Introduction

Electronic Parking Brakes (EPB) devices provide 10 Analog to Digital Converter (ADC) channels to get bridges' voltages and current measurements.

Purpose of this document is to describe the accuracy of ADC channels and to show some strategy to compensate possible errors.
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1 ADC channels

The following channels are available:

<table>
<thead>
<tr>
<th>CH #</th>
<th>CH Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>VSBRIDGE_A</td>
<td>Drain connection of the external H-Bridge A High-side NFET and measurement input for H-bridge supply voltage</td>
</tr>
<tr>
<td>2</td>
<td>VSBRIDGE_B</td>
<td>Drain connection of the external H-Bridge B High-side NFET and measurement input for H-bridge supply voltage</td>
</tr>
<tr>
<td>3</td>
<td>SH1_A</td>
<td>Side 1 source connection of the H-Bridge High-side NFET for wheel brake actuator A</td>
</tr>
<tr>
<td>4</td>
<td>SH1_B</td>
<td>Side 1 source connection of the H-Bridge High-side NFET for wheel brake actuator B</td>
</tr>
<tr>
<td>5</td>
<td>SH2_A</td>
<td>Side 2 source connection of the H-Bridge High-side NFET for wheel brake actuator A</td>
</tr>
<tr>
<td>6</td>
<td>SH2_B</td>
<td>Side 2 source connection of the H-Bridge High-side NFET for wheel brake actuator B</td>
</tr>
<tr>
<td>7</td>
<td>CS1_A</td>
<td>Motor current high side sense of external H-Bridge A</td>
</tr>
<tr>
<td>8</td>
<td>CS1_B</td>
<td>Motor current high side sense of external H-Bridge B</td>
</tr>
<tr>
<td>9</td>
<td>CS2_A</td>
<td>Motor current low side sense of external H-Bridge A</td>
</tr>
<tr>
<td>10</td>
<td>CS2_B</td>
<td>Motor current low side sense of external H-Bridge B</td>
</tr>
</tbody>
</table>

ADC data values can be read through SPI registers together with synchronization and H-Bridge status information.
2 ADC channels data

ADC 12 and 13 bit data need to be converted to obtain the corresponding voltage and current values; the following formulas have to be applied:

### Table 2. ADC data conversion

<table>
<thead>
<tr>
<th>CH #</th>
<th>CH Name</th>
<th>Conversion formulas (CODE is the ADC bare data)</th>
<th>Bit n.</th>
<th>LSB</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>VSBRIDGE_A</td>
<td>( V_{SB} ) = 34.2 \times (4095 - CODE) / 4096</td>
<td>12</td>
<td>8.35 mV</td>
<td>0( \pm )34.2 V</td>
</tr>
<tr>
<td>2</td>
<td>VSBRIDGE_B</td>
<td>( V_{SB} ) = 34.2 \times CODE / 4096</td>
<td>12</td>
<td>8.35 mV</td>
<td>0( \pm )34.2 V</td>
</tr>
<tr>
<td>3</td>
<td>SH1_A</td>
<td>( V_{SH1} ) = 34.2 \times (CODE - 4096) / 4096</td>
<td>13</td>
<td>8.35 mV</td>
<td>( \pm )34.2 V</td>
</tr>
<tr>
<td>4</td>
<td>SH1_B</td>
<td>( V_{SH1} ) = 34.2 \times (CODE - 4096) / 4096</td>
<td>13</td>
<td>8.35 mV</td>
<td>( \pm )34.2 V</td>
</tr>
<tr>
<td>5</td>
<td>SH2_A</td>
<td>( V_{SH2} ) = 34.2 \times ((8191 - CODE) - 4096) / 4096</td>
<td>13</td>
<td>8.35 mV</td>
<td>( \pm )34.2 V</td>
</tr>
<tr>
<td>6</td>
<td>SH2_B</td>
<td>( V_{SH2} ) = 34.2 \times ((8191 - CODE) - 4096) / 4096</td>
<td>13</td>
<td>8.35 mV</td>
<td>( \pm )34.2 V</td>
</tr>
<tr>
<td>7</td>
<td>CS1_A</td>
<td>( I(A) = ((CODE/8192 \times 410mV) - 205 mV) / R_{sense} )</td>
<td>13</td>
<td>17/25 mA(^{(3)})</td>
<td>( \pm )68/102 A</td>
</tr>
<tr>
<td>8</td>
<td>CS1_B</td>
<td>( I(A) = ((CODE/8192 \times 410mV) - 205 mV) / R_{sense} )</td>
<td>13</td>
<td>17/25 mA(^{(3)})</td>
<td>( \pm )68/102 A</td>
</tr>
<tr>
<td>9</td>
<td>CS2_A</td>
<td>( I(A) = ((CODE/8192 \times 410mV) - 205 mV) / R_{sense} )</td>
<td>13</td>
<td>17/25 mA(^{(3)})</td>
<td>( \pm )68/102 A</td>
</tr>
<tr>
<td>10</td>
<td>CS2_B</td>
<td>( I(A) = ((CODE/8192 \times 410mV) - 205 mV) / R_{sense} )</td>
<td>13</td>
<td>17/25 mA(^{(3)})</td>
<td>( \pm )68/102 A</td>
</tr>
</tbody>
</table>

1. The channel code is inverted.
2. \( R_{sense} \) expressed in m\( \Omega \).
3. The LSB voltage weight is ~50 \( \mu \)A corresponding to ~25mA for a 2 m\( \Omega \) shunt resistor and to ~17mA for a 3 m\( \Omega \) shunt.
3 ADC accuracy

ADC channels can be divided into three different categories:

- 12 bit voltage measurement channels: VSBRIDGE_A and VSBRIDGE_B;
- 13 bit voltage measurement channels: SH1_A, SH2_A, SH1_B and SH2_B;
- 13 bit current measurement channels: CSA1_A, CSA2_A, CSA1_B and CSA2_B.

3.1 VSBRIDGE accuracy

<table>
<thead>
<tr>
<th>Voltage range</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>VSBRIDGE_A ≤ 5 V</td>
<td>± 200 mV max</td>
</tr>
<tr>
<td>VSBRIDGE_A &gt; 5 V</td>
<td>± 4% max</td>
</tr>
</tbody>
</table>

3.2 SH accuracy

<table>
<thead>
<tr>
<th>Voltage range</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>SHx_y ≤ 4.8 V</td>
<td>± 216 mV max</td>
</tr>
<tr>
<td>SHx_y &gt; 4.8 V</td>
<td>± 4.5% max</td>
</tr>
</tbody>
</table>

The accuracy in measuring the voltage difference between SH1_y and SH2_y pairs (matching) is 6% max.
3.3 CSA accuracy

Current sense data are affected by an offset error at 0A: a correct accuracy measurement requires an offset compensation.

Because of the current measurement redundancy data of CSA1_y and CSA2_y channel can be used to increase the overall current measurement accuracy.

3.3.1 CSA offset at 0A

The maximum current offset at I = 0 A is ±16.8LSB corresponding to ~280 mA for a 3 mΩ shunt resistor and ~420 mA for a 2 mΩ shunt resistor.

3.3.2 CSA single channel offset compensation

The offset compensation is performed subtracting the offset from the ADC channel data; using this strategy the single current sense channel accuracy, in terms of voltage, is:

<table>
<thead>
<tr>
<th>Voltage absolute value range</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 mV &lt;</td>
<td>V</td>
</tr>
<tr>
<td>2.4 mV ≤</td>
<td>V</td>
</tr>
<tr>
<td>7.5 mV ≤</td>
<td>V</td>
</tr>
</tbody>
</table>

Table 5. Single CSA channel accuracy after offset compensation

3.3.3 CSA average compensation

CSA1_y and CSA2_y channels measure the voltage across two shunt resistors crossed by the same current flow; the following accuracy can be obtained computing the average of the two channels:

<table>
<thead>
<tr>
<th>Voltage absolute value range</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.4 mV &lt;</td>
<td>V</td>
</tr>
<tr>
<td>3.0 mV &lt;</td>
<td>V</td>
</tr>
<tr>
<td>6.0 mV &lt;</td>
<td>V</td>
</tr>
<tr>
<td>9.0 mV &lt;</td>
<td>V</td>
</tr>
</tbody>
</table>

Table 6. Single CSA channel accuracy after offset compensation and average
3.3.4 C code example

The following example shows a very simplified C code to compute the offset compensation and the average:

```c
#define CSA_0_CURRENT_CODE 0x1000

s16 CSA1_A_Offset = 0 ; // Signed 16 bit
s16 CSA2_A_Offset = 0 ;
s16 CSA1_B_Offset = 0 ;
s16 CSA2_B_Offset = 0 ;

void SetOffset ( s16 CSA1_A_Code , s16 CSA2_A_Code ,
                s16 CSA1_B_Code , s16 CSA2_B_Code )
{
    /* Signed subtractions between ADC code read at 0 current */
    /* condition and the expected value */
    CSA1_A_Offset = CSA1_A_Code - CSA_0_CURRENT_CODE ;
    CSA2_A_Offset = CSA2_A_Code - CSA_0_CURRENT_CODE ;
    CSA1_B_Offset = CSA1_B_Code - CSA_0_CURRENT_CODE ;
    CSA2_B_Offset = CSA2_B_Code - CSA_0_CURRENT_CODE ;
}
```

```c
void GetCSAValues ( s16 CSA1_A_Code , s16 CSA2_A_Code ,
                    s16 CSA1_B_Code , s16 CSA2_B_Code ,
                    s16 *CSA_A_Val  , s16 *CSA_B_Val )
{
    /* */
    /* */
    /* */
    /* */
}
```
void GetCSAValues ( s16 CSA1_A Code , s16 CSA2_A_Code ,
    s16 CSA1_B_Code , s16 CSA2_B_Code )
    s16 *CSA_A_Val , s16 *CSA_B_Val )
{
    /* Subtract the offset from each ADC value and compute the average */
    /* of the two currents measured on the same H-Bridge */

    *CSA_A_Val = ( ( CSA1_A_Code - CSA1_A_Offset ) + ( CSA2_A_Code -
    CSA2_A_Offset ) ) / 2 ;
    *CSA_B_Val = ( ( CSA1_B_Code - CSA1_B_Offset ) + ( CSA2_B_Code -
    CSA2_B_Offset ) ) / 2 ;
}

The offset computation could be executed on system startup and/or periodically and/or just
before H-Bridges' actuation.

3.4 ADC formulas with offset
To take into account 0V or 0A offsets ADC formulas of table 2 are still valid but the CODE
variable has to be substituted with (CODE - OFFSET) where OFFSET is the difference
between the expected value at 0V or 0A and the effectively read code.

3.4.1 VS_Bridge_A
If CODE_{0V} is the code returned by the ADC at 0V, the offset is:
OFFSET = 4095 - CODE_{0V}.
The VS_Bridge_A computing formula becomes:

Equation 1: \( V_{SB_A}(V) = 3.42 \times \frac{(4095 - CODE) - OFFSET}{4096} \)

3.4.2 VS_Bridge_B
If CODE_{0V} is the code returned by the ADC at 0V, the offset is:
OFFSET = CODE_{0V}.
The VS_Bridge_B computing formula becomes:

Equation 2: \( V_{SB_B}(V) = 3.42 \times \frac{(CODE - OFFSET)}{4096} \)

3.4.3 SH1_A and SH1_B
If CODE_{0V} is the code returned by the ADC at 0V, the offset is:
OFFSET = CODE_{0V} - 4096.
The SH1_A and SH1_B computing formula becomes:

Equation 3: \( V_{SH1_A/B}(V) = 3.42 \times \frac{(CODE - 4096 - OFFSET)}{4096} \)
3.4.4 SH2_A and SH2_B

If CODE<sub>0V</sub> is the code returned by the ADC at 0V, the offset is:

\[ \text{OFFSET} = \text{CODE}_{0V} - 4096. \]

The SH2_A and SH2_B computing formula becomes:

**Equation 4:** \[ \text{SH2}_{A/B}(V) = 34.2 \times \frac{(8191 - \text{CODE}) - \text{OFFSET} - 4096}{4096} \]

3.4.5 CSA

If CODE<sub>0V</sub> is the code returned by the ADC at 0A (and 0V), the offset is:

\[ \text{OFFSET} = \text{CODE}_{0V} - 4096. \]

The CSA computing formula becomes:

**Equation 5:** \[ V_{CSA}(mV) = \left( 410 \times \frac{(\text{CODE} - \text{OFFSET})}{8192} \right) - 205 \]

**Equation 6:** \[ I_{CSA}(A) = \frac{V_{CSA}(mV)}{R_{\text{shunt(mOhm)}}} = \frac{410 \times (\text{CODE} - \text{OFFSET}) - 205}{8192} \]
Appendix A  CSA correction curves

In the following paragraph CSA curves will be exposed in order to see the correction algorithm behavior.

The graphs show the following data:

<table>
<thead>
<tr>
<th>Voltage absolute value range</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>X-axis</td>
<td>Expected voltage</td>
</tr>
<tr>
<td>CSA1</td>
<td>Voltage measured at CSA1 pin</td>
</tr>
<tr>
<td>CSA1_COMP</td>
<td>Voltage measured at CSA1 pin compensated subtracting 0 V offset</td>
</tr>
<tr>
<td>CSA2</td>
<td>Voltage measured at CSA2 pin</td>
</tr>
<tr>
<td>CSA2_COMP</td>
<td>Voltage measured at CSA2 pin compensated subtracting 0 V offset</td>
</tr>
<tr>
<td>Average</td>
<td>Average value of CSA1_COMP and CSA2_COMP</td>
</tr>
</tbody>
</table>

Figure 1. -3 to 3 mV range

Figure 2. -1 to 1 mV range

Figure 3. -6 to -3 mV range

Figure 4. 3 to 6 mV range
Figure 5. -9 to 6 mV range

Figure 6. 6 to 9 mV range

Figure 7. -30 to -9 mV range

Figure 8. 9 to 30 mV range
## Revision history

<table>
<thead>
<tr>
<th>Date</th>
<th>Revision</th>
<th>Changes</th>
</tr>
</thead>
<tbody>
<tr>
<td>05-Jun-2019</td>
<td>1</td>
<td>Initial release.</td>
</tr>
</tbody>
</table>

Table 8. Document revision history
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