AN4470
Application note

The STPM3x application calibration

Introduction

The STPM3x is an ASSP family designed for high accuracy measurement of power and energy in power line systems using the Rogowski coil, current transformer or shunt current sensors. The STPM3x devices embed a full set of calibration and compensation parameters which allow the meter to fit tight accuracy standards (EN 50470x, IEC 62053-2x, ANSI12.2x for AC watt meters) using low cost components, after a fast calibration procedure explained in this document.

According to energy meter measurements, the customer has to pay for energy consumption. The correct operation of the meter, as well as its accuracy and reliability are very important features both for the customer and the electricity company. That's why the quality control of meter is so important and strict.

Special care has to be given both to the design stage and the calibration procedure.

The former allows the right dimensioning of analog front-end components so to fit the current dynamics and the meter constant pulse. The latter impacts on many meter key ratings directly.

Contents

1 Calibration principles and underlying theory

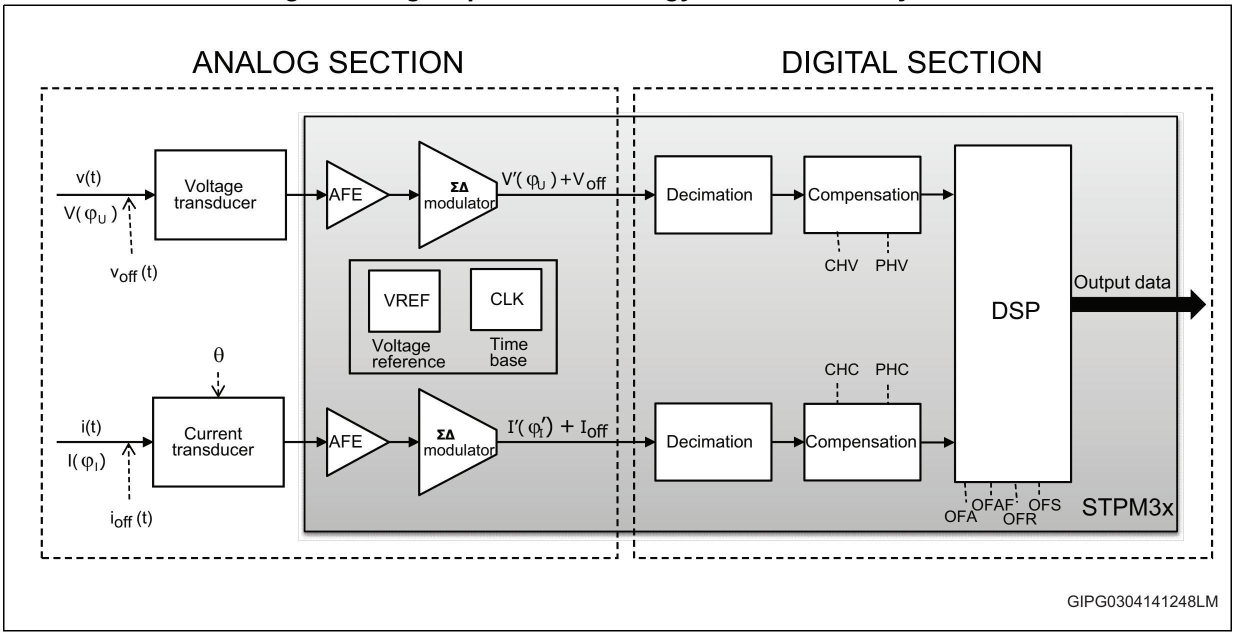
1.1 Principles of digital energy measurement system

Digital energy measuring system, based on the STPM3x, is composed of:

- Analog section with high-resolution sigma-delta analog/digital converters (ADCs)
- Digital section with powerful digital signal processor (DSP) to perform power and energy measurement, as well as other secondary parameters

The main scheme of this system is indicated in *Figure 1*.

Figure 1. Digital power and energy measurement system



Voltage and current paths include the following blocks:

– Sensors for voltage and current
– Signal conditioning (to optimize signals to match the required ADC input level)
– ADCs

Common section consists of the following elements:

– System DC reference voltage
– System time base, provided by a quartz crystal oscillator or by an external (MCU) clock

A/D converters collect samples of phase current and phase-to-neutral voltage synchronized to the sample clock. Outputs of the analog section are samples of voltage and current in digital form with an exact time relationship.

The digital section consists of DSP providing real time calculation based on the voltage and current sampled values to calculate power, energy, RMS values and other parameters through standard mathematical formulas.

A correction algorithm hardwired in DSP corrects amplitude and phase-angle errors of the measured samples, while correction parameters are calculated during the calibration phase.

From the same set of corrected samples, power, energy and all other parameters are calculated in real time through standard mathematical formulas. Calculated values are stored in 32-bit registers, from which output pulses are generated with frequency proportional to the measured power.

Basic definitions and formulas are given below:

Active power

Equation 1

$$P = V \cdot I \cdot \cos\varphi$$

Apparent power

Equation 2

$$S = V \cdot I$$

Reactive power

Equation 3

$$Q = \sqrt{S^2 - P^2} = V \cdot I \cdot \sin\varphi$$

Power factor

Equation 4

$$PF = \cos\varphi = \frac{P}{S}$$

where:

V, I = effective values of voltage and current

$\varphi = \varphi_V - \varphi_I$ current-to-voltage phase-angles

φ_V φ_I voltage and current to common reference phase-angles

Measured active power

Equation 5

$$P' = V' \cdot I' \cdot \cos\varphi' + P_{off}$$

where:

$V' = V (1 + \varepsilon_V)$

$I' = I (1 + \varepsilon_I)$

$\varphi' = \varphi + \theta$

ε_V = voltage amplitude error

ε_i = current amplitude error

θ = current-to-voltage phase-angle error

P_{off} = power offset (due to V_{off}, I_{off} residual signals)

Neglecting term εv*εi, the measured active power is

Equation 6

$$P' = V \cdot I \cdot (1 + \varepsilon_v + \varepsilon_i) \cdot \cos(\varphi + \theta) + P_{off}$$

1.2 Accuracy and stability influence factors

All components, which have some influence on system accuracy and stability, can be found in the input analog section.

Only a limited number of internal components determines system accuracy:

- Voltage and current sensors
- Signal conditioning section
- Oscillator frequency
- Internal reference voltage source
- Analog-to-digital converter gain

To reach the desired stability and linearity, high quality components have to be used.

Moreover, the circuit has to be carefully designed to minimize some issues such as: short-time repeatability, linearity or immunity degrade.

Besides, external influences can affect meter accuracy, such as:

- Capacitive and inductive coupling to inputs and between phases (crosstalk)
- High frequency electrical and magnetic fields (EMC)
- Common-mode voltage between inputs and to earth
- Low frequency magnetic fields
- Measuring setup (wiring, earth connection ground loop)
- Source (stability of V, I, φ, signal quality)
- Long-time drift
- Humidity

Undesired external influences should be reduced to minimum through the shielding of the analog part or compensated in hardware or software.

If system is not immune to external influences, it can only work under very special conditions and results cannot be reproduced in other locations, where there may be a different measuring setup. In this case, also statistical effects, due to noise, have higher impact on short-time repeatability.

External influences on total system accuracy can be more important than the basic specified error.

Note: The STPM3x does not introduce any crosstalk error neither between voltage and current inputs nor among different phases. However, the voltage front-end handles considerable amplitude voltages, which make it a potential source of noise. Disturbances could be readily emitted into current measurement circuitry, interfering with the signal to be measured. Typically, this shows a non-linear error at small signal amplitudes and non-unity power factors. At unity power factor, voltage and current signals are in phase, and crosstalk between voltage and current channels appears as a gain error, which can be calibrated.

When voltage and current are not in phase, crosstalk has a non-linear effect on measurements, which cannot be calibrated. Crosstalk is minimized by a well-planned PCB and the correct use of filter components.

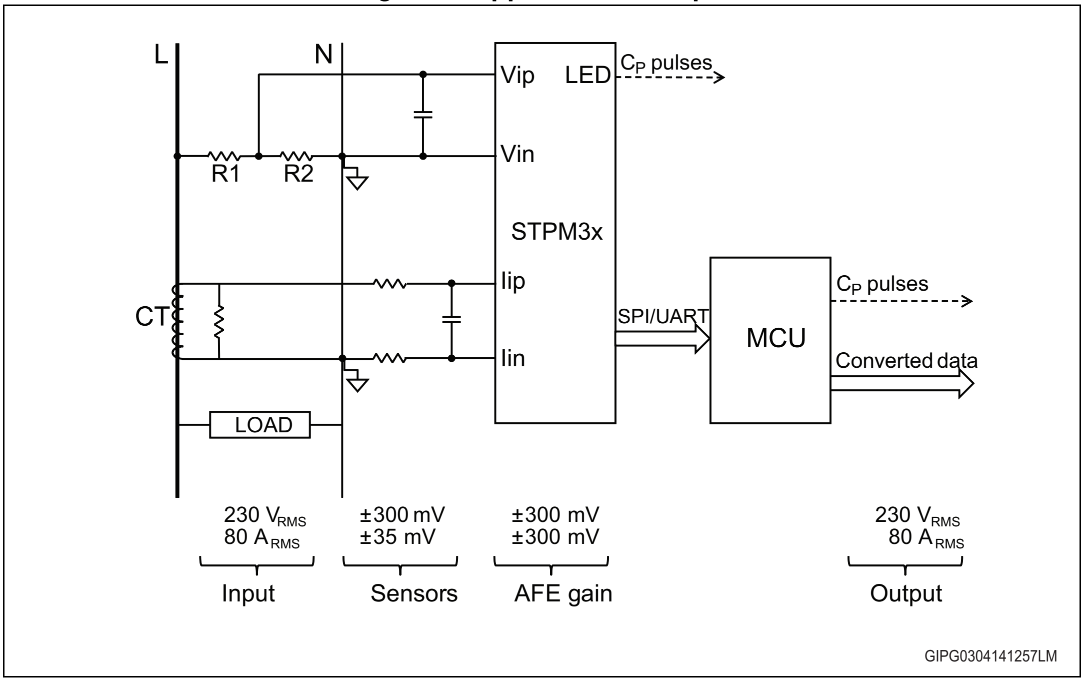
2 Measuring system design

The maximum voltage and current measurement, the number of pulses per kWh (indicated as C_P, constant pulses) and the measurement accuracy are the main ratings of the meter.

A correct analog front-end component choice allows the line signal to fit the device input dynamics; selectable gain of internal current amplifier scales the input signal according to sensor sensitivity.

A typical application example is shown in *Figure 2*.

Figure 2. Application example



The choice of external components in the transduction section of the application is a crucial point of the application design, affecting the precision and the resolution of the whole system.

A compromise has to be found among the following needs:

1. Maximizing signal-to-noise ratio in the voltage and current channel
2. Choosing k_S current-to-voltage conversion ratio and the voltage divider ratio, to achieve calibration for a given C_P
3. Choosing k_S to take advantage of the whole current dynamic range according to the desired maximum current and resolution

Rules for a good application design are described in this section. After the design phase, any tolerance of the real components respect to these values or the device internal parameter drift can be compensated by calibration. This stage is necessary to get the desired C_P after calibration. To reach C_P target output constant pulse, the analog front-end component dimensioning can be carried out in two ways:

- Choosing the value of R_1 voltage divider resistor, given R_2 and k_S current sensor sensitivity
- Choosing k_S given R_1 and R_2 voltage divider resistors

Calculations for these two methods are developed below:

- First method: constant k_S

Given R_2 (smaller voltage divider resistor), k_S (current sensor sensitivity) and C_P, target meter constant pulse (pulses/kWh), as calculation inputs, R_1 voltage divider resistor value derives from the following formula:

Equation 7

$$R_1 = R_2\left(\frac{1800 \cdot k_S \cdot A_V \cdot A_I \cdot cal_V \cdot cal_I \cdot DClk}{V^2{}_{ref} \cdot C_P} - 1\right)[\Omega]$$

- Second method: constant R_1

Given R_1, R_2 (voltage divider resistors) and C_P target meter constant pulse (pulses/kWh) as calculation inputs, k_S current sensor value derives from the following formula:

Equation 8

$$k_S = \frac{V^2{}_{ref} \cdot C_P \cdot (1 + R_1/R_2)}{1800 \cdot A_V \cdot A_I \cdot cal_V \cdot cal_I \cdot DClk}[(mV)/A]$$

C_P value can be scaled by a division factor through LPWx[3:0] bits in DSP_CR1, DSP_CR2 for the two channels according to the device p/n.

Note: The resistor (in the first method) or the current channel sensor (in the second method) has to be chosen as closer as possible to the target value; small tolerance is compensated by calibration.

2.1 Design example

This example shows the correct dimensioning of a meter using a current transformer with the following specifications:

Table 1. Example 1 design data

Parameter	Value
V_N nominal voltage	230 V_{RMS}
I_N nominal current	5 A_{RMS}
I_{Max} maximum current	40 A_{RMS}
C_P constant pulses	1000 imp/kWh

The values of voltage divider resistors are 770 kΩ and 470 Ω.

Setting C_P = 64000 pulses/kWh (at LED_PWM = 1, the device default value) and according to the previous calculation, the following values are obtained:

Table 2. Example 1 calculated data

Parameter	Value
Current sensor sensitivity	$k_S = \frac{V^2_{ref} \cdot C_P \cdot (1 + R_1/R_2)}{1800 \cdot A_V \cdot A_I \cdot cal_V \cdot cal_I \cdot DClk} = 3.508\ mV/A$
V_{MAX}	$V_{MAX} = \frac{1}{2} \cdot \frac{V_{ref}}{A_V \cdot \sqrt{2}} \cdot \frac{R_1 + R_2}{R_2} = 347.8\ V$
I_{MAX}	$I_{MAX} = \frac{1}{2} \cdot \frac{V_{ref}}{A_I \cdot \sqrt{2}} \cdot \frac{1}{k_S} = 60.5\ A$

To set the desired LED pulse output, a division factor can be set through LPWx[3:0] bits in DSP_CR1 and DSP_CR2 configuration registers. Any tolerance, producing C_P small variation respect to 1000 imp/kWh, is compensated by calibration.

3 System calibration

The calibration procedure is a key feature among main meter requirements. In fact, it impacts directly on accuracy, cost, manufacturing and reliability of the meter. After the final assembly phase, an energy meter requires a calibration procedure due to unknown tolerances respect to nominal values of the following analog blocks:

- Voltage and current sensors
- Oscillator frequency
- Internal or external reference voltage source
- Analog-to-digital converter gain

The STPM3x device is composed of independent channels for line voltage and current respectively. Each channel includes its own 12-bit digital calibrator to adjust the signal amplitude, digital filter to remove any signal DC component; moreover the device embeds phase calibration registers for each line and power offset compensation registers.

Calibration is carried out in three steps:

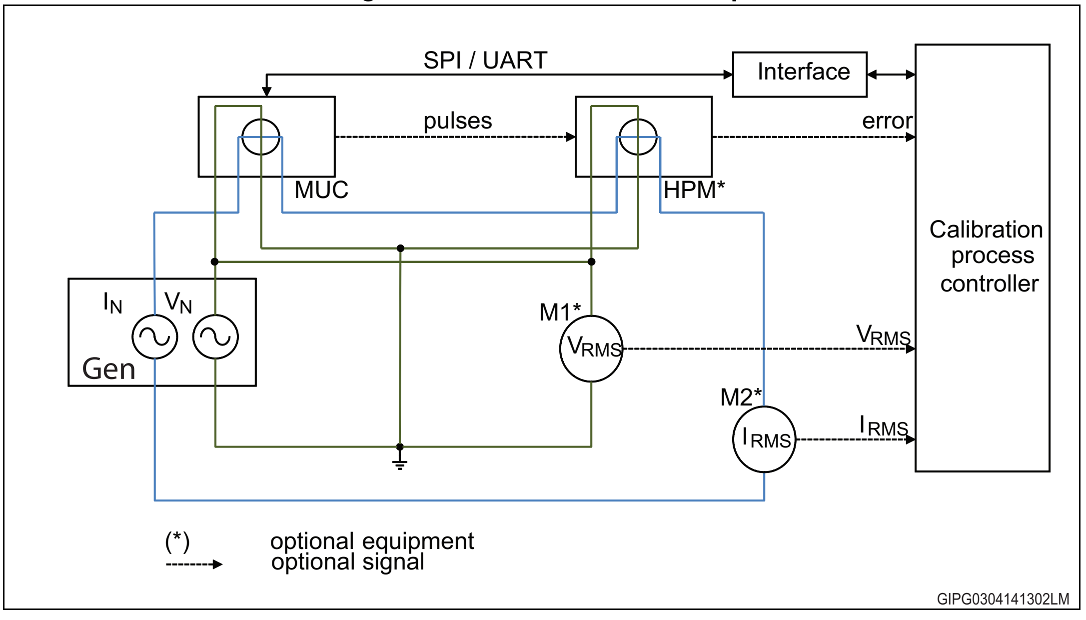
- Amplitude calibration is mandatory for class accuracy higher than Class 2
- Phase-shift calibration is mandatory for CT-based meters
- Power offset calibration (optional for class accuracy higher than 0.2)

To calibrate, the following equipment has to be interfaced:

- Precision current and voltage source (Gen)
- Meter under calibration (MUC)
- Higher class precision energy meter (HPM) (optional)
- Calibration process controller (CPC)
- UART/SPI interface to the STPM3x device

Please, see *Figure 3*:

Figure 3. Meter calibration setup



Gen equipment generates voltage and current line signals at the same frequency and a phase-shift between them. HPM and MUC equipment measures the same signals, and HPM computes the error by comparing LED frequency output.

If HPM is not available, amplitude calibration can be performed having either a precise voltage/current generator or a voltage/current RMS meter.

Calibration process controller is an automated system which runs calibration process routines to configure the STPM3x device on MUC before calibration, controls Gen, monitors HPM equipment, reads from the device, calculates the correction parameters and writes them into the device. Since the STPM3x hasn't any non-volatile memory, CPC should take into account the permanent storage of calculated calibrators.

CPC can be interfaced to the STPM3x through its SPI/UART peripherals.

If an STPM3x evaluation board is used, the following interfaces are available:

- The STPM3x parallel programmer
- The STEVAL-IPE023V1 USB isolated interface
- RS232 interface (as the one embedded in the STPM3x evaluation board)

The STPM3x evaluation software, running automatic calibration procedure, can be found on www.st.com; it can be used with all above listed interfaces. Further information is available in the UM1719.

For all available tools and software please visit www.st.com.

3.1 Amplitude calibration

Any energy measure performed by the device (active wideband and active fundamental, reactive or apparent power and energy) is calculated digitally (without error) from current and voltage signals. This means that every measure is automatically calibrated if current and voltage channels are calibrated.

C_P (power sensitivity constant pulse) target value is achieved by amplitude calibration of these signals.

Independent and precise line signal generators could be used for this calibration, because line frequency and phase between line signals have not a significant impact, observing RMS values.

If the line generator is precise and stable enough, theoretically, the additional precision energy meter (HPM) is not necessary to perform the calibration; in fact signal amplitudes (voltage and current RMS value) are calibrated and DC offset is rejected, thanks to the almost ideal linearity of the STPM3x. This may simplify the generation of reference line signals of accurate output values. If accuracy is not guaranteed, reference values of line signals can be obtained by RMS meters.

Meter calibration is achieved by calibrating the device, just one measuring point, at nominal values, such as: 230 V_{RMS}, 5 A_{RMS}, 50 Hz.

Calibrating voltage and current in a single operating point leads to a very short (one second in an automated environment) calibration time.

Each voltage and current channel of the device (according to the p/n) have to be compensated following the same procedure.

Given the device internal parameters in *Table 3*, and having one between R_1 or k_S calculated as stated in *Equation 7* and *Equation 8*, voltage and current RMS register target values, X_V and X_I respectively, are calculated by DSP as follows:

Voltage register value at V_N nominal voltage

Equation 9

$$X_V = \frac{V_N \cdot \sqrt{2} \cdot A_V \cdot k_{RMS} \cdot 2^{15}}{V_{ref} \cdot (1 + R_1 / R_2)}$$

Current register value at I_N nominal voltage

Equation 10

$$X_V = \frac{I_N \cdot \sqrt{2} \cdot A_I \cdot k_{RMS} \cdot k_{int} \cdot k_S \cdot 2^{15}}{V_{ref}}$$

Table 3. STPM3x internal parameters

Parameter	Value	
Voltage reference	V_{ref} =1.20 [V]	
Decimation clock	*DCLK*=7812.5 [Hz]	
Integrator gain (for Rogowski coil only)	k_{int} = 1	if ROC bit = 0 in DSP_CR1,2
	k_{int} = 0.8155773	if ROC bit = 1 in DSP_CR1,2
RMS block gain	k_{RMS} = 0.6184	
Voltage channel gain	A_V = 2	
Current channel gain	A_I= 2/16	

A_V voltage ADC gain is constant, while A_I current ADC gain is chosen according to the sensor used and to the desired current input dynamics.

The calibration procedure has as final result K_V and K_I correction parameters which, applied to the STPM3x voltage and current, introduce signal path attenuation or amplification compensating small tolerances of analog components.

K_V and K_I calibration parameters are the decimal representation of the corresponding voltage and current 12-bit calibrators: CHVx[11:0], CHCx[11:0] (where x = 1 or 2 respectively for primary and secondary channel according to the device p/n) from DSP_CR5 to DSP_CR8 registers.

Through hardwired formulas, K_V and K_I fine-tune measured values from 0,75 to 1 in 4096 steps, according to CHV and CHC values.

For example: CHV = 0 generates a correction factor -12.5% (K_V = 0.75) and CHV = 4065 determines a correction factor +12.5% (K_V = 1) following below equations:

Voltage correction factor

Equation 11

$$k_V = 0.125 \cdot \frac{CHV}{2048} + 0.75$$

Current correction factor

Equation 12

$$k_I = 0.125 \cdot \frac{CHV}{2048} + 0.75$$

When system is connected and powered on, having the applied V_N and I_N nominal values, a certain number of readings has to be performed to average voltage and current RMS values. After RMS register samples have been read and averaged, obtaining V_{AV} and I_{AV} values, voltage and current channel calibrators are calculated as follows:

Voltage calibrator

Equation 13

$$CHC = 14336 \cdot \frac{X_V}{V_{AV}} - 12288$$

Current calibrator

Equation 14

$$CHC = 14336 \cdot \frac{X_I}{I_{AV}} - 12288$$

where X_V and X_I are those calculated in *Equation 9* and *Equation 10*.

K_I and K_V correction parameters can fine-tune measured values only within the calibration range of ±12.5% of voltage or current channel.

If after the calibration, CHV or CHC calculated values are out of range (less than 0 or more than 4095), the application cannot reach the target value of C_P power sensitivity. In this case, design and calibration phase should be repeated choosing a smaller C_P value.

If one or more calibrator values are out of range, energy meter board could be not able to perform these measurements, maybe because component tolerance is too big, or due to some issues during the layout phase, so the application has to be redesigned.

Otherwise, calibrator values can be written into the STPM3x, the average RMS readings are very close to X_I and X_V target values and LED output frequency is very close to HPM frequency output.

3.1.1 Step-by-step amplitude calibration procedure

The following steps summarize the calibration procedure explained above:

1. Design the application as stated in *Section 3.1* so that the relationship among R_1, R_2, k_S an C_P is coherent with *Equation 7* and *Equation 8*
2. Reset the STPM3x to have registers in the default state
3. Configure the device through CPC according to the chosen application. The following registers have to be configured (one or both primary and secondary channels, according to the application and to the device p/n):
- ROCx (in DSP_CR1 or DSP_CR2)
  - 0: for CT or shunt
  - 1: for Rogowski coil
- GAINx (in DFE_CR1 or DFE_CR2) to set the correct current gain channel
- CHVx and CHCx (in DSP_CR5 and DSP_CR8) have to be set to default (0x800) obtaining a calibration range of ±12.5% of voltage or current channel
4. Apply stable and accurate nominal values of V_N and I_N voltage and current signals, with PF =1 to one or both primary and secondary channels. For the stability of the source please refer to the equipment documentation; add 0.5 seconds to the maximum so that the STPM3x RMS values are stable
5. Perform RMS register sample acquisition (DSP_REG14 and/or DSP_REG15) through CPC; average the values to obtain V_{AV} and I_{AV}; minimum suggested values are 20 samples in 5 line cycles
6. Calculate CHVx and CHCx calibrators using *Equation 13* and *Equation 14*
7. Write calibration values to the device and store them in a non-volatile memory

The whole procedure requires one second in an automated environment.

3.2 Phase-shift calibration

The STPM3x does not introduce any phase-shift between voltage and current channels.

However, voltage and current signals come from transducers, which could have inherent phase errors. For example, a phase error from 0.1 ° to 0.3 ° is common for a current transformer (CT). These phase errors can vary from part-to-part, and have to be corrected in order to perform accurate power calculations. Errors associated with phase mismatch are particularly evident at low power factors.

The phase compensation block provides a digital correction of the phase-shift for primary and secondary channel independently. This block introduces a delay between current and voltage samples which is fine-tuned by PHCx[9:0] and PHVx[1:0] phase calibration bits in DSP_CR4. The delay (in degree) introduced by these registers on the waveforms is given below:

Current shift

Equation 15

$$\varphi_C = \frac{f_{line}}{SCLK} \cdot PHCx[9:0] \cdot 360^{\circ}$$

Voltage shift

Equation 16

$$\varphi_V = \frac{f_{line}}{SCLK} \cdot PHVx[1:0] \cdot 2^9 \cdot 360^\circ$$

Global phase-shift

Equation 17

$$\varphi = \frac{f_{line}}{SCLK} \cdot (PHVx[1:0] \cdot 2^9 - PHCx[9:0]) \cdot 360^\circ$$

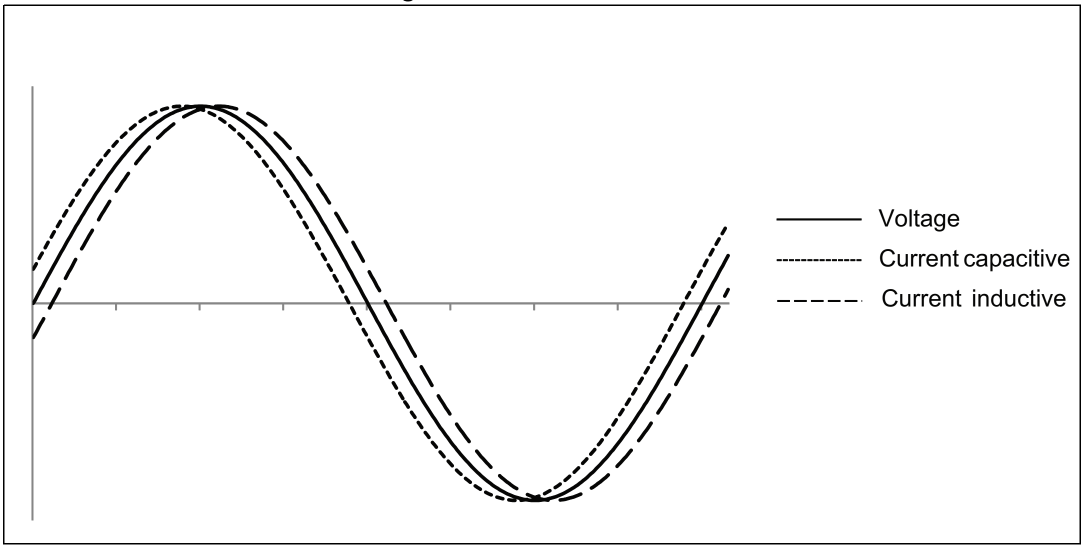
Where SCLK = 4 MHz and f_{line} is voltage and current signal frequency.

PHVx influences the calculation of power and energies related to both current channels.

As shown in *Figure 4*, capacitive behavior is determined by the current leading the voltage waveform to a certain angle. In this case, the compensation is given, delaying the current waveform, by the same angle through PHCx register.

An inductive behavior has the opposite effect, so that current lags the voltage waveform. In this case, the compensation occurs using PHVx register to delay the voltage waveform to invert the behavior to capacitive and then, acting on PHCx register, to fine-tune the current waveform.

Figure 4. Phase-shift error



From *Equation 17* the following correction range is calculated for 50 and 60 Hz line signals:

Table 4. Phase error correction range

Line frequency	Minimum value	Maximum value	Step
50 Hz	-4.608 °	6.9504 °	0.0045 °
60 Hz	-5.5296 °	8.2944 °	0.0054 °

To compensate phase-shift, stable nominal values of voltage and current signals (V_N and I_N) shifted by φ = 60 ° angle, have to be applied to MUC.

Given e, the error on active power (averaged over a certain number of samples through HPM), the phase-shift angle (θ) between voltage and current can be measured as shown below.

Without any phase-shift error, the ideal active power at φ = 60° is

Equation 18

$$P_I = V \cdot I \cdot \cos(60)$$

Since voltage and current are shifted by angle θ, the measured power is

Equation 19

$$P_M = V \cdot I \cdot \cos(60 + \theta)$$

Leading to an error, at PF = 0.5, equal to

Equation 20

$$e = \frac{P_I - P_M}{P_I} = \frac{V \cdot I \cdot \cos(60) - V \cdot I \cdot \cos(60 + \theta)}{V \cdot I \cdot \cos(60)} = 1 - 2\cos(60 + \theta)$$

By measuring the error, the phase-shift derives from the above formula as follows

Equation 21

$$\theta = \cos^{-1}\left(\frac{1 - e}{2}\right) - 60^{\circ}$$

To compensate this error, PHCx and PHVx bits have to be set as below, to introduce a correction factor φ = -θ, according to the following table:

Table 5. Phase compensation

Parameter	Value
$\varphi < 0$	$PHVx = 0x0$ $PHCx = \frac{\varphi \cdot SCLK}{360 \cdot f_{line}}$
$0 < \varphi < \frac{f_{line}}{SCKL} \cdot 2^{10} \cdot 360^{\circ}$	$PHVx = 0x2$ $PHCx = PHVx \cdot 2^9 - \frac{\varphi \cdot SCLK}{360 \cdot f_{line}}$
$\frac{f_{line}}{SCKL} \cdot 2^{10} \cdot 360^{\circ} < \varphi < \frac{f_{line}}{SCKL} \cdot 3 \cdot 2^9 \cdot 360^{\circ}$	$PHVx = 0x3$ $PHCx[9] = 0x0$ $PHCx[8:0] = PHVx \cdot 2^9 - \frac{\varphi \cdot SCLK}{360 \cdot f_{line}}$

3.2.1 Step-by-step phase-shift calibration procedure

The following steps summarize the calibration procedure explained above:

1. Perform MUC amplitude calibration following steps listed in *Section 3.1.1*
2. Configure the device through CPC. All registers should be in default state; the following registers have to be configured (according to the channel under calibration and to the device p/n):

- ROCx (in DSP_CR1 or DSP_CR2)
  - 0: for CT, shunt
  - 1: for Rogowski coil
- GAINx (in DFE_CR1 or DFE_CR2) to set the correct current gain channel
- CHVx and CHCx (in DSP_CR5 or DSP_CR8) have to be set as calculated in *Section 3.1.1*
- PHVx and PHCx (in DSP_CR4) are preset to default (0x0)
- LCSx (in DSP_CR1 and DSP_CR2) is set to 0 or 1 to output on LEDx the desired channel
- LPSx is set to zero (to output on LEDx the active power signal)

3. Apply stable and accurate nominal values of V_N and I_N voltage and current signals shifted by $\varphi = 60\,°$ angle
4. Read from HPM the e error on the active power from LED frequency
5. Calculate phase-shift error from *Equation 21* and correction factor from *Table 5*
6. Write PHVx, PHCx to the device and store them in a non-volatile memory

3.2.2 Example: phase-shift compensation

In a 50 Hz line, after amplitude calibration, the error on active power at PF = 0,5 is measured as: e = 0.038 = 3.8%.

From *Equation 21*, the current waveform is leading the voltage to θ =1.25 °, so the value to introduce is φ = -θ through PHCx[9:0] = 0x116 (φ_C=1.251 °).

If the voltage is leading current to the same angle, values to introduce are PHV[1:0]=0x1 (φ_V = 2.304 °) and PHCx[9:0]=0xEA (φ_C =1.053 °) the current shift, respect to the voltage, is: φ_V - φ_C = 1.251 °.

3.3 Offset calibration

The STPM3x has power offset compensation register for all measured powers to compensate, for each channel, the amount of power measured due to noise capture in the application.

Power offset compensation registers: OFAx[9:0], OFRx[9:0], OFAFx[9:0], OFSx[9:0], compensating active, reactive, active fundamental and apparent power for each channel (according to the p/n) are located in registers from DSP_CR9 to DSP_CR12.

When no power is applied to the meter, if one or more average values of power registers are not null, the error is due to external influences, then an opposite value in the power offset register is needed to compensate them.

Power registers are signed values, (MSB is the sign, and negative values are two's complemented); power offset registers are signed registers as well, and LSB value is equal to 4 times power LSB.

Power register LSB

Equation 22

$$LSB_P = \frac{LED\_PWM \cdot V_{ref}^2 \cdot (1 + R_1/R_2)}{k_{int} \cdot A_V \cdot A_I \cdot k_S \cdot cal_V \cdot cal_I \cdot 2^{28}} \left[\frac{W}{LSB}\right]$$

LSB power offset register

Equation 23

$$LSB_{PO} = LSB_P \cdot 2^2 = \frac{LED\_PWM \cdot V_{ref}^2 \cdot (1 + R_1/R_2)}{k_{int} \cdot A_V \cdot A_I \cdot k_S \cdot cal_V \cdot cal_I \cdot 2^{28}} \cdot 2^2 \left[\frac{W}{LSB}\right]$$

LSB value of power and power offset registers is equal in all power types (reactive, apparent, fundamental).

3.3.1 Step-by-step offset calibration procedure

The following steps summarize the calibration procedure explained above:

1. Perform MUC amplitude and phase calibration following steps listed in *Section 3.1.1* and *Section 3.2.1*
2. Configure the device through CPC. All registers should be in default state; the following registers have to be configured (according to the channel under calibration and to the device p/n):

- ROCx (in DSP_CR1 or DSP_CR2)
  - 0: for CT, shunt
  - 1: for Rogowski coil
- GAINx (in DFE_CR1 or DFE_CR2) to set the correct current gain channel
- CHVx and CHCx (in DSP_CR5 or DSP_CR8) have to be set as calculated in *Section 3.1.1*
- PHVx and PHCx (in DSP_CR4) have to be set as calculated in *Section 3.2.1*
- OFAx[9:0], OFRx[9:0], OFAFx[9:0], OFSx[9:0] power offset compensation registers from DSP_CR9 to DSP_CR12 are set to zero

3. Apply stable and accurate nominal values of V_N voltage signal while $I_N = 0$
4. Perform acquisition of samples of power registers (PHx_REG4 to PHx_REG9) through CPC and average the values; minimum suggested values are 40 samples in 5 line cycles
5. Calculate the compensation value like the average values with changed sign
6. Write OFAx, OFRx, OFAFx, OFSx to the device and store them in a non-volatile memory

4 Revision history

Table 6. Document revision history

Date	Revision	Changes
08-Apr-2014	1	Initial release.