Atmel

APPLICATION NOTE

ATM90Exx Auto Calibration

ATM90Exx

Features

- ATM90E2x single-phase measurement and metering auto calibration
- ATM90E3x poly-phase measurement and metering auto calibration

Preface

Atmel® single-phase metering ICs (ATM90E2x) and poly-phase metering ICs (ATM90E3x) support traditional calibration based on energy pulses and measurement values. Users may get familiar with this traditional calibration procedure by referring to application notes reference[4], reference[5], and reference[6]. This kind of energy pulse error based calibration has advantages like higher accuracy and higher stability, but also brings disadvantage like relatively lower efficiency. For a meter designer or manufacturer, the calibration accuracy and efficiency shall be balanced. A newly developed calibration method called auto calibration is widely accepted by many customers now, which could help achieve higher efficiency and higher accuracy simultaneously. Basically the calibration software (normally PC-based) calculates all the calibration parameters and delivers them to MCU in application system in the traditional calibration, while auto calibration is a new calibration method in which a stable power source is provided and MCU in application system calculates the parameters of calibration, thus this calculation could be done in parallel. And luckily, this auto calibration method is supported by Atmel metering ICs. This application note describes the procedure of how to use auto calibration method with Atmel single-phase and ploy-phase metering ICs.

Table of Contents

1. Introduction

1.1 Introduction

This application note introduces the auto calibration method of measurement and metering for Atmel single-phase and poly-phase metering ICs.

Normally, Metering ICs deliver values like line voltage RMS, line current RMS, mean power, phase angle between voltage and current, voltage frequency etc. are regarded as measurement values, while active energy, reactive energy *etc.* are regarded as metering values.

The measurement calibration means the calibration of voltage RMS (Urms) gain and current RMS (Irms) gain. And the metering calibration only needs to calibrate the active energy gain (if needed) and phase angle. There is no need to calibrate reactive energy since accuracy is guaranteed by chip design.

Measurement and metering function both need to be accredited by factory calibration. Compared with the traditional calibration method, auto calibration could be a better choice when large quantity meters waiting to be calibrated on factory product line. Generally, the auto calibration procedure could be divided into the following steps:

- Prepare a stable power source;
- The PC-based software delivers the parameters of standard power source to each Meter-Under-Calibration on the meter tester (calibration bench);
- The application firmware in MCU reads the AFE chip's current RMS, voltage RMS, mean power, phase angle *etc.* and calculates the proper calibration parameters, e.g. current gain, voltage gain.

There are some differences between single-phase auto calibration procedure and poly-phase metering ICs auto calibration procedure, e.g. some constants used in calibration algorithm are different. So this application note will describe the auto calibration procedure for single-phase and poly-phase applications separately.

Note1: There are four power working modes for poly-phase metering ICs ATM90E32AS/ATM90E36A: normal mode, partial measurement mode, detection mode and idle mode. Auto calibration method proposed in this application shall be only implemented in normal mode. Please refer to reference[5] and reference[6] for the calibration method for the other three power modes.

Note2: ATM90E26, ATM90E32AS and ATM90E36A have reactive energy metering function. And reactive energy metering function does not need to be calibrated since the performance is guaranteed by design.

Note3: Metering ICs like ATM90E26 and ATM90E36A have N line measurement function. N line calibration could also be supported in this auto calibration method.

1.2 Prerequisites

- Metering AFE is running under normal mode.
- Stable power source.
- High accuracy meter tester.

2. Auto Calibration Procedure

The auto calibration procedure could be divided into two steps mainly: the first step is PL constant configuration and the second step is Ugain, Igain, Phase Angle, Phase Energy Gain calibration. Benefiting from Atmel metering ICs' wide dynamic range, only single-point calibration is needed over the entire dynamic range. Figure 2-1 Auto Calibration Flow shows the detailed auto calibration working flow.

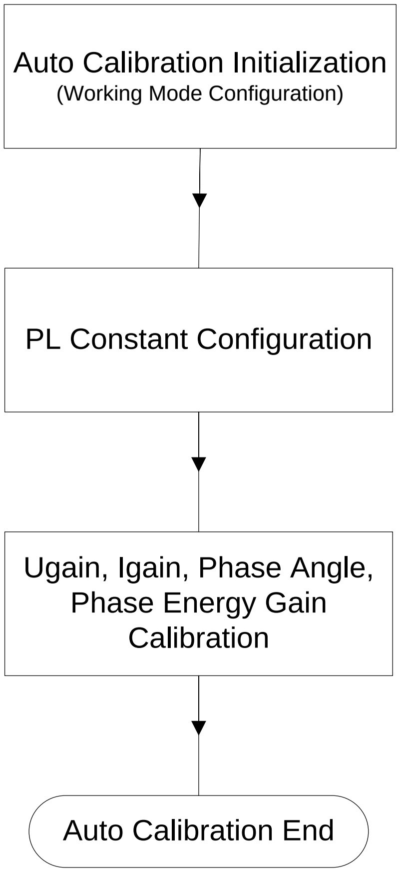

Figure 2-1. Auto Calibration Flow

2.1 Auto Calibration for Poly-phase Metering ICs

The basic but most important step is working mode configuration which shall be performed before whole auto calibration procedure is performed. The majority task of this step is to prepare the working mode parameters like setting metering mode, meter type *etc.* according to detailed hardware design. After the working mode parameters are correctly configured, the calibration start function (ATM90E32AS: CfgRegAccEn; ATM90E36A: ConfigStart, CalStart, HarmAdj, AdjStart) shall be enabled. Only after that, the calibration registers could be accessed. Please refer to corresponding datasheet for this calibration start function control registers.

2.1.1 Start Calibration

For ATM90E32AS, metering function shall be enabled by MeterEn register and all the calibration registers could be accessible only after a golden value is written in to startup command register. Detailed startup command register definition is listed in Table 2-1 Startup Command Registers:

Table 2-1. Startup Command Registers

Name	Address	Start Calibration Setting	Note
MeterEn	00H	FFH	Meter enable command
CfgRegAccEn	7FH	55AAH	Startup command. Allow register configuration access.

For ATM90E36A, startup command registers listed in Table 2-2 Startup Command Registers shall be enabled before start auto calibration.

Table 2-2. Startup Command Registers

Name	Address	Start Calibration Setting	Note
ConfigStart	30H	5678H	Function configuration startup.
CalStart	40H	5678H	Metering calibration startup.
HarmAdj	50H	5678H	Harmonic calibration startup.
AdjStart	60H	5678H	Measurement calibration startup.

2.1.2 Working Mode Configuration

For poly-phase metering ICs ATM90E32AS/36A, working mode could be configured through power mode configuration pins: Table 2-3 Power Mode Configuration and according MMode: Table 2-4 MMode Register Configuration.

Table 2-3. Power Mode Configuration

Name	Pin No.	I/O	Type	Note
PM0 PM1	33 34	I	LVTTL	**PM1/0: Power Mode Configuration** 00: Idle (I mode); 01: Detection (D mode); 10: L Partial Measurement (M mode); 11: Normal (N mode);

Note: ATM90E32AS/ATM90E36 shall be configured in normal mode for auto calibration.

Table 2-4. MMode Register Configuration

Name	Address	MMode0 Setting	Note
MMode0	33H	Metering Method Configuration	
MMode1	34H	PGA Gain Configuration	

Note: Configuration principle of PGA gain.

(a) Ensure that the ADC channel analog input signal should be within the dynamic range of 0~720mVrms
(b) Configure PGA gain to be the maximum value within the whole dynamic range

For ATM90E32AS, additional registers like ChannelMapI [01H] and ChannelMapU [02H] need to be configured according to hardware design.

Example:

- ChannelMapI = 0210H, ADC Input source I2 for phase C current channel, I1 for phase B and I0 for phase A
- ChannelMapU = 0654H, ADC Input source U2 for phase C voltage channel, U1 for phase B and U0 for phase A

2.1.3 PL Constant Configuration

The PL Constant configuration shall be done after the register access control is enabled. The PL Constant registers defined in ATM90E32AS/36A consist of the PLconstH[31H] and PLconstL[32H] registers, corresponding to high word and low word of PL Constant respectively.

PL Constant is calculated as below:

$$\mathrm{PL_{Constant}} = \frac{450{,}000{,}000{,}000}{\mathrm{MC \times k\_i \times k\_u}}$$

Where 450,000,000,000: Constant;
MC: Meter Constant, unit is imp/kWh or imp/kvarh;
k_i means Irms registers value will be calibrated to 1/k_i of the actual value during calibration;
k_u means Urms registers value will be calibrated to 1/k_u of the actual value during calibration;

Example with following MC parameters:

- Meter Constant MC = 3200 imp/kWh
- k_u = 1, k_i = 2

$$\mathrm{PL_{Constant}} = \frac{450{,}000{,}000{,}000}{3200 \times 2 \times 1} = 70{,}312{,}500 = \mathrm{430E234H}$$

‘0430H’ should be written to the PLconstH register [31H], and 'E234H' should be written to the PLconstL register [32H]. All ATM90E32AS/36A registers are 16 bits wide.

2.1.4 Measurement and Metering Calibration Algorithm

All the metering calibration and measurement calibration could be processed simultaneously in this auto calibration method for poly-phase metering ICs. The following lists the detailed process procedure:

[1] Phase power offset are calibrated with below power source settings:

- Ua = Ub = Uc = Un; Reference voltage (U_n) applied voltage input phase A, phase B and phase C simultaneously;
- Ia = Ib = Ic = 0;
- Power Factor = N/A;

Below is an example command which should be sent through general communication port by using PC based terminal tools.

“Calibration (ua=220.00,ia=0.000,ub=220.00,ib=0.000,uc=220.0,ic=0.000,pha=0.00)”

After the Meters-Under-Calibration receive the power offset calibration parameters, the metering MCU firmware should adjust power offset automatically based on the AFE measured values and the received normative values. The power offset adjustment algorithms are described in below steps:

For ATM90E32AS:

- Read phase mean active power registers (32 bits). It is suggested to read 8 times to get the averaged value and each register reading interval shall be at least 320ms (one register refresh period), 500ms recommended.
- Invert all bits and add 1 (2’s complement);
- Write the lower 16-bit result to the offset register

For ATM90E36A:

- Read phase mean active power registers (32 bits). It is suggested to read 8 times to get the averaged value and each register reading interval shall be at least 320ms (one register refresh period), 500ms recommended.
- Calculate: register value x 100,000 / 65,536;

- Right shift the calculated result data by 8 bits (ignore the lowest 8 bits);
- Invert all bits and add 1 (2's complement);
- Write the lower 16-bit result to the offset register.

The corresponding offset register and measurement value registers are shown in Table 2-5 Offset and Measurement Registers:

Table 2-5. Offset and Measurement Registers

Offset Register		Measurement Value Registers			
Address	Register Name	Address	Register Name	Address	Register Name
41H	PoffsetA	0B1H	PmeanA	0C1H	PmeanALSB
42H	QoffsetA	0B5H	QmeanA	0C5H	QmeanALSB
43H	PoffsetB	0B2H	PmeanB	0C2H	PmeanBLSB
44H	QoffsetB	0B6H	QmeanB	0C6H	QmeanBLSB
45H	PoffsetC	0B3H	PmeanC	0C3H	PmeanCLSB
46H	QoffsetC	0B7H	QmeanC	0C7H	QmeanCLSB

[2] Phase voltage, current and angle are calibrated with below power source settings:

- $U_A = U_B = U_C = U_n$; Reference voltage(U_n) applied voltage input phase A, phase B and phase C simultaneously.
- $I_A = I_B = I_C = I_b$; Basic current(I_b) applied on current input phase A, phase B and phase C simultaneously. Note: it's better to select the I_b by using this formula: MAX(I_b, 5A);
- Power Factor = 0.5L;

Example: Set up the power source supplying with the above suggested sources to all Meters-Under-Calibration. Following shows an example command of parameters delivered to metering MCU for auto calibration, the command could be sent through general communication port by using PC based terminal tools.

"Calibration (ua=220.00,ia=5.000,ub=220.00,ib=5.000,uc=220.0,ic=5.0,pha=60.00)"

After the Meters-Under-Calibration receive all the calibration parameters, the metering MCU firmware should adjust the Ugain, Igain, Phase Angle automatically based on the AFE measured values and the received normative values. The gain and angle adjustment algorithms are described in below steps.

[3] Voltage measurement results U_{meas_x} could be read out from the Urms_x registers and reference voltage Un is the actual voltage value, voltage RMS gain Ugain_x is calculated as below formula:

For ATM90E32AS, $\mathrm{Ugain\_x} = \mathrm{int}(32768 \times \frac{U_n}{U_{meas\_x} \times k\_u})^{\mathrm{Note4}}$

For ATM90E36A, $\mathrm{Ugain\_x} = \mathrm{int}(52800 \times \frac{U_n}{U_{meas\_x} \times k\_u})^{\mathrm{Note4}}$

In the above two formulas, the unit of U_n is V, $U_{meas\_x}{}^{\mathrm{Note5}}$ is the readout value of the Urms_x register. Subscript "_x" represents phase A, phase B and phase C accordingly when different phase voltage gain calculated. k_u means the Urms register value will be calibrated to 1/k_u of the actual value during calibration.

[4] If the readout of phase current RMS value is I_{meas_x} and the actual current RMS is the basic current I_b, then the formula for Igain_x, the current RMS gain is:

For ATM90E32AS, $\mathrm{Igain\_x} = \mathrm{int}(32768 \times \frac{I_b}{I_{meas\_x} \times k\_i})^{\mathrm{Note4}}$

For ATM90E36A, $\mathrm{Igain\_x} = \mathrm{int}(30000 \times \frac{I_b}{I_{meas\_x} \times k\_i})^{\mathrm{Note4}}$

In the above two formulas, the unit for I_b is A, $I_{meas\_x}{}^{\mathrm{Note6}}$ is the readout value of the Irms_x register. Subscript "_x" represents phase A, phase B and phase C accordingly when different phase current gain calculated. k_i means the Irms register value will be calibrated to 1/k_i of the actual value during calibration.

All the calculated $\mathrm{Ugain\_x}$ and $\mathrm{Igain\_x}$ shall be written into the corresponding phase voltage/current gain registers. Table 2-6 Ugain, Igain and Measurement Registers shows detailed description for Ugain_x registers, Igain_x, Urms_x registers and Irms_x registers:

Table 2-6. Ugain, Igain and Measurement Registers

	Gain Register		Measurement Value Registers			
	Address	Register Name	Address	Register Name	Address	Register Name
Voltage	61H	UgainA	0D9H	UrmsA	0E9H	UrmsALSB
	65H	UgainB	0DAH	UrmsB	0EAH	UrmsBLSB
	69H	UgainC	0DBH	UrmsC	0EBH	UrmsCLSB
Current	62H	IgainA	0DDH	IrmsA	0EDH	IrmsALSB
	66H	IgainB	0DEH	IrmsB	0EEH	IrmsBLSB
	6AH	IgainC	0DFH	IrmsC	0EFH	IrmsCLSB
	6DH[Note7]	IgainN[Note7]	0D8H[Note7]	IrmsN[Note7]	-	-

Note4: It is not mandatory to restore all the gain registers with the default value when the previous calibration result is not satisfied. That means calibration can be performed repeatedly based on the current calibrated value. In this way, calibration formulas could be redefined as below:

$$\text{New voltage gain} = \text{int}(\text{currently voltage gain x } \frac{\text{reference voltage value}}{\text{voltage measurement value}})$$

$$\text{New current gain} = \text{int}(\text{currently current gain x } \frac{\text{reference current value}}{\text{current measurement value}})$$

Note5: Voltage RMS is unsigned and the minimum unit 1LSB of the UrmsA/UrmsB/UrmsC registers is 0.01V. Only the higher 8 bits of the UrmsALSB/UrmsBLSB/UrmsCLSB registers are valid, the lower 8 bits are always 0, and 1LSB is 0.01/256 V.

Note6: Current RMS is unsigned and the minimum unit 1LSB of the IrmsA/IrmsB/IrmsC registers is 0.001A. Only the higher 8 bits of the IrmsALSB/IrmsBLSB/IrmsCLSB registers are valid, the lower 8 bits are always 0, and 1LSB is 0.001/256 A.

Note7: N line measurement is only supported by ATM90E36A, not by ATM90E32AS.

[5] This step is only applied when the AFE is ATM90E36A. 'FFD3H' shall be written into phase calibration gain GainA [47H], GainB [49H] and GainC [4BH].

[6] If the readout value of phase mean active power is $P_{mean\_meas\_x}$ and the readout value of phase mean apparent power is $S_{mean\_meas\_x}$, the calculated phase angle could be calculated by below formula:

$$\text{Calculated Phase\_x Angle} = \arccos(\frac{P_{mean\_meas\_x}}{S_{mean\_meas\_x}})$$

The phase angle calibration could be calculated by the below formula:

$$\text{Phi\_x} = \text{round}(\text{Calculated Phase\_x Angle} - \text{Actual Phase\_x Angle}) \text{ x } 113.778)$$

Where parameter 113.778 is a constant.

All the calculated phase angle calibration values shall be written into the corresponding phase angle calibration registers. Table 2-7 Phase Angle Calibration Registers shows detailed description of phase angle calibration registers:

Table 2-7. Phase Angle Calibration Registers

	Address	Description
PhaseA	48H	PhiA
PhaseB	4AH	PhiB
PhaseC	4CH	PhiC

2.1.5 Example for Poly-phase Calibration Algorithm

[1] Suppose choosing ATM90E32AS poly-phase metering IC as AFE, with 1000:1 CT as current sampling sensor and voltage divider ratio of 1680(1680KΩ:1KΩ).

[2] PC based terminal broadcasts following command to all Meters-Under-Calibration through general communication port:

"cnf (mt=1,mc=3200,freq=50.0,pga=1,k_u=1,k_i=2)"

This command indicates the meters are testing with following conditions:

- mt =1, means meter type is 1;
- mc = 3200, means meter constant is 3200imp/kWh;
- freq = 50.0, means main's frequency is 50.0Hz;
- pga = 1, means AFE's PGA setting is 1;
- k_u = 1, means Urms is calibrated with actual value.
- k_i = 2, means Irms is calibrated with ½ of actual value.

MCU application records the above parameters and enters into auto calibration process.
Please be noted this step is optional because these configurations could be predefined in MCU application firmware.

[3] MCU auto calibration process configures start calibration register with setting shown in Table 2-8 Start Calibration Registers:

Table 2-8. Start Calibration Registers

Name	Address	Register Setting	Note
MeterEn	00H	FFH	Meter enable command
CfgRegAccEn	7EH	55AAH	Startup command.

MCU initializes calibration related registers with settings shown in Table 2-9 Calibration Registers Initialization:

Table 2-9. Calibration Registers Initialization

Name	Address	Register Setting	Note
UgainA	61H	8000H	Default value.
IgainA	62H	8000H	Default value.
UgainB	65H	8000H	Default value.
IgainB	66H	8000H	Default value.
UgainC	69H	8000H	Default value.
IgainC	6AH	8000H	Default value.

MCU initializes metering mode control register with settings shown in Table 2-10 Metering Mode Register:

Table 2-10. Metering Mode Register

Name	Address	Register Setting	Note
MMode0	33H	0087H	3P4W.
MMode1	34H	0000H	Gain is 1 for all voltage and current channels.

[4] PL Constant register configuration:

$$\mathrm{PL_{Constant}} = \frac{450000000000}{3200 \times 2 \times 1} = 70312500 = 430E234H$$

'0430H' should be written to the PLconstH register [31H], and'E234H' should be written to the PLconstL register [32H].

[5] PC based terminal broadcasts the following command to all Meters-Under-Calibration through general communication port:

"Calibration (ua=220.00,ia=0.000,ub=220.00,ib=0.000,uc=220.0,ic=0.000,pha=0.00)"

This command indicates the power source is supplying following sources:

- Ua = Ub = Uc = 220.00V;
- Ia = Ib = Ic = 0;
- Power Factor = N/A;

After MCU receives the power offset calibration command, MCU starts to calibrate power offset; MCU reads out the Pmean value 8 times consecutively and then calculates the power offset:

$$\text{Phase A Power Offset} = \frac{\text{FFC4H+ FFCAH + FFCAH+ FFDCH+ FFC5H+ FFCBH+ FFCAH+ FFCCH}}{8} = \text{FFCBH}$$

Values FFC4H, FFCAH, FFCAH, FFDCH, FFC5H, FFCBH, FFCAH and FFCCH are the calculated results based on the algorithm: ((Readout Pmean Values x 100000) / 65536) >> 8. And the complement value '35H' should be written to the PoffsetA register [41H].

$$\text{Phase B Power Offset} = \frac{\text{FFCCH+ FFCAH + FFCAH+ FFDCH+ FFC5H+ FFCBH+ FFCAH+ FFCCH}}{8} = \text{FFCCH}$$

Values FFC4H, FFCAH, FFCAH, FFDCH, FFC5H, FFCBH, FFCAH and FFCCH are the calculated results based on the algorithm: ((Readout Pmean Values x 100000) / 65536) >> 8. And the complement value '34H' should be written to the PoffsetB register [43H].

$$\text{Phase C Power Offset} = \frac{\text{FFC4H+ FFCAH + FFCAH+ FFDCH+ FFC5H+ FFCBH+ FFCAH+ FFC4H}}{8} = \text{FFCAH}$$

Values FFC4H, FFCAH, FFCAH, FFDCH, FFC5H, FFCBH, FFCAH and FFCCH are the calculated results based on the algorithm: ((Readout Pmean Values x 100000) / 65536) >> 8. And the complement value '36H' should be written to the PoffsetC register [45H].

[6] PC based terminal broadcasts following command to all Meters-Under-Calibration through general communication port:

"Calibration (ua=220.00,ia=5.000,ub=220.00,ib=5.000,uc=220.00,ic=5.000,pha=60.00)"

This command indicates the power source is supplying following sources:

- Ua = Ub = Uc = 220.00V;
- Ia = Ib = Ic = 5.000A;
- Power Factor = 0.5L;

MCU application records the above parameters and begins to calibrate the Metering and Measurement.

[7] MCU calculates the Ugain:

$$\text{UgainA} = \text{int}\left(32768 \text{ x } \frac{220.00}{138.46 \text{ x } 1}\right) = 52066 = \text{CB62H}$$

'CB62H' should be written to the phase A voltage RMS gain register UgainA [61H]. 138.46V is the measured phase A voltage RMS value. 220.00V is the actual voltage RMS value supplied by power source. The parameter 1 is k_u.

$$\text{UgainB} = \text{int}\left(32768 \text{ x } \frac{220.00}{138.40 \text{ x } 1}\right) = 52085 = \text{CB75H}$$

'CB75H' should be written to the phase B voltage RMS gain register UgainB [65H]. 138.40V is the measured phase B voltage RMS value. 220.00V is the actual voltage RMS value supplied by power source. The parameter 1 is k_u.

$$\text{UgainC} = \text{int}\left(32768 \text{ x } \frac{220.00}{138.63 \text{ x } 1}\right) = 52001 = \text{CB21H}$$

'CB21H' should be written to the phase C voltage RMS gain register UgainC [69H]. 138.63V is the measured phase C voltage RMS value. 220.00V is the actual voltage RMS value supplied by power source. The parameter 1 is k_u.

[8] MCU calculates the Igain:

$$\text{IgainA} = \text{int}\left(32768 \text{ x } \frac{5.000}{2.539 \text{ x } 2}\right) = 32263 = \text{7E07H}$$

'7E07H' should be written to the phase A current RMS gain register IgainA [62H]. 2.539A is the measured phase A current RMS value. 5.000A is the actual current RMS value supplied by power source. The parameter 2 is k_i.

$$\mathrm{IgainB} = \mathrm{int}\left(32768 \text{ x } \frac{5.000}{2.543 \text{ x } 2}\right) = 32214 = \mathrm{7DD6H}$$

'7DD6H' should be written to the phase B current RMS gain register IgainB [66H]. 2.543A is the measured phase B current RMS value. 5.000A is the actual current RMS value supplied by power source. The parameter 2 is k_i.

$$\mathrm{IgainC} = \mathrm{int}\left(32768 \text{ x } \frac{5.000}{2.543 \text{ x } 2}\right) = 32214 = \mathrm{7DD6H}$$

'7DD6H' should be written to the phase C current RMS gain register IgainC [6AH]. 2.543A is the measured phase C current RMS value. 5.000A is the actual current RMS value supplied by power source. The parameter 2 is k_i.

[9] MCU calculates the Phi:

$$\text{Calculated Phase A Angle} = \arccos\left(\frac{275.665}{550.000}\right) = 59.92°$$

275.665 is the measured phase A active power and 550.000 is measured the phase A apparent power. The phase angle calibration could be calculated by the below formula:

$$\mathrm{PhiA} = \mathrm{round}((59.92 - 60.00) \text{ x } 113.778) = 9 = \mathrm{0009H}$$

'0009H' should be written to the PhiA register [48H].

$$\text{Calculated Phase B Angle} = \arccos\left(\frac{275.581}{550.000}\right) = 59.93°$$

275.581 is the measured phase B active power and 550.000 is the measured phase B apparent power. The phase angle calibration could be calculated by the below formula:

$$\mathrm{PhiB} = \mathrm{round}((59.93 - 60.00) \text{ x } 113.778) = 8 = \mathrm{0008H}$$

'0008H' should be written to the PhiB register [4AH].

$$\text{Calculated Phase C Angle} = \arccos\left(\frac{275.831}{550.000}\right) = 59.90°$$

275.831 is the measured phase C active power and 550.000 is the measured phase C apparent power. The phase angle calibration could be calculated by the below formula:

$$\mathrm{PhiC} = \mathrm{round}((59.90 - 60.00) \text{ x } 113.778) = 10 = \mathrm{000BH}$$

'000BH' should be written to the PhiC register [4CH].

2.2 Auto Calibration for Single-phase Metering ICs

The working mode configuration procedure for single-phase metering ICs are almost the same as that for poly-phase metering ICs which is described in 2.1.2 Working Mode Configuration. After the working mode parameters are correctly configured, calibration start function (ATM90E26: CalStart, AdjStart) shall be enabled. Only after that, the calibration registers could be accessed. Please refer to related datasheet for this calibration start function control registers.

2.2.1 Start Calibration

Metering and measurement calibration startup command registers shall be enabled before start auto calibration. Detailed registers definitions listed in Table 2-11 Startup Command Registers.

Table 2-11. Startup Command Registers

Name	Address	Register Access Enable Value	Note
CalStart	20H	5678H	Metering calibration startup.
AdjStart	30H	5678H	Measurement calibration startup.

2.2.2 Working Mode Configuration

For single-phase metering IC ATM90E26, working more could be configured through metering mode configuration pins: Table 2-12 Metering Mode Configuration and according MMode register: Table 2-13 MMode Register Configuration.

Table 2-12. Metering Mode Configuration

Name	Pin No.	I/O	Type	Note
MMD1 MMD0	1 28	I	LVTTL	**MMD1/0: Metering Mode Configuration** 00: anti-tampering mode (larger power); 01: L line mode (fixed L line); 10: L+N mode (applicable for single-phase three-wire system); 11: flexible mode (line specified by the LNSel bit (MMode, 2BH));

Table 2-13. MMode Register Configuration

Name	Address	MMode Setting	Note
MMode	2BH	Metering Mode Configuration	

Example: ATM90E26 metering board hardware design with the following configuration:

- Shunt resistor for sampling current in L line, gain is '24';
- CT for sampling current in N line, gain is '1';
- L line metering enabled;
- Both HPF0 and HPF1 are enabled;
- Forward (inductive) or reverse (capacitive) energy pulse output;
- All zero-crossing;
- Default threshold for anti-tampering mode.

New configuration value 7C22H should be written into the MMode register [2BH] for the above example.

2.2.3 PL Constant Configuration

For ATM90E26, PL Constant configuration is determined by L line hardware parameters. The PL Constant configuration shall be done after the register access control is enabled. PL Constant is calculated as below formula:

$$\mathrm{PL_{Constant}} = \mathrm{int}(838860800 \text{ x } \frac{\mathrm{G_L \text{ x } V_L \text{ x } V_U}}{\mathrm{MC \text{ x } U_n \text{ x } I_b}})$$

Where MC: pulse constant of the energy meter, unit is imp/kWh or imp/kvarh;
$\mathrm{U_n}$: Reference voltage, unit is V;

I_b: Basic current, unit is A;
G_L: L line current circuit gain;
V_L: Sampling voltage of the L line circuit at I_b, unit is mV;
V_U: Sampling voltage of the voltage circuit at U_n, unit is mV;
838860800: constant.

Example with following L line parameters:

- Assume MC=3200 imp/kWh;
- U_n = 220V;
- I_b = 5A;
- G_L= 24;
- L line shunt resistor = 200 μΩ, so V_L = 1mV;
- Voltage divider coefficient = 880, so V_U = 250mV;
- Unit of the ADC sampling data of the voltage and current circuits is mV:

$$PL_{Constant} = \mathrm{int}\left(838860800 \text{ x } \frac{G_L \text{ x } V_L \text{ x } V_U}{MC \text{ x } U_n \text{ x } I_b}\right) = 1429876.36 = 15D174H$$

'0015H' should be written to the PLconstH register [21H], and'D174H' should be written to the PLconstL register [22H].

2.2.4 Measurement and Metering Calibration Algorithm

All the metering calibration and measurement calibration could be processed simultaneously in this auto calibration method for single-phase metering ICs. Following lists the detailed process procedure:

[1] Line power offset is calibrated with below power source settings:

- U = U_n; Reference voltage (U_n) applied voltage input channel.
- I = 0;
- Power Factor = N/A;

Below is an example command that should be sent through general communication port by using PC based terminal tools.

“Calibration (u=220.00,i=0.000,pha=0.00)”

After the Meters-Under-Calibration receive the power offset calibration parameters, the metering MCU firmware should adjust active power offset automatically based on the AFE measured values and the received normative values. The power offset adjustment algorithms are described in below steps:

- Write 'A987H' to the SmallPMod register (04H) to enter small-power mode;
- Read out active / reactive power in small-power mode. It is suggested to read 8 times to get the averaged value and each register reading interval shall be at least 320ms (one register refresh period), 500ms recommended.
- Write the complement of the above mean value to the corresponding active / reactive power offset registers;
- Write any 0000H value to the SmallPMod register (04H) to exit small-power mode;

The corresponding offset register and measurement value registers are shown in Table 2-14 Offset and Measurement Registers:

Table 2-14. Offset and Measurement Registers

	Offset Register		Measurement Value Registers			
	Address	Register Name	Address	Register Name	Address	Register Name
All-wave Powers	37H	PoffsetL	4AH	Pmean	-	-
	38H	QoffsetL	4BH	Qmean	-	-

[2] Line voltage, current and angle are calibrated with below power source settings:

- U = U_n; Reference voltage (U_n) applied voltage input channel.

- I = I_b; Basic current (I_b) applied on current input channel. Note: it's better to select the I_b by using this formula: MAX(I_b, 5A);
- Power Factor = 0.5L;

Example: Set up the power source supplying with the above suggested sources to all Meters-Under-Calibration. Following shows an example command of parameters delivered to metering MCU for auto calibration, the command could be sent through general communication port by using PC based terminal tools.

"Calibration (u=220.00,i=5.000,pha=60.00)"

After the Meters-Under-Calibration receive all the calibration parameters, the metering MCU firmware could adjust the Ugain, Igain, L line angle and L line gain based on the AFE measured values and the received normative values. The gain and angle adjustment algorithms are described in below steps.

[3] Voltage measurement result U_{meas} could be read out from the Urms register [49H] and reference voltage Un is the actual voltage, voltage RMS gain Ugain is calculated as below formula:

$$\mathrm{Ugain} = \mathrm{int}(26400 \text{ x } \frac{U_n}{U_{meas} \text{ x } k\_u})$$

In the above formula, the unit of Un is V, U_{meas} is the readout value of the Urms register (hex should be changed to decimal and divided by 100, unit is V), and 26400 is the decimal of 6720H which is the power-on value of the voltage RMS gain register Ugain [31H]. k_u means Urms registers value will be calibrated to 1/k_u of the actual value during calibration.

[4] If the readout of L line current RMS Irms [48H] is I_{meas} and the actual current RMS is the basic current I_b, then the formula for Igain, the current RMS gain is:

$$I_{gainL} = \mathrm{int}(31251 \text{ x } \frac{I_b}{I_{meas} \text{ x } k\_i})$$

In the above formula, the unit for Ib is A, I_{meas} is the readout value of the Irms register (hex should be changed to decimal and divided by 1000, unit is A), and 31251, or 7A13H, is the power-on value of L line current RMS gain register IgainL [32H]. k_i means Irms registers value will be calibrated to 1/k_i of the actual value during calibration.

[5] After the Ugain and Igain are correctly calibrated, the MCU needs to wait at least 3 register refresh periods (about 320ms per refresh period). And then start to calibrate the Lgain:

$$\mathrm{LRATIO} = \left(\frac{I_{gainL} \text{ x } k\_i \text{ x } U_{gain} \text{ x } k\_u \text{ x } PL_{Constant} \text{ x } MC}{838860800 \text{ x } 4.5 \text{ x } 10^9}\right) - 1$$

And the formula for Lgain, the L line calibration gain is:

If $\mathrm{LRATIO} \geq 0$, $\mathrm{Lgain} = \mathrm{int}(2^{15} \text{ x } \mathrm{LRATIO})$

If $\mathrm{LRATIO} < 0$, $\mathrm{Lgain} = \mathrm{int}(2^{16} + 2^{15} \text{ x } \mathrm{LRATIO})$

[6] If the readout value of L line mean active power is P_{mean_meas} and the readout value of L line mean apparent power is S_{mean_meas}, the calculated line angle could be calculated by below formula:

$$\text{Calculated Line Angle} = \arccos(\frac{P_{mean\_meas}}{S_{mean\_meas}})$$

The line angle calibration could be calculated by the below formula:

$$\mathrm{Lphi} = \mathrm{round}((\text{Calculated Line Angle} - \text{Actual Line Angle}) \text{ x } 113.778)$$

Where parameter 113.778 is a constant.

2.2.5 Example for Single-phase Calibration Algorithm

[1] Suppose choosing ATM90E26 single-phase metering IC as AFE, with 150uΩ shunt as current sampling sensor and voltage divider ratio of 840(840KΩ:1KΩ).

[2] PC based terminal broadcasts following command to all Meters-Under-Calibration through general communication port:

"cnf (mt=2,mc=3200,freq=50.0,pga=24,k_u=1,k_i=2)"

This command indicates the meters are tested with following conditions:

- mt = 2, means meter type is 2;
- mc = 3200, means meter constant is 3200imp/kWh;
- freq = 50.0, means main's frequency is 50.0Hz;
- pga = 24, means AFE's PGA setting is 24;
- k_u = 1, means Urms is calibrated with actual value.
- k_i = 2, means Irms is calibrated with ½ of actual value.

MCU application records the above parameters and enters into auto calibration process.
Please be noted this step is optional because these configurations could be predefined in MCU application firmware.

[3] MCU auto calibration process configures start calibration registers with settings shown in Table 2-15 Startup Command Registers:

Table 2-15. Startup Command Registers

Name	Address	Register Setting	Note
CalStart	20H	5678H	Metering calibration startup.
AdjStart	30H	5678H	Measurement calibration startup.

MCU initializes calibration related registers with settings shown in Table 2-16 Calibration Registers Initialization:

Table 2-16. Calibration Registers Initialization

Name	Address	Register Setting	Note
Ugain	31H	6720H	Default value.
IgainL	32H	7A13H	Default value.
Lgain	23H	0000H	Default value.
Lphi	24H	0000H	Default value.

MCU initializes metering mode control register with settings shown in Table 2-17 Metering Mode Register:

Table 2-17. Metering Mode Register

Name	Address	Register Setting	Note
MMode	2BH	7C22H	[1] Shunt resistor for sampling current in L line, gain is '24'; [2] CT for sampling current in N line, gain is '1'; L line metering enabled; [3] Both HPF0 and HPF1 are enabled; [4] Forward (inductive) or reverse (capacitive) energy pulse output; [5] All zero-crossing; [6] Default threshold for anti-tampering mode.

[4] PL Constant register configuration:

$$PL_{Constant} = int\left(838860800 \text{ x } \frac{G_L \text{ x } V_L \text{ x } V_U}{MC \text{ x } U_n \text{ x } I_b}\right) = int\left(838860800 \text{ x } \frac{24 \text{ x } 0.75 \text{ x } 262}{3200 \text{ x } 220 \text{ x } 5}\right) = 1123882 = 11262AH$$

- MC= 3200 imp/kWh;
- U_n = 220V;
- I_b = 5A;
- G_L= 24;
- L line shunt resistor = 150 µΩ, so V_L = 150uΩ x 5A = 0.75mV;
- Voltage divider coefficient = 840, so V_U = 220V / 840kΩ = 262mV;

- Unit of the ADC sampling data of the voltage and current circuits is mV:

  '0011H' should be written to the PLconstH register [21H] and '262AH' should be written to the PLconstL register [22H].

[5] PC based terminal broadcasts the following command to all Meters-Under-Calibration through general communication port:

"Calibration (u=220.00,i=0.000,pha=0.00)"

This command indicates the power source is supplying following sources:

- U = 220.00V;
- I = 0;
- Power Factor = N/A;

After MCU receives the power offset calibration command, MCU writes 'A987H' to the SmallPMod register (04H) to enter small-power mode;

MCU calculates the power offset:

$$\mathrm{Lphi} = \frac{\mathrm{FFC4H+\ FFCAH + FFCAH+\ FFDCH+\ FFC5H+\ FFCBH+\ FFCAH+\ FFCCH}}{8} = \mathrm{FFCBH}$$

Read out L line active power 8 times consecutively. The values are FFC4H, FFCAH, FFCAH, FFDCH, FFC5H, FFCBH, FFCAH and FFCCH averaged as FFCBH. The complement value '35H' should be written to the PoffsetL register [37H]. And then write any '0000H' value to the SmallPMod register [04H] to exit small-power mode.

[6] PC based terminal broadcasts the following command to all Meters-Under-Calibration through general communication port:

"Calibration (u=220.00,i=5.000,pha=60.00)"

This command indicates the power source is supplying following sources:

- U = 220.00V;
- I = 5.000A;
- Power Factor = 0.5L;

MCU application records the above parameters and begins to calibrate the Metering and Measurement.

[7] MCU calculates Ugain:

$$\mathrm{Ugain} = \mathrm{int}\left(26400 \text{ x } \frac{\mathrm{U_n}}{\mathrm{U_{meas}} \text{ x k\_u}}\right) = \mathrm{int}\left(26400 \text{ x } \frac{220.00}{226.04 \text{ x } 1}\right) = 25695 = 645\mathrm{FH}$$

'645FH' should be written to the voltage RMS gain register Ugain [31H]. 226.04V is the read out voltage RMS value from register Urms [49H] (hex should be changed to decimal and divided by 100, unit is V). 220.00V is the actual voltage RMS value supplied by power source. The parameter 1 is k_u.

[8] MCU calculates $\mathrm{I_{gainL}}$:

$$\mathrm{I_{gainL}} = \mathrm{int}\left(31251 \text{ x } \frac{\mathrm{I_b}}{\mathrm{I_{meas}} \text{ x k\_i}}\right) = \mathrm{int}\left(31251 \text{ x } \frac{5.000}{3.719 \text{ x } 2}\right) = 21007 = 520\mathrm{FH}$$

'520FH' should be written to the current RMS gain register IgainL [32H]. 3.719A is the read out current RMS value from register Urms [48H] (hex should be changed to decimal and divided by 1000, unit is A). 5.000A is the actual current RMS value supplied by power source. The parameter 2 is k_i.

[9] After Ugain and Igain are correctly calibrated, the MCU needs to wait 1 second (about 3 register refresh periods).

[10] MCU calculates Lgain:

$$\mathrm{LRATIO} = \left(\frac{21007 \text{ x } 1 \text{ x } 25695 \text{ x } 2 \text{ x } 1123882 \text{ x } 3200}{838860800 \text{ x } 4.5 \text{ x } 10^9}\right) - 1 = 0.028515718$$

$$\mathrm{Lgain} = \mathrm{int}(0.028515718 \text{ x } 2^{15}) = 934 = 03\mathrm{A}6\mathrm{H}$$

'03A6H' should be written to the line calibration gain register Lgain [23H]. The parameter 1 is k_u and 2 is k_i.

[11] MCU calculates Lphi:

$$\text{Calculated Line Angle} = \arccos\left(\frac{276}{550}\right) = 59.88°$$

276 is the L line mean active power and 550 is the L line mean apparent power. And the line angle calibration could be calculated by the below formula:

$$\text{Lphi} = \text{round}\left(\frac{59.88° - 60°}{0.52734375'}\right) = 14 = 000\text{CH}$$

'000CH' should be written to the LPhi register [24H]

3. References and Suggested Literature

[1] Atmel-46002-SE-ATM90E26-Datasheet.pdf
[2] Atmel-46003-SE-ATM90E32AS-Datasheet.pdf
[3] Atmel-46004-SE-ATM90E36A-Datasheet.pdf
[4] Atmel-46102-SE-ATM90E26-ApplicationNote.pdf
[5] Atmel-46103-SE-ATM90E32AS-ApplicationNote.pdf
[6] Atmel-46104-SE-ATM90E36A-ApplicationNote.pdf

4. Revision History

Doc. Rev.	Date	Comments
A	03/17/2014	Initial release.

Enabling Unlimited Possibilities®

Atmel Corporation
1600 Technology Drive
San Jose, CA 95110
USA
Tel: (+1)(408) 441-0311
Fax: (+1)(408) 487-2600
www.atmel.com

Atmel Asia Limited
Unit 01-5 & 16, 19F
BEA Tower, Millennium City 5
418 Kwun Tong Road
Kwun Tong, Kowloon
HONG KONG
Tel: (+852) 2245-6100
Fax: (+852) 2722-1369

Atmel Munich GmbH
Business Campus
Parkring 4
D-85748 Garching b. Munich
GERMANY
Tel: (+49) 89-31970-0
Fax: (+49) 89-3194621

Atmel Japan G.K.
16F Shin-Osaki Kangyo Bldg.
1-6-4 Osaki, Shinagawa-ku
Tokyo 141-0032
JAPAN
Tel: (+81)(3) 6417-0300
Fax: (+81)(3) 6417-0370