Freescale Semiconductor, Inc.
Application Note

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Two-Point Power Meter Calibration Technique

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Contents

1. Introduction

Modern electronic power meters are designed to achieve energy measurement accuracy of ±0.5 % (or even better) in the current range from 0.15 to 120 A. To achieve such accuracy, calibrating of the power meter using a high-precision calibration equipment is used. Such calibration equipment comprises of an accurate reference meter and power source (see Figure 1).

The power source supplies power with an alternating voltage U and current I to the load through the power meter. The power meter measures the electrical quantities, calculates the active energy, and generates pulses on the calibration LED; each pulse equals to the active energy amount in kWh/imp[1] consumed by the load. The pulses generated by the power meter are compared with pulses generated by the reference meter using a pulse comparator. The errors of many pulses are averaged to determine the energy measurement accuracy.

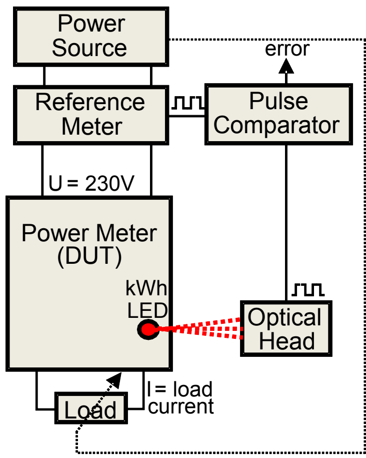


Figure 1. Production calibration and testing equipment setup

2. Error calculation

In some cases, it is necessary to calibrate the power meter using a production calibration equipment that comprises of an accurate reference meter and inaccurate (or even unregulated) power source. Such calibration systems are capable of measuring the energy errors with high accuracy, but you cannot rely on the accuracy of the phase voltage and phase current waveforms amplitudes generated by the power source. In such cases, calibrating of the power meter is based on energy errors computed by the pulse comparator.

The pulse comparator computes an energy error as a difference between the energy consumption measured by the calibrated power meter and the reference energy consumption measured by the reference power meter.

The energy error (in percent) is computed as follows:

$$\textit{Eq. 1} \qquad error = \frac{T_{mtr}-T_{ref}}{T_{ref}} * 100,$$

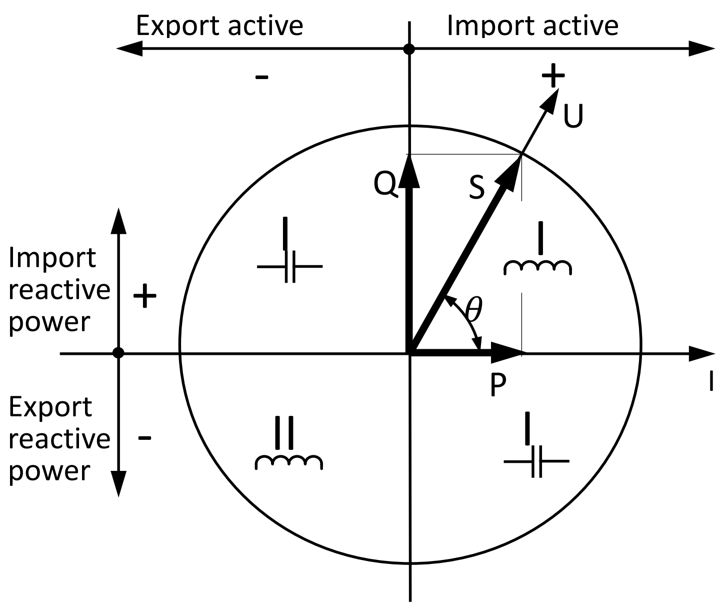
where T_{mtr} is the period of the calibrated power meter pulse output, and T_{ref} is the period of the reference power meter pulse output.

[1] The imp stands for the power meter impulse number, which is typically in the range from 1,000 to 100,000.

The purpose of the power meter is to register the active and reactive energy consumption precisely in four energy quadrants (see Figure 2).

The active and reactive energy consumption is accumulated in respective energy counters. The values of energy counters are either communicated or made accessible to utilities for billing purposes using LCD. The energy must be registered with an accuracy mandated by the standard, for example IEC 62053-21 for static meters for active energy (classes 1 and 2) and IEC 62053-23 for static meters for reactive energy (classes 2 and 3).

Figure 2. Power meter operation in energy quadrants



To calibrate the power meter with all accuracy requirements addressed, the power gain A_{PWR} and correction phase angle φ_c calibration coefficients must be chosen appropriately. The common calibration technique can be used only with calibration equipment that comprises of a power source capable to generate precise load points (see *Kinetis-M One-Phase Power Meter Reference Design* (document DRM143)). If precise generation of the load point is not guaranteed, use the calibration technique described in this document.

3. Calibration technique

The calibration technique is based on measuring and comparing of energy errors. The energy errors are computed as a difference in the pulse output rate of the calibrated and reference power meters. The goal of the power meter calibration is to choose suitable power gain A_{PWR} and correction phase angle φ_c coefficients, and to apply them after calibration.

The active power after calibration is computed as follows:

$$\textbf{Eq. 2} \qquad P = \frac{1}{A_{PWR}} * U * I * cos(\theta - \varphi_c),$$

where θ is the phase-angle between phase voltage and current phasor, U is the RMS voltage, and I is the RMS current.

Because you must compute two calibration coefficients, you must form at least two equations, each representing the active power of the power meter at the unique load point.

For example, the first equation can represent the measurement at the power factor $cos(\theta) = 1$ and the second equation can represent the measurement at the power factor $cos(\theta) = 0.5L$.

Choosing these power factors leads to equations for computing the power gain A_{PWR} and correction phase angle φ_c calibration coefficients that are easy to calculate using a microcontroller (MCU) or a digital signal processor (DSP).

The active powers prior to calibration, expressed for power factors $cos(\theta) = 1$ and $cos(\theta) = 0.5L$, are as follows:

$$\textbf{Eq. 3} \qquad P_{cos(\theta)=1} = A_{PWR} * U * I * cos(0 + \varphi_c)$$

$$\textbf{Eq. 4} \qquad P_{cos(\theta)=0.5L} = A_{PWR} * U * I * cos(60 + \varphi_c)$$

The power errors determined for each power factor are expressed as follows:

$$\textbf{Eq. 5} \qquad error_{cos(\theta)=1} = \left(\frac{P_{cos(\theta)=1}}{U*I} - 1\right) * 100 = \left(A_{PWR} * cos(\varphi_c) - 1\right) * 100$$

$$\textbf{Eq. 6} \qquad error_{cos(\theta)=0.5L} = \left(\frac{A_{PWR} * cos(60+\varphi_c)}{0.5} - 1\right) * 100$$

By solving equations Eq. 5 and Eq. 6 for power gain A_{PWR} and correction phase angle φ_c calibration coefficients, you can derive the solution for calibrating the power meter using two load points.

$$\textbf{Eq. 7} \qquad A_{PWR} = \frac{\frac{error_{cos(\theta)=1}}{100} + 1}{cos(\varphi_c)}$$

$$\textbf{Eq. 8} \qquad \varphi_c = atan\left(\frac{\frac{error_{cos(\theta)=1}}{100} - \frac{error_{cos(\theta)=0.5L}}{100}}{\sqrt{3} * \left(\frac{error_{cos(\theta)=1}}{100} + 1\right)}\right)$$

The calibration coefficients are easy to calculate, and by applying them during normal power meter operation (after the power meter is calibrated) both the active and reactive powers/energies will be measured accurately by the power meter. You can use such power meter calibration for billing purposes. The way to apply these coefficients in power meter firmware is described by equation Eq. 2.

4. Verification

The accuracy and applicability of equations Eq. 7 and Eq. 8 in power meter production was verified using Kinetis-M one-phase power meter reference design (see *Kinetis-M One-Phase Power Meter Reference Design* (document DRM143)). This reference design was programmed using Freescale filter-based metering algorithms (see *Filter-Based Algorithm for Metering Applications* (document AN4265)). To enable current measurement up to 100 A, the reference design integrates a 150 μΩ shunt resistor as the current-sensing element. The power meter with all these attributes was installed on the metering test bench and calibrated (see Figure 3).

NOTE

The Kinetis-M one-phase power meter reference design is driven by the MKM34Z128CLL5 MCU (see *Kinetis KM34 Sub-Family Reference Manual* (document MKMXXZXXACXX5RM)).

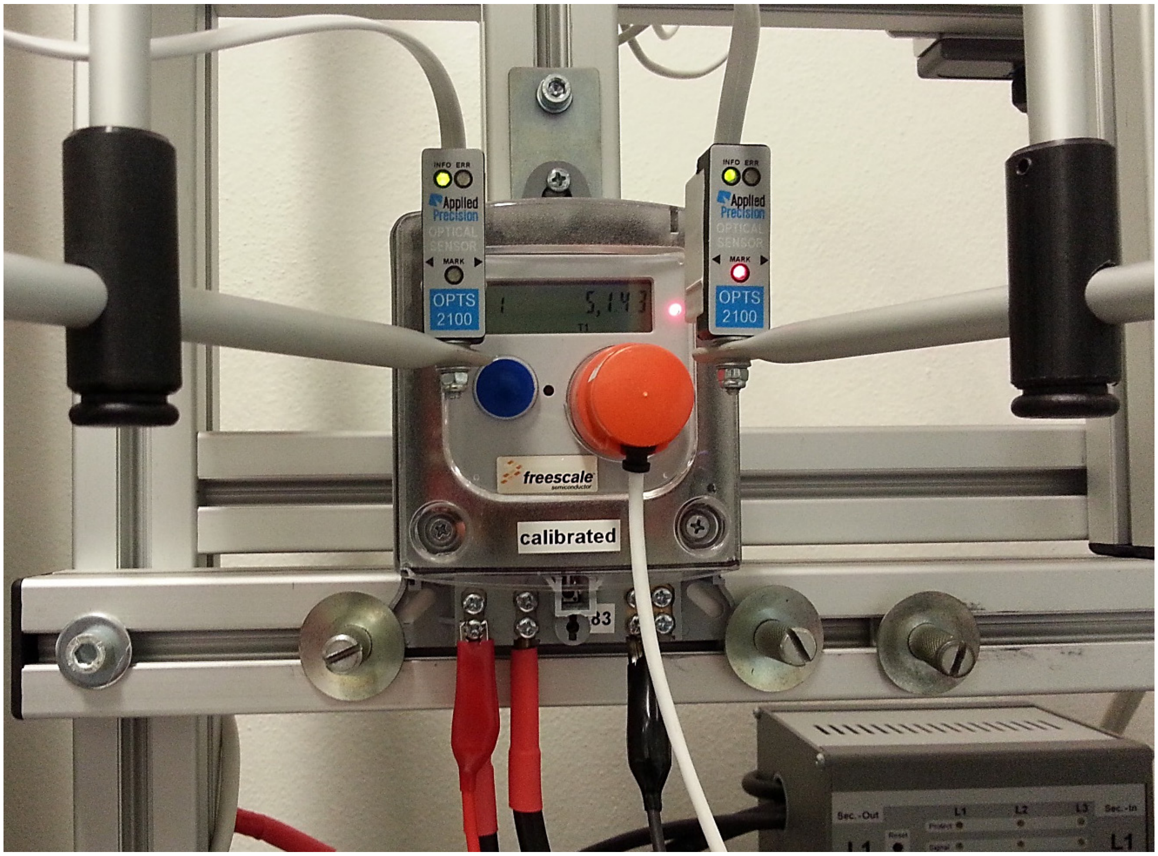


Figure 3. One-phase Kinetis-M-based power meter

These steps were performed to successfully complete the power meter calibration:

1. The accuracy of the active energy measurement was measured at the first load point: U=230 V, I=5 A, and PF=1. The active energy error detected by the test bench corresponded to $\mathrm{error}_{cos(\theta)=1} = 5.64\%$.
2. The power source was configured to generate the second load point: U=230 V, I=5 A, and PF=0.5L. For this particular load point, the active energy error detected by the test bench corresponded to $\mathrm{error}_{cos(\theta)=0.5l} = 6.44\%$.
3. The power gain $A_{PWR} = 0.9464$ and correction phase angle $\varphi_c = 0.2554^0$ coefficients were calculated using the errors obtained by measurements performed using an uncalibrated power meter in previous steps.
4. The calculated calibration coefficients were written into the power meter firmware application, and the performance of the calibrated power meter was evaluated on the test bench. The accuracy of the active and reactive energy measurement was verified in current dynamic range of 1600:1 and thoroughly documented in the calibration protocol (see Table 1).

Table 1. Calibration protocol

Meter Test Report No. : 14.7.2014 **Date:** 14.7.2014
Meter Type : Photon **Voltage :** 230 V **Class:**
Frequency : 50 Hz **Manufact.** Freescale
Tested by : mienkina **Current :** 5(80) A **Mtr. Const:** 50000

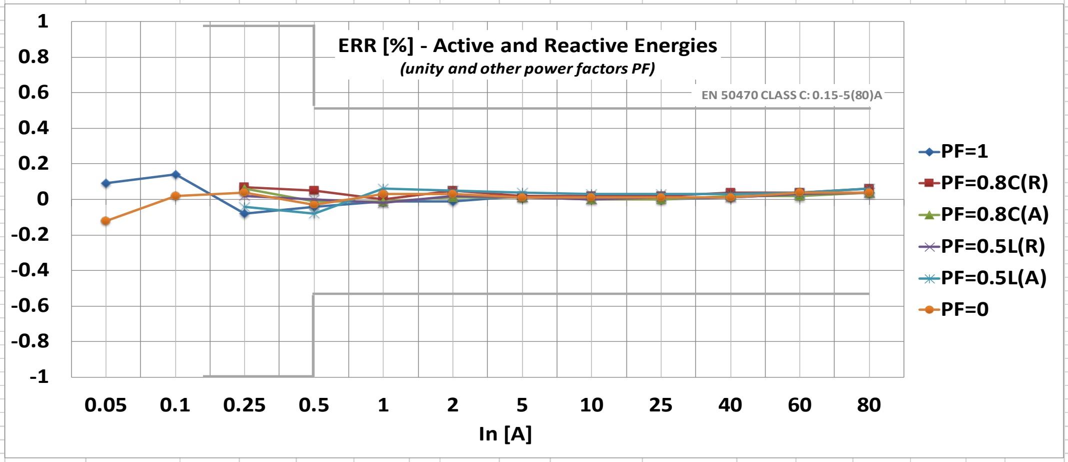
Measurement	Iref(%)	Iref(A)	U(V)	PF	Freq	ERR (%)	STDEV [%]
Serial Number							0
200%In, 100%Un, preheating	200						0
100%In, 100%Un, 0.707L (45°), active, calib. point	100	5	230	PF=0.707L(A)	50		0
100%In, 100%Un, 0.707L (45°), reactive, calib. point	100	5	230	PF=0.707L(R)	50		0
Starting Current Test			230		50		0
0.3%In, 100%Un, 1L (0°), active	0.3	0.015	230	PF=1	50	**0.46**	0.25
0.3%In, 100%Un, 0L (90°), reactive	0.3	0.015	230	PF=0	50	**0**	0.35
1%In, 100%Un, 1L (0°), active	1	0.05	230	PF=1	50	**0.09**	0.16
1%In, 100%Un, 0L (90°), reactive	1	0.05	230	PF=0	50	**-0.12**	0.12
2%In, 100%Un, 1L (0°), active	2	0.1	230	PF=1	50	0.14	0.064
2%In, 100%Un, 0L (90°), reactive	2	0.1	230	PF=0	50	0.02	0.093
5%In, 100%Un, 1L (0°), active	5	0.25	230	PF=1	50	-0.08	0.029
5%In, 100%Un, 0L (90°), reactive	5	0.25	230	PF=0	50	0.04	0.035
5%In, 100%Un, 0.5L (60°), active	5	0.25	230	PF=0.5L(A)	50	-0.04	0.032
5%In, 100%Un, 0.5L (60°), reactive	5	0.25	230	PF=0.5L(R)	50	0.02	0.063
5%In, 100%Un, 0.8C (323°), active	5	0.25	230	PF=0.8C(A)	50	0.06	0.044
5%In, 100%Un, 0.8C (323°), reactive	5	0.25	230	PF=0.8C(R)	50	0.07	0.046
7.5%In, 100%Un, 1L (0°C), active	7.5	0.375	230	PF=1	50	0.01	0.027
7.5%In, 100%Un, 0L (90°C), reactive	7.5	0.375	230	PF=0	50	0.04	0.033
10%In, 100%Un, 1L (0°), active	10	0.5	230	PF=1	50	-0.04	0.042
10%In, 100%Un, 0L (90°), reactive	10	0.5	230	PF=0	50	-0.03	0.017
10%In, 100%Un, 0.5L (60°), active	10	0.5	230	PF=0.5L(A)	50	-0.08	0.059
10%In, 100%Un, 0.5L (60°), reactive	10	0.5	230	PF=0.5L(R)	50	0	0.037
10%In, 100%Un, 0.8C (323°), active	10	0.5	230	PF=0.8C(A)	50	-0.01	0.062
10%In, 100%Un, 0.8C (323°), reactive	10	0.5	230	PF=0.8C(R)	50	0.05	0.019
20%In, 100%Un, 1L (0°), active	20	1	230	PF=1	50	-0.01	0.011
20%In, 100%Un, 0L (90°), reactive	20	1	230	PF=0	50	0.03	0.0068
20%In, 100%Un, 0.5L (60°), active	20	1	230	PF=0.5L(A)	50	0.06	0.021
20%In, 100%Un, 0.5L (60°), reactive	20	1	230	PF=0.5L(R)	50	-0.02	0.019
20%In, 100%Un, 0.8C (323°), active	20	1	230	PF=0.8C(A)	50	-0.01	0.02
20%In, 100%Un, 0.8C (323°), reactive	20	1	230	PF=0.8C(R)	50	0	0.017
40%In, 100%Un, 1L (0°), active	40	2	230	PF=1	50	-0.01	0.0095
40%In, 100%Un, 0L (90°), reactive	40	2	230	PF=0	50	0.03	0.01
40%In, 100%Un, 0.5L (60°), active	40	2	230	PF=0.5L(A)	50	0.05	0.019
40%In, 100%Un, 0.5L (60°), reactive	40	2	230	PF=0.5L(R)	50	0.02	0.0084
40%In, 100%Un, 0.8C (323°), active	40	2	230	PF=0.8C(A)	50	0.01	0.0092
40%In, 100%Un, 0.8C (323°), reactive	40	2	230	PF=0.8C(R)	50	0.05	0.017
100%In, 100%Un, 1L (0°), active	100	5	230	PF=1	50	0.02	0.0037
100%In, 100%Un, 0L (90°), reactive	100	5	230	PF=0	50	0.01	0.0086
100%In, 100%Un, 0.5L (60°), active	100	5	230	PF=0.5L(A)	50	0.04	0.012
100%In, 100%Un, 0.5L (60°), reactive	100	5	230	PF=0.5L(R)	50	0.01	0.01
100%In, 100%Un, 0.8C (323°), active	100	5	230	PF=0.8C(A)	50	0.01	0.0024
100%In, 100%Un, 0.8C (323°), reactive	100	5	230	PF=0.8C(R)	50	0.02	0.008
200%In, 100%Un, 1L (0°), active	200	10	230	PF=1	50	0.01	0.0032
200%In, 100%Un, 0L (90°), reactive	200	10	230	PF=0	50	0.01	0
200%In, 100%Un, 0.5L (60°), active	200	10	230	PF=0.5L(A)	50	0.03	0.0037
200%In, 100%Un, 0.5L (60°), reactive	200	10	230	PF=0.5L(R)	50	0	0.0068
200%In, 100%Un, 0.8C (323°), active	200	10	230	PF=0.8C(A)	50	0	0.002
200%In, 100%Un, 0.8C (323°), reactive	200	10	230	PF=0.8C(R)	50	0.02	0.01
500%In, 100%Un, 1L (0°), active	500	25	230	PF=1	50	0	0.002
500%In, 100%Un, 0L (90°), reactive	500	25	230	PF=0	50	0.01	0.002
500%In, 100%Un, 0.5L (60°), active	500	25	230	PF=0.5L(A)	50	0.03	0.0063
500%In, 100%Un, 0.5L (60°), reactive	500	25	230	PF=0.5L(R)	50	0.01	0.0077
500%In, 100%Un, 0.8C (323°), active	500	25	230	PF=0.8C(A)	50	0	0.0045
500%In, 100%Un, 0.8C (323°), reactive	500	25	230	PF=0.8C(R)	50	0.02	0.0092
800%In, 100%Un, 1L (0°), active	800	40	230	PF=1	50	0.01	0.002
800%In, 100%Un, 0L (90°), reactive	800	40	230	PF=0	50	0.01	0.002
800%In, 100%Un, 0.5L (60°), active	800	40	230	PF=0.5L(A)	50	0.03	0.0068
800%In, 100%Un, 0.5L (60°), reactive	800	40	230	PF=0.5L(R)	50	0.01	0.012
800%In, 100%Un, 0.8C (323°), active	800	40	230	PF=0.8C(A)	50	0.02	0.0058
800%In, 100%Un, 0.8C (323°), reactive	800	40	230	PF=0.8C(R)	50	0.04	0.0068
1200%In, 100%Un, 1L (0°), active	1200	60	230	PF=1	50	0.03	0.002
1200%In, 100%Un, 0L (90°), reactive	1200	60	230	PF=0	50	0.04	0.0087
1200%In, 100%Un, 0.5L (60°), active	1200	60	230	PF=0.5L(A)	50	0.04	0.0058
1200%In, 100%Un, 0.5L (60°), reactive	1200	60	230	PF=0.5L(R)	50	0.03	0.0055
1200%In, 100%Un, 0.8C (323°), active	1200	60	230	PF=0.8C(A)	50	0.02	0.0058
1200%In, 100%Un, 0.8C (323°), reactive	1200	60	230	PF=0.8C(R)	50	0.04	0.0098
1600%In, 100%Un, 1L (0°), active	1600	80	230	PF=1	50	0.04	0.002
1600%In, 100%Un, 0L (90°), reactive	1600	80	230	PF=0	50	0.04	0.006
1600%In, 100%Un, 0.5L (60°), active	1600	80	230	PF=0.5L(A)	50	0.06	0.0058
1600%In, 100%Un, 0.5L (60°), reactive	1600	80	230	PF=0.5L(R)	50	0.04	0.0068
1600%In, 100%Un, 0.8C (323°), active	1600	80	230	PF=0.8C(A)	50	0.04	0.0025
1600%In, 100%Un, 0.8C (323°), reactive	1600	80	230	PF=0.8C(R)	50	0.06	0.0081
100%In, 100%Un, 1L (0°), 49.0Hz	100	5	230	PF=1	49	0.06	0.004
100%In, 100%Un, 0L (90°), 49.0Hz	100	5	230	PF=0	49	-0.39	0.0077
100%In, 100%Un, 1L (0°), 51.0Hz	100	5	230	PF=1	51	0.05	0.0037
100%In, 100%Un, 0L (90°), 51.0Hz	100	5	230	PF=0	51	0.44	0.0088
50%Imax, 100%Un, 1L (0°), 5-th harm. to U&I, active	50	2.5	230	PF=1	1+5	0.01	0.0081
No Load						+	0

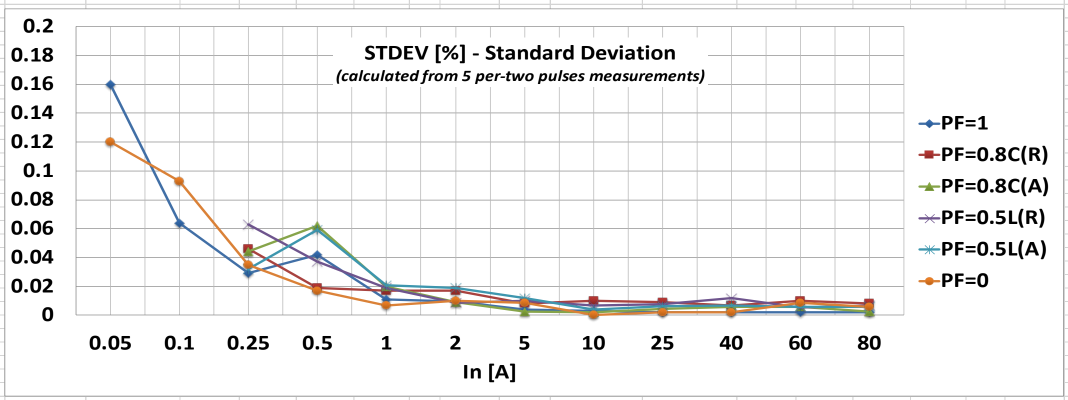
Measurement	(Multiple Items)
Freq	50

Sum of ERR (%) Row Labels	PF=1	PF=0.8C(R)	PF=0.8C(A)	PF=0.5L(R)	PF=0.5L(A)	PF=0	Grand Total
0.05	0.09					-0.12	-0.03
0.1	0.14					0.02	0.16
0.25	-0.08	0.07	0.06	0.02	-0.04	0.04	0.07
0.5	-0.04	0.05	-0.01	0	-0.08	-0.03	-0.11
1	-0.01	0	-0.01	-0.02	0.06	0.03	0.05
2	-0.01	0.05	0.01	0.02	0.05	0.03	0.15
5	0.02	0.02	0.01	0.01	0.04	0.01	0.11
10	0.01	0.02	0	0	0.03	0.01	0.07
25	0	0.02	0	0.01	0.03	0.01	0.07
40	0.01	0.04	0.02	0.01	0.03	0.01	0.12
60	0.03	0.04	0.02	0.03	0.04	0.04	0.2
80	0.04	0.06	0.04	0.04	0.06	0.04	0.28
Grand Total	**0.2**	**0.37**	**0.14**	**0.12**	**0.22**	**0.09**	**1.14**

Measurement	(Multiple Items)
Freq	50

Sum of STDEV [%] Row Labels	PF=1	PF=0.8C(R)	PF=0.8C(A)	PF=0.5L(R)	PF=0.5L(A)	PF=0	Grand Total
0.05	0.16					0.12	0.28
0.1	0.064					0.093	0.157
0.25	0.029	0.046	0.044	0.063	0.032	0.035	0.249
0.5	0.042	0.019	0.062	0.037	0.059	0.017	0.236
1	0.011	0.017	0.02	0.019	0.021	0.0068	0.0948
2	0.0095	0.017	0.0092	0.0084	0.019	0.01	0.0731
5	0.0037	0.008	0.0024	0.01	0.012	0.0086	0.0447
10	0.0032	0.01	0.002	0.0068	0.0037	0	0.0257
25	0.002	0.0092	0.0045	0.0077	0.0063	0.002	0.0317
40	0.002	0.0068	0.0058	0.012	0.0068	0.002	0.0354
60	0.002	0.0098	0.0058	0.0055	0.0058	0.0087	0.0376
80	0.002	0.0081	0.0025	0.0068	0.0058	0.006	0.0312
Grand Total	**0.3304**	**0.1509**	**0.1582**	**0.1762**	**0.1714**	**0.3091**	**1.2962**





NOTE

The accuracy of the power meter reference design after the two-point calibration for active and reactive energies and all power factors was in range of -0.12/+0.14 % in current dynamic range of 1600:1.

Besides using the one-phase power meter with filter-based metering algorithms, the technique was also verified using Kinetis-M two-phase power meter with FFT-based metering algorithms (see *FFT-Based Algorithm for Metering Application*s (document AN4255)). The two-phase power meter was calibrated eight times using the two-point calibration technique. The accuracy of the power meter was measured at the calibration points after each calibration. All measured accuracies were in range of ±0.02 %.

5. Summary

This application note describes the power meter calibration approach suitable for using with test equipment with unregulated power source. The described two-point calibration technique is based on measuring energy errors of the power meter at two load points: $cos(\theta) = 1$ and $cos(\theta) = 0.5L$.

The equations for calculating the calibration coefficients from measured energy errors were determined, and their accuracy was verified by experiments. The Freescale Kinetis-M one-phase power meter reference design was installed on the metering test bench, calibrated using the two-point calibration technique, and the accuracy of the reference design was verified after the calibration. The accuracy for imported active and reactive energies and all power factors was -0.12/+0.14 % in the current range of 1600:1.

The repeatability of the two-point calibration technique was also verified. The resulting accuracy of the Kinetis-M two-phase power meter measured at the calibration points was within the range of ±0.02 % for eight consecutive calibrations.

The described two-point calibration technique is suitable for use on production lines. It provides an excellent accuracy and repeatability. This calibration technique can be used for both the filter-based and FFT-based metering algorithms provided by Freescale. Although the calibration speed is two times slower when compared to the one-point calibration technique, you can use the two-point calibration in cases whenever amplitudes of the current and voltage waveforms generated by the test equipment are unpredictable.

6. References

The following documents are available on www.freescale.com. You can find additional documents not listed here on the Kinetis M Series product page.

1. *Kinetis-M One-Phase Power Meter Reference Design* (document DRM143)
2. *Kinetis KM34 Sub-Family Reference Manual* (document MKMXXZXXACXX5RM)
3. *Filter-Based Algorithm for Metering Applications* (document AN4265)
4. *Kinetis-M Bare-metal Software Drivers* (document KMSWDRVAPIRM)
5. *FFT-Based Algorithm for Metering Applications* (document AN4255)

7. Revision history

The following table summarizes the changes done to this document since the initial release.

Table 2. Revision history

Revision number	Date	Substantive changes
0	09/2015	Initial release

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