltage, drop voltage should be considered in design.



6.3 Current consumption

- CAB current consumption will be much higher at 8V than nominal 13.5V supply voltage LEM's recommendation is to supply CAB with voltage close to nominal voltage for best reliability over lifetime.
- CAB will send the 'StatusPowerSupply' flag if it detects to be too close to the minimum 8.0V supply and maximum 16V supply.

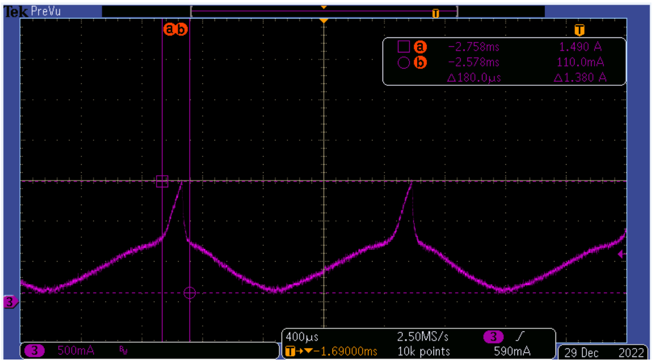




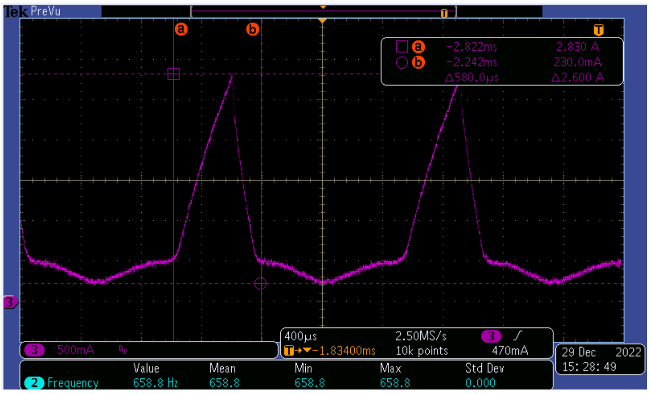
6.4 Input peak current

- CAB family products are designed based on fluxgate technology, and fluxgate switching will lead input peak current, frequency is same with fluxgate switching frequency.
- Based on above information, LEM's recommendation is considering a margin on power supply.

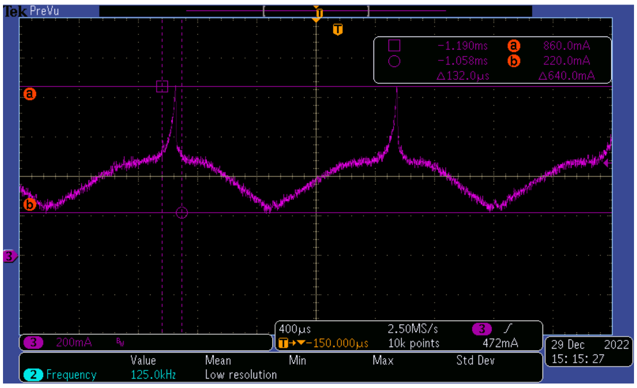
Waveform to show input peak current _13.5V with I_P =1500A, input peak current is 1.49A.



Waveform to show input peak current _9V with I_P =1500A, input peak current is 2.83A.



Waveform to show input peak current _9V with I_P =1000A, input peak current is 0.86A.



7 CAN parameter configuration

7.1 Aim

The aim of Customer Access Parameter Configuration is to:

- express the procedure customer can follow to read or write the parameters in CAB1500 family transducer.
- clarify access right on each parameter which is accessible to customer.

7.2 Function requirement

7.2.1 Communication interface

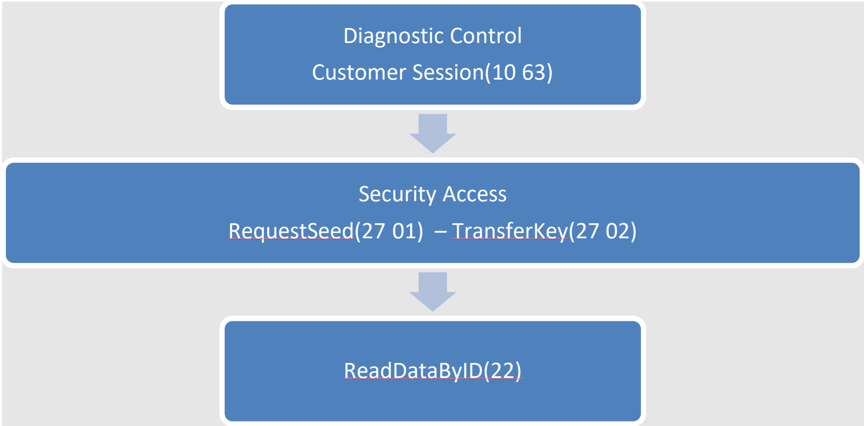
Name	CAN_Interface
Short description	CAB1500 supports communication on CAN interface
Description	It uses the ISO 15765-2:2011 standard for the transport protocol definition. It uses the ISO 14229-1:2013 standard for the services definition.

Name	UDS
Short description	Parameter read/write action can be realized by UDS
Description	Default UDS RxID: 0x68D (Physical requests from Tester to ECU) UDS TxID: 0x68E (Physical response from ECU to Tester) The software supports a set of customer access UDS diagnostic services specified in UDS Software Specification

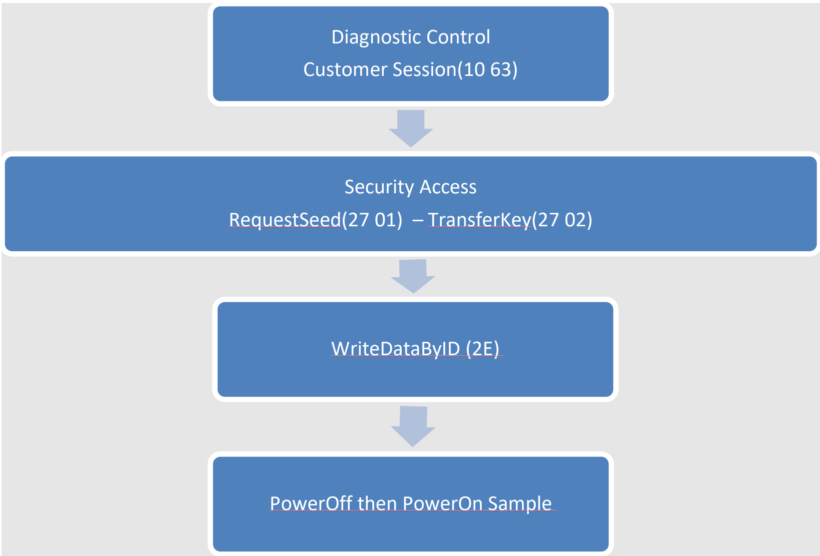
7.2.2 Parameter Access Protocol

Name	Parameter Read protocol.001
Short description	Parameter read is realized by UDS ReadDataById service

Description	See below for the protocol and example



Name	Parameter Write protocol.001
Short description	Parameter read is realized by UDS WriteDataById service
Description	See below for the protocol and example



7.3 UDS SOFTWARE SPECIFICATION

7.3.1 Diagnostic service list

Name	UDS_Services.001
Short description	The software implements a set of services by physical addressing
Description	The table below is the list of the services implemented (see ISO 14229 for further details).

Service	Default session (0x01)	Customer session (0x63)
DiagnosticSessionControl – 0x10	x	x
SecurityAccess – 0x27	-	x
TesterPresent – 0x3E	x	x
ReadDataByIdentifier – 0x22	x (a)	x
WriteDataByIdentifier – 0x2E	-	x

x: the service is available in the corresponding type of session.

-: the service is not implemented in the corresponding type of session

(a) only for non-secured data

All services available in Default session are accessible in customer session, without Security Access restriction.

Customer session is restricted by the Security Access service, and thus require the server to be in “unlocked” state before use.

Without any message from the client for 4 seconds the server shall return to the default session and security access to be locked.

7.3.2 Diagnostic and Communication Management Functional Unit

7.3.2.1 Diagnostic session control

Name	UDS_DiagSessionCtrl.001
Short description	UDS Diagnostic session control service and sub-functions
Description	The service Diagnostic Session Control (0x10) implements the following sub-functions which are open to customer: - Default session (0x01) - Customer session (0x63)

7.3.2.2 Security Access

Name	UDS_SecurityAccess.001
Short description	UDS Security Access key algorithm
Description	Upon request from the client, the system sends a pseudo-random 32-bit seed **Key computation:** **1. Compute CRC16 : Algorithm CRC-16/CCITT-FALSE** **2. Compute KeyCRC32** **KeyCRC32 = CRC16 + (CRC16 << 16)** **3. Compute final 32-bit key** **Key = KeyCRC32 ^ 0xC3A55A3C** The server compares the keys and unlocks the protected services if match.

Name	UDS_SecurityAccessFunctions.001
Short description	UDS Security Access service and sub-functions
Description	The Security Access (0x27) service implements the following sub-functions: - 0x01: requestSeed - 0x02: sendKey All other sub-functions are not supported

7.3.2.3 ReadDataById and WriteDataById

Name	UDS_ReadWriteDataById.002
Short description	UDS ReadWriteDataByIdentifier list of data
Description	The services ReadDataByIdentifier (0x22) and WriteDataByIdentifier (0x2E) supports the data listed in Table1

Table 1 : Detailed list of RDBID and WDBID

Array ID	Data name	Size (bytes)	Session availability Customer (0x63)	Formatting	Default value
0x0303	Application SW version	2	R	MSB to LSB : MMNN	-
0x0500	Frame id 1: current	4	R/W	CAN ID format	0x3C2
0x0600	UDS frame id Rx	4	R/W	CAN ID format	0x68D
0x0601	UDS frame id Tx	4	R/W	CAN ID format	0x68E
0x0700	Frame period 1	2	R/W	Integer : 10, 20, 30, 40, 50, 60, 70, 80, 90, 100. Unit: ms	10
0x0800	Baudrate	1	R/W	Enumeration : 0X10 is 125Kbps, 0X11 is 250Kbps, 0X12 is 500Kbps	500kbps

7.4 Example

7.4.1 Example Read software version

Service	ID(hex)	DataLength	DataByte (hex)
Enter customer session	068D	8	02 10 63 00 00 00 00 00
	068E	8	02 50 63 00 00 00 00 00
Security Access: RequestKey	068D	8	02 27 01 00 00 00 00 00
	068E	8	06 67 01 76 12 F3 B1 00
Security Access: SendKey	068D	8	06 27 02 FE E2 67 7B 00
	068E	8	02 67 02 00 00 00 00 00
ReadDataById	068D	8	03 22 03 03 00 00 00 00
	068E	8	05 62 03 03 01 0F 00 00

Key computation

Seed : 0x7612F3B1

1. Compute CRC16

   Online CRC-8 CRC-16 CRC-32 Calculator (crccalc.com)

Algorithm	Result	Check	Poly	Init	RefIn	RefOut	XorOut
CRC-16/CCITT-FALSE	0x3D47	0x29B1	0x1021	0xFFFF	false	false	0x0000

   ➔ CRC16 = 0x3D47

2. Compute KeyCRC32

   KeyCRC32 = CRC16 + (CRC16 << 16);

   ➔ KeyCRC32 =0x3D473D47

3. Compute final 32-bit key

   Key = KeyCRC32 ^ 0xC3A55A3C

   ➔ 0xFEE2677B

7.4.2 Example Change CAN ID

Service	ID(hex)	DataLength	DataByte (hex)
Enter customer session	068D	8	02 10 63 00 00 00 00 00
	068E	8	02 50 63 00 00 00 00 00
Security Access: RequestKey	068D	8	02 27 01 00 00 00 00 00
	068E	8	06 67 01 E9 95 7D E4 00
Security Access: SendKey	068D	8	06 27 02 60 9E F9 07 00
	068E	8	02 67 02 00 00 00 00 00
WriteDataByID	068D	8	07 2E 05 00 00 00 00 10
	068E	8	03 6E 05 00 00 00 00 00

Power off then power on sample, then CAN frame with new CAN ID (0x10) can be observed.

8 Return Busbar

8.1 Aim

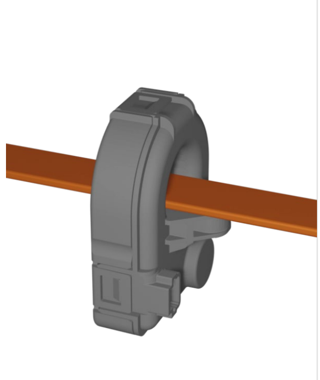
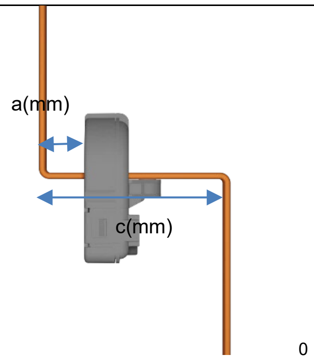
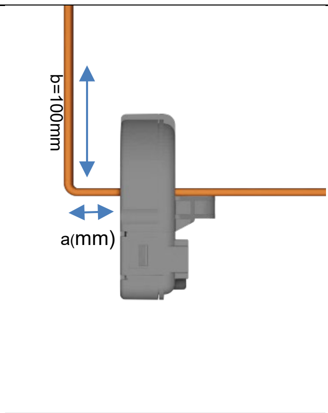
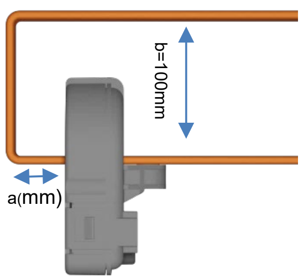
- Aim is to present external busbar disturbance with different busbar shapes, this can be referred during BDU structure design.

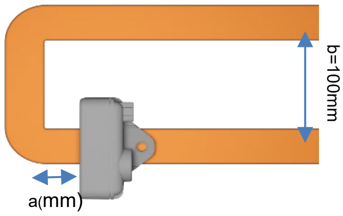
8.2 Notes

- The busbar dimension for test: 22mm (Width) x4mm (Thickness).
- Environment: 25 ° C.
- Error calculation formula: Error %=($I_{measure}$- I_P)/ I_P
- Due to the complexity of practical application, the examples cannot cover all the application conditions

8.3 Busbar shapes recommendation

- Brief Summary, more details see corresponding charts by busbar shape.
- Recommendation for busbar design:
- Straight and S-shaped are recommended busbar design.
- L-shaped busbar, recommend for AL, AR, DL direction application but not DR direction application.
- C1 and C2 are not recommended busbar design.

Busbar -shapes	Accuracy impact	Shape
Straight	Error≤0.5%	
S	Error≤0.5% (Busbar set up for C⩾46mm, a⩾ 5mm)	
L	Error≤0.5% DR direction and meantime a≤10mm & I_P >1200A, the error >0.5%. I_P >1400A, the error >1%	
C1	C1 shape busbar will impact measurement accuracy, especially I_P current higher than 1000A. The external busbar is as far as possible, which can reduce the impact of measurement accuracy.	

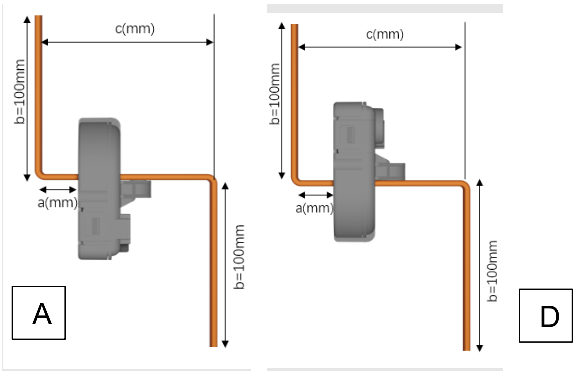
Busbar -shapes	Accuracy impact	Shape
C2	C2 shape busbar will impact measurement accuracy, especially I_P current higher than 1000A. The external busbar is as far as possible, which can reduce the impact of measurement accuracy.	

8.3.1 Straight busbar

Because of no external busbar influence, straight busbar can achieve performance which the error is not worse than the tolerance 0.5%(Refer to PV test report).

8.3.2 S shape busbar

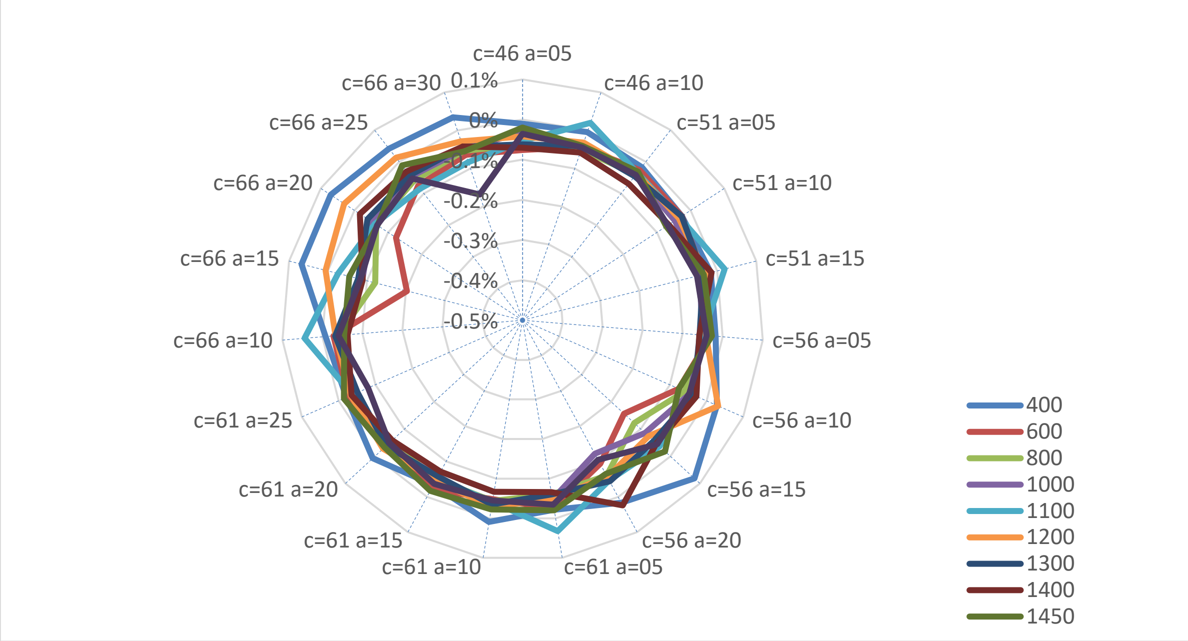
8.3.2.1 S shape Busbar



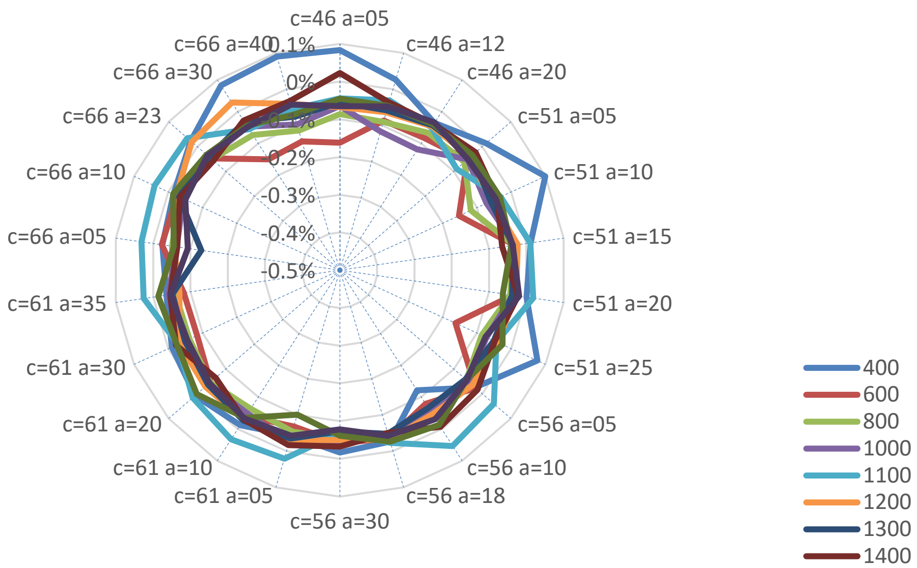
Notes:

1. A direction: the nose of sensor is under the busbar.
2. D direction: the nose of sensor is upon the busbar.

8.3.2.2 S shape busbar - A



8.3.2.3 S shape busbar - D



S shape busbar has no impact on measurement accuracy and achieve performance which the error is not worse than the tolerance 0.5%.

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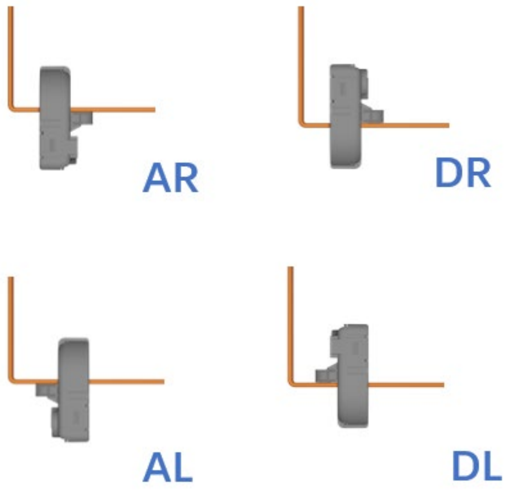
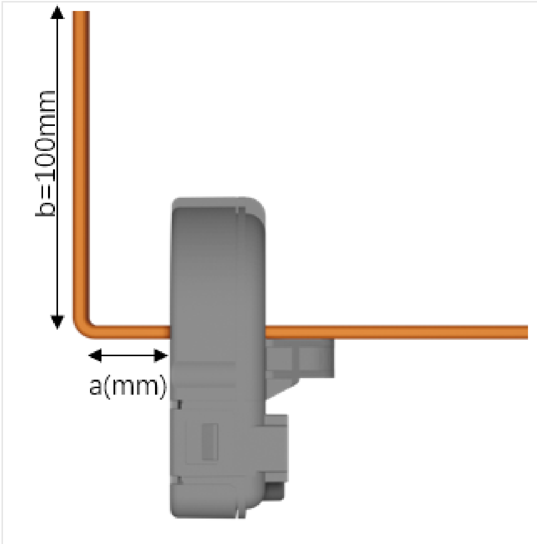
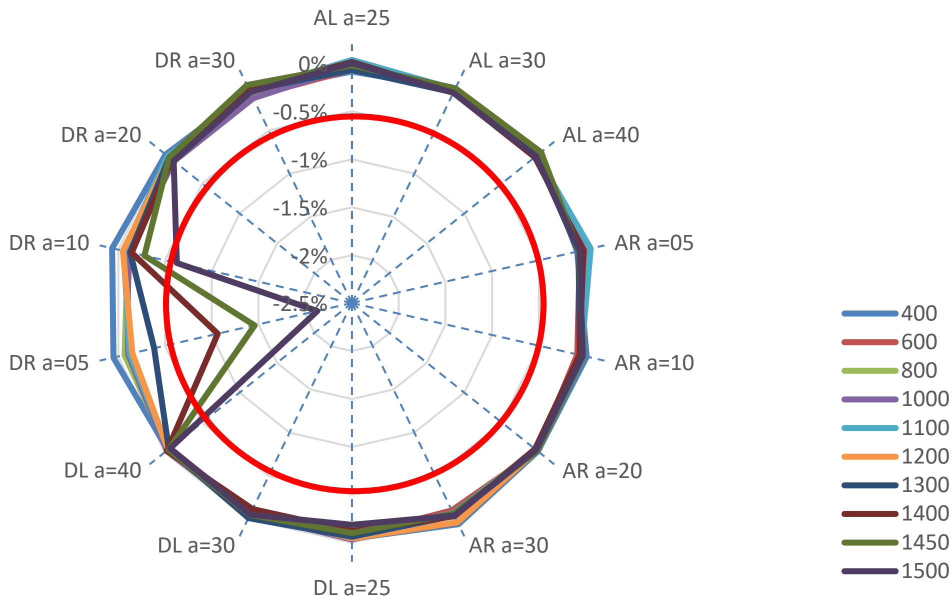
8.3.3 L shape busbar





Notes:

1. **A** direction: the **nose** of sensor is **under** the busbar.
2. **D** direction: the **nose** of sensor is **upon** the busbar.
3. **R** direction: the **nose** of sensor is on the **right** side.
4. **L** direction: the **nose** of sensor is on the **left** side.



Application on DR direction and meantime a≤10mm & I_P>1200A, the error is worse than 0.5%.

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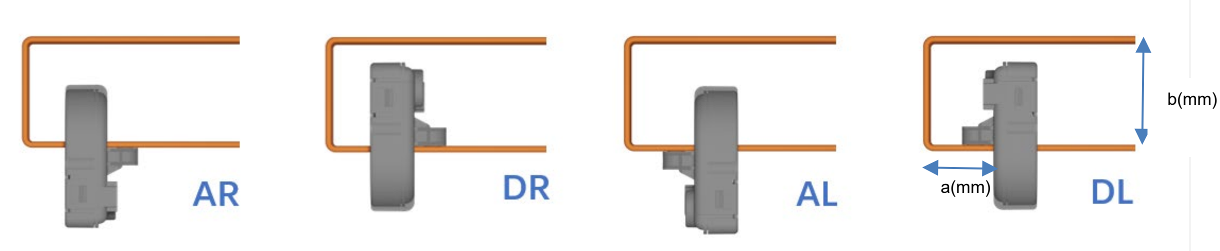
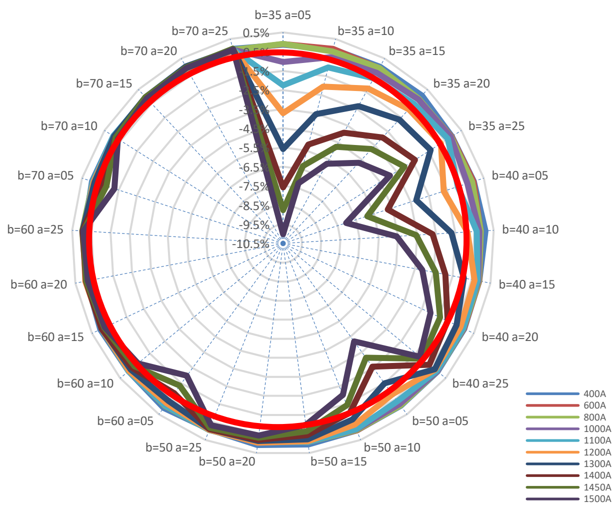
8.3.4 C1 shape busbar

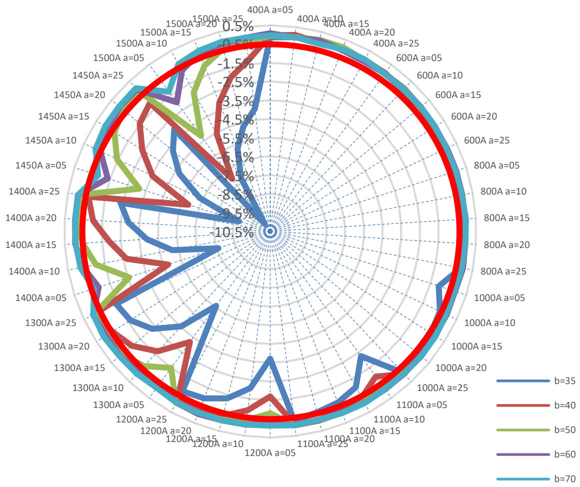


Notes:

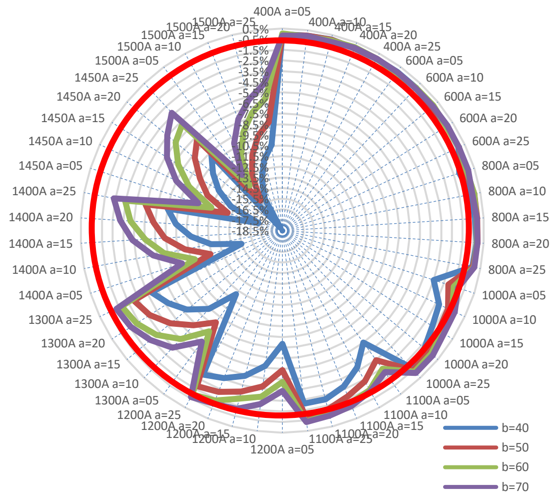
1. **A** direction: the **nose** of sensor is **under** the busbar.
2. **D** direction: the **nose** of sensor is **upon** the busbar.
3. **R** direction: the **nose** of sensor is on the **right** side.
4. **L** direction: the **nose** of sensor is on the **left** side.

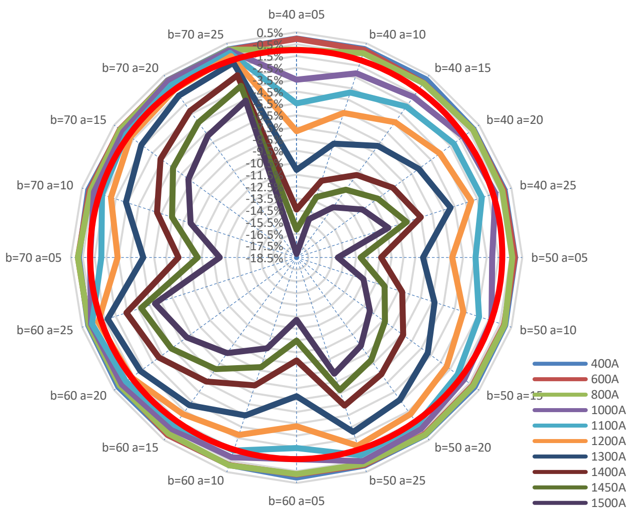
8.3.4.1 C1 shape busbar - AR





8.3.4.2 C1 shape busbar - DR





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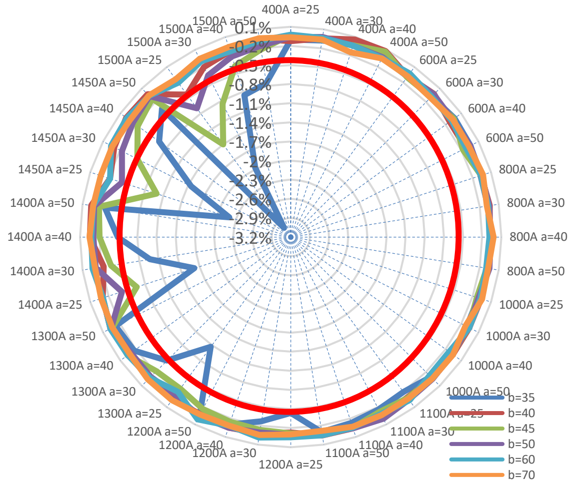
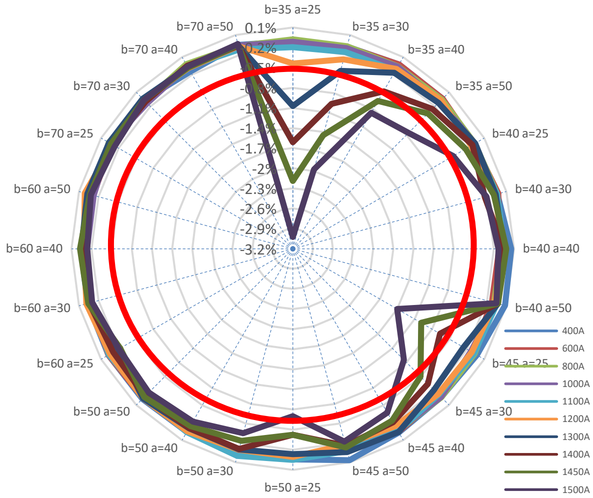
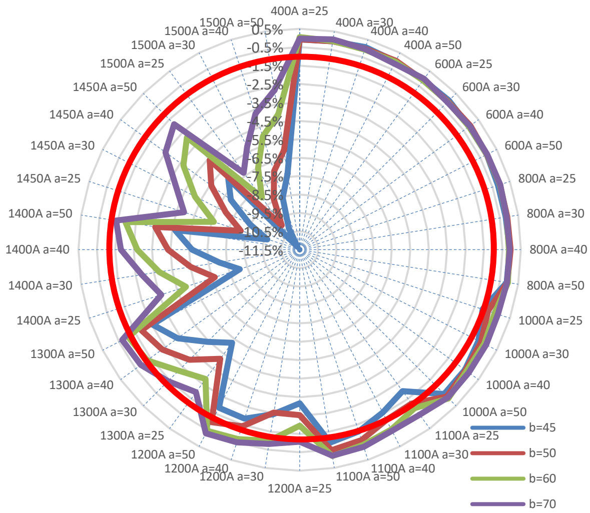
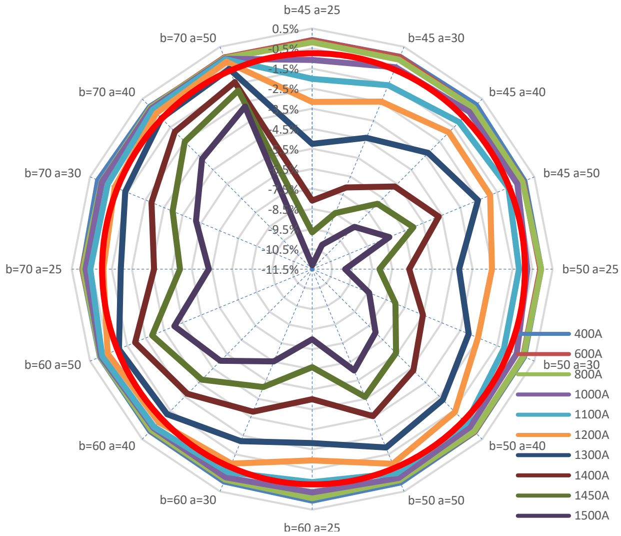
8.3.4.3 C1 shape busbar- AL





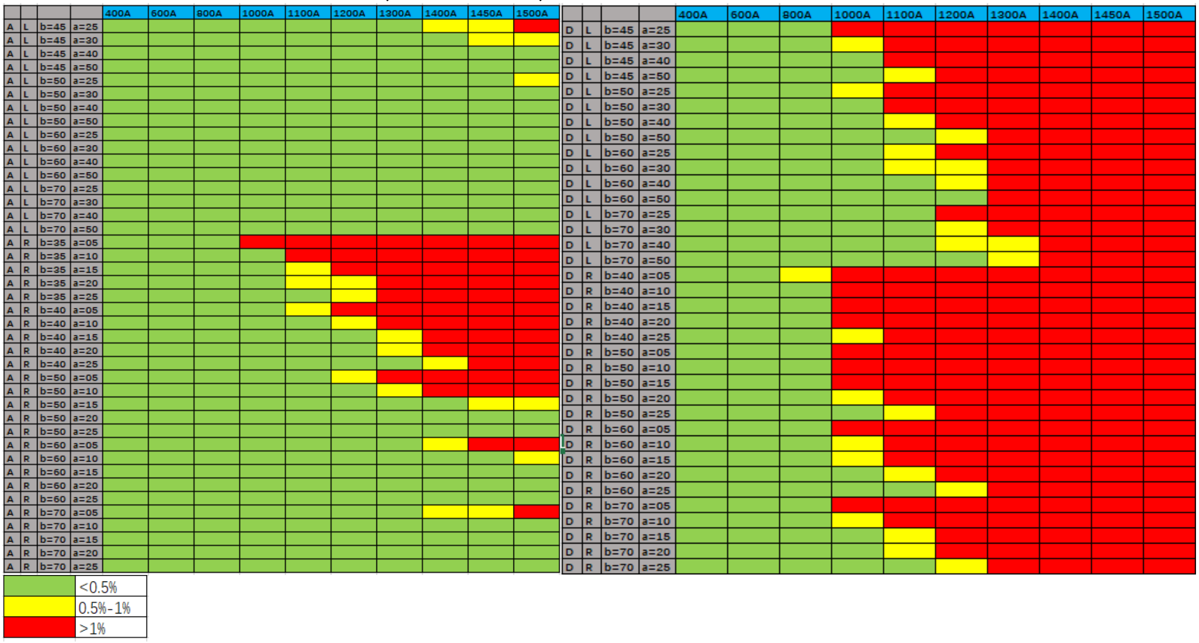
8.3.4.4 C1 shape busbar - DL





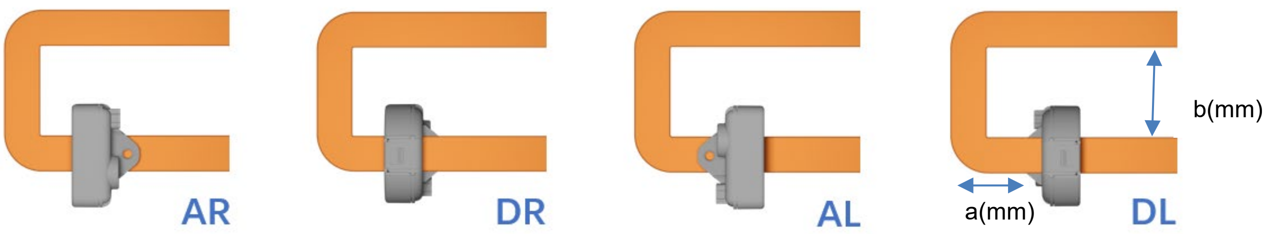
8.3.4.5 *Summary*

Matrix of various directions, distances, IP current values



C1 shape busbar will impact measurement accuracy, especially IP current higher than 1000A.
The external busbar is as far as possible, which can reduce the impact of measurement accuracy.
If the other factors are same, R direction is a little better than L direction.
If the other factors are same, A direction is much better than D direction.

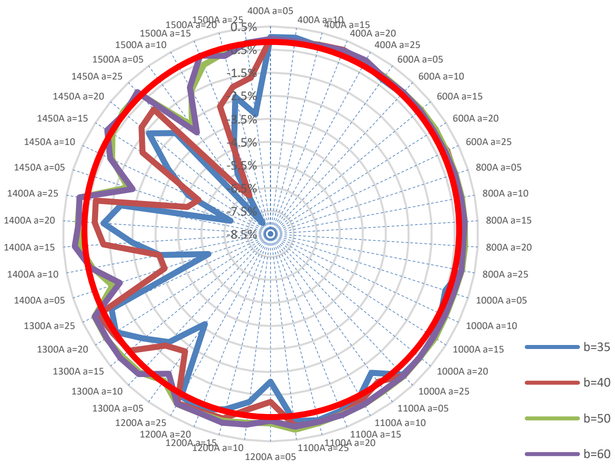
8.3.5 C2 shape busbar

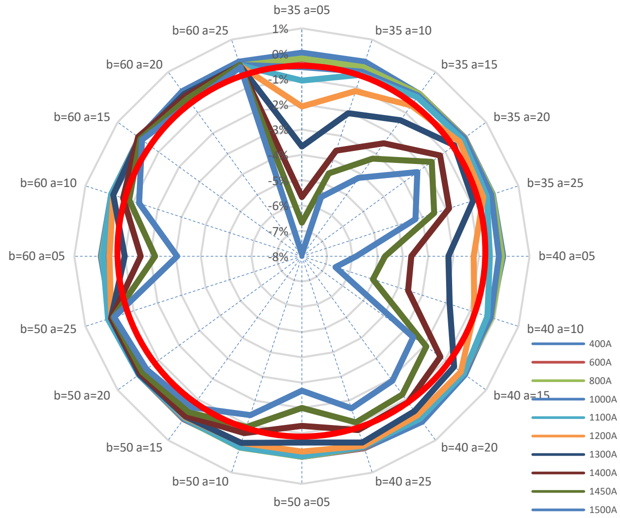


Notes:

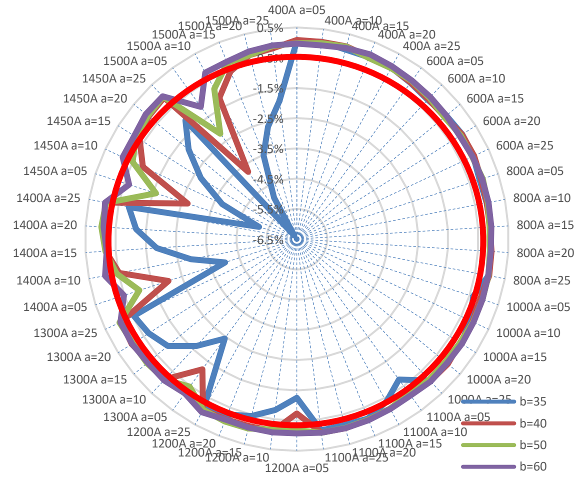
1. **A** direction: the **nose** of sensor is **upon** the busbar.
2. **D** direction: the **nose** of sensor is **under** the busbar.
3. **R** direction: the **nose** of sensor is on the **right** side.
4. **L** direction: the **nose** of sensor is on the **left** side.

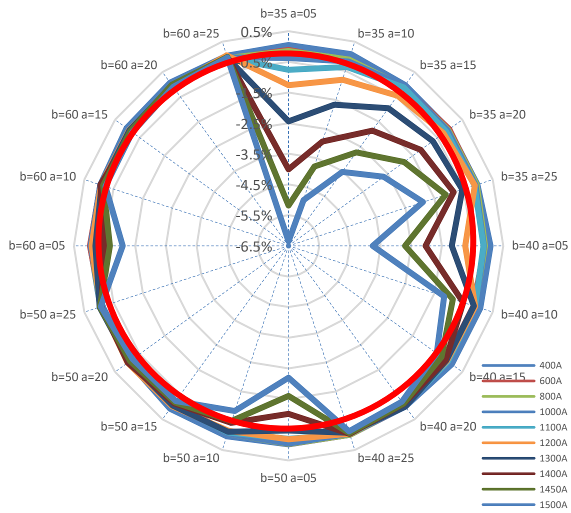
8.3.5.1 C2 shape busbar - DR



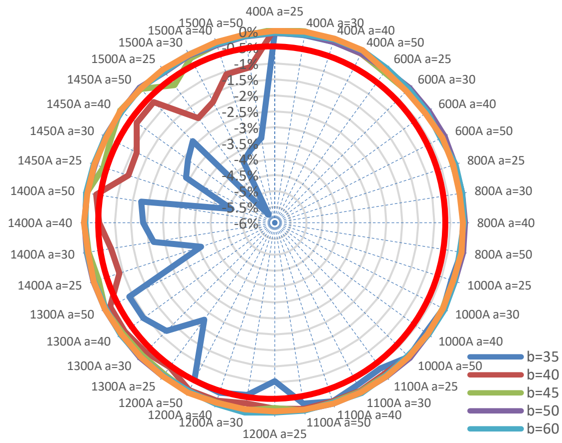


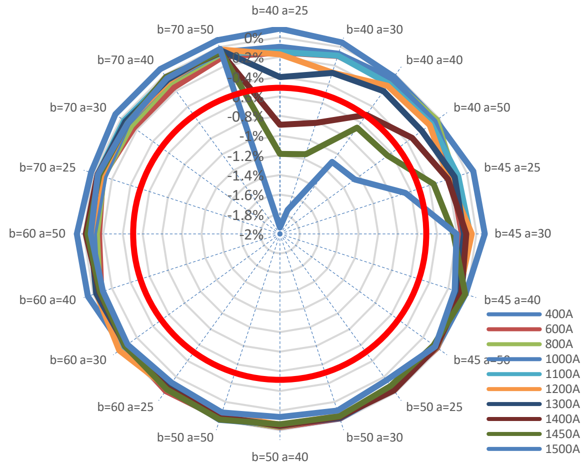
8.3.5.2 C2 shape busbar - DR



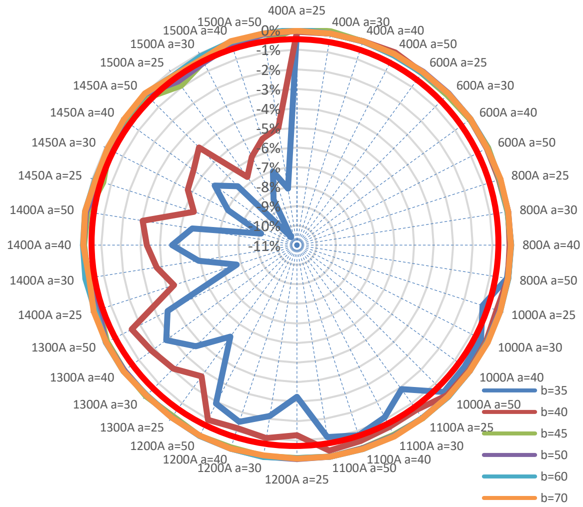


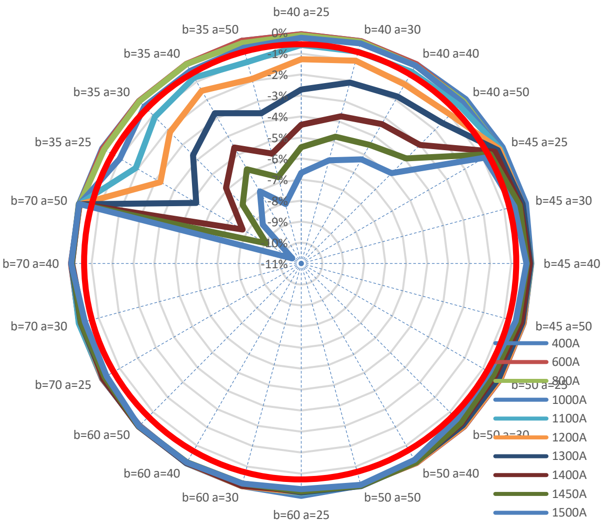
8.3.5.3 C2 shape busbar - AL





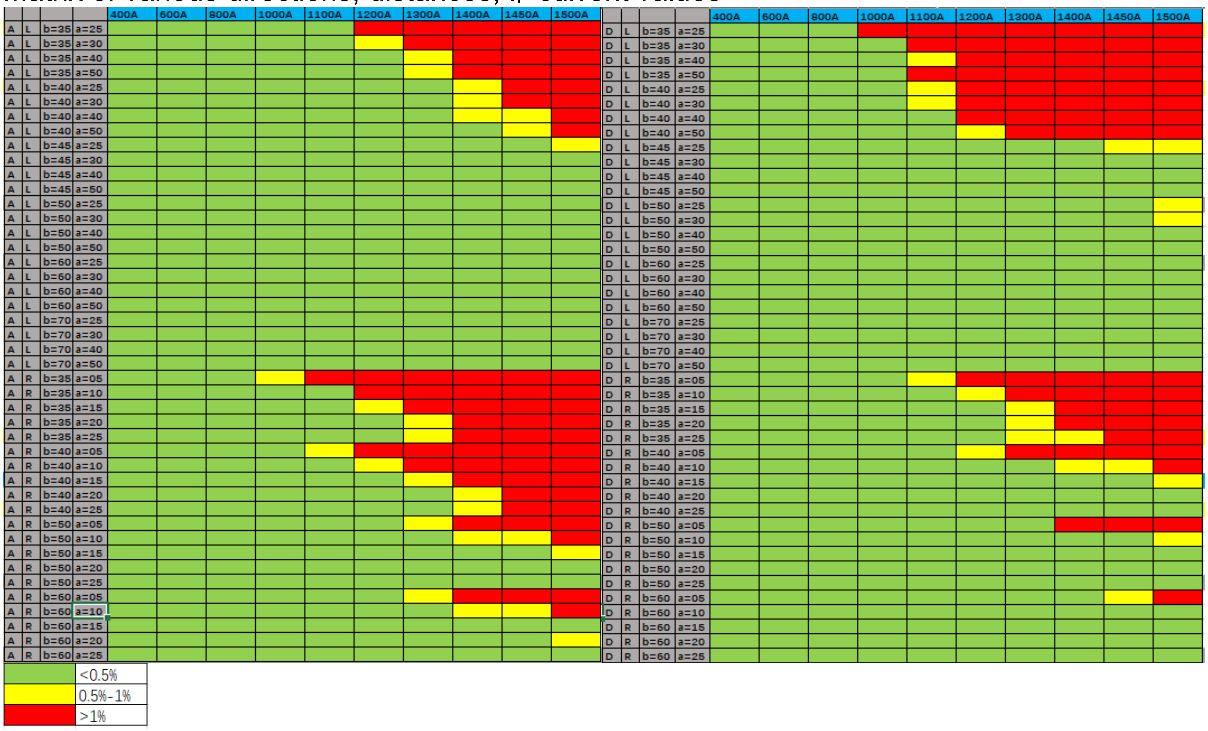
8.3.5.4 C2 shape busbar - DL





8.3.5.5 *C2 shape summary*

Matrix of various directions, distances, I_P current values



C2 shape busbar will impact measurement accuracy, especially IP current higher than 1000A.
The external busbar is as far as possible, which can reduce the impact of measurement accuracy.
If the other factors are same, R direction is a little better than L direction.
If the other factors are same, AL is better than DL, DR is better than AR.

9 Current ripple

9.1 Aim

- Aim is to illustrate AC current ripple's impact on CAB 1500 series products.
- CAB 1500 series products are designed for BMS application which is capable to measurement DC current only.
- LEM recommends avoiding the applications at below AC current ripple cases.

9.2 CAB 1500 current sensor on-power

- CAB1500 will report 'Internal Error' at specific current ripple frequency.
- Preliminary test is recommended to confirm if current ripple on application may impact the behaviour of CAB. *1

  *1 Please contact LEM technical support team for current ripple references.

9.3 CAB 1500 current sensor off-power

- By theoretically, Current ripple ratio ($\frac{\frac{1}{2} \times I\_ACpp}{I\_DC}$) over 60% may apply stress on key components of off-power CAB1500 current sensor.
- Prohibition of flowing current in power off state.

10 Internal error information

- Aim to present 'Internal Error' potential causes and behaviors.

CAB 1500-00X

Internal Error	Current Analog measurement	Potential Cause & comment
1	0xFFFFFF	- Hardware malfunction - Current ripple. Error stay for limited period of time. Automatically recover if ripple disappear - $\lvert I_P \rvert > \lvert \hat{I}_{P\ max} \rvert$ *2
1	1550000mA	Overcurrent detection. $\lvert I_P \rvert$ is over 1550A (less than $\lvert \hat{I}_{P\ max} \rvert$)

CAB-SF 1500-00X

Internal Error	Current Analog measurement	Potential Cause & comment
1	0xFFFFFF	- Hardware malfunction - Current ripple. Error stay for limited period of time. Automatically recover if ripple disappear - $\lvert I_P \rvert > \lvert \hat{I}_{P\ max} \rvert$ *2
1	I_P	Malfunction on redundant hardware for functional safety, **Current measurement accuracy is not guaranteed**
1	1550000mA	Overcurrent detection. $\lvert I_P \rvert$ is over 1550A (less than $\lvert \hat{I}_{P\ max} \rvert$)

*2 $\lvert \hat{I}_{P\ max} \rvert \approx 1700$ A

LEM
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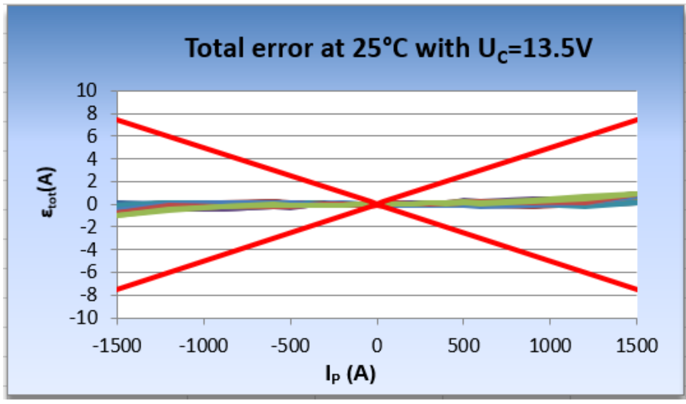
11 Accuracy with 1 and 10 CAN Frames average

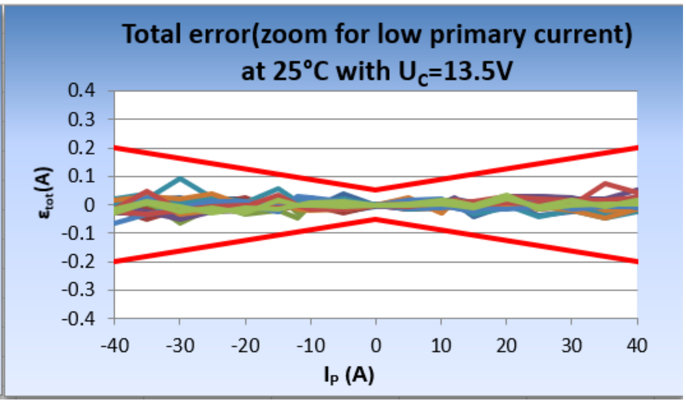
11.1 Aim

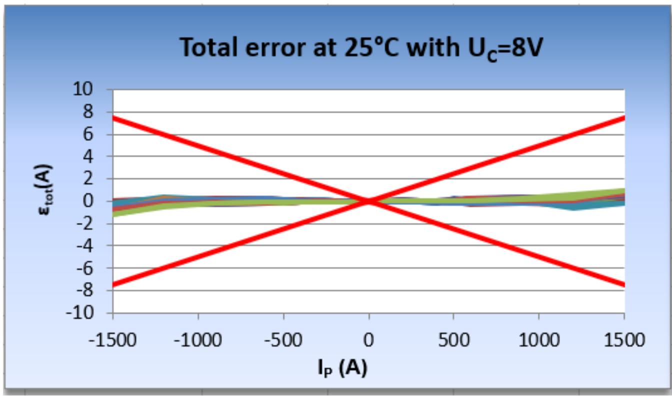
- Aim is to present CAB 1500 accuracy performance with 10 CAN frames average and 1 CAN frame average, datasheet suggest 20 CAN frames average to achieve more stable accuracy.

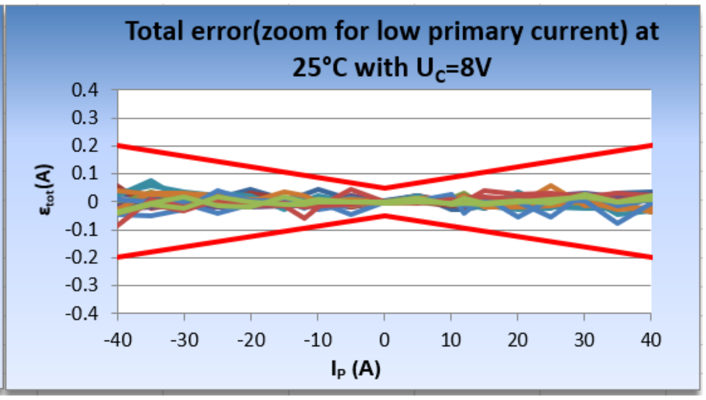
11.2 10 CAN Frames average accuracy

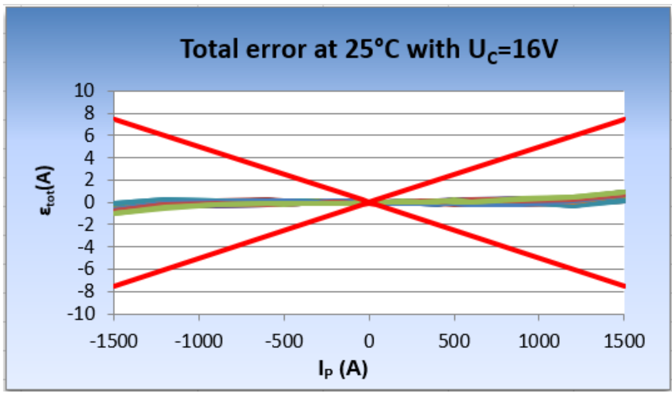
11.2.1 25degC performance

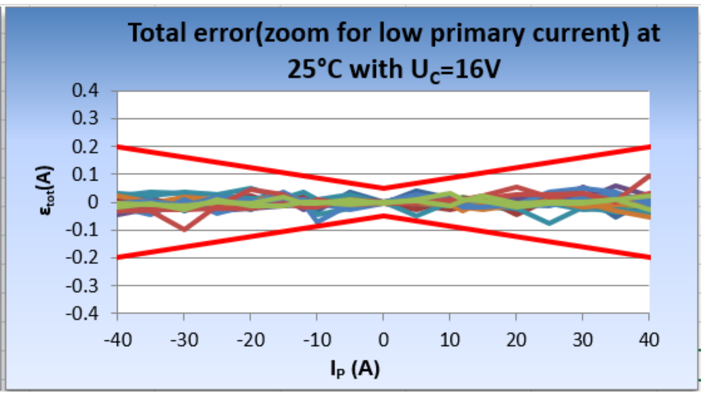




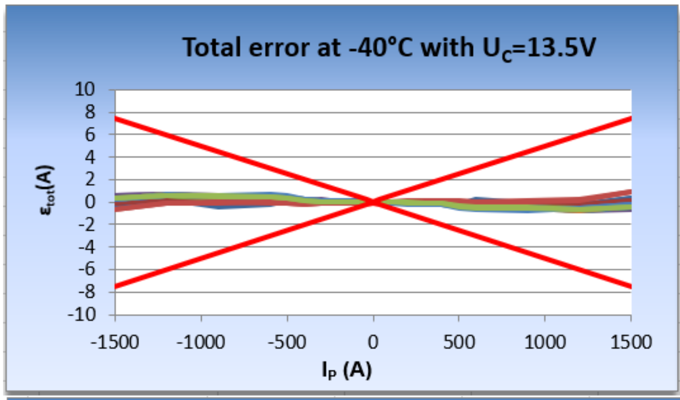


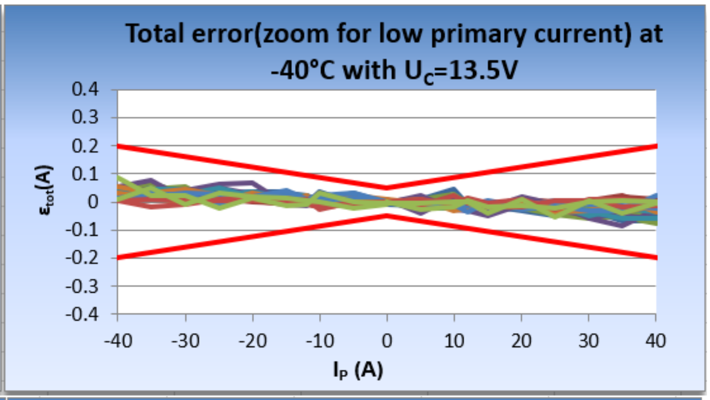


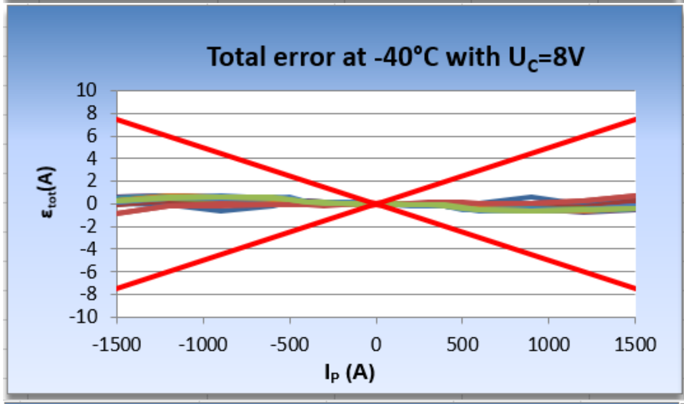


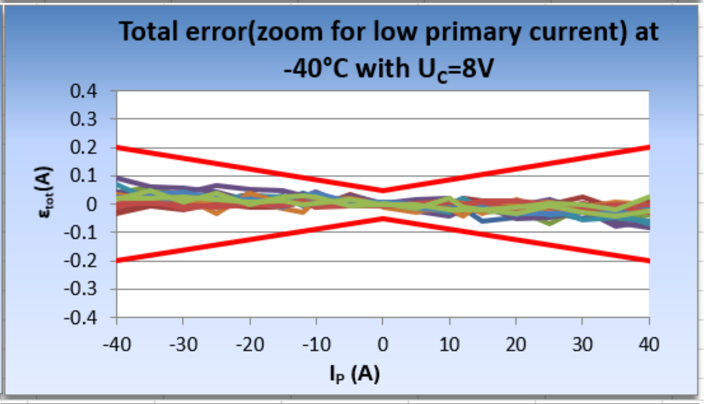


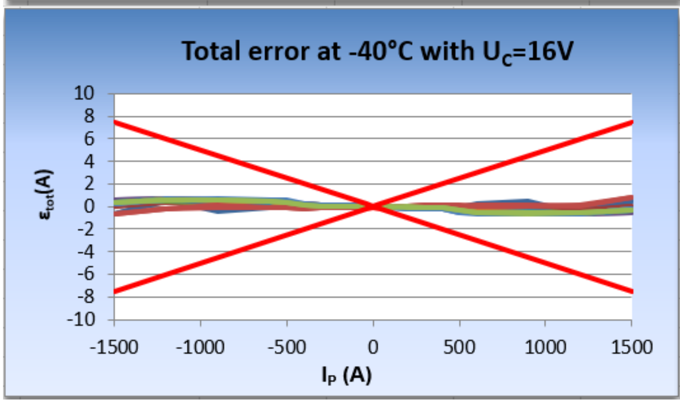
11.2.2 -40degC performance

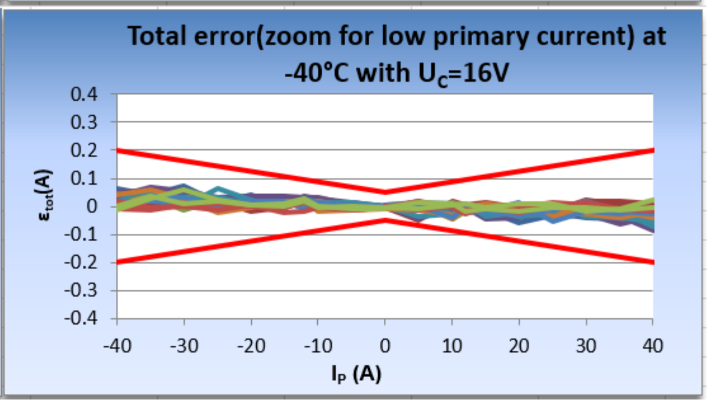




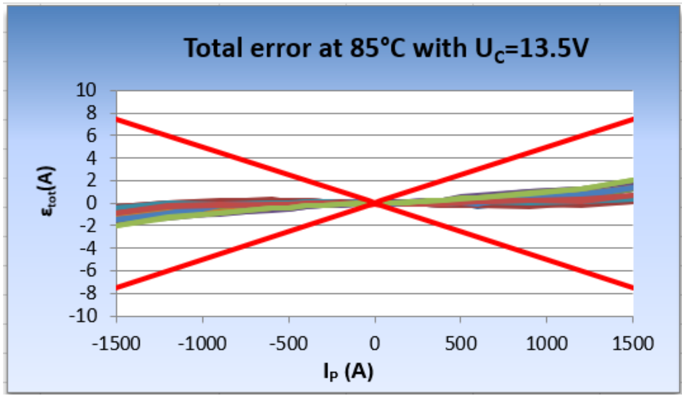


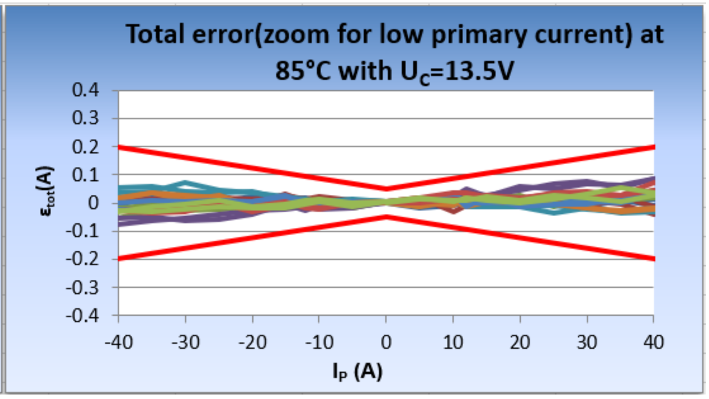


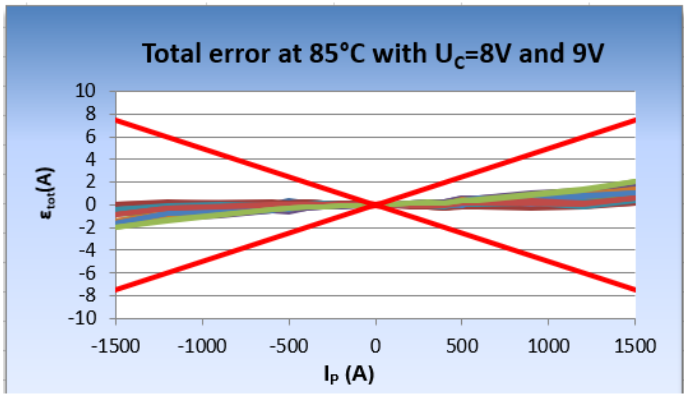


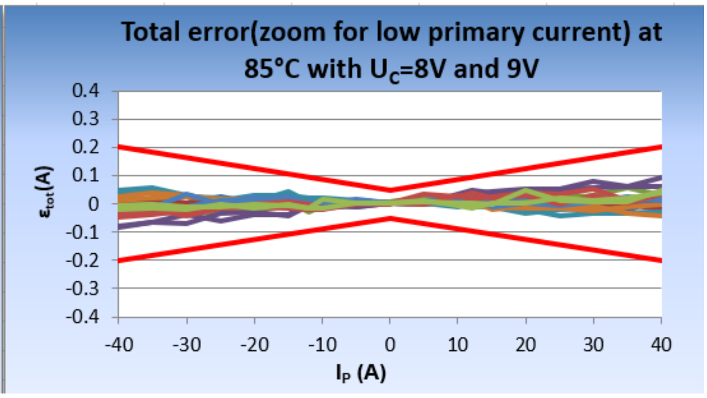


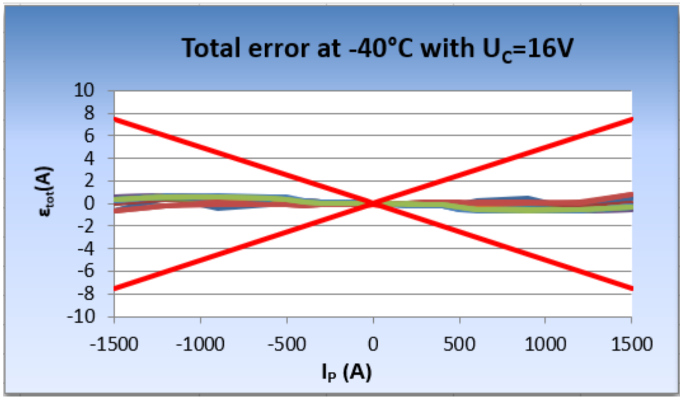
11.2.1 85degC performance

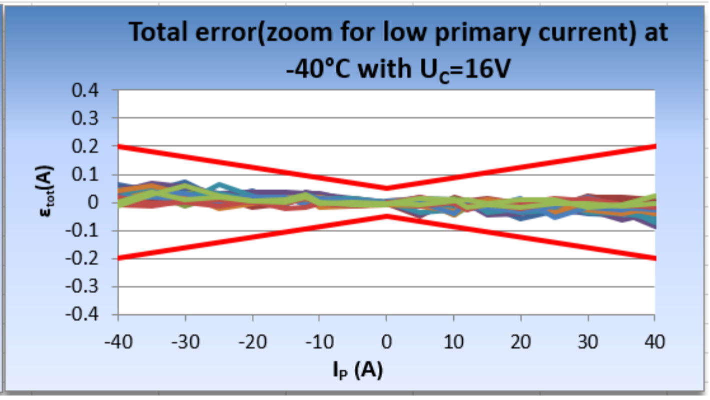






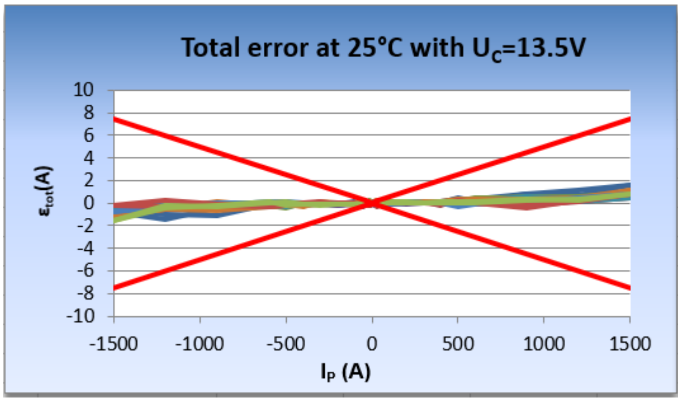


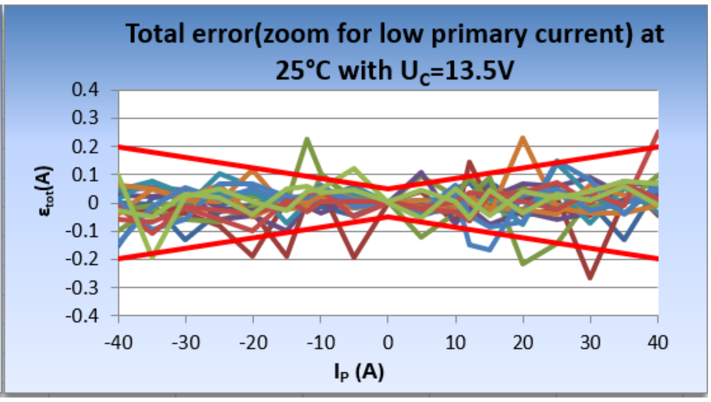


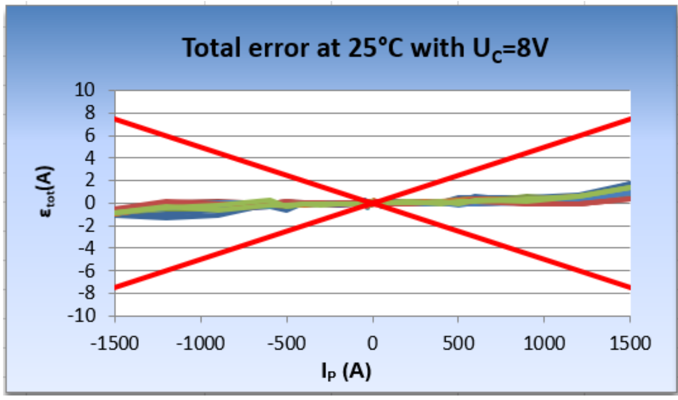


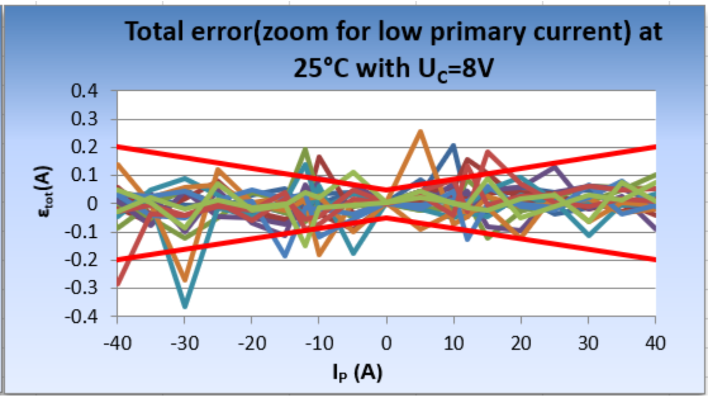
11.31 CAN Frame average accuracy

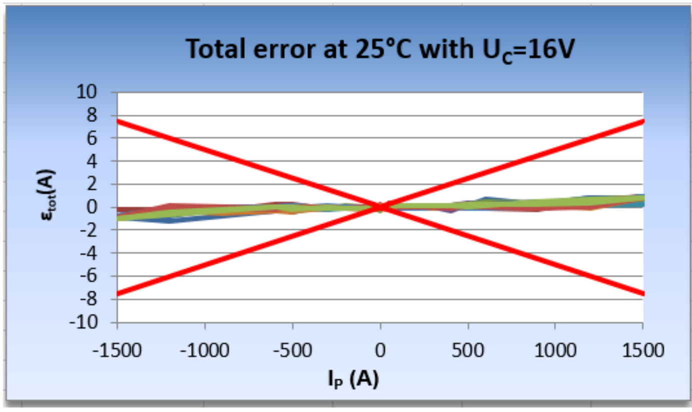
11.3.1 25degC performance

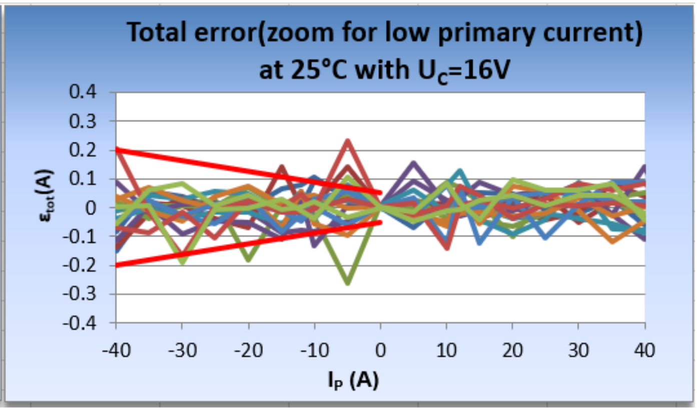




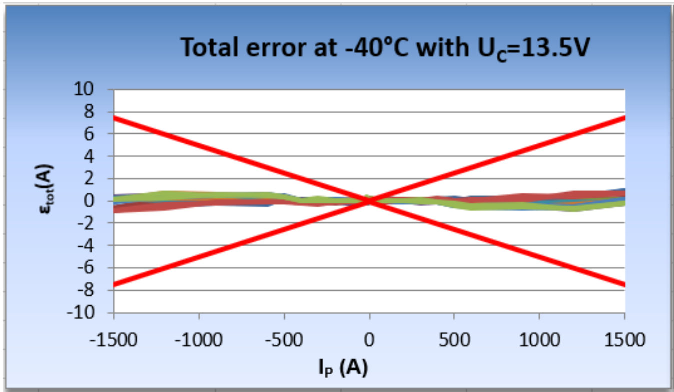


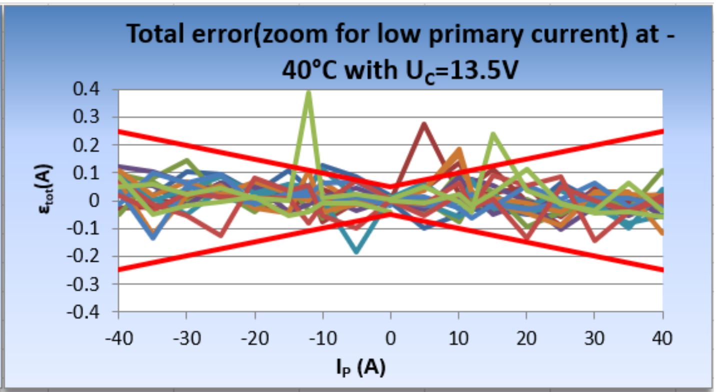


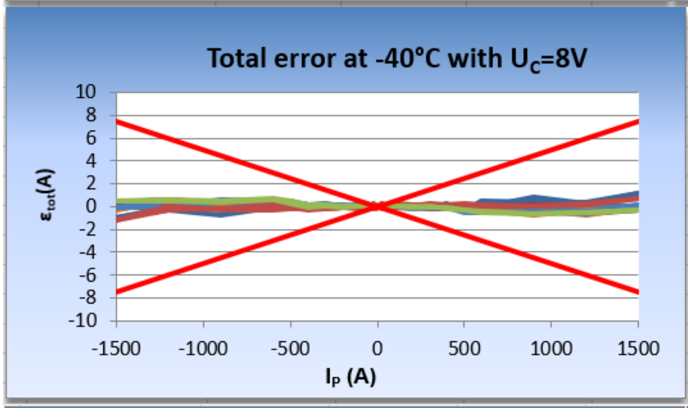


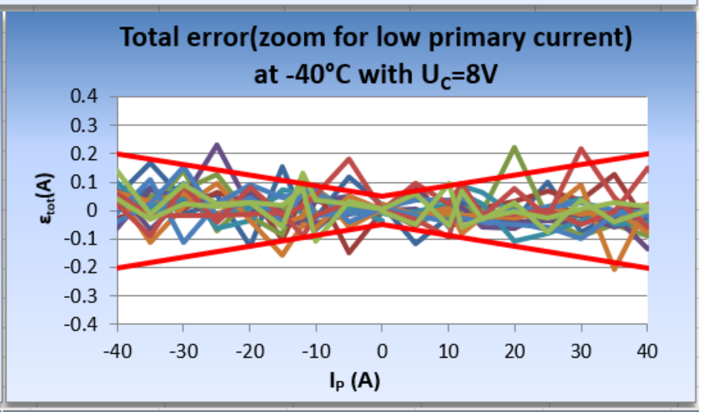


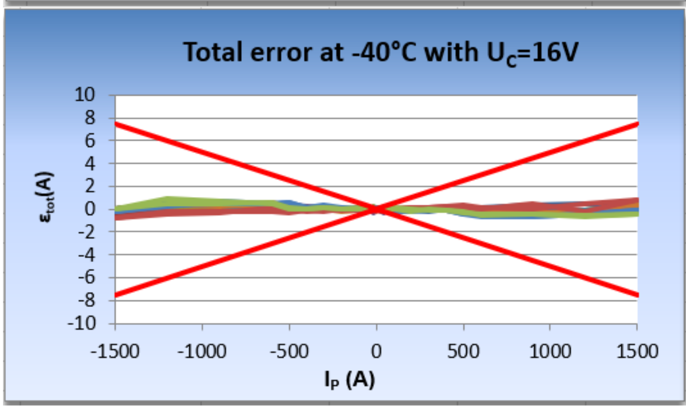
11.3.2 -40degC performance

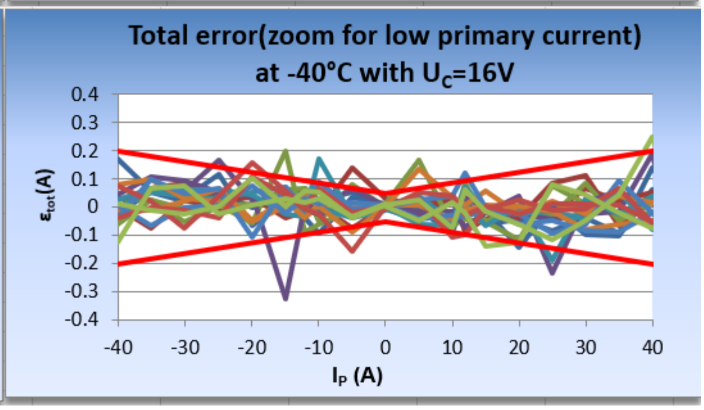












11.3.3 85degC performance