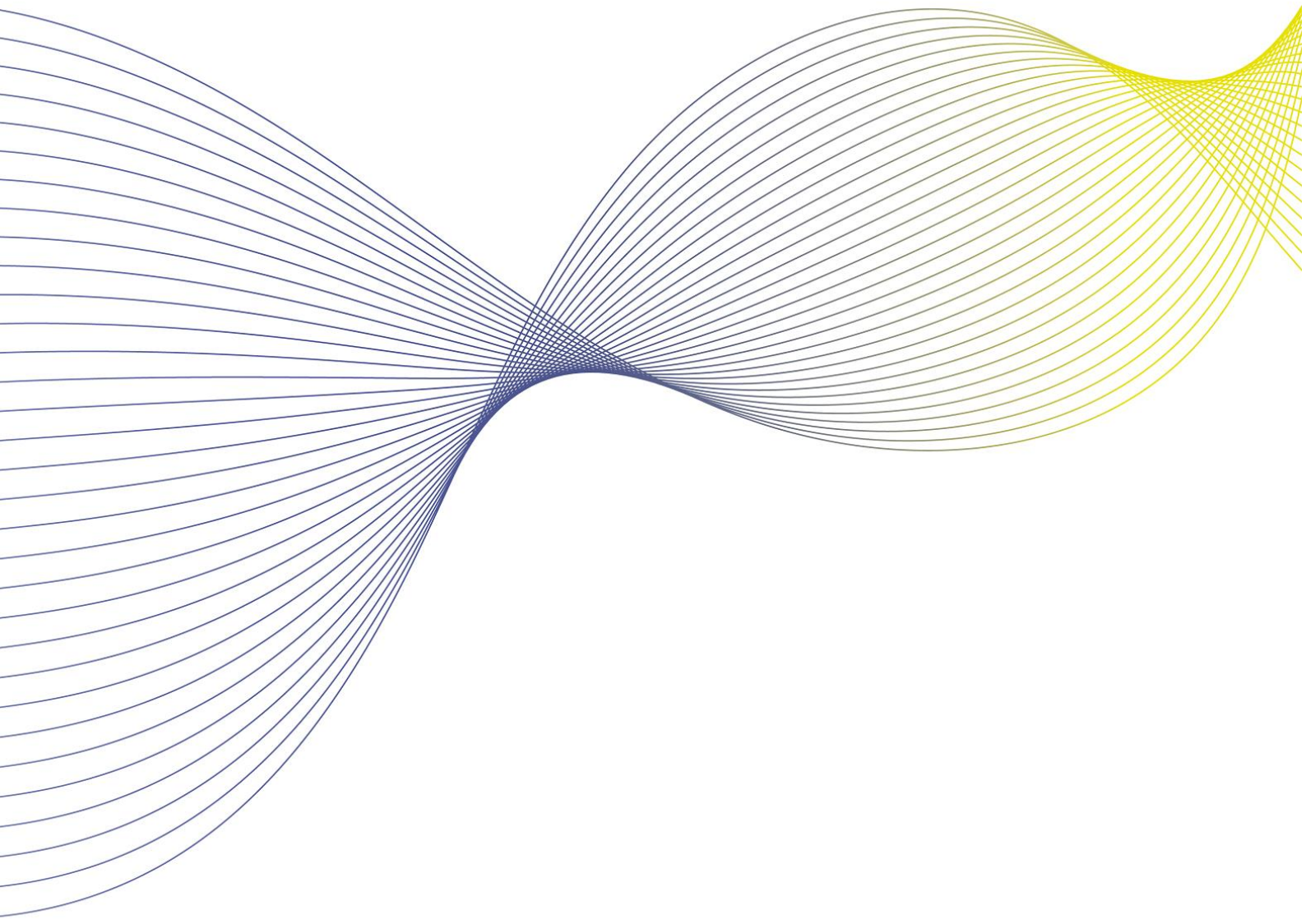
CAB 1500 APPLICATION NOTES

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
1	25/August/2023	hjc	Add requirement for UDS service access Add internal error data acquisition setting recommendation; Add Busbar ESD level recommendation. Add SafetyGoalViolation signal in CAB-SF 1500-00X internal error information
2	25/April/2024	wlw	Remove UDS related information. (Refer to '*Application Note_CAB 1500 Generic - on Customer Access Parameter Configuration*' for further information regarding to UDS)

2 CLARIFICATION

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

3 Abbreviation

- CAN: Controller Area Network
- CRC: Cyclic Redundancy Check
- ECU: Electronic Control Unit

4 E2E CRC

4.1 Aim

- Aim to clarify CAB1500 Series E2E Protection Instruction.

4.2 Reference

- Refer to 'AutoSAR_PRS_E2EProtocal' profile 1

4.3 CAB 1500 SERIES EXCEPT CAB-SF 1500-002

4.3.1 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

4.3.2 Counter

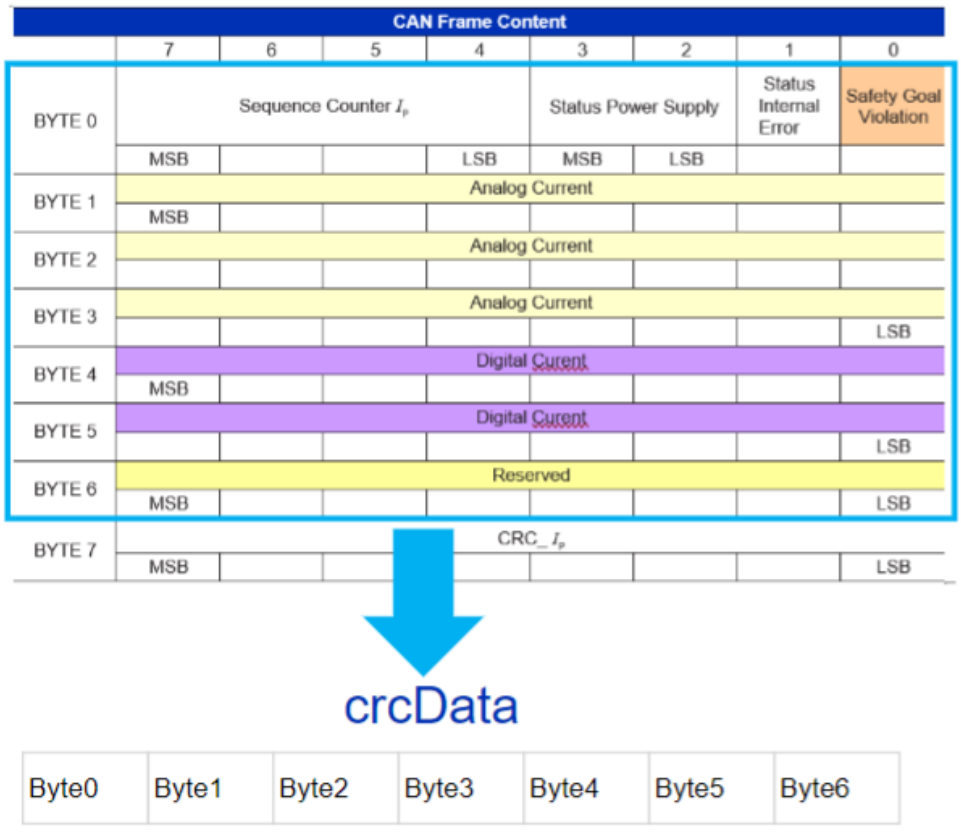
- Initialized with 0 for the first CAN frame transmission
- Incremented by 1 for every subsequent send request
- When the counter reaches the value 15, then it shall restart with 1 for the next send request

4.3.3 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)

4.3.4 CRC calculation

4.3.4.1 CRC calculation data



4.3.4.2 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

4.4 CAB-SF 1500-002

4.4.1 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		OverCurrent Status	SafetyGoal Violation	OtherHardware Error

4.4.2 Counter

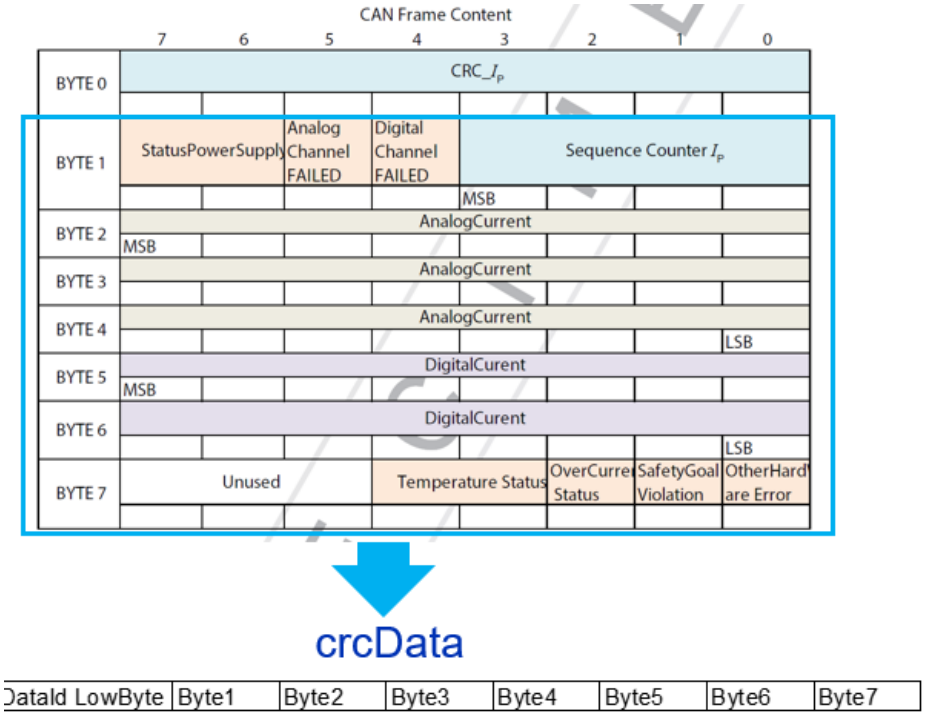
- Initialized with 0 for the first CAN frame transmission
- Incremented by 1 for every subsequent send request
- When the counter reaches the value 15, then it shall restart with 1 for the next send request

4.4.3 DataID

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

4.4.4 CRC calculation

4.4.4.1 CRC calculation data



4.4.4.2 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.

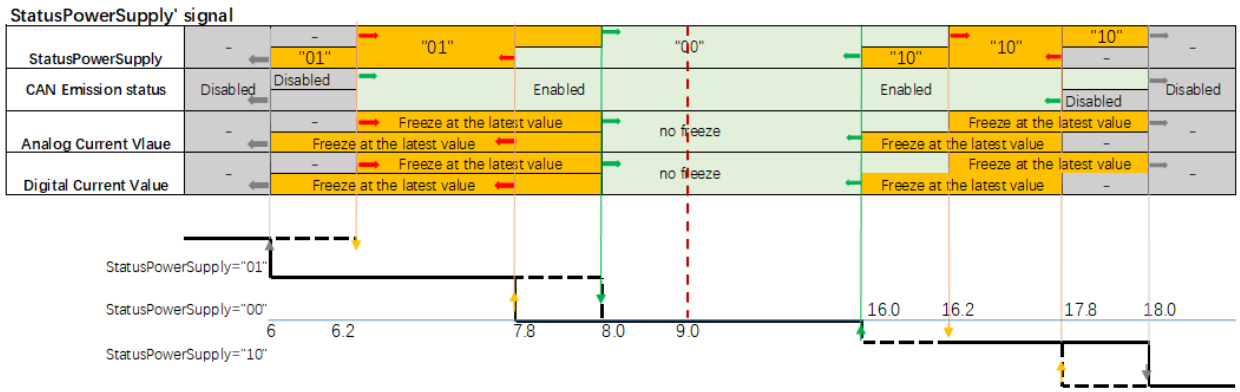
5 Power supply instruction

5.1 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.

5.2 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 I_P				StatusPowerSupply		Status internal error	Safety Goal violation
	MSB			LSB	MSB	LSB		

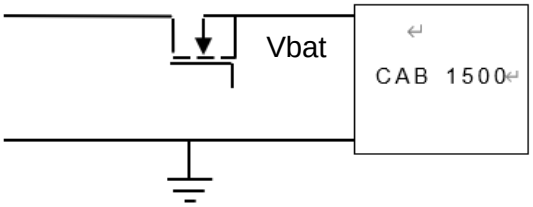
- Power Supply range

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	

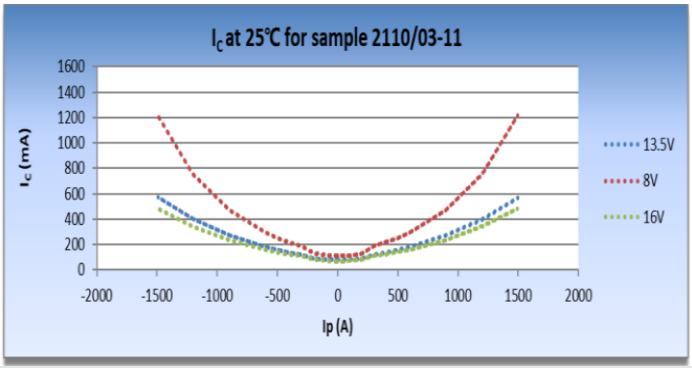
Note:Test condition ,room tempertuare, I_P=0A, voltage measurement position CAB supply pin side.
Different application may lead slightly difference with the result.

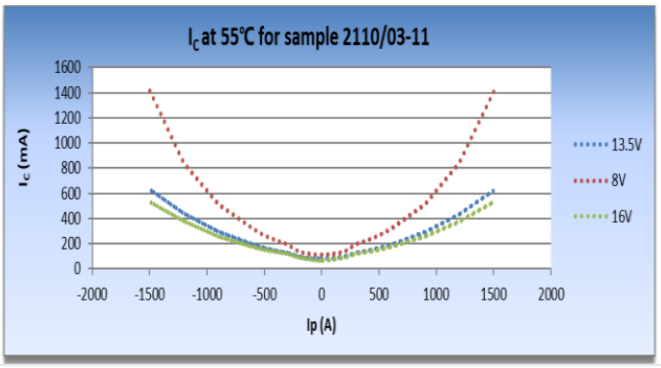
2) When Power Supply voltage measurement is not available, then 'StatusPowerSupply' = "1 1"
At sensor start-up, if supply voltage < 7.8 V or > 16.2 V, no CAN frame emission
3) The Vbat voltage mentioned above is the real voltage supplied on CAB terminals
Suggestion: if there is a MOSFET or transistor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



5.3 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.

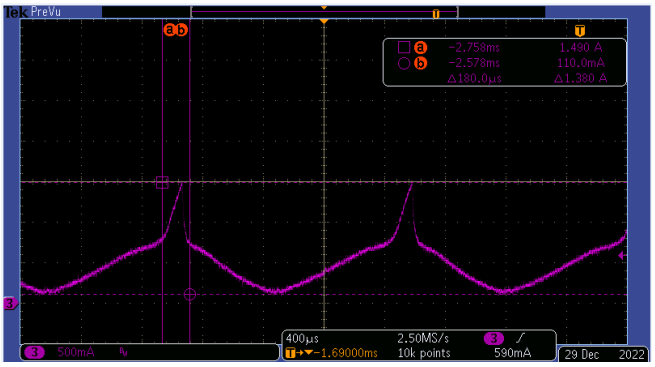




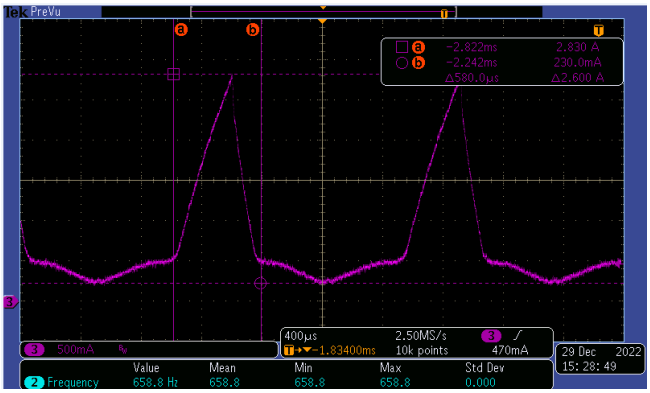
5.4 Input peak current

- 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.

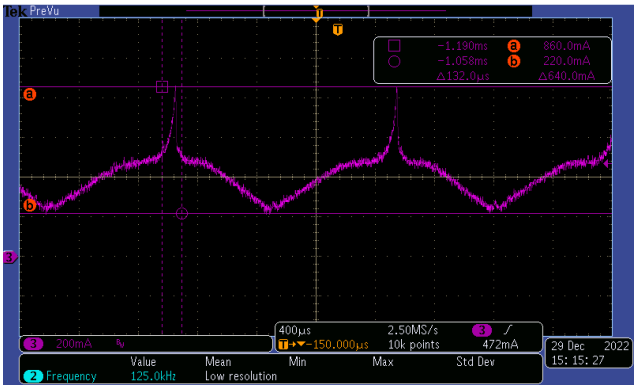
Waveform to show input peak current _13.5V with I_P =1500A, input peak current is 1.49A.



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.



6 Busbar design recommendation

6.1 Aim

- Aim is to recommend busbar design and mounting requirements:
  - External busbar disturbance with different busbar shapes, this can be referred during BDU structure design.
  - ESD control is required during assembling and testing process.

6.2 ESD requirement

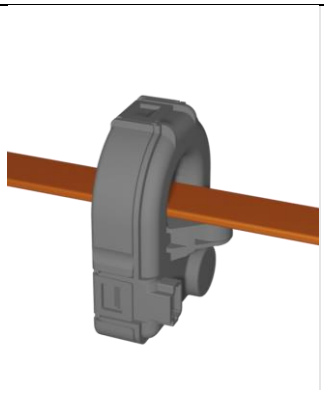
- LEM recommends that datasheet ESD requirements should be strictly followed while handling, assembling, and testing of the CAB1500.

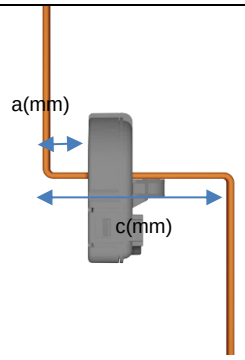
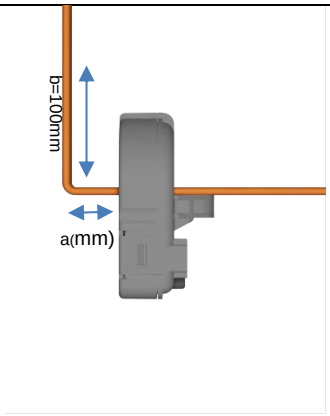
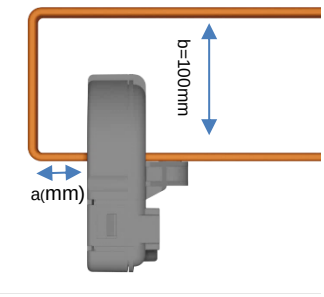
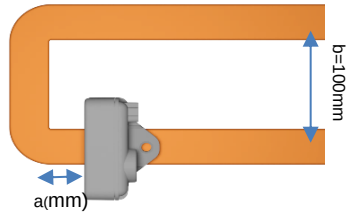
6.3 Return busbar test notes

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

6.4 Busbar shapes recommendation

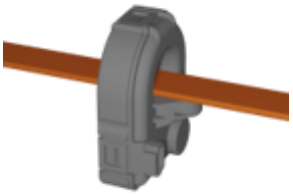
- Brief Summary, more details see corresponding charts by busbar shape.
- Recommendation for busbar design:
- Straight and S-shaped are recommended busbar design.
- L-shaped busbar, recommend for AL, AR, DL direction application but not DR direction application.
- C1 and C2 are not recommended for busbar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

Busbar -shapes	Accuracy impact	Shape
Straight	Error≤0.5%	

Busbar -shapes	Accuracy impact	Shape
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.	
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.	

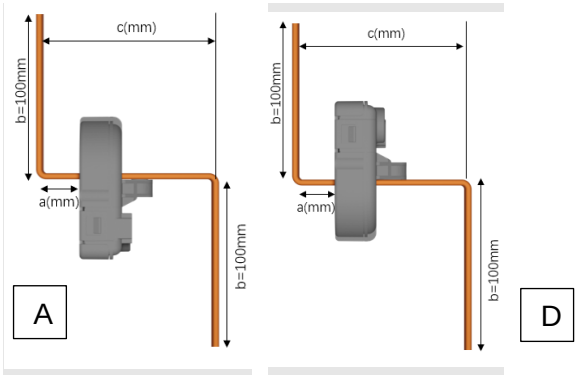
6.4.1 Straight busbar

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).



6.4.2 S shape busbar

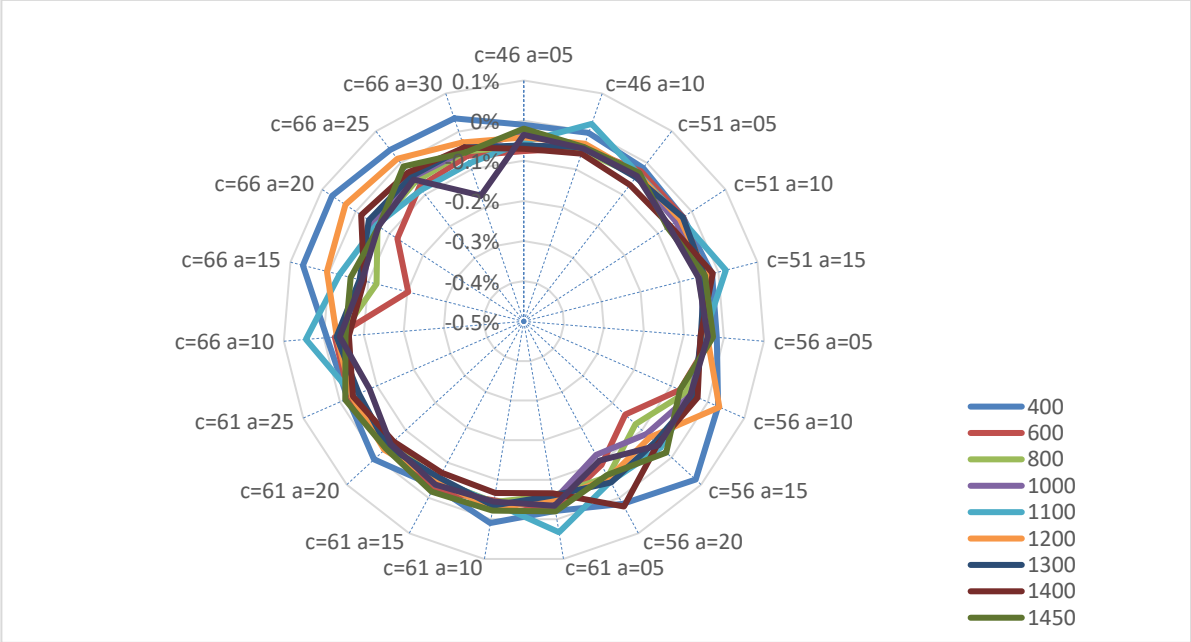
6.4.2.1 S shape Busbar



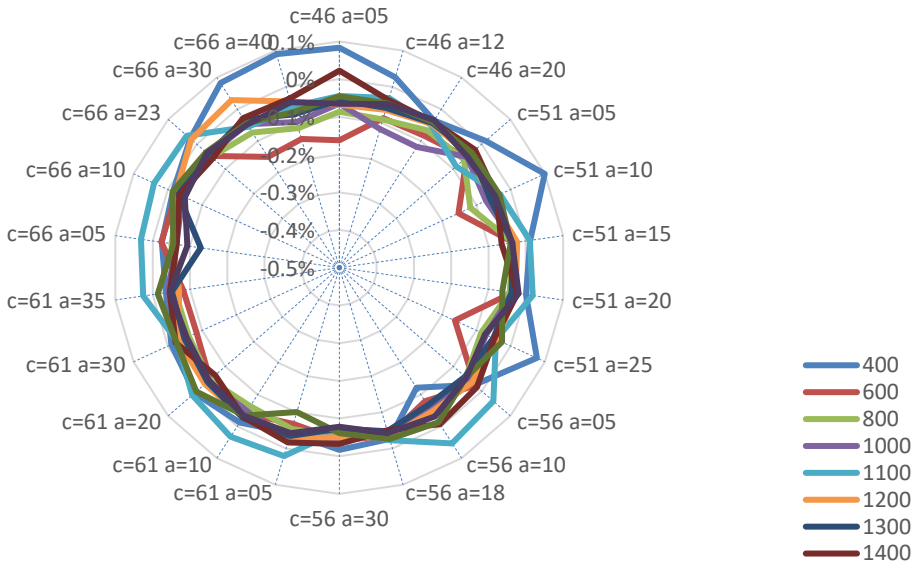
Notes:

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

6.4.2.2 S shape busbar - A

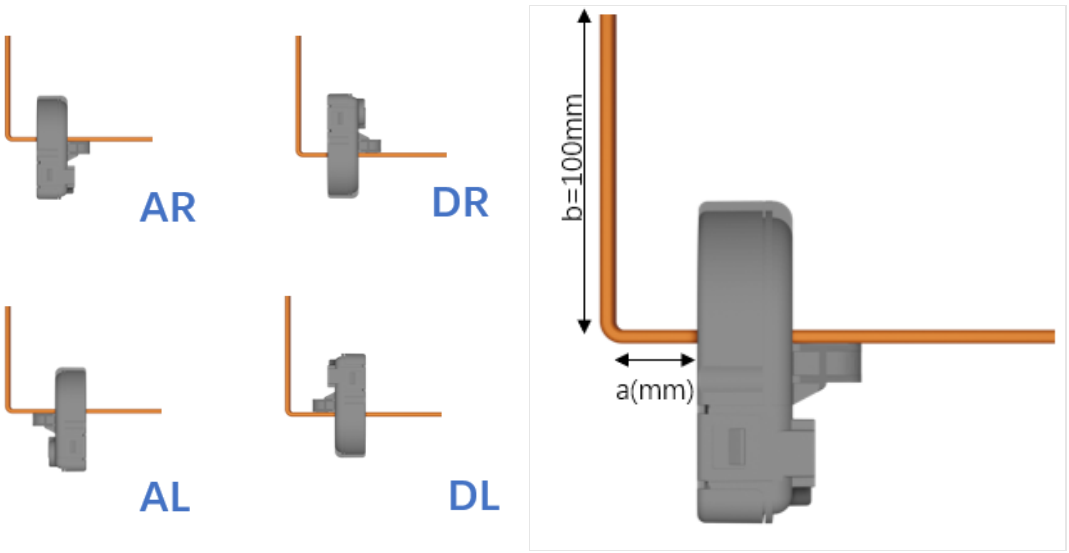


6.4.2.3 S shape busbar - D



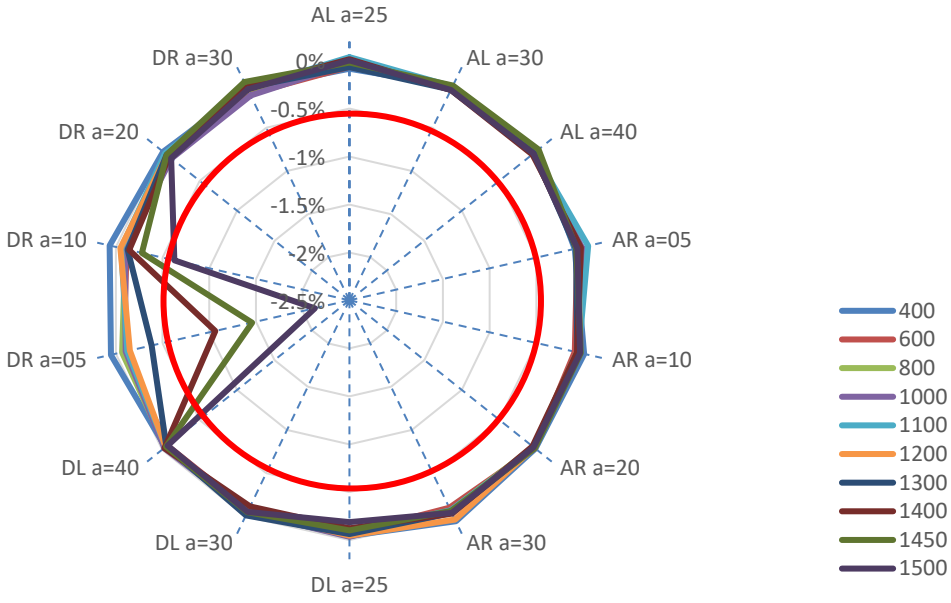
S shape busbar has no impact on measurement accuracy and achieve performance which the error is not worse than the tolerance 0.5%.

6.4.3 L shape busbar



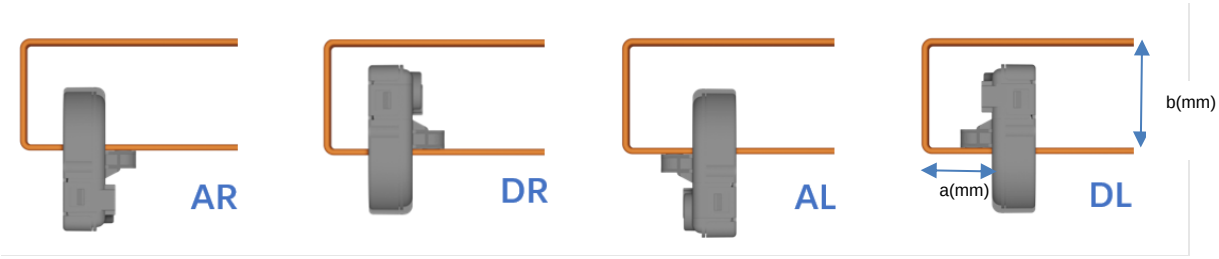
Notes:

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%.

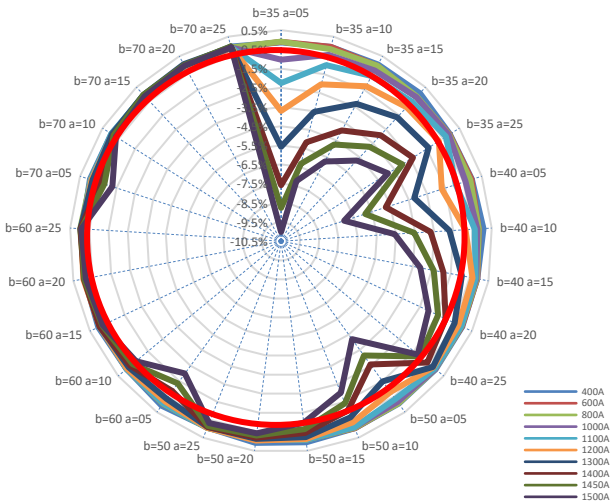
6.4.4 C1 shape busbar

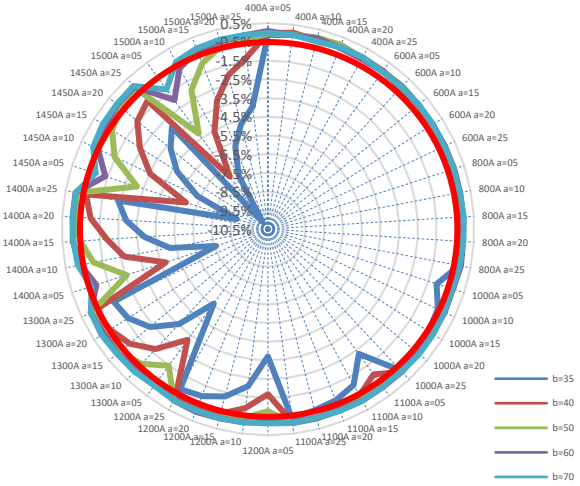


Notes:

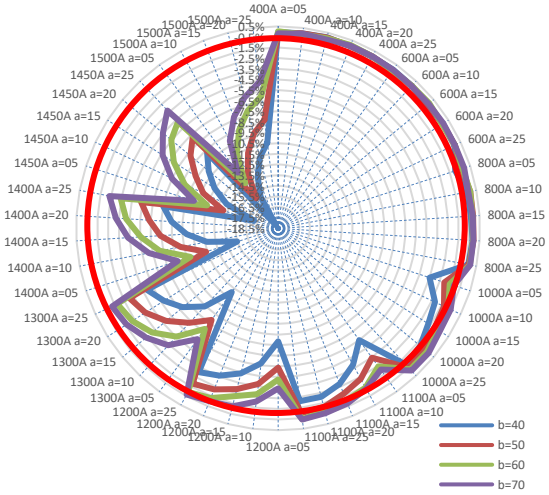
1. **A** direction: the **nose** of sensor is **under** the busbar.
2. **D** direction: the **nose** of sensor is **upon** the busbar.
3. **R** direction: the **nose** of sensor is on the **right** side.
4. **L** direction: the **nose** of sensor is on the **left** side.

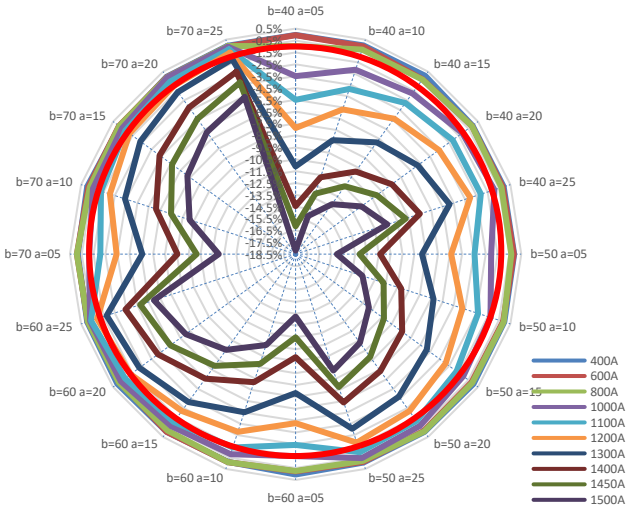
6.4.4.1 C1 shape busbar - AR



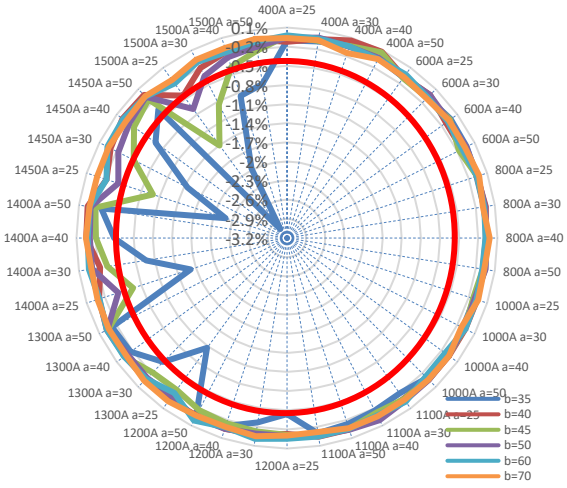


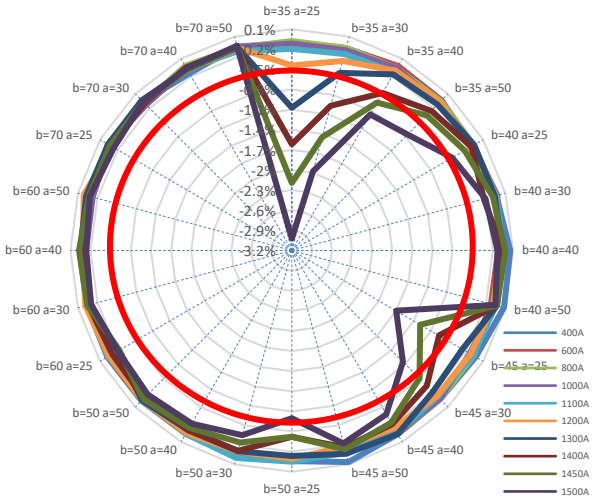
6.4.4.2 C1 shape busbar - DR



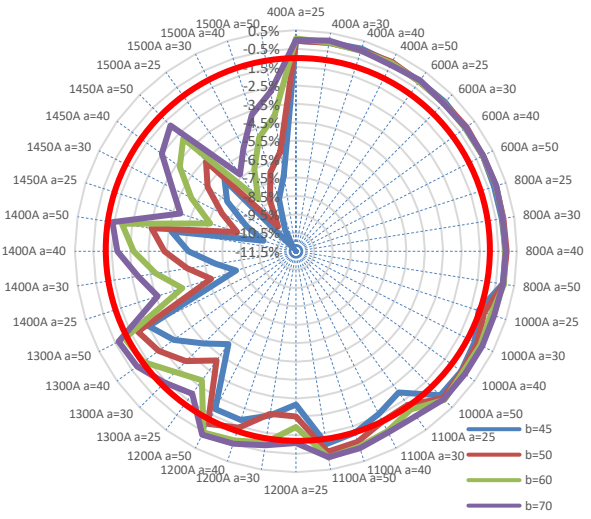


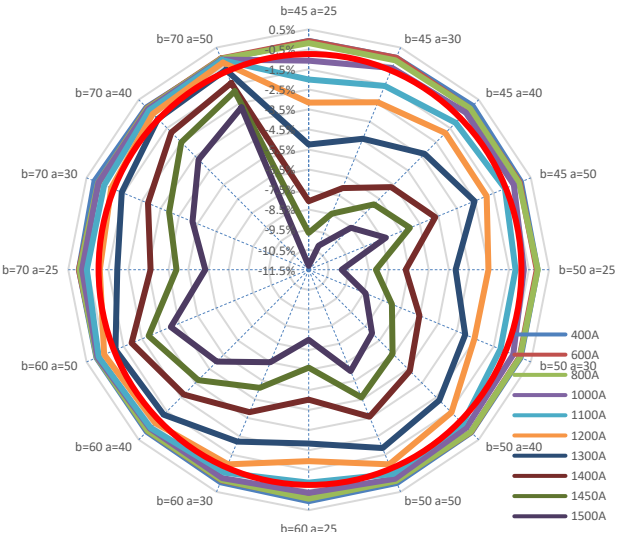
6.4.4.3 C1 shape busbar- AL





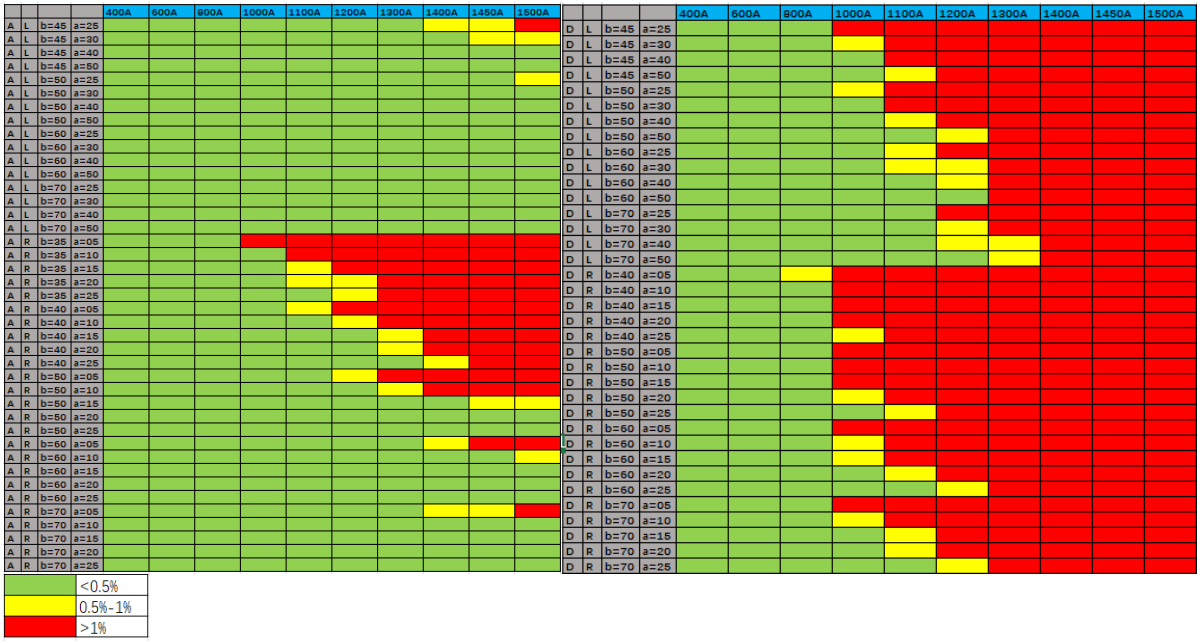
6.4.4.4 C1 shape busbar - DL





6.4.4.5 *Summary*

Matrix of various directions, distances, I_P current values



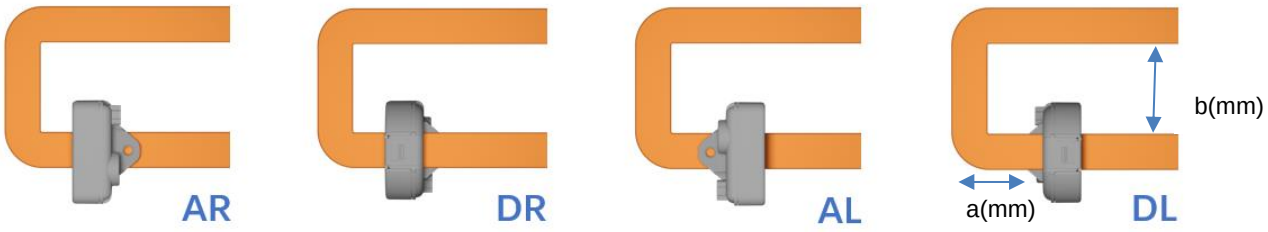
C1 shape busbar will impact measurement accuracy, especially I_P current higher than 1000A.

The external busbar is as far as possible, which can reduce the impact of measurement accuracy.

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.

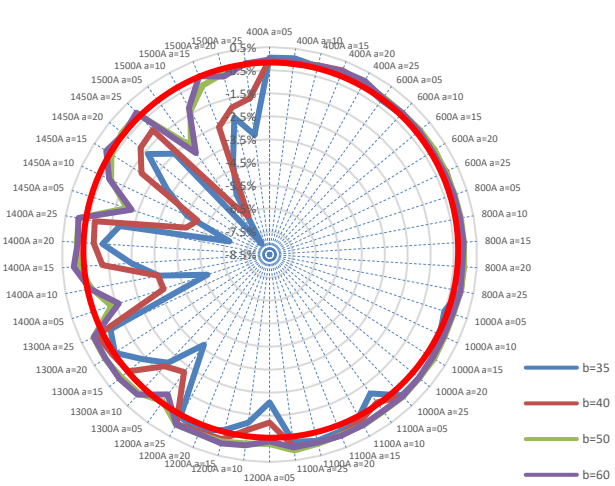
6.4.5 *C2 shape busbar*

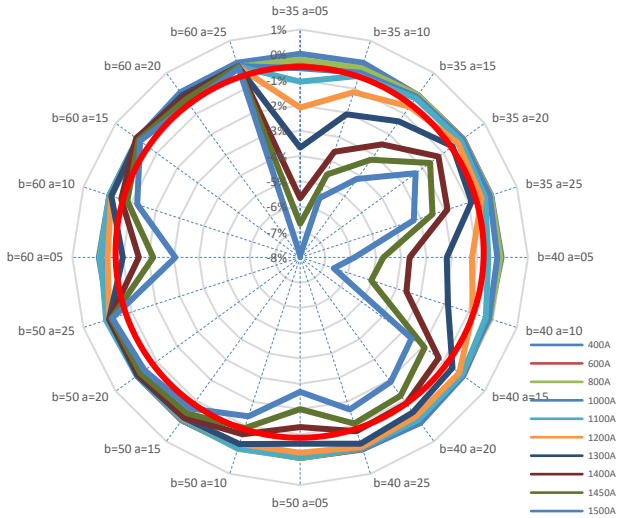


Notes:

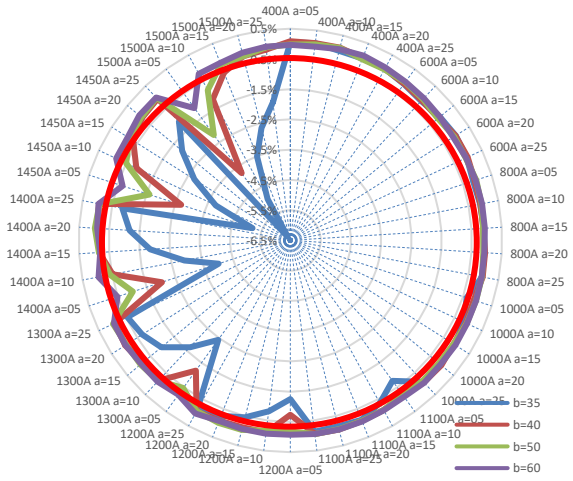
1. **A** direction: the **nose** of sensor is **upon** the busbar.
2. **D** direction: the **nose** of sensor is **under** the busbar.
3. **R** direction: the **nose** of sensor is on the **right** side.
4. **L** direction: the **nose** of sensor is on the **left** side.

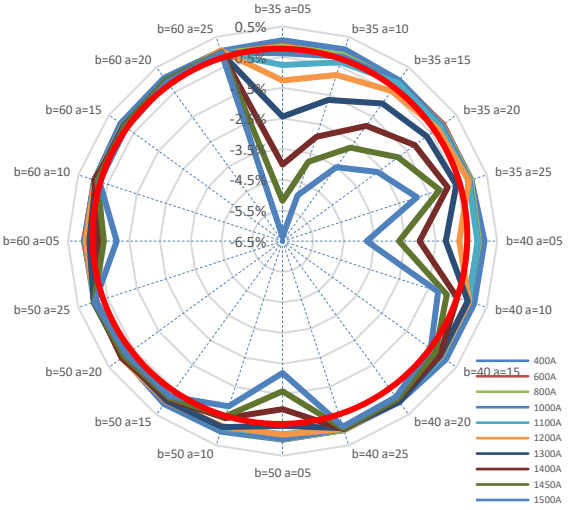
6.4.5.1 C2 shape busbar - DR



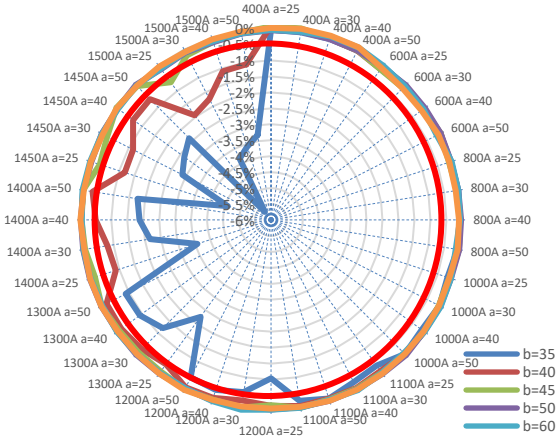


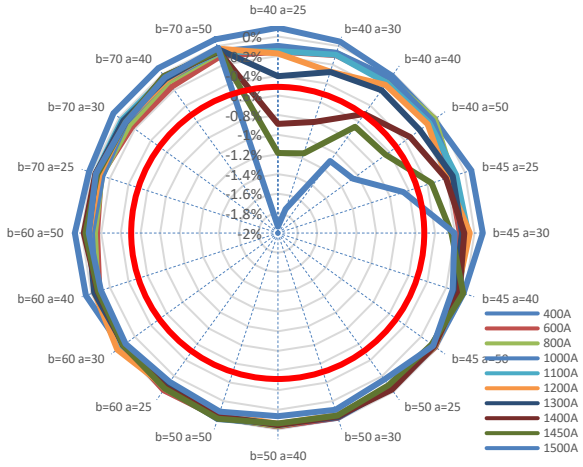
6.4.5.2 C2 shape busbar - DR



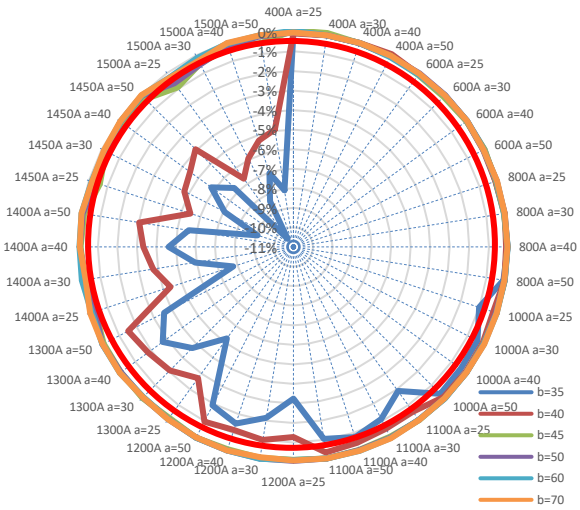


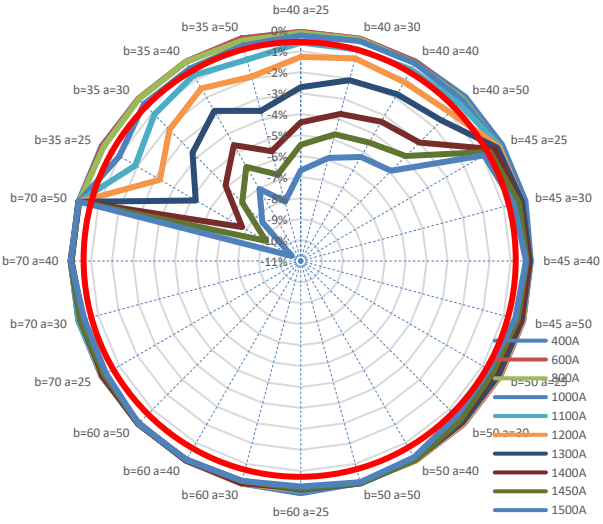
6.4.5.3 C2 shape busbar - AL





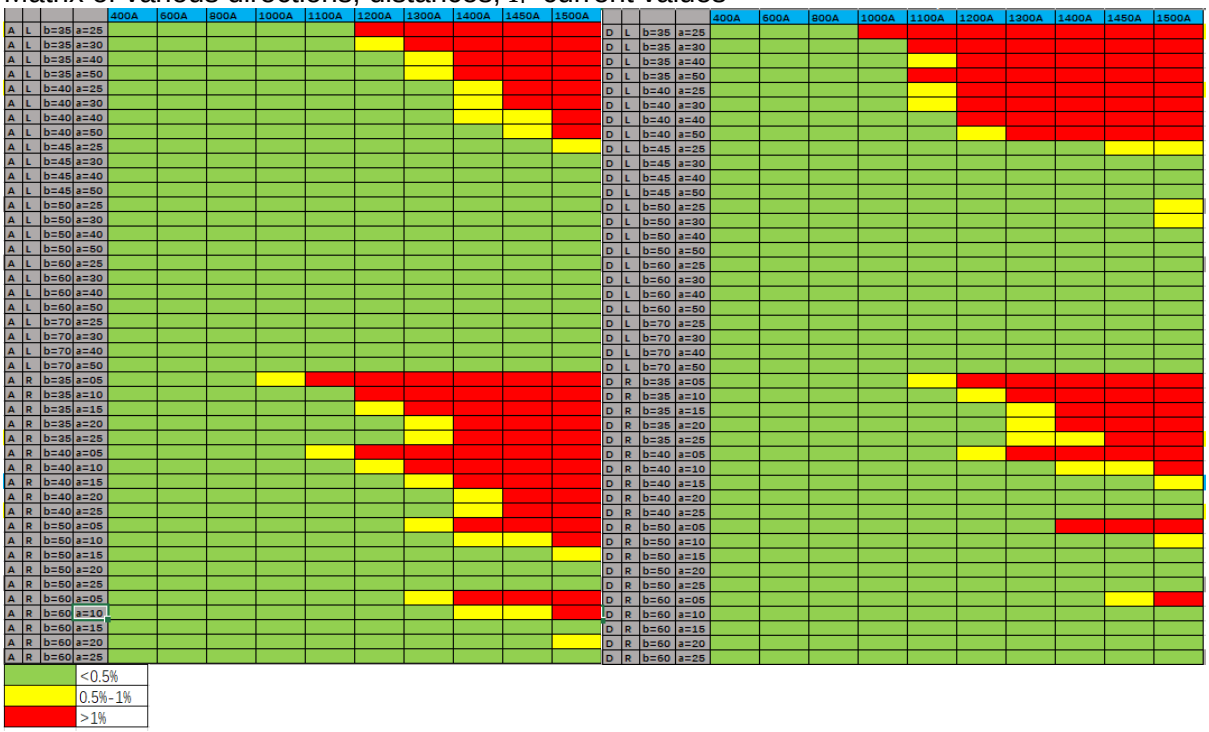
6.4.5.4 C2 shape busbar - DL





6.4.5.5 C2 shape summary

Matrix of various directions, distances, I_P current values



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.
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.

7 Current ripple

7.1 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.

7.2 CAB 1500 current sensor on-power

- CAB1500 will report 'Internal Error' or "SafetyGoalViolation" at specific current ripple frequency ranges.
- 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.

7.3 CAB 1500 current sensor off-power

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

8 Internal error information

- Aim to present 'Internal Error' potential causes and behaviors.
- Except internal error, other CAN signals(analog current signal, digital current signal, and power status signal, SafetyGoalViolation signal etc.) in CAN frame are required to distinguish error types. LEM highly recommends all the CAN signals to be recorded when internal error flag set.

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 1600A (less than $\lvert \hat{I}_{P\,max} \rvert$)

CAB-SF 1500-00X

Internal Error	SafetyGoal Violation Signal	Current Analog measurement	Potential Cause & comment
1	0	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	0	I_P	- Malfunction on redundant hardware for functional safety, - Current ripple. Error stay for limited period of time. Automatically recover if ripple disappear. **Current measurement accuracy is not guaranteed**

1	0	1550000mA	Overcurrent detection. $\lvert I_P \rvert$ is over 1600A (less than $\lvert \hat{I}_{P\,max} \rvert$)
0 or 1*4	1	I_P	- Hardware malfunction result in Analog current and Digital current measurement deviation over safety goal limit*3 - Current ripple. Error stay for limited period of time, then it will Automatically recover if ripple disappear

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

*3 In the current range of [−1500 A; −220 A [and] +220 A; +1500 A], if there is more than 20% of difference between analog current level and digital current level.
In the current range of [−220 A; 220 A], if there is a gap above 44 A between analog current level and digital current level.
*4 If only “SafetyGoalViolation” set 1, “internal error” stays at 0; if at the meantime, other error occurs internal error set to be 1.

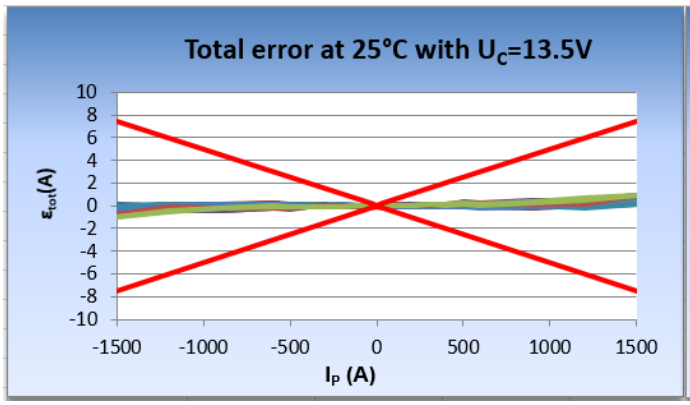
9 Accuracy with 1 and 10 CAN Frames average

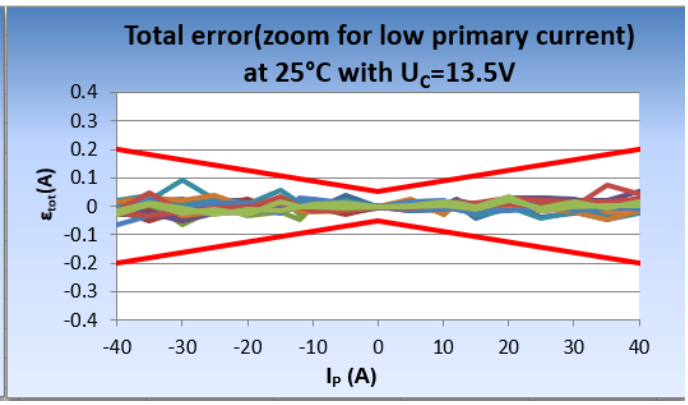
9.1 Aim

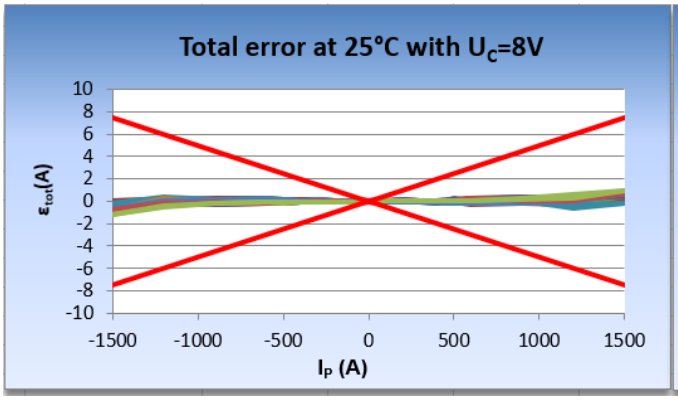
- Aim is to present CAB 1500 accuracy performance with 10 CAN frames average and 1 CAN frame average, datasheet suggest 20 CAN frames average to achieve more stable accuracy.

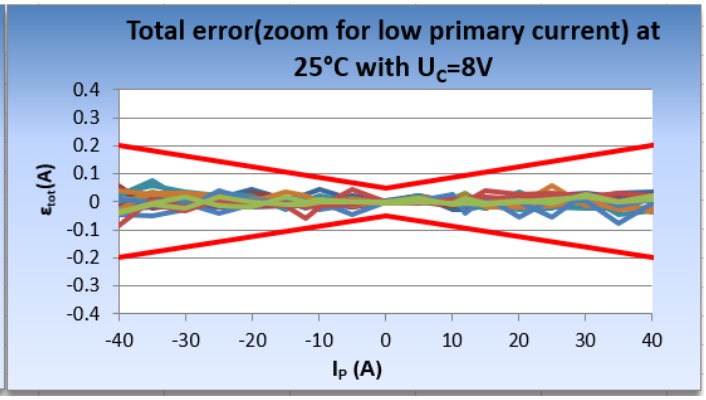
9.2 10 CAN Frames average accuracy

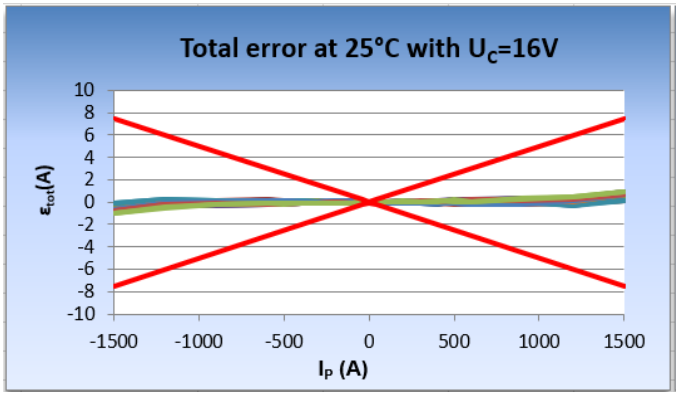
9.2.1 25degC performance

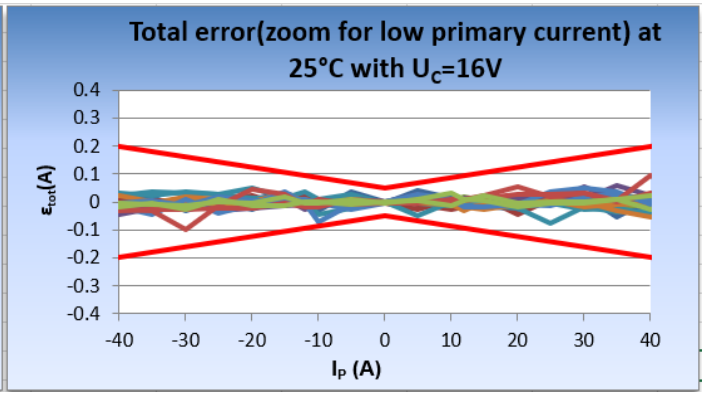




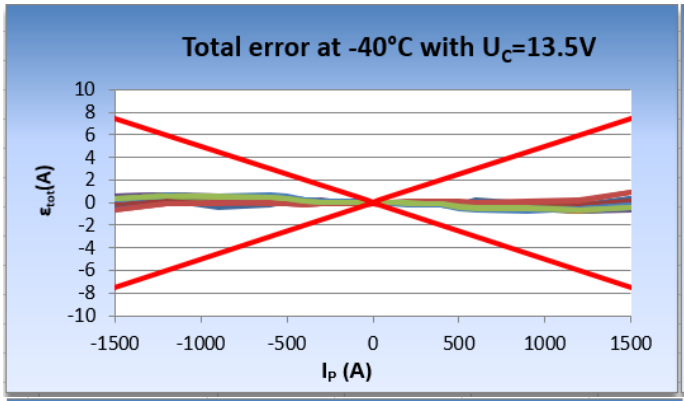


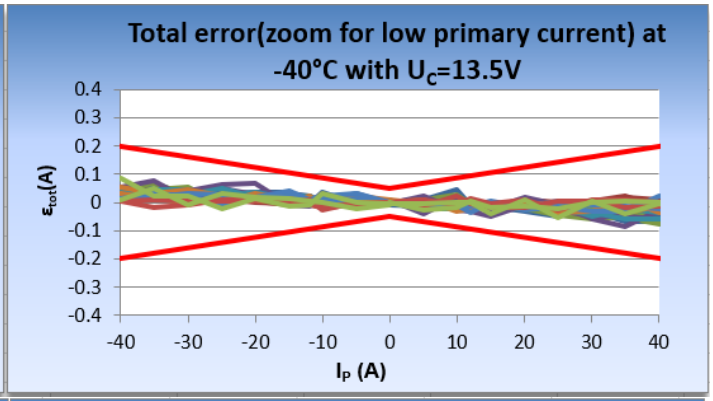


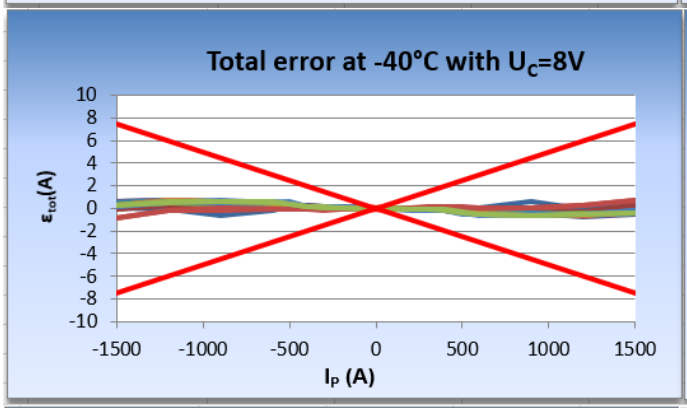


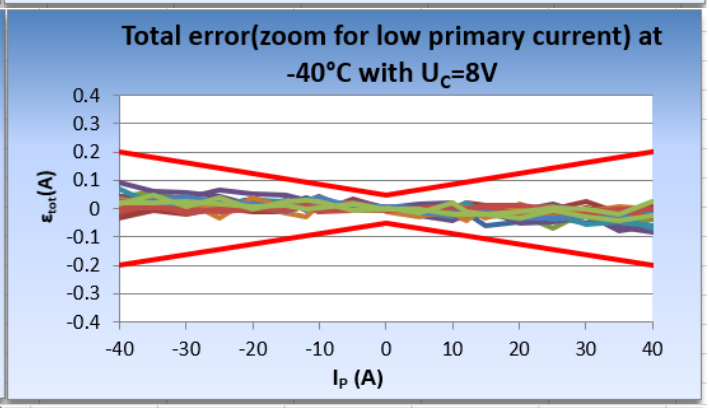


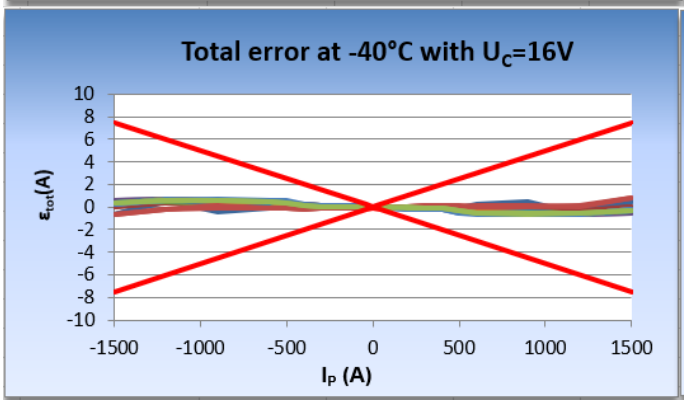
9.2.2 -40degC performance

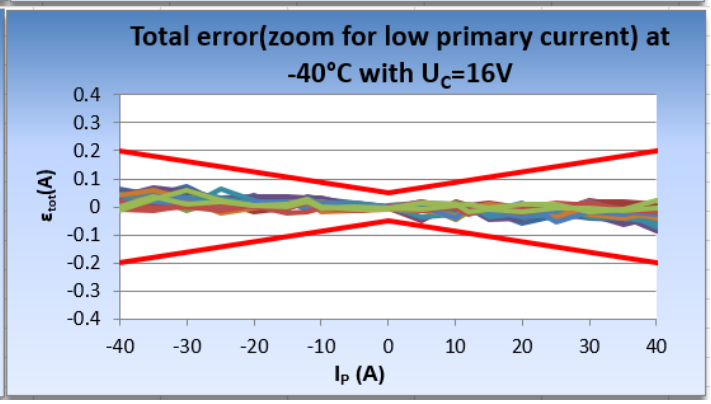




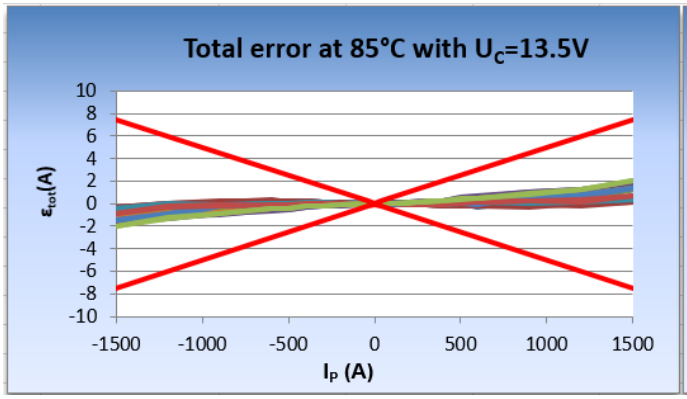


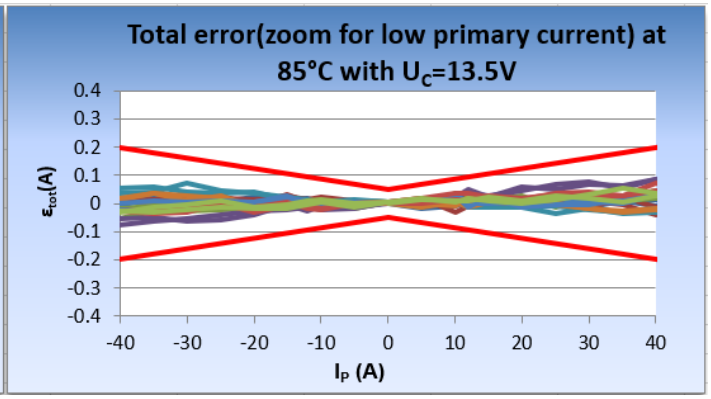


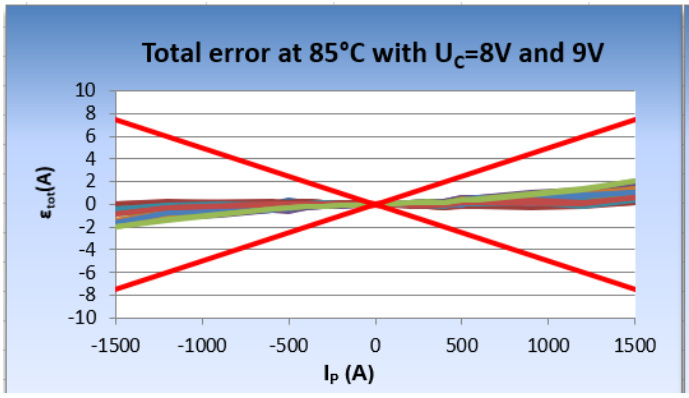


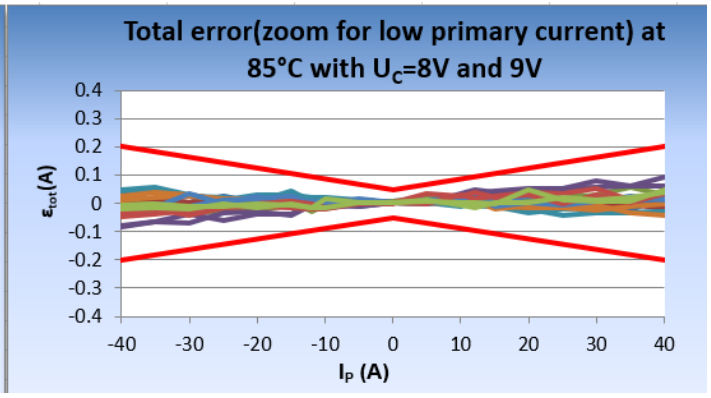


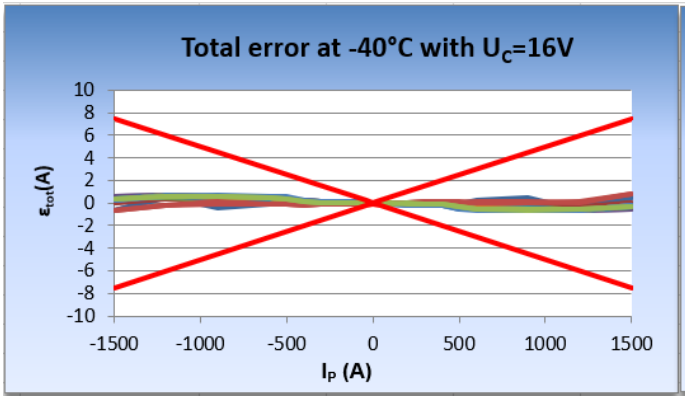
9.2.1 85degC performance

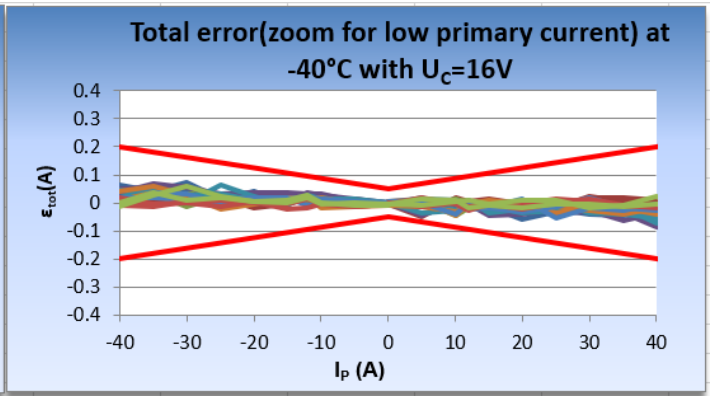






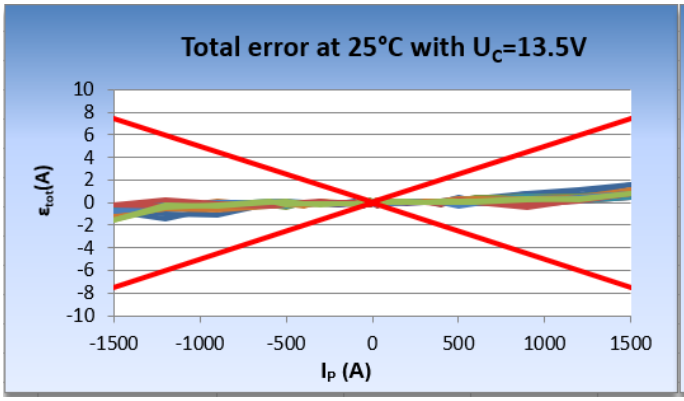


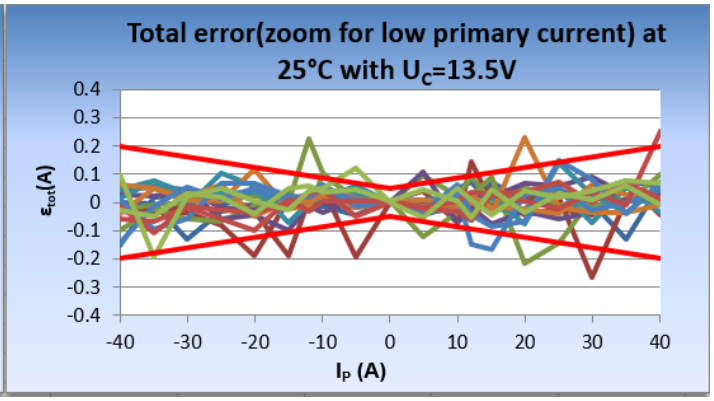


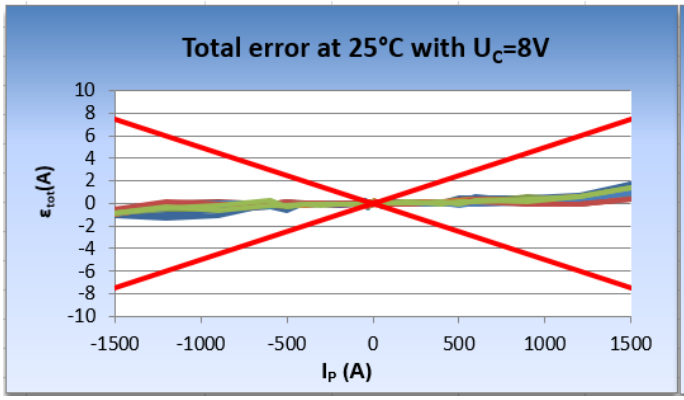


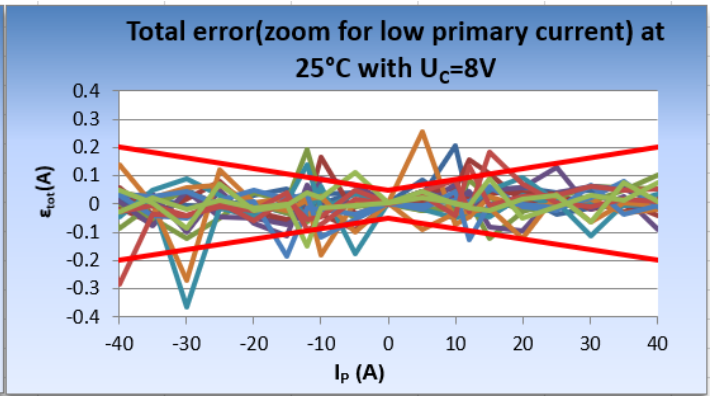
9.3 1 CAN Frame average accuracy

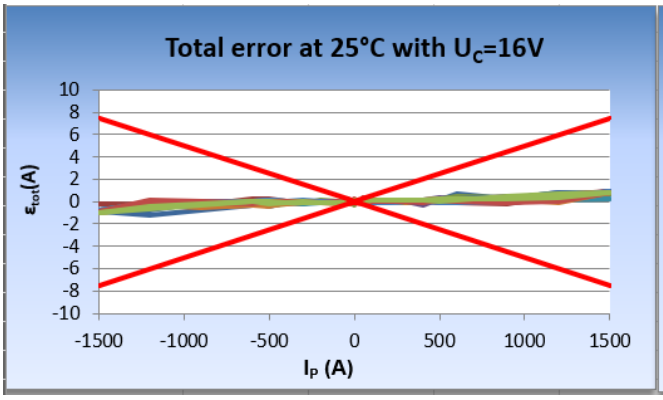
9.3.1 25degC performance

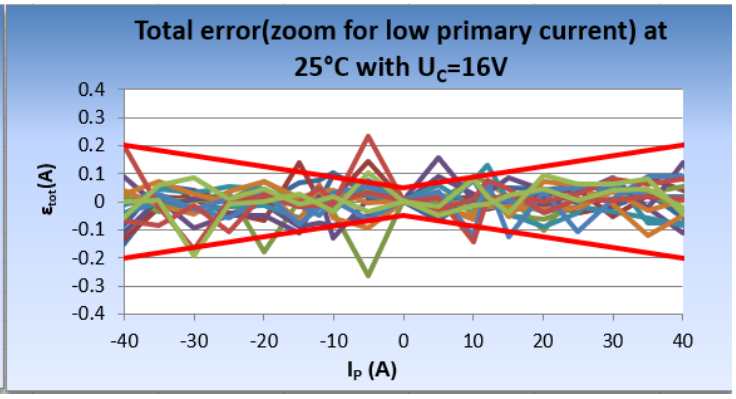




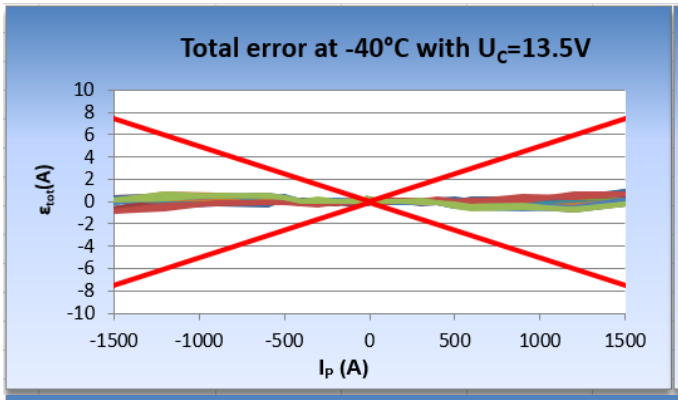


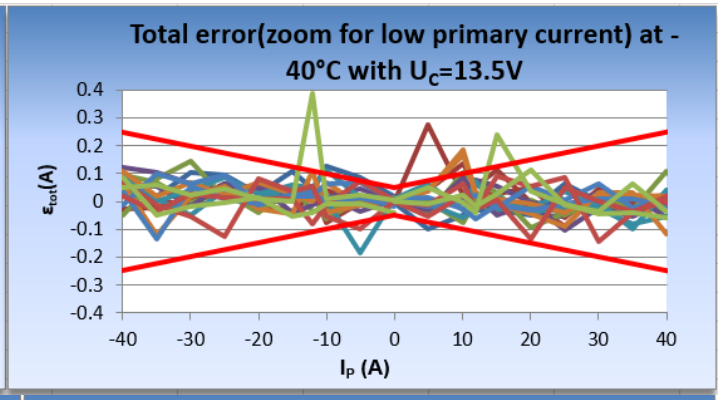


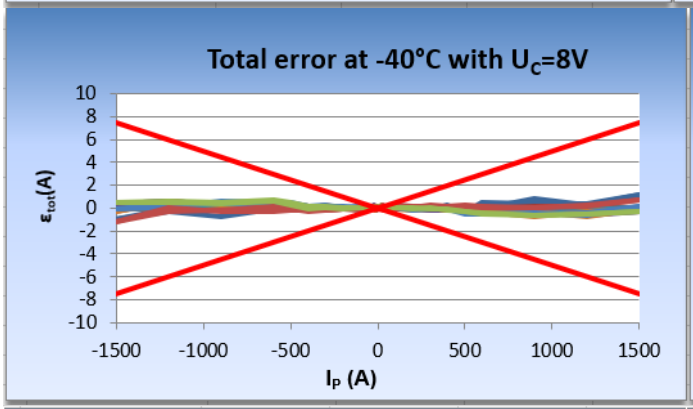


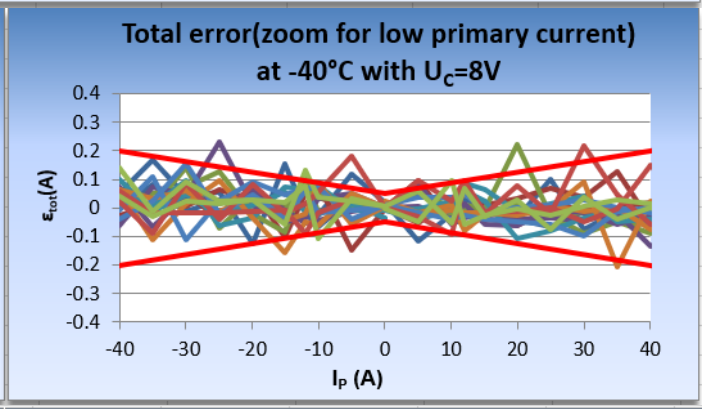


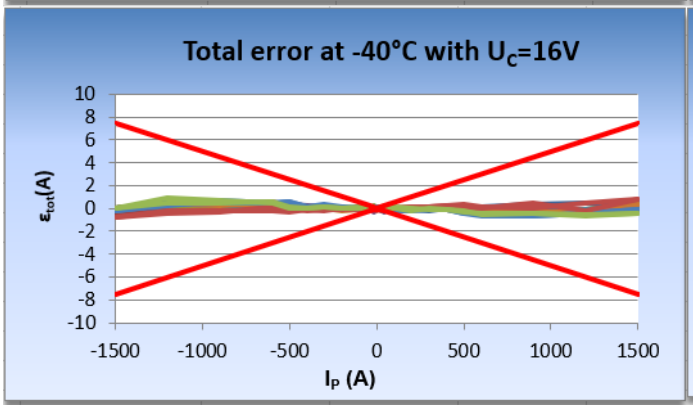
9.3.2 -40degC performance

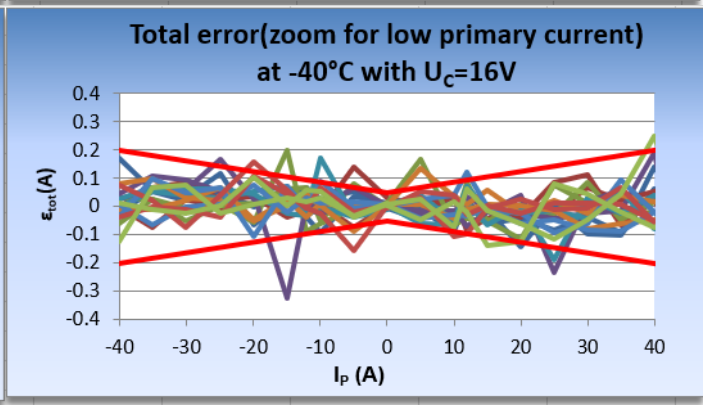




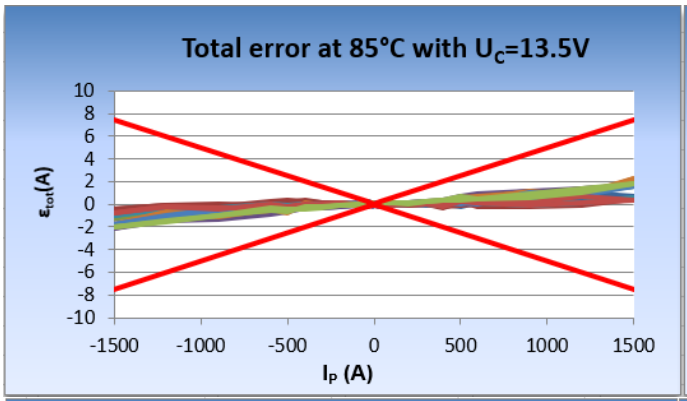


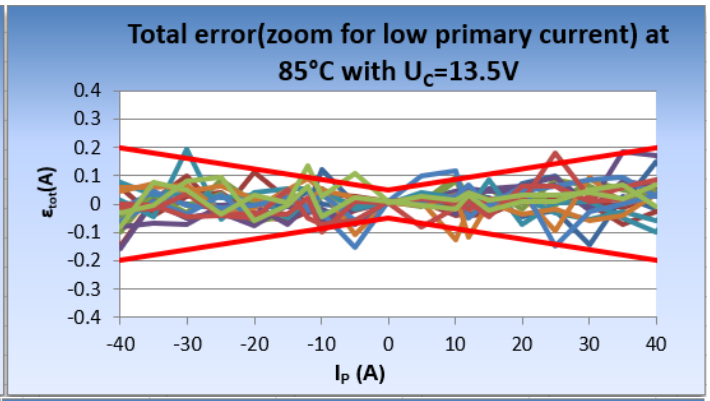


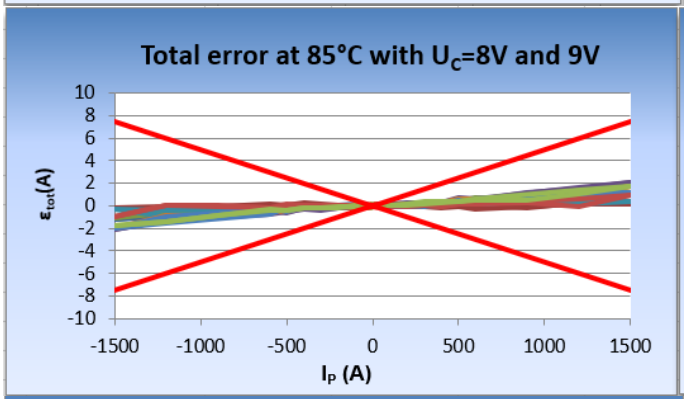


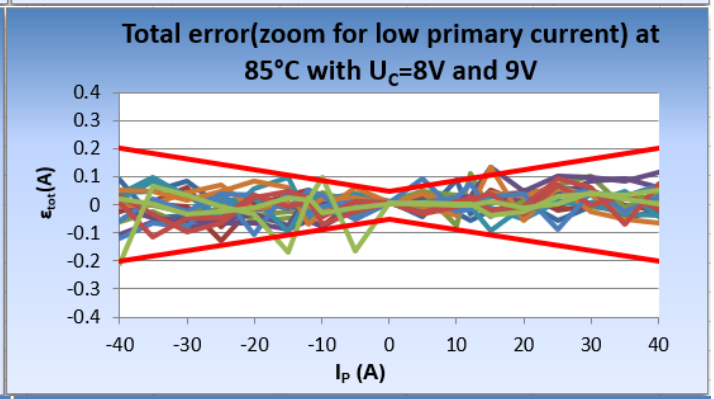


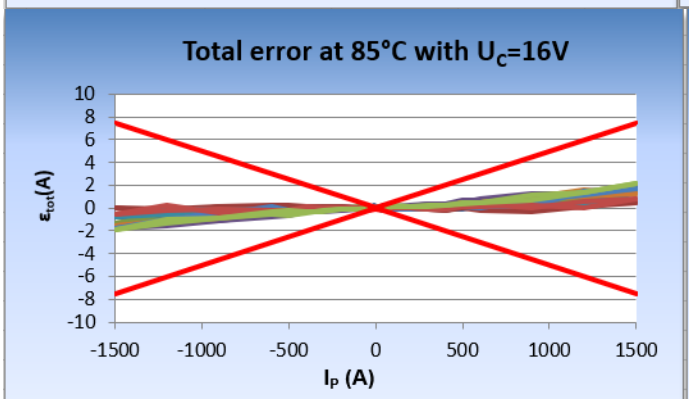
9.3.3 85degC performance

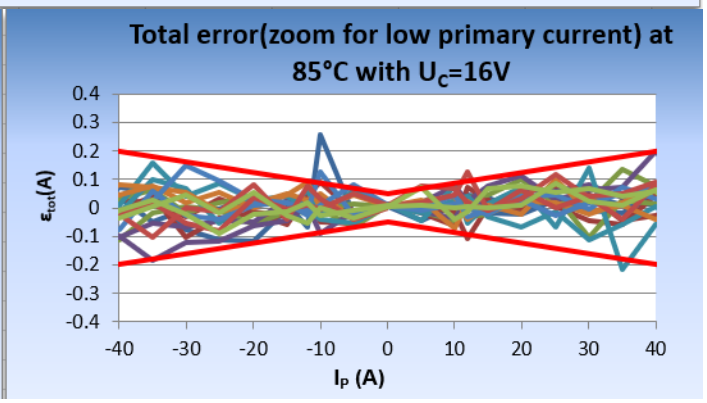












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