



### Fast digital calibration procedure for STPMC1 based energy meters

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#### Introduction

The STPMC1 device functions as an energy calculator and is an ASSP designed for effective energy measurement in power line systems utilizing Rogowski coil, current transformer, and Shunt or Hall current sensors. Used in combination with one or more STPMSx ICs, it implements all the functions needed in a 1, 2, or 3-phase energy meter.

Due to its internal structure and features, STPMC1 allows a more effective and innovative calibration procedure, which is explained in this document.

Advantages of this procedure are:

- reduced calibration time
- no need for re-calibration (calibration parameter can be written in a permanent way).

For further information about the device please refer to the STPMC1 datasheet.

This application note integrates the AN2299 application note for the STPMC1 metering chip.

Sections 1, 2, and 3.1 of the AN2299 application note can be considered valid also for the STPMC1 device, sharing the same architecture as STPM01 and STPM10 devices, whilst the calibration calculations shown in section 3.2 of AN2299 and in this document are slightly different and are reported below.

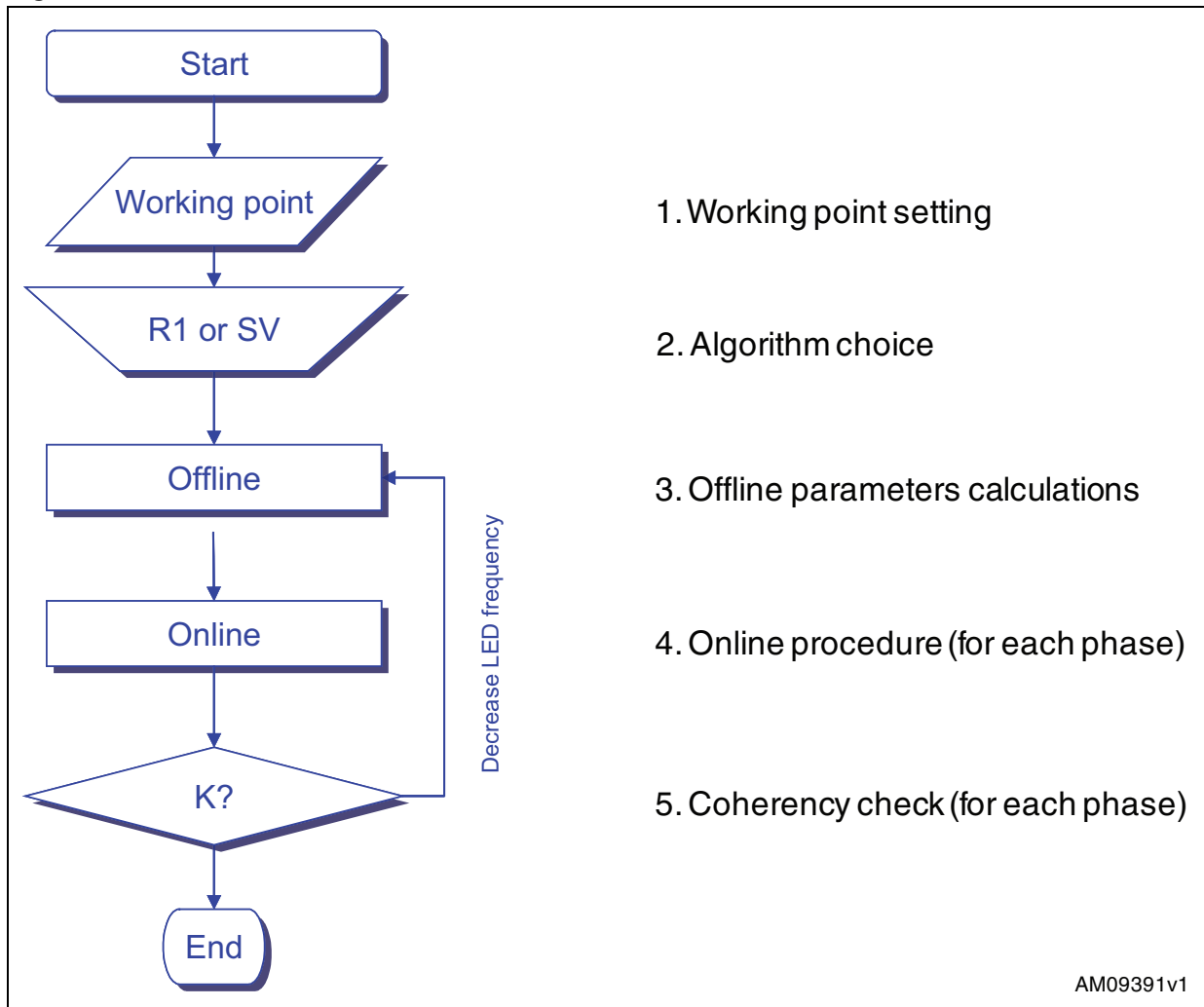
# Contents

<b>1</b>	<b>Calibration flow chart</b> .....	<b>3</b>
1.1	Calibration procedure .....	3
1.1.1	Working point setting .....	3
1.1.2	Algorithm choice .....	6
1.1.3	Offline parameter calculations .....	6
1.1.4	Online procedure .....	9
1.1.5	Coherency check .....	9
<b>2</b>	<b>Revision history</b> .....	<b>10</b>

# 1 Calibration flow chart

The calibration procedure can be summarized in the following steps, which are examined in [Section 1.1](#).

Figure 1. Calibration flow chart



## 1.1 Calibration procedure

### 1.1.1 Working point setting

According to the information contained in AN2299, the STPMC1 device can also be calibrated in a single point for each phase.

Therefore, voltage and current nominal values of the selected phase must be defined before running the calibration procedure, for example:

**Table 1. Working point setting**

Parameter	Value	Description
Vn	230 V	Phase to neutral RMS voltage
In	5 A	Phase RMS current

The other parameters, which follow, and the constants of the STPMC1 metering device (and relative tolerances) are also known:

**Table 2. STPMC1 internal parameters**

Parameter	Value	Description
K <sub>V</sub>	0.875	Voltage calibrator ideal value if PM = 0 <sup>(1)</sup>
	0.9375	Voltage calibrator ideal value if PM = 1
K <sub>I</sub>	0.875	Current calibrator ideal value if PM = 0
	0.9375	Current calibrator ideal value if PM = 1
len <sub>i</sub>	2 <sup>16</sup>	Current register length
len <sub>u</sub>	2 <sup>12</sup>	Voltage register length
Kint <sub>comp</sub>	1.004	Gain of decimation filter
π	3.14159	
FM	4 * 10 <sup>6</sup>	If oscillator frequency is 4.000 or 8.000 MHz
	2 <sup>22</sup>	If oscillator frequency is 4.194 or 8.388 MHz
	4915200	If oscillator frequency is 4.915 or 9.830 MHz
D <sub>UD</sub>	2 <sup>17</sup>	Internal parameter
Vref	1.23	Internal voltage reference
A <sub>u</sub>	4	Amplification of voltage ADC for STPMS1
	2	Amplification of voltage ADC for STPMS2
A <sub>i</sub>	8	Amplification of current ADC for STPMS1
	32	
	2	Amplification of current ADC for STPMS2
	16	
Kint	0.815	Gain of integrator @ line frequency = 50 Hz
	0.679	Gain of integrator @ line frequency = 60 Hz
Kdif	0.6135	Gain of differentiator @ line frequency = 50 Hz
	0.7359	Gain of differentiator @ line frequency = 60 Hz

1. PM is CFG 21, which sets the meter precision (Class 1 or Class 0.1).

Only analog parameters are objects of calibration because they introduce a certain error. Voltage ADC amplification  $A_v$  is constant, while  $A_i$  is chosen according to the used sensors.

The calibration procedure has, as a final result, correction parameters called  $K_{VR}$ ,  $K_{VS}$ ,  $K_{VT}$  and  $K_{IR}$ ,  $K_{IS}$ ,  $K_{IT}$  and  $K_{IN}$  (if used) which, applied to STPMC1 voltage and current measurements, compensate small tolerances of analog components that affect energy calculations.

As  $K_{VR}$ ,  $K_{VS}$ ,  $K_{VT}$  and  $K_{IR}$ ,  $K_{IS}$ ,  $K_{IT}$  and  $K_{IN}$  calibration parameters are the decimal representation of the corresponding configuration bytes CVR, CVS, CVT and CIR, CIS, CIT, CIN, the values of those bits are obtained at the end of calibration.

In the following procedure CVR, CVS, and CVT are indicated as  $C_v$ ; CIR, CIS, CIT, and CIN are indicated as  $C_i$ ;  $K_{VR}$ ,  $K_{VS}$ , and  $K_{VT}$  are indicated as  $K_v$ , and  $K_{IR}$ ,  $K_{IS}$ ,  $K_{IT}$ , and  $K_{IN}$  are indicated as  $K_i$ .

Through hardwired formulas,  $K_v$  and  $K_i$  tune measured values varying from 0.75 to 1 in 256 steps, according to the value of  $C_v$  and  $C_i$  (from 0 to 255).

If  $PM=1$ , two bits are appended to each  $C_v$  and  $C_i$  (see the STPMC1 datasheet for details), and the corresponding tunings vary from 0.875 to 1 in 1024 steps.

To initially obtain the greatest correction dynamic, calibrators are set in the middle of the range, therefore obtaining a calibration range of  $\pm 12.5\%$  ( $\pm 6.25\%$  when  $PM$  is set) per voltage or current channel:

**Table 3. Calibrator value according to PM**

PM	Calibrator value
0	$K_v = K_i = 0.875$ $C_i = C_v = 128$
1	$K_v = K_i = 0.9375$ $C_i = C_v = 512$

In this way it is possible to tune  $K_v$  and  $K_i$  having a precise measurement: for example, with  $PM=0$ ,  $C_v=0$  generates a correction factor of  $-12.5\%$  ( $K_v=0.75$ ) and  $C_v=255$  determines a correction factor of  $+12.5\%$  ( $K_v=1$ ), and so on.

According to the information above, the following formulas, which relate  $K_{v,i}$  and  $C_{v,i}$  to each other are obtained:

**Equation 1**

$$K_{v,i} = (C_{v,i}/128) * 0.125 + 0.75$$

**Equation 2**

$$C_{v,i} = 1024 * K_{v,i} - 768$$

or when  $PM = 1$

**Equation 3**

$$K_{v,i} = (C_{v,i}/512) * 0.0625 + 0.875$$

**Equation 4**

$$C_{v,i} = 8192 * K_{v,i} - 7168$$

Indicating, with  $AvI$  and  $AvV$ , the average values read from the device and with  $X_I$  and  $X_V$  the ideal values of RMS current and voltage readings, the following can be reported:

PM = 0:

**Equation 5**

$$X_V = (K_v * AvV) / 0.875$$

**Equation 6**

$$X_I = (K_i * AvI) / 0.875$$

PM = 1:

**Equation 7**

$$X_V = (K_v * AvV) / 0.9375$$

**Equation 8**

$$X_I = (K_i * AvI) / 0.9375$$

### 1.1.2 Algorithm choice

It is possible to use two different algorithms to calculate the parameters to be used during calibration:

1.  $R_1$  and  $R_2$  constant in order to carry out the sensor sensitivity  $K_S$
2. Current sensor sensitivity and  $R_2$  constant in order to carry out  $R_1$ .

The methods are the same and the choice is left to the designer.

According to the chosen algorithm, the next calibration step produces the value of sensor  $K_S$  or resistor  $R_1$  to be mounted on the measurement board to achieve calibration.

Algorithm formulas are reported below for both current transformer/Shunt and Rogowski coil current sensors.

### 1.1.3 Offline parameter calculations

First of all, it is necessary to determine the target power sensitivity (from the LED pin) to be achieved with the calibration process, for example:

$$C = 128000 \text{ pulses/kWh}$$

The calibration procedure outputs  $C_v$  and  $C_i$  values that allow the above power sensitivity of the meter.

This sensitivity is used to calculate target frequency at the LED pin for nominal voltage and current values:

**Equation 9**

$$X_F = f * 64$$

with:

**Equation 10**

$$f = (C/64 * \ln * V_n) / 3600000$$

### Current transformer or Shunt - Constant R<sub>1</sub>

In this algorithm voltage divider sensitivity is fixed, therefore, resistor values R<sub>1</sub> and R<sub>2</sub> are the known values of the voltage divider resistor.

From the values above and for both the given amplification factor A<sub>i</sub> and the initial calibration data, the following target values can be calculated:

Voltage divider output:

#### Equation 11

$$V_{DIV} = V_n * R_2 / (R_1 + R_2)$$

Target RMS reading for given V<sub>n</sub>:

#### Equation 12

$$X_V = (V_{DIV} / V_{REF}) * 2 * K_{dif} * A_v * K_v * K_{int\_comp} * K_{int} * \ln_u$$

Target RMS reading for given I<sub>n</sub>:

#### Equation 13

$$X_I = f * \ln_u * \ln_i * D_{UD} / (FM * X_V)$$

From which current sensor sensitivity K<sub>S</sub> is obtained:

#### Equation 14

$$K_S = X_I * V_{REF} * 1000 / (\ln * A_i * K_i * K_{int\_comp} * K_{int} * K_{dif} * \ln_i) \text{ [mV/A]}$$

### Current transformer or Shunt - Constant K<sub>S</sub>

In this case the type of current sensor and its nominal value of sensitivity must be known and is equal to K<sub>S</sub>.

From the values above and for both the given amplification factor A<sub>i</sub> and the initial calibration data, the following target values can be calculated:

Target RMS reading for given I<sub>n</sub>:

#### Equation 15

$$X_I = \ln * K_S * A_i * K_i * K_{int} * K_{int\_comp} * K_{dif} * \ln_i / (V_{REF} * 1000)$$

Target RMS reading for given V<sub>n</sub>:

#### Equation 16

$$X_V = f * \ln_u * \ln_i * D_{UD} / (FM * X_I)$$

Voltage divider output:

#### Equation 17

$$V_{DIV} = X_V * V_{REF} / (2 * K_{dif} * A_v * K_v * K_{int\_comp} * K_{int} * \ln_u)$$

From which R<sub>1</sub> resistor value is obtained:

#### Equation 18

$$R_1 = R_2 * (V_n - V_{DIV}) / V_{DIV} \text{ [Ohm]}$$

### Rogowski coil - Constant $R_1$

As before, the voltage divider sensitivity is fixed, therefore, resistor values  $R_1$  and  $R_2$  are the known values of the voltage divider resistor.

From the values above and for both the given amplification factor  $A_i$  and the initial calibration data, the following target values can be calculated:

Voltage divider output:

#### Equation 19

$$V_{DIV} = V_n * R_2 / (R_1 + R_2)$$

Target RMS reading for given  $V_n$ :

#### Equation 20

$$X_V = (V_{DIV} / V_{REF}) * A_v * K_v * K_{int\_comp} * len\_u$$

Target RMS reading for given  $I_n$ :

#### Equation 21

$$X_I = f * len\_u * len\_i * D_{UD} / (FM * X_V)$$

From which current sensor sensitivity  $K_S$  is obtained:

#### Equation 22

$$K_S = X_I * V_{REF} * 1000 / (I_n * A_i * K_i * K_{int\_comp} * K_{int} * len\_i) \text{ [mV/A]}$$

### Rogowski coil - Constant $K_S$

The sensor's nominal value of sensitivity must again be known, for example, it is  $K_S$ .

From the values above and for both the given amplification factor  $A_i$  and the initial calibration data, the following target values can be calculated:

Target RMS reading for given  $I_n$ :

#### Equation 23

$$X_I = I_n * K_S * A_i * K_i * K_{int} * K_{int\_comp} * len\_i / (V_{REF} * 1000)$$

Target RMS reading for given  $V_n$ :

#### Equation 24

$$X_V = f * len\_u * len\_i * D_{UD} / (FM * X_I)$$

Voltage divider output:

#### Equation 25

$$V_{DIV} = X_V * V_{REF} / (A_v * K_v * K_{int\_comp} * len\_u)$$

From which  $R_1$  resistor value is obtained:

#### Equation 26



$$R_1 = R_2 * (V_n - V_{DIV}) / V_{DIV} \text{ [Ohm]}$$

### 1.1.4 Online procedure

According to the used current sensor and the chosen algorithm, a component (resistor or current sensor) of the value calculated through the formulas above must be mounted on the board.

To start the online calibration procedure, the following must be verified:

- EM is connected to the calibration system and is properly configured according to the chosen application
- EM calibrator parameters are preset to initial data
- Target values of line signals are stable.

A 3-phase voltage signal must be provided to all phases and current signal only to the phase under calibration.

When the system is connected and powered on, a certain number of readings of the RMS values must be performed.

Due to the fact that 0.4% of ripple is present in the measured RMS values, more than ten readings of these values should be gathered each cycle (20 ms at 50 Hz) and the average values of RMS current and voltage readings  $Av_I$  and  $Av_V$  should be computed.

Consequently, having the average values  $Av_I$  and  $Av_V$ , a pair of final 8-bit (or 10-bit if PM = 1) calibration data can be calculated as shown below:

#### Equation 27

$$Ci,v = 896 * X_{I,V} / Av_I, V - 768; (PM = 0)$$

#### Equation 28

$$Ci,v = 8192 * X_{I,V} / Av_I, V - 7168; (PM = 1)$$

where  $X_V$  and  $X_I$  are those calculated in one of the four previous cases.

### 1.1.5 Coherency check

We can assume that the EM works correctly and that built-in voltage and current sensors allow the target power sensitivity constant to be achieved, because the correction parameters  $K_i$  and  $K_v$  can tune measured values within the calibration range of  $\pm 12.5\%$  or  $\pm 6.25\%$  if PM = 1 per voltage or current channel.

If, after the calibration, calculated values for  $C_v$  or  $C_i$  are out of their 8 or 10-bit range, it may mean that the application cannot reach the target value of power sensitivity. In this case, steps 3 and 4 must be repeated choosing a smaller power sensitivity value. If the values of  $C_v$  or  $C_i$  are out of range even for small values of PM, it may mean that the energy meter board is not good enough to perform such measurements, possibly because the tolerance of the components is too big, or no care has been taken in the layout phase, so the application must be re-designed.

Otherwise, if the final calibrator data is written into STPMC1, the average RMS readings are very close to target values  $X_I$  and  $X_V$  and the frequency of the LED output are very close to the target value  $f$ .

## 2 Revision history

**Table 4. Document revision history**

Date	Revision	Changes
16-Nov-2011	1	First release

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