On-board function test,

measurement of initial offset of accelerometer,

and estimation of offset and sensitivity of accelerometer of AS9888

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Abstract

This document introduces a method of function tests of a magnetometer and an accelerometer in the products with AS9888 at the on-board test.

The offset of an accelerometer of AS9888 is roughly adjusted at the shipment. Due to solder implementation or deformations of PCB, the offset value may vary after assemble. Therefore, if the offset accuracy of an accelerometer is significant to application software, an accurate offset value must be measured in advance. A measurement of an accelerometer offset value is necessary as well as a shipment function tests of a magnetometer and an accelerometer.

The document also describes a method of calculating an offset and a sensitivity of an accelerometer according to temperature using the measured offset values and registered values in EEPROM of AS9888.

0. Notice

This method for function test is indicated as reference information in order to help the factory plan inspection processes of the product. This also intends to examine functions and to find an initial defect easily without special equipments. An adoption of the method and criteria of judgment are your responsibilities.

1. Magnetic sensor functioning test

Ideally, it is necessary to apply 3D magnetic field arbitrarily to a magnetometer in order to examine functions. However, it is impossible to vary a magnetic field quantitatively. Therefore, the method indicated below requires a fixed posture of a product and use a magnetic field generator built in AS9888. That is, this function test is qualitative.

2. Accelerometer functioning test

Ideally, it is necessary to apply 3D acceleration arbitrarily to an accelerometer in order to examine functions. However, it is impossible to vary acceleration quantitatively. Therefore, the method indicated below requires a fixed (horizontal) posture of a product and apply a natural acceleration (gravity acceleration). That is, the method is a qualitative function test.

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3. Measurement of offset of accelerometer

In initial adjustment of acceleration offset, AS9888 is held stable and horizontally, and measurement data is obtained. Then the offset value is stored as adjustment data and this data is used in following measurements. The offset value is defined as difference from zero acceleration if the axis is in a horizontal plane and from 1G if the axis is vertical.

If strong thermal shocks by the reflow soldering etc. is given to the acceleration sensor and to the circuit board, the distortion changes and the amount of the offset of the acceleration sensor may changes. The change by thermal shock is irreversible, and the offset become stable after specific relaxation time passes after solder mount. Therefore, adjustment of acceleration offset should be executed after enough time passes after assembly of your product.

Moreover, acceleration offset may vary if a strong shock is applied to the sensor. To prepare for such an accident, we recommend that manufacturer provides some repair method which can be done by products user.

4. Measuring environment

It is important for checking operation of magnetometer that the environment for testing is stable and magnetic field outside the product is enough small. Concretely speaking, the magnetic field must be stable in 7.3ms, while a magnetometer of AS9888 is measuring. The sum of magnetic offset in the product, which means the total magnetic value of magnetic components in the product, and magnetic field radiated by testing equipments must not exceed a measurement range of AS9888 (±1200uT).

Regarding accelerometer, it is necessary to keep the product horizontal and stable in order to set AS9888 horizontal. Horizontal posture means one of X,Y,Z-axis is vertical. If a surface of AS988 and a reference plane of the product is inclined, pay attention to the posture of holding the product. It is necessary to avoid vibration from surrounding equipments. If the environment is not stable, it is necessary to increase measurements and average values.

5. Process flow

Step	Purpose	Process	Remarks
1	Check solder connection Read adjustment value (EEPROM) Initialize for processes after Step1	Check function of digital IF Check function of register R/W Read out adjusted value (EEPROM) Store adjustment value to register	Check the connection of RSTN,SO/CAD1,I2C,VID,SK/SCL, SI/SDA,CSB/CAD0,VDD pin (Note1)
2	Check function of magnetometer	Check function of magnetometer using internal magnetic oscillator	Check the connection of INT1 pin and INT2 pin (Note2)
3	Check function of accelerometer Measure basic data for offset calculation	Measure acceleration in horizontal posture	

4	Store adjustment values of sensors	Store measurement data of Step3 and data from EEPROM into nonvolatile memory.	

Note1 : Pins which can be checked depend on the type of connection. SO pin can not be checked under I2C connection.

Note2 : Only monitored pins can be checked.

5.1. step1 : Check solder connection, Read adjustment values (EEPROM), Set initial values for processes after Step1

Step	Process	Register (PIN)	Operation R:read W:write	Data Writing operation data	Judgment
1-1	Power ON				
1-2	Reset	(RSTN)	Reset signal Input 5us<		
1-3	Time until reset finish		Wait:>100us		
1-4	Read out WIA device ID register	WIA	R	01001000	fixed value
1-5	Set the operation mode EEPROM access mode	MS	W	00000100	
1-6	EEPROM rise time		Wait:300us<		
1-7	Read out EEPROM (EREF1)	EREF1	R		
1-8	Read out EEPROM (EREF2)	EREF2	R		
1-9	Read out EEPROM (EREF3)	EREF3	R		
1-10	Read out EEPROM (EOSC)	EOSC	R		
1-11	Read out EEPROM (EHCX)	EHCX	R		
1-12	Read out EEPROM (EHCY)	EHCY	R		
1-13	Read out EEPROM (EHCZ)	EHCZ	R		
1-14	Read out EEPROM (EAXGA)	EAXGA	R		
1-15	Read out EEPROM (EAYGA)	EAYGA	R		
1-16	Read out EEPROM (EAZGA)	EAZGA	R		
1-17	Read out EEPROM (EAXDT)	EAXDT	R		
1-18	Read out EEPROM (EAYDT)	EAYDT	R		
1-19	Read out EEPROM (EAZDT)	EAZDT	R		
1-20	Read out EEPROM (EAXDA)	EAXDA	R		
1-21	Read out EEPROM (EAYDA)	EAYDA	R		
1-22	Read out EEPROM (EAZDA)	EAZDA	R		
1-23	Read out EEPROM (EAXGTD)	EAXGTD	R		
1-24	Read out EEPROM (EAYGTD)	EAYGTD	R		
1-25	Read out EEPROM (EAZGTD)	EAZGTD	R		

1-26	Read out EEPROM (ET1)	ET1	R		
1-27	Read out EEPROM (ET2)	ET2	R		
1-28	Set operation mode Power-down mode	MS	W	00000000	
1-29	Wait time for setup mode		Wait:>100us		
1-30	Set adjustment value of reference circuit	REF1	W	EREF1 data	
1-31	Set adjustment value of reference circuit	REF2	W	EREF2 data	
1-32	Set adjustment value of reference circuit	REF3	W	0x18 + Lower 3 bits of EREF3	
1-33	Adjustment value of oscillator circuit	OSC	W	Data of EOSC	
1-34	Set X-axis gain of accelerometer	AXGA	W	Lower 7 bits of EAXGA	
1-35	Set Y-axis gain of accelerometer	AYGA	W	Lower 7 bits of EAYGA	
1-36	Set Z-axis gain of accelerometer	AZGA	W	Lower 7 bits of EAZGA	
1-37	Set X-axis DAC of accelerometer	AXDA	W	Data of EAXDA	
1-38	Set Y-axis DAC of accelerometer	AYDA	W	Data of EAYDA	
1-39	Set Z-axis DAC of accelerometer	AZDA	W	Data of EAZDA	

5.2. step2：Magnetic sensor function test

Step	Process	Register (PIN)	Operation	Data	Judgment
2-1	Set INT1EN pin	INT1EN	W	00000001	Enable DRI1
2-2	Set SLCT2	SLCT2	W	00000100	Turn on measurement of magnetometer
2-3	Set measurement mode Single measurement mode	MS	W	00000001	
2-4	Wait until measurement finishes	(INT1)	Wait until data becomes “H"		If INT1 pin is not monitored, monitor DRDY bit of ST1 register or DR1 bit of INT1ST register, and wait until the monitored bit becomes “1”.
2-5	Read out INT1ST register	INT1ST	R	00000001	Confirm the status of INT1 pin is reflected in INT1ST register.
2-6	Read out ST1 register	ST1	R	00000001	Confirm the measurement normally finishes by checking DRDY
2-7	Read out HXL register	HXL	R	HXH/L ≠ -4096 ∩ HXH/L ≠ 4095	Confirm the measurement finishes and overflow doesn’t occur
2-8	Read out HXH register	HXH	R		
2-9	Read out HYL register	HYL	R	HYH/L ≠ -4096 ∩ HYH/L ≠ 4095	
2-10	Read out HYH register	HYH	R		
2-11	Read out HZL register	HZL	R	HZH/L ≠ -4096 ∩ HZH/L ≠ 4095	
2-12	Read out HZH register	HZH	R		
2-13	Read out ST2 register	ST2	R	00000000	Confirm the measurement normally finishes by checking HST
2-14	Set operation mode Self-test mode	MS	W	00001000	
2-15	Wait until measurement finishes	(INT1)	Wait until data becomes “H"		If INT1 pin is not monitored, monitor DRDY bit of ST1 register or DR1 bit of INT1ST register, and wait until the monitored bit becomes “1”.

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Option	Read out INT1ST register	INT1ST	R		Fall of INT1 pin. Since INT1 pin automatically falls when the next operation mode is set, this process is optional.
2-16	Read out ST1 register	ST1	R	00000001	Confirm the measurement normally finishes
2-17	Read out HXL register	HXL	R	-100 ≤ HXH/L(*) ≤ 100	Confirm magnetometer function using internal magnetic oscillator. (*)Values are after sensitivity adjustment. Sensitivity adjustment is calculated from the following formula. H*((EHC-128)*0.5/128+ 1) H is measured value of data register. Corresponding values of sensitivity adjustment of axis for measurement (EHCX/Y/Z register value) is EHC.
2-18	Read out HXH register	HXH	R		
2-19	Read out HYL register	HYL	R	-100 ≤ HYH/L(*) ≤ 100	
2-20	Read out HYH register	HYH	R		
2-21	Read out HZL register	HZL	R	300 ≤ HZH/L(*) ≤ 1000	
2-22	Read out HZH register	HZH	R		
2-23	Read out ST2 register	ST2	R	00000000	Confirm the measurement normally finishes by checking HST

5.3. step3：Accelerometer function test and measurement of basic data for offset estimation

Step	Process	Register (PIN)	Operation	Data	Judgment
3-1	Set SLCT2	SLCT2	W	00000000(LPF off) 00001000(LPF on)	Magnetometer measurement off Accelerometer LPF off or off
3-2	Set measurement mode Single measurement mode	MS	W	00000001	
3-3	Wait until measurement finishes	(INT1)	Wait until data becomes “H"		If INT1 pin is not monitored, monitor DRDY bit of ST1 register or DR1 bit of INT1ST register, and wait until the monitored bit becomes “1”.
Option	Read out INT1ST register	INT1ST	R		Fall of INT1 pin. Since INT1 pin automatically falls when the next operation mode is set, this process is optional.
3-4	Read out ST1 register	ST1	R	00000001	Confirm the measurement normally finishes by checking DRDY
3-5	Read out TMPS register	TMPS	R	TMPS = [0x28, 0xE0]	Confirm the measurement finishes and temperature is within the specification
3-6	Read out EMPT register	EMPT	R	00000000	
3-7	Read out A1XL register	A1XL	R	-2048 < AXH/L ∩ AXH/L < 2047	1) Confirm the measurement finishes and overflow doesn’t occur 2) Measure more than once and use the average value
3-8	Read out A1XH register	A1XH	R		
3-9	Read out A1YL register	A1YL	R	-2048 < AYH/L ∩ AYH/L < 2047	
3-10	Read out A1YH register	A1YH	R		
3-11	Read out A1ZL register	A1ZL	R	-2048 < AZH/L ∩ AZH/L < 2047	
3-12	Read out A1ZH register	A1ZH	R		
3-13	Read out ST2 register	ST2	R	00000010	Confirm the

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					measurement normally finishes ※Magnetometer is off (HST=1)
3-14	Judge maximum value of X-axis sensor signal			AXH/L ≠ -2048 ∩ AXH/L ≠ 2047	Judge maximum, minimum, and fluctuation (maximum – minimum) values of each axis signal (Step 3-32 ~ 3-37). Judgment value of fluctuation must be set according to test environment. (Note 3)
3-15	Judge maximum value of Y-axis sensor signal			AYH/L ≠ -2048 ∩ AYH/L ≠ 2047	
3-16	Judge maximum value of Z-axis sensor signal			AZH/L ≠ -2048 ∩ AZH/L ≠ 2047	
3-17	Judge minimum value of X-axis sensor signal			AXH/L ≠ -2048 ∩ AXH/L ≠ 2047	
3-18	Judge minimum value of Y-axis sensor signal			AYH/L ≠ -2048 ∩ AYH/L ≠ 2047	
3-19	Judge minimum value of Z-axis sensor signal			AZH/L ≠ -2048 ∩ AZH/L ≠ 2047	
3-20	Judge fluctuation of X-axis sensor signal			Set according to test environment	
3-21	Judge fluctuation of Y-axis sensor signal			Set according to test environment	
3-22	Judge fluctuation of Z-axis sensor signal			Set according to test environment	
3-23	Estimate optimal DAC value				cf. 6.5 How to estimate offset values
3-24	Set X-axis DAC of accelerometer	AXDA	W	Data of EAXDA	
3-25	Set Y-axis DAC of accelerometer	AYDA	W	Data of EAYDA	
3-26	Set Z-axis DAC of accelerometer	AZDA	W	Data of EAZDA	
3-27	Set measurement mode Single measurement mode	MS	W	00000001	
3-28	Wait until measurement finishes	(INT1)	Wait until data becomes “H"		If INT1 pin is not monitored, monitor DRDY bit of ST1 register or DR1 bit of INT1ST register, and wait until the monitored

					bit becomes “1”.
Option	Read out INT1ST register	INT1ST	R		Fall of INT1 pin. Since INT1 pin automatically falls when the next operation mode is set, this process is optional.
3-29	Read out ST1 register	ST1	R	00000001	Confirm the measurement normally finishes by checking DRDY
3-30	Read out TMPS register	TMPS	R	TMPS = [0x28, 0xE0]	Confirm the measurement finishes and temperature is within the specification
3-31	Read out EMPT register	EMPT	R	00000000	
3-32	Read out A1XL register	A1XL	R	-2048 < AXH/L ∩ AXH/L < 2047	1) Confirm the measurement finishes and overflow doesn’t occur 2) Measure more than once and use the average value
3-33	Read out A1XH register	A1XH	R		
3-34	Read out A1YL register	A1YL	R	-2048 < AYH/L ∩ AYH/L < 2047	
3-35	Read out A1YH register	A1YH	R		
3-36	Read out A1ZL register	A1ZL	R	-2048 < AZH/L ∩ AZH/L < 2047	
3-37	Read out A1ZH register	A1ZH	R		
3-38	Read out ST2 register	ST2	R	00000010	Confirm the measurement normally finishes ※Magnetometer is off (HST=1)
3-39	Judge maximum value of X-axis sensor signal			AXH/L ≠ -2048 ∩ AXH/L ≠ 2047	Judge maximum, minimum, and fluctuation (maximum – minimum) values of each axis signal (Step 3-32 ~ 3-37). Judgment value of fluctuation must be set according to test environment. (Note 3)
3-40	Judge maximum value of Y-axis sensor signal			AYH/L ≠ -2048 ∩ AYH/L ≠ 2047	
3-41	Judge maximum value of Z-axis sensor signal			AZH/L ≠ -2048 ∩ AZH/L ≠ 2047	
3-42	Judge minimum value of X-axis sensor signal			AXH/L ≠ -2048 ∩ AXH/L ≠ 2047	
3-43	Judge minimum value of Y-axis sensor signal			AYH/L ≠ -2048 ∩ AYH/L ≠ 2047	
3-44	Judge minimum value of Z-axis sensor signal			AZH/L ≠ -2048 ∩ AZH/L ≠ 2047	

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3-45	Judge fluctuation of X-axis sensor signal			Set according to test environment	
3-46	Judge fluctuation of Y-axis sensor signal			Set according to test environment	
3-47	Judge fluctuation of Z-axis sensor signal			Set according to test environment	

Note1 : Hold equipment (or the circuit board) stable and horizontal to keep AS9888 horizontal. Horizontal means that one of X, Y and Z axis of accelerometer is vertical. It is not cared whichever the axis is, or which is up or down.

Note2 : Measure accelerometer more than 10 times and use average of those data. When the data is not stable because of oscillation from circumstances, increase averaging number. If environmental temperature varies while measuring, please use the measurement data which are acquired after the temperature becomes stable. (Data is used at Step 4-1)

If measurement fluctuation is different between LPF on and off, different numbers of average can be set in order to minimize the difference.

For example, please take the following steps to determine the measurement time. (When the measurement noise follows the normal distribution)

(a) Determine the permissible error of averaged measurement data (Σ) acquired in step 3-32 ~ 3-37. 1 LSB is roughly equivalent to 0.22 degree pitch/roll angle error.

(b) Determine the standard deviation of averaged measurement data (σ) by repeating step 3-32 ~ 3-37 (where n is the number of measurement) using the same device. Moreover confirm that averaged measurement data follows the normal distribution.

(c) Determine the number of measurement N by using following equation (where Σ is defined in step(a), σ is defined in step(b))

$$N \geqq n \times (\sigma / \Sigma)^2$$

When AKSC_Decomp9888 function is used for calculating the average value, N must be 1, 2, 4, 8, 16, or 32. If the calculated value N exceeds this limitation, the measurement environment needs to be reviewed or another function is needed which calculates average value.

e.g. Permissible error is 5Σ = 10LSB, standard deviation 5σ = 40LSB, when the measurement time n = 1.

$$N = 1 \times (40 / 10)^2 = 16 \text{ times}$$

Note3 : We recommend the measurement environment to which the judging value for step 3-20 ~ 3-22, 3-39 ~ 3-47 is 15 at most to be constructed. Therefore, the final judgment value must be set under your own responsibility.

Note4 : Measured values (average values) of step 3-32 ~ 3-37 are used to estimate offset which is suitable for environmental temperature. Error of measured value causes error of offset estimation. Take care of the followings and execute step 3.

(a) Accuracy of measurement posture (horizontal)

Error of the angle during shipment test becomes a calculation error of pitch/roll angle calculated by an accelerometer data.

(b) Temperature

An acceleration offset depends on temperature of the device. Please measure after the temperature becomes stable.

An offset of acceleration varies within the following range:

offset@T ≦ (offset@25℃) ± 10.2 × (T − 25), T ; device temperature(℃)

Please change this formula according to AS9888 characteristic.

10 LSB is roughly equivalent to 2.2 degree pitch/roll angle error.

Conversion formula for T and TMPS register is;

T=(176-TMPS)/1.6

(c) Noise caused by oscillation

An unexpected shock is applied while measuring acceleration, correct measurement result is not obtained. For that case, please measure again. Moreover, please try to get rid of a source of oscillation. The less vibration produces better measurement result. (cf. Note2)

Note5 : The offset of acceleration sensor becomes stable after specific relaxation time passes after reflow soldering. The offset adjustment must be executed after enough time passes after assembled. Moreover, the offset adjustment must be executed on final product.

5.4. Step4 : Store adjustment values of accelerometer

<table>
<tr><th>Step</th><th>Process</th><th>Register
(PIN)</th><th>Operation</th><th>Judge</th><th>Remarks</th></tr>
<tr><td>4-1</td><td colspan="5">Store values of EEPROM of Step 1-7~1-27, and values of accelerometer in horizontal posture of Step 3-32~3-37 into nonvolatile memories.
1-7~1-10 are adjustment values of whole device.
1-10~1-13 are sensitivity adjustment values of magnetometer
Estimate offsets and sensitivity of accelerometer at an arbitrary temperature using values of 1-14~1-27 and 3-32~3-37.</td></tr>
</table>

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6. How to estimate offset and sensitivity of accelerometer

6.1. Configuration of EEPROM

	7	6	5	4	3	2	1	0
EREF3	Temperature at test room temperature (delta from TMPS) (signed value:-16~15)							
EAGA		Gain value (AGA register) (unsigned:7~43,71~107)						
EADT	Temperature property (signed:-256~255)							
EADA	DAC value (ADA register) (unsigned:0~67,128~195)							
EAGTD	Temperature property of sensitivity (unsigned:0~7)			Detailed value of sensitivity (signed:-16~15)				

6.2. Temperature of test room temperature at DMT

tRT = 136+EREF3[7:3]

6.3. Gain values

EAX/Y/ZGA[6:0] values are read and copied to AX/Y/ZGA[6:0].

6.4. How to estimate sensitivity

6.4.1. Sensitivity values StRTX/Y/Z at room temperature 'tRT'

StRTX/Y/Z = 256+EAX/Y/ZGTD[4:0]

StRTX/Y/Z; sensitivity at tRT

6.4.2. Temperature coefficients of sensitivity KsteX/Y/Z

EAGTD[7:5]	Kste	Unit
0	-0.428125	%/degC (sensitivity standard at temperature tRT)
1	-0.384375	
2	-0.340625	
3	-0.296875	
4	-0.253125	
5	-0.209375	
6	-0.165625	
7	-0.121875	

3. How to estimate sensitivities StX/Y/Z at any temperature 't'

StX/Y/Z = {KsteX/Y/Z * (t – tRT) + 1} * StRTX/Y/Z

6.5. How to estimate offset values

6.5.1. How to estimate offsets OtLX/Y/Z at test temperature 'tL' at horizontal level test

OtLX = AX + StLX * GX

OtLY = AY + StLY * GY

OtLZ = AZ + StLZ * GZ

G =(GX, GY, GZ); Direction of gravity at horizontal level. Assuming the positive direction of Z-axis is vertically upward, G=(0,0,-1)

6.5.2. How to estimate temperature coefficients of offsets KoteX/Y/Z

KoteX/Y/Z = (EAX/Y/ZGA[7:7]&EAX/Y/ZDT[7:0])*1.5/ΔT

ΔT; (High test temperature at DMT) – (test room temperature at DMT)

Usually high temperature is 60℃, room temperature is 25℃ → ΔT=35℃

6.5.3. How to estimate offsets OtX/Y/Z at any temperature 't'

OtX/Y/Z = KoteX/Y/Z * (t – tL) + OtLX/Y/Z

6.6. Calculate optimal DAC value

6.6.1. Definition of function

6.6.1.1. lin2dac()

```
void AKSC_lin2dac(
    const    intvec*    GA,                //(i) : EAGA
    const    intvec*    _DALinearCode,     //(i) : linear DAC code
             intvec*    DA                 //(o) : DAC
)
{
   intvec     DALinearCode;
   DALinearCode = *_DALinearCode;

   if ((0x40&GA->u.x) == 0x40) {
             DALinearCode.u.x = -DALinearCode.u.x;
}
if ((0x40&GA->u.y) == 0x40) {
             DALinearCode.u.y = -DALinearCode.u.y;
}
if ((0x40&GA->u.z) == 0x40) {
             DALinearCode.u.z = -DALinearCode.u.z;
}

DA->u.x = ((DALinearCode.u.x >= 0) ? (DALinearCode.u.x + 0x80) : (-DALinearCode.u.x));
DA->u.y = ((DALinearCode.u.y >= 0) ? (DALinearCode.u.y + 0x80) : (-DALinearCode.u.y));
```


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```
    DA->u.z = ((DALinearCode.u.z >= 0) ? (DALinearCode.u.z + 0x80) : (-DALinearCode.u.z));
    }
```

6.6.1.2. dac2lin()

```
    void AKSC_dac2lin(
        const    intvec*   GA,              //(i) : GAIN
        const    intvec*   DA,              //(i) : DAC
                 intvec*   DALinearCode     //(o) : linear DAC code
    )
    {
        DALinearCode->u.x = ((DA->u.x >= 0x80) ? (DA->u.x - 0x80) : (-DA->u.x));
        DALinearCode->u.y = ((DA->u.y >= 0x80) ? (DA->u.y - 0x80) : (-DA->u.y));
        DALinearCode->u.z = ((DA->u.z >= 0x80) ? (DA->u.z - 0x80) : (-DA->u.z));

    if ((0x40&GA->u.x) == 0x40) {
         DALinearCode->u.x = -DALinearCode->u.x;
    }
    if ((0x40&GA->u.y) == 0x40) {
         DALinearCode->u.y = -DALinearCode->u.y;
    }
    if ((0x40&GA->u.z) == 0x40) {
         DALinearCode->u.z = -DALinearCode->u.z;
    }
}
```

6.6.2. Estimate DACopt value (optimal DAC)

DACopt = lin2dac(AGA, dac2lin(AGA,ADA) – rint(EAGA[5:0]+16)/2048*OtL))

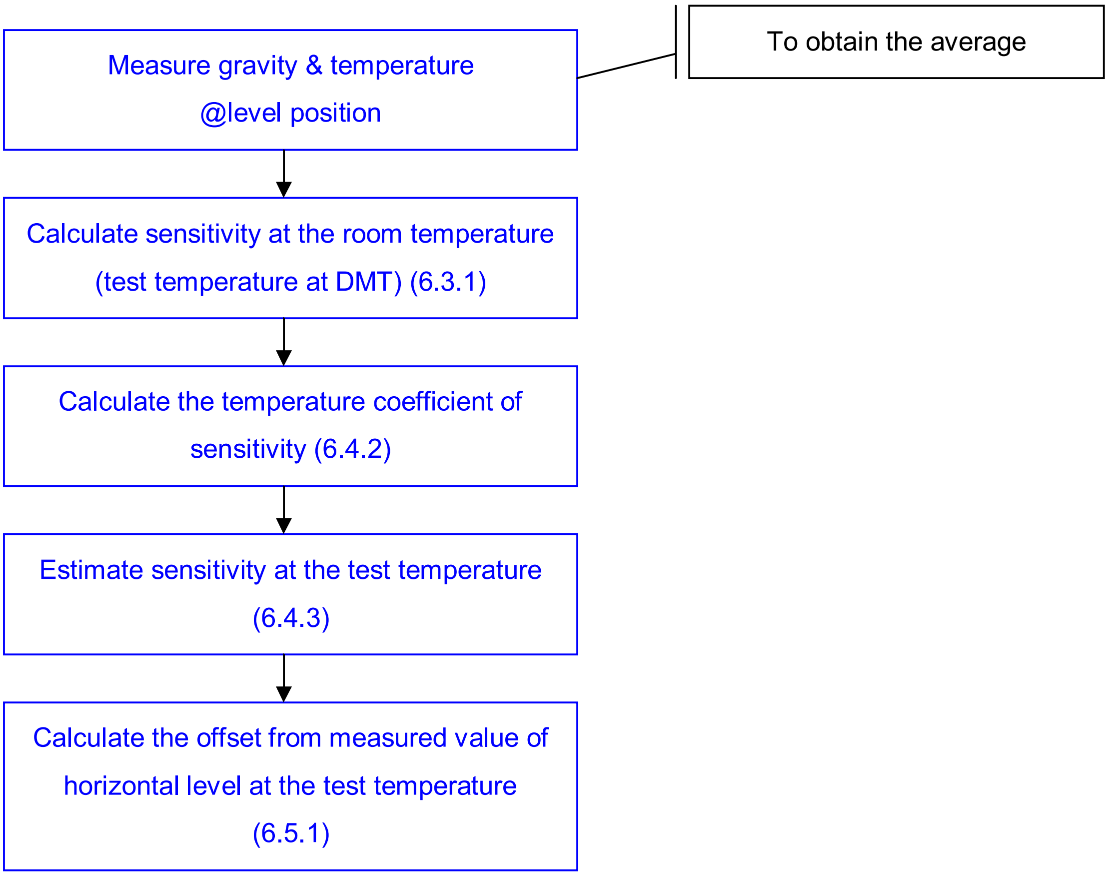
AGA; gain (AX/Y/ZGA register) value

ADA ; current DAC (AX/Y/ZDA) value

OtL; offset value when ADA is set.

lin2dac and dac2lin are implemented as these functions return the value of output arguments.

6.6.3. Flow of optimal DAC estimation



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