Kinetis-M One-Phase Power Meter Reference Design

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1   Introduction

The electro-mechanical power meter has been gradually replaced by the electronic meter. Modern electronic meters have a number of advantages over their electro-mechanical predecessors. Their mechanical construction is more cost-effective due to the fact that there are no moving parts. In addition, electronic meters have a one percent accuracy, or even better, in the dynamic range of power measurement of 1000:1, whereas electro-mechanical meters have a two percent accuracy in the dynamic range of 80:1. The higher the accuracy and dynamic range of the measurement, the more precise the energy bills.

This design reference manual describes a solution for a one-phase electronic power meter based on the MKM34Z128CLL5 microcontroller. This microcontroller is part of the Freescale Kinetis-M microcontroller family. The Kinetis-M microcontrollers address accuracy needs by providing a high-performance analog front-end (24-bit AFE) combined with an embedded Programmable Gain Amplifier (PGA). Besides high-performance analog peripherals, these new devices integrate memories, input-output ports, digital blocks, and a variety of communication options. Moreover, the ARM Cortex-M0+ core, with support for 32-bit math, enables fast execution of metering algorithms.

Contents

The one-phase power meter reference design is intended for the measurement and registration of active and reactive energies in one-phase two-wire networks. It is pre-certified according to the European EN50470-1, EN50470-3, classes B and C, and also to the IEC 62053-21 and IEC 62052-11 international standards for electronic meters of active energy classes 2 and 1. The Electromagnetic Compatibility (EMC) has been tested according to the EN 61326-1:2007 for use in industrial environments.

The integrated Switched-mode Power Supply (SMPS) enables an efficient operation of the power meter electronics and provides enough power for optional modules, such as non-volatile memories (NVM) for data logging and firmware storage, a low-power 3-axis Xtrinsic tilt sensor for electronic tamper detection, and an RF communication module for AMR and remote monitoring. The power meter electronics are backed-up by a 3.6 V Li-SOCI$_2$ battery when disconnected from the mains. This battery activates the power meter whenever the user button is pressed or a tamper event occurs. The permanent triggers for tamper events include two tamper switches protecting the main and terminal covers. An additional optional tamper event is generated by a low-power 3-axis Xtrinsic tilt sensor. With the tilt sensor populated, the meter electronics are powered when the coordinates of the installed meter unexpectedly change. The tilt sensor in the meter not only prevents physical tampering, but can also activate the power meter electronics to disconnect a house from the mains in the case of an earthquake.

The power meter reference design is prepared for use in real applications, as suggested by its implementation of a Human Machine Interface (HMI) and communication interfaces for remote data collecting.

1.1 Specification

As already indicated, the Kinetis-M one-phase power meter reference design is ready for use in a real application. More precisely, its metrology portion has undergone thorough laboratory testing using the test equipment ELMA8303 [1]. Thanks to intensive testing, an accurate 24-bit AFE, and continual algorithm improvements, the one-phase power meter calculates active and reactive energies more accurately and over a higher dynamic range than required by common standards. All information, including accuracies, operating conditions, and optional features, are summarized in the following table:

Table 1-1. Kinetis-M one-phase power meter specification

Type of meter	One-phase residential
Type of measurement	4-Quadrant
Metering algorithm	Filter-based
Precision (accuracy)	IEC50470-3 class C, 0.5% (for active and reactive energy)
Voltage range	90…265 V$_{RMS}$
Current Range	0…120 A (5 A is nominal current, peak current is up to 152 A)
Frequency range	47…53 Hz
Meter constant (imp/kWh, imp/kVArh)	500, 1000, 2000, 5000, 10000, 20000, 50000 (default), 100000, 200000, 500000, 1000000, 2000000, 4000000 and 6000000. Note, that pulse numbers above 50000 are applicable only for low-current measurement.
Functionality	V, A, kW, kVAr, kVA, kWh (import/export), kVARh (lead/lag), Hz, time, date
Voltage sensor	Voltage divider
Current sensor	Shunt resistor down to 120 µΩ
Energy output pulse interface	Two red LEDs (active and reactive energy)

Energy output pulse parameters: • Maximum frequency • On-Time • Jitter	600 Hz 20 ms (50% duty cycle for frequencies above 25 Hz) ±10 µs at constant power
User interface	LCD, one push-button, one user LED (red)
Tamper detection	Two hidden buttons (terminal cover and main cover)
IEC1107 infrared interface	4800/8-N-1 FreeMASTER interface
Optoisolated pulse output (optional)	optocoupler (active or reactive energy)
Isolated RS232 serial interface (optional)	19200/8-N-1
RF interface (optional)	2.4 GHz RF 1322x-LPN internal daughter card
External NVMs (optional) • Flash • EEPROM	W25X10CLSN, 128 KB CAT25040VE, 4 KB
Electronic tamper detection (optional)	MMA8491Q, 3-axis digital accelerometer
Internal battery	1/2AA, 3.6 V Lithium-Thionyl Chloride (Li-SOCl2) 1.2 Ah
Power consumption @ 3.3V and 22 °C: • Normal mode (powered from mains) • Standby mode (powered from battery) • Power-down mode (powered from battery)	10.88 mA 245 µA 5.6 µA (both cover closed), 4.4 µA (covers opened)

2 MKM34Z128 microcontroller series

Freescale's Kinetis-M microcontroller series is based on the 90-nm process technology. It has on-chip peripherals, and the computational performance and power capabilities to enable development of a low-cost and highly integrated power meter (see **Figure 2-1**). It is based on the 32-bit ARM Cortex-M0+ core with CPU clock rates of up to 50 MHz. The measurement analog front-end is integrated on all devices; it includes a highly accurate 24-bit Sigma Delta ADC, PGA, high-precision internal 1.2 V voltage reference (VRef), phase shift compensation block, 16-bit SAR ADC, and a peripheral crossbar (XBAR). The XBAR module acts as a programmable switch matrix, allowing multiple simultaneous connections of internal and external signals. An accurate Independent Real-time Clock (IRTC), with passive and active tamper detection capabilities, is also available on all devices.
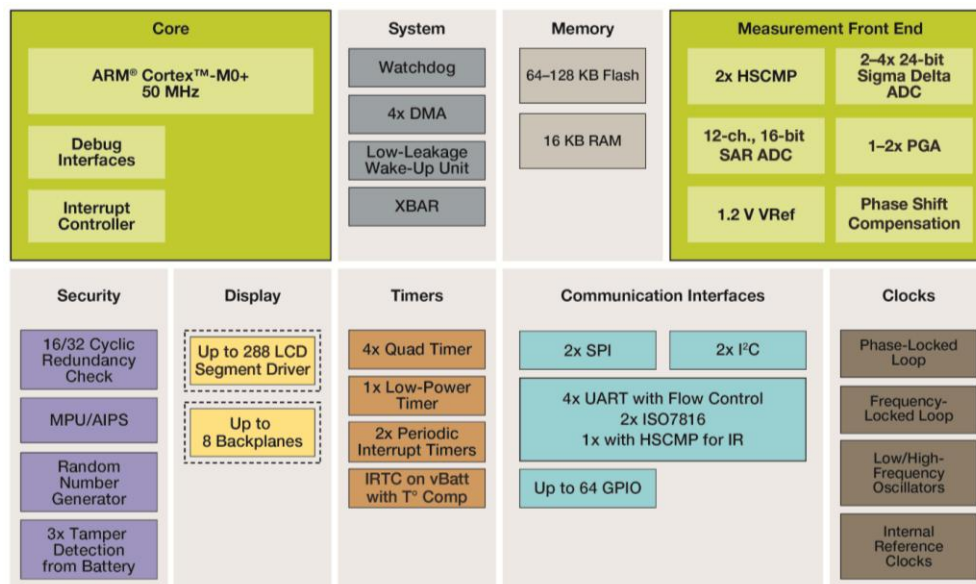

Figure 2-1. Kinetis-M block diagram

In addition to high-performance analog and digital blocks, the Kinetis-M microcontroller series has been designed with an emphasis on achieving the required software separation. It integrates hardware blocks supporting the distinct separation of the legally relevant software from other software functions. The hardware blocks controlling and/or checking the access attributes include:

- ARM Cortex-M0+ Core
- DMA Controller Module
- Miscellaneous Control Module
- Memory Protection Unit
- Peripheral Bridge
- General Purpose Input-Output Module

The Kinetis-M devices remain first and foremost highly capable and fully programmable microcontrollers with application software driving the differentiation of the product. Nowadays, the necessary peripheral software drivers, metering algorithms, communication protocols, and a vast number of complementary software routines are available directly from semiconductor vendors or third parties. Because Kinetis-M microcontrollers integrate a high-performance analog front-end, communication peripherals, hardware blocks for software separation, and are capable of executing a variety of ARM Cortex-M0+ compatible software, they are ideal components for development of residential, commercial and light industrial electronic power meter applications.

3 Basic theory

The critical task for a digital processing engine or a microcontroller in an electricity metering application is the accurate computation of the active energy, reactive energy, active power, reactive power, apparent power, RMS voltage, and RMS current. The active and reactive energies are sometimes referred to as the billing quantities. The remaining quantities are calculated for informative purposes, and they are referred as non-billing. Further follows a description of billing and non-billing metering quantities and calculation formulas.

3.1 Active energy

The active energy represents the electrical energy produced, flowing or supplied by an electric circuit during a time interval. The active energy is measured in the unit of watt hours (Wh). The active energy in a typical one-phase power meter application is computed as an infinite integral of the unbiased instantaneous phase voltage u(t) and phase current i(t) waveforms.

$$\boldsymbol{Wh} = \int_{\boldsymbol{0}}^{\infty} \boldsymbol{u(t)}\,\boldsymbol{i(t)}\boldsymbol{dt} \qquad\qquad\qquad\textbf{Eq. 3-1}$$

3.2 Reactive energy

The reactive energy is given by the integral, with respect to time, of the product of voltage and current and the sine of the phase angle between them. The reactive energy is measured in the unit of volt-ampere-reactive hours (VARh). The reactive energy in a typical one-phase power meter is computed as an infinite integral of the unbiased instantaneous shifted phase voltage u(t-90°) and phase current i(t) waveforms.

$$VARh = \int_0^\infty u(t - 90°)\, i(t)\, dt \qquad\qquad \textbf{Eq. 3-2}$$

3.3 Active power

The active power (P) is measured in watts (W) and is expressed as the product of the voltage and the in-phase component of the alternating current. In fact, the average power of any whole number of cycles is the same as the average power value of just one cycle. So, we can easily find the average power of a very long-duration periodic waveform simply by calculating the average value of one complete cycle with period T.

$$P = \frac{1}{T} \int_0^\infty u(t)\, i(t)\, dt \qquad\qquad \textbf{Eq. 3-3}$$

3.4 Reactive power

The reactive power (Q) is measured in units of volt-amperes-reactive (VAR) and is the product of the voltage and current and the sine of the phase angle between them. The reactive power is calculated in the same manner as active power, but in reactive power the voltage input waveform is 90 degrees shifted with respect to the current input waveform.

$$Q = \frac{1}{T} \int_0^\infty u(t - 90°)\, i(t)\, dt \qquad\qquad \textbf{Eq. 3-4}$$

3.5 RMS current and voltage

The Root Mean Square (RMS) is a fundamental measurement of the magnitude of an alternating signal. In mathematics, the RMS is known as the standard deviation, which is a statistical measure of the magnitude of a varying quantity. The standard deviation measures only the alternating portion of the signal as opposed to the RMS value, which measures both the direct and alternating components.

In electrical engineering, the RMS or effective value of a current is, by definition, such that the heating effect is the same for equal values of alternating or direct current. The basic equations for straightforward computation of the RMS current and RMS voltage from the signal function are the following:

$$IRMS = \sqrt{\frac{1}{T} \int_0^T [i(t)]^2\, dt} \qquad\qquad \textbf{Eq. 3-5}$$

$$URMS = \sqrt{\frac{1}{T} \int_0^T [u(t)]^2\, dt} \qquad\qquad \textbf{Eq. 3-6}$$

3.6 Apparent Power

Total power in an AC circuit, both absorbed and dissipated, is referred to as total apparent power (S). The apparent power is measured in the units of volt-amperes (VA). For any general waveforms with higher harmonics, the apparent power is given by the product of the RMS phase current and RMS phase voltage.

$$S = IRMS * URMS$$ **Eq. 3-7**

For sinusoidal waveforms with no higher harmonics, the apparent power can also be calculated using the power triangle method, as a vector sum of the active power (P) and reactive power (Q) components.

$$S = \sqrt{P^2 + Q^2}$$ **Eq. 3-8**

Due to better accuracy, we preferably use **Eq. 3-7** to calculate the apparent power of any general waveforms with higher harmonics. In purely sinusoidal systems with no higher harmonics, both **Eq. 3-7** and **Eq. 3-8** will provide the same results.

3.7 Power factor

The power factor of an AC electrical power system is defined as the ratio of the active power (P) flowing to the load, to the apparent power (S) in the circuit. It is a dimensionless number between -1 and 1.

$$\cos(\varphi) = \frac{P}{S}$$ **Eq. 3-9**

where angle φ is the phase angle between the current and voltage waveforms in the sinusoidal system.

Circuits containing purely resistive heating elements (filament lamps, cooking stoves, and so forth) have a power factor of one. Circuits containing inductive or capacitive elements (electric motors, solenoid valves, lamp ballasts, and others) often have a power factor below one.

The Kinetis-M one-phase power meter reference design uses a filter-based metering algorithm [2]. This particular algorithm calculates the billing and non-billing quantities according to formulas given in this section. Thanks to using digital filters, the algorithm requires only instantaneous voltage and current samples to be provided at constant sampling intervals. After slight modification of the application software, it is also possible to use FFT based algorithms [3], [8].

4 Hardware design

This section describes the power meter electronics. The power meter electronics are divided into three parts:

- Power supply
- Digital circuits
- Analog signal conditioning circuits

The power supply part comprises an 85-265 V AC-DC SMPS, low-noise 3.6 V linear regulator, and power management. This power supply topology has been chosen to provide low-noise output voltages for supplying the power meter electronics. A simple power management block is present and works autonomously; it supplies the power meter electronics from either the 50 Hz (60 Hz) mains or the 3.6 V Li-SOCl$_2$ battery, which is also integrated. The battery serves as a backup supply in cases when the power meter is disconnected from the mains, or the mains voltage drops below 85 V AC. For more information, refer to **Subsection 4.1-Power supply**.

The digital part can be configured to support both basic and advanced features. The basic configuration comprises only the circuits necessary for power meter operation; i.e. microcontroller (MKM34Z128MCLL5), debug interface, LCD interface, LED interface, IR (IEC1107), isolated open-collector pulse output, isolated RS232, push-button, and tamper detection. In contrast to the basic configuration, all the advanced features are optional and require the following additional components to be populated: 128 KB SPI flash for firmware upgrade, 4 KB SPI EEPROM for data storage, 3-axis multifunction digital accelerometer for electronic tampering, and UMI and RF MC1323x-IPB interfaces for AMR communication and remote monitoring. For more information, refer to **Subsection 4.2-Digital circuits**.

The Kinetis-M devices allow differential analog signal measurements with a common mode reference of up to 0.8 V and an input signal range of ±250 mV. The capability of the device to measure analog signals with negative polarity brings a significant simplification to the phase current and phase voltage sensors' hardware interfaces (see **Subsection 4.3-Analog circuits)**.

The power meter electronics have been realized using a four-layer printed circuit board (PCB). We have chosen the more expensive four-layer PCB, comparing to a cheaper two-layer one, in order to validate the accuracy of the 24-bit SD ADC on the metering hardware optimized for measurement accuracy. **Figure B-1** and **Figure B-2** show respectively the top and bottom views of the power meter PCB.

4.1 Power supply

The user can use the 85-265 V AC-DC SMPS, which is directly populated on the PCB, or any other modules with different power supply topologies. If a different AC-DC power supply module is to be used, then the AC (input) side of the module must be connected to JP2, JP4, and the DC (output) side to JP1, JP5. The output voltage of the suitable AC-DC power supply module must be 4.0 V ±5%.

As already noted, the reference design is pre-populated with an 85-265 V AC-DC SMPS power supply. This SMPS is non-isolated and capable of delivering a continuous current of up to 80 mA at 4.125 V [**4**]. The SMPS supplies the SPX3819 low dropout adjustable linear regulator, which regulates the output voltage (VPWR) by using two resistors (R23 and R24) according to the formula:

$$VPWR = 1.235\left[1 + \frac{R23}{R24}\right]$$

<div align="right">**Eq. 4-1**</div>

The resistor values R23=45.3 kΩ and R24=23.7 kΩ were chosen to produce a regulated output voltage of 3.6 V. The following supply voltages are all derived from the regulated output voltage (VPWR):

- VDD – digital voltage for the microcontroller and digital circuits,
- VDDA – analog voltage for the microcontroller's 24-bit SD ADC and 1.2 V VREF,
- SAR_VDDA – analog voltage for the microcontroller's 16-bit SAR ADC.

In addition, the regulated output voltage also supplies those circuits with higher current consumption: 128 KB SPI flash (U2), Isolated RS232 interface (U3 and U4), Isolated pulse output (U6), and potential external modules attached to the UMI and RF MC1323x-IPB connectors (J200 and J201). All these circuits operate in normal mode when the power meter is connected to the mains.

The battery voltage (VBAT) is separated from the regulated output voltage (VPWR) using the D5 and D6 diodes. When the power meter is connected to the mains, then the electronics are supplied through the bottom D6 diode from the regulated output voltage (VPWR). If the power meter is disconnected from the mains, then the D5 and upper D6 diodes start conducting and the microcontroller device, including a few additional circuits operating in standby and power-down modes, are supplied from the battery (VBAT). The switching between the mains and battery voltage sources is performed autonomously, with a transition time that depends on the rise and fall times of the regulated output supply (VPWR).

The analog circuits within the microcontroller usually require decoupled power supplies for the best performance. The analog voltages (VDDA and SAR_VDDA) are decoupled from the digital voltage (VDD) by the chip inductors L1 and L2, and the small capacitors next to the power pins (C9, C10, C11, C18, C19, and C20). Using chip inductors is especially important in mixed signal designs such as a power meter application, where digital noise can disrupt precise analog measurements. The L1 and L2 inductors are placed between the analog supplies (VDDA and SAR_VDDA) and digital supply (VDD) to prevent noise from the digital circuitry from disrupting the analog circuitries.
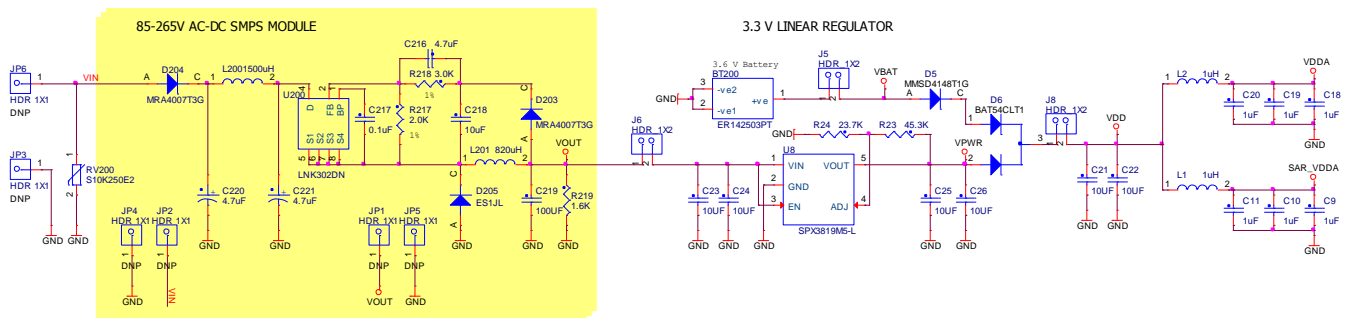
Figure 4-1. Power supply

NOTE

The digital and analog voltages VDD, VDDA and SAR_VDDA are lower by a voltage drop on the diode D6 (0.35 V) than the regulated output voltage VPWR.

4.2 Digital circuits

All the digital circuits are supplied from the VDD, VPWR, and VAUX voltages. The digital voltage (VDD), because of being backed-up by the 1/2AA 3.6 V Li-SOCl$_2$ battery (BT200), is active even if the power meter electronics are disconnected from the mains. It supplies the microcontroller device (U7) and the 3-axis digital accelerometer (U5). The regulated output voltage (VPWR) supplies the digital circuits that can be switched off during the standby and power-down operating modes. These components are: Isolated RS232 interface (U6), Isolated open-collector pulse output interface (U3 and U4), UMI and RF MC1323x-IPB interfaces (J200 and J201), and the 128 KB SPI flash (U2). In order to optimize power consumption of the meter electronics in standby and power-down modes, the auxiliary voltage (VAUX) is sourced from the PTF7 pin of the microcontroller. The microcontroller uses this pin to power the 4KB SPI EEPROM (U1) and IR Interface (Q1), if in use.

4.2.1 MKM34Z128MCLL5

The MKM34Z128MCLL5 microcontroller (U7) is the most noticeable component on the metering board (see **Figure A-1**). The following components are required for flawless operation of this microcontroller:

- Filtering ceramic capacitors C8, C13, C202-C205, C207, C209, and C212-C214
- External reset filter C12 and R17
- 32.768 kHz crystal Y1

An indispensable part of the power meter is the Human Machine Interface (HMI) consisting of an LCD (DS1) and user push-button (SW1). The charge pump for the LCD is part of the MCU and it requires four ceramic capacitors (C202-C205) on the board. Two connectors (J3 and J5) are also populated to interface the terminal cover and the main cover switches to the MCU tamper detection circuit. Connector J2 is the SWD interface for MCU programming.

<div align="center">

CAUTION

The debug interface (J2) is not isolated from the mains supply. Use only galvanically isolated debug probes for programming the MCU when the power meter is supplied from the mains supply.

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4.2.2 Output LEDs

The microcontroller uses two timer channels to control the calibration LEDs (D1 and D2). The timers' outputs are routed to the respective device pins (PXBAR_OUT4 and PXBAR_OUT3) through the peripheral crossbar module, a programmable switch matrix interconnecting internal and external logic signals. The timers were chosen to produce a low-jitter and high dynamic range pulse output waveform; the method for low-jitter pulse output generation using software and timer is being patented.
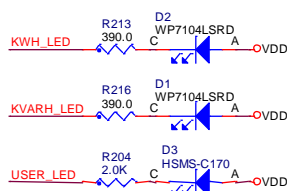

Figure 4-2. Output LEDs control

The user LED (D3) is driven by software through output pin PTH7. It blinks when the power meter enters the calibration mode, and turns solid after the power meter is calibrated and is operating normally.

4.2.3 Isolated open-collector pulse output interface

Figure 4-3 shows the schematic diagram of the open collector pulse output. This may be used for switching loads with a continuous current as high as 50 mA and with a collector-to-emitter voltage of up to 70 V. The interface is controlled through the peripheral crossbar (PXBAR_OUT6) pin of the microcontroller, and hence it may be controlled by a variety of internal signals, for example timer channels generating pulse outputs. The isolated open-collector pulse output interface is accessible on connector J1.
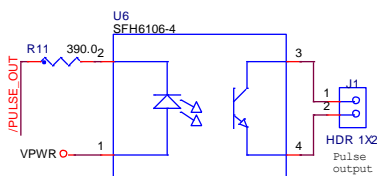
Figure 4-3. Open-collector pulse output control

4.2.4 IR interface (IEC1107)

The power meter has a galvanically isolated optical communication port, as per IEC 1107 / ANSI / PACT, so that it can be easily connected to a hand-held common meter reading instrument for data exchange. The IR interface is driven by UART0. Because of the very small supply current of the NPN phototransistor (Q1), it is powered directly by the PTF7 pin of the microcontroller. Powering from the pin allows the microcontroller to switch off the phototransistor circuit, and thus minimize current consumption. The IR interface schematic is shown in the following figure:
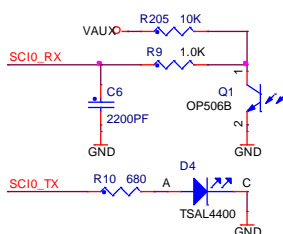
Figure 4-4. IR control

4.2.5 Isolated RS232 interface

This communication interface is used primarily for real-time visualization using FreeMASTER [**5**]. The communication is driven by the UART1 module of the microcontroller. Communication is optically isolated through the optocouplers U3 and U4. Besides the RXD and TXD communication signals, the interface implements two additional control signals, RTS and DTR. These signals are usually used for transmission control, but this function is not used in the application. As there is a fixed voltage level on these control lines generated by the PC, it is used to supply the secondary side of the U4 and the primary side of the U3 optocouplers. The communication interface, including the D200-D202, C3, R3, and R4 components, required to supply the optocouplers from the transition control signals, is shown in the following figure:
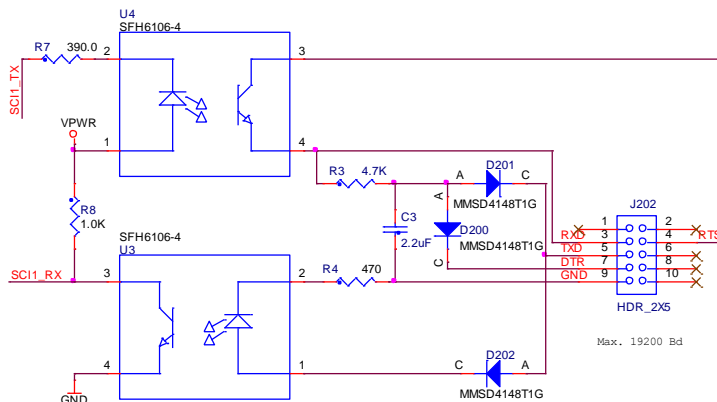
Figure 4-5. RS232 control

4.2.6 MMA8491Q 3-axis digital accelerometer

This sensor is optional and can be used for advanced tamper detection. In the schematic diagram, the MMA8491Q 3-axis digital accelerometer is marked as U5 (see **Figure 4-6**). The accelerometer communicates with the microcontroller through the I2C data lines; therefore, the external pull-ups R5 and R6 on the SDA and SCL lines are required. In addition to I2C communication, the sensor interfaces with the microcontroller through the MMA_XOUT, MMA_YOUT, and MMA_ZOUT signals. With the help of the direct connection, the accelerometer sensor can wake-up the microcontroller when the coordinates of the installed power meter unexpectedly change.
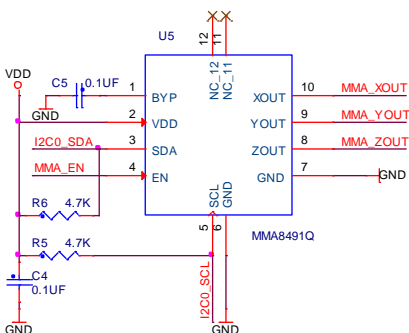
Figure 4-6. MMA8491Q sensor control

4.2.7 128 KB SPI flash

The 128 KB SPI flash (W25X10CLSN) can be used to store a new firmware application and/or load profiles. The connection of the flash memory to the microcontroller is made through the SPI1 module, as shown in **Figure 4-7**. The SPI1 module of the MKM34Z128MCLL5 device supports a communication speed of up to 12.5 Mbit/s. This memory is supplied from the regulated output voltage (VPWR), hence it operates when the power meter is supplied from the mains.
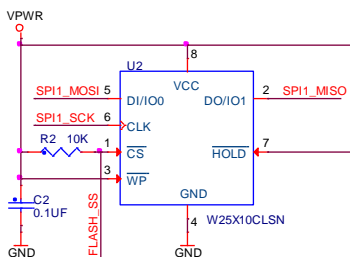
Figure 4-7. 128 KB SPI flash control

4.2.8 4 KB SPI EEPROM

The 4 KB SPI EEPROM (CAT25040VE) can be used for parameter storage. The SPI0 module of the MKM34Z128MCLL5 is dedicated to interfacing (see **Figure 4-8**). Similarly to the IR interface, the EEPROM memory is also powered directly from the PTF7 pin of the MKM34Z128MCLL5 device. This topology supports power meter parameter reading when the electronics run from the backup battery supply. The maximum communication throughput is limited by the CAT25040VE device to 10 Mbit/s.
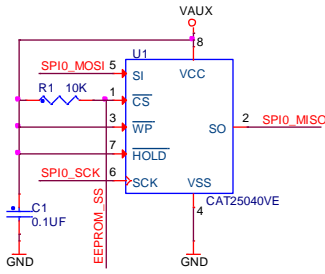
Figure 4-8. 4 KB SPI EEPROM control

4.2.9 UMI and RF MC1323x-IPB interfaces

The Universal Metering Interface (UMI) is an SPI-based communication interface to help you develop secure, inter-operable smart metering and smart home products [**6**]. This interface enables the power meter to communicate through a variety of ZigBee, Wireless M-Bus, GSM, and WiFi modules. All signals are digital, driven at 0 V or VDD (which is typically 3.25 V).

The RF MC1323x-IPB interface (J200) is intended to interface the power meter with Freescale's ZigBee small factor modules. This interface comprises connections to UART3 and the I2C1 peripherals, as well as to several I/O lines for module reset, handshaking, and control.
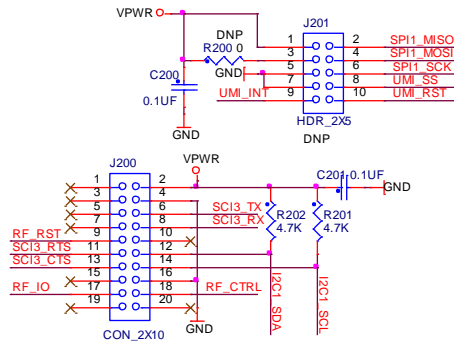
Figure 4-9. UMI and RF MC1323x-IPB interfaces control

NOTE

Both the UMI and RF MC1323x-IPB interfaces are designed to supply the external communication modules from the regulated output voltage VPWR. Therefore, use only communication modules with a supply voltage of 3.6 V and a continuous current of up to 60 mA.

4.3 Analog circuits

An excellent performance of the metering AFE, including external analog signal conditioning, is crucial for a power meter application. The most critical is the phase current measurement, due to the high dynamic range of the current measurement (800:1 and higher) and the relatively low input signal range (from microvolts to several tens of millivolts). All analog circuits are described in the following subsections.

4.3.1 Phase current measurement

Although the Kinetis-M one-phase power meter reference design is optimized for shunt resistors, a variety of current transformers and Rogowski coils can also be used. The only limitations are that the sensor output signal range must be within ±0.5 V peak and the dimensions of the enclosure. The interface of a current sensor to the MKM34Z128MCLL5 device is very straightforward; only anti-aliasing low-pass filters attenuating signals with frequencies greater than the Nyquist frequency must be populated on the board (see **Figure 4-10)**. The cut-off frequency of the analog filters implemented on the board is 72.3 kHz; such a filter has an attenuation of 32.56 dB at Nyquist frequency of 3.072 MHz.
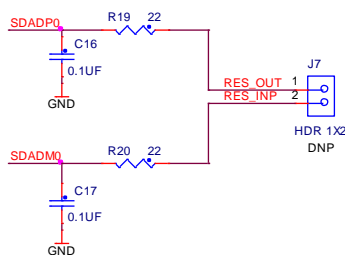
Figure 4-10. Phase current signal conditioning circuit

4.3.2 Phase voltage measurement

A simple voltage divider is used for the line voltage measurement. In a practical implementation, it is better to design this divider from several resistors connected serially due to the power dissipation. One half of this total resistor consists of R12, R13, R14, and R15, the second half consists of resistor R21. The resistor values were selected to scale down the 325.26 V peak input line voltage to the 0.2113 V peak input signal range of the 24-bit SD ADC. The voltage drop and power dissipation on each of the R12-R15 MELF0204[1] resistors are below 57.5 V and 22 mW, respectively. The anti-aliasing low-pass filter of the phase voltage measurement circuit is set to a cut-off frequency of 27.22 kHz. Such an anti-aliasing filter has an attenuation of 41.05 dB at Nyquist frequency of 3.072 MHz.

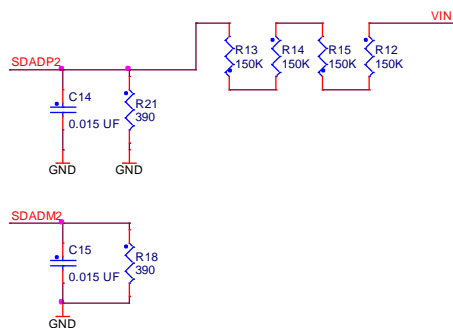**Figure 4-11. Phase voltage signal conditioning circuit**

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[1] Vishay Beyschlag's MELF0204 resistors' maximum operating voltage is 200 V. The maximum power dissipation is 0.25 W for a temperature range of up to 70 °C.

4.3.3 Auxiliary measurements

Figure 4-12 shows the schematic diagram of the battery voltage divider. This resistor divider scales down the battery voltage to the input signal range of the 16-bit SAR ADC. The 16-bit SAR ADC is configured for operation with an internal 1.0 V PMC band gap reference. The resistors values R220=1.6 MΩ and R221=4.7 MΩ were calculated to allow measurement of the battery voltage up to 3.94 V whilst keeping the battery discharge current low. For the selected resistor values, the current flowing through the voltage divider is 571 nA at 3.6 V.
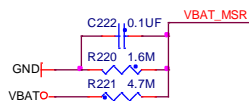
Figure 4-12. Battery voltage divider circuit

Status information on whether the power meter is connected or disconnected from the mains is critical for transitioning between the power meter operating modes. The presence of a mains AC voltage is signaled by the logic signal PWR_MSR that is derived from the regulated output voltage (VPWR). If the power meter is connected to the mains (VPWR=3.6 V), the PWR_MSR will transition to 3.15 V and the software will read this signal from the PTC5 pin as logic 1. On the other hand, a power meter disconnected from the mains will be read by the microcontroller device as logic 0.
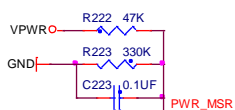
Figure 4-13. Supply voltage divider circuit

5 Software design

This section describes the software application of the Kinetis-M one-phase power meter reference design. The software application consists of measurement, calculation, calibration, user interface, and communication tasks.

5.1 Block diagram

The application software has been written in C-language and compiled using the IAR Embedded Workbench for ARM (version 6.50.6) with full optimization for execution speed. The software application is based on the Kinetis-M bare-metal software drivers [**7**] and the filter-based metering algorithm library [**2**].

The software transitions between operating modes, performs a power meter calibration after first start-up, calculates all metering quantities, controls the active and reactive energies pulse outputs, runs the HMI (LCD display and button), stores and retrieves parameters from the NVMs, and allows application remote monitoring and control. The application monitoring and control is performed through FreeMASTER.

Figure 5-1 shows the software architecture of the power meter including interactions of the software peripheral drivers and application libraries with the application kernel.

Figure 5-1. Software architecture (see below)

4x22 Segment LCD Display

User Button and User LED

Communications and FreeMASTER

IR interface (IEC1107) — UART0 Driver

FreeMASTER Protocol Library

Segment LCD Controller Driver

HMI

GPIO & PORT Drivers

Pulse Output Generation

Quad Timer (TMR) Driver — Peripheral Crossbar (XBAR) Driver — Isolated open-collector output

Peripheral Crossbar (XBAR) Driver — kWh and kVARh LEDs

Isolated RS232 interface — UART1 Driver

I2C1 Driver

UMI and RF MC1323x-IPB interfaces — UART3 Driver

SPI1 Driver

Application Kernel

Calibration Task *(executes after first POR)*

Operating Mode Control *(executes after each POR)*

Data Processing *(executes periodically)*

Calculation Billing Quantities *(executes periodically)*

Calculation Non-billing Quantities *(executes periodically)*

HMI Control / Interaction Task *(execute periodically)*

Communication Tasks *(event triggered execution)*

Parameter Management Tasks *(event triggered execution)*

Phase Voltage Frequency Measurement

Quad Timer (TMR) Driver — High-Speed Comparator (CMP) Driver

Peripheral Crossbar (XBAR) Driver

Analog Measurements and Energy Calculations

Filter Based Metering Algorithm Library — Analogue Front-End (AFE) Driver — Phase Voltage and Current Signal Conditioning Circuit

Auxiliary Measurements

Analog-to-Digital Converter (ADC) Driver — Battery Voltage Conditioning Circuit / Supply Voltage Conditioning Circuit

Clock Management

32.768 kHz External Crystal — Independent Real Time Clock (IRTC) Driver / Phase-Locked Loop (PLL) Driver

Advanced Tampering

MMA8491Q 3-axis digital accelerometer — I2C0 Driver / GPIO & PORT Drivers

Device Initialization and Security

Watchdog (WDOG) Driver / Voltage Reference (VREF) Driver

System Integration Module (SIM) Driver / Low Leakage Wakeup (LLWU) Driver

Power Management

System Mode Controller (SMC) Driver / Power Management Controller (PMC) Driver

Reset Controller Module (RCM) Driver / Low Power Timer (LPTMR) Driver

Application Reset

Non-volatile Memory (NVM) Driver — Flash 1 KB sector (0x1FC00-0x1FFFF)

SPI1 Driver / SPI0 Driver

Parameter Storage

W25X10CLSN 128 KB SPI flash / CAT25040VE 4 KB SPI EEPROM

Legend: Bare-metal drivers | Application software | Libraries

Figure 5-1. Software architecture

All tasks executed by the Kinetis-M one-phase power meter software are briefly explained in the following subsections.

5.2 Software tasks

The software tasks are part of the application kernel. They're driven by events (interrupts) generated either by the on-chip peripherals or the application kernel. The list of all tasks, trigger events, and calling periods are summarized in the following table:

Table 5-1. List of software tasks.

Task name	Description	Source file(s)	Function name	Trigger source	Interrupt priority	Calling period
Power meter calibration	Performs power meter calibration and stores calibration parameters.	config.c config.h	CONFIG_UpdateOffsets CONFIG_CalcCalibData	device reset	-	after first device reset, and a special load point is applied by the test equipment
Operating mode control	Controls transitioning between power meter operating modes.		main	device reset	-	after every device reset
Data processing	Reads digital values from the AFE and performs scaling.		afech2_callback		Level 0 (highest)	periodic 166.6 µs
Calculation billing quantities	Calculates billing and non-billing quantities.	mk341ph.c	auxcalc_callback	AFE CH2 conversion complete interrupt	Level 1	periodic 833.3 µs
Calculation non-billing quantities						
HMI control	Updates LCD with new values and transitions to new LCD screen after user button is pressed.		display_callback		Level 3 (lowest)	periodic 250 ms
FreeMASTER communication	Application monitoring and control	freemaster_*.c freemaster_*.h	FMSTR_Init	UART0 Rx/Tx interrupts	Level 2	asynchronous
	Recorder		FMSTR_Recorder	AFE CH2 conversion complete interrupt	Level 1	periodic 833.3 µs
Parameter management	Writes/reads parameters from the flash	config.c config.h	CONFIG_SaveFlash CONFIG_ReadFlash	after successful calibration or controlled by user	-	

5.2.1 Power meter calibration

The power meter is calibrated with the help of test equipment. The calibration task runs whenever a non-calibrated power meter is connected to the mains. The running calibration task measures the phase voltage and phase current signals generated by the test equipment; it scans for a 230 V phase voltage and 5.0 A phase current waveforms with a 45 degree phase shift. If the calibration task detects such a load point, then, after 35 s of collecting data, the calibration task calculates the calibration offsets, gains, and phase shift using the following formulas:

$$gain_U = 230/URMS \qquad \text{Eq. 5-1}$$

$$gain_I = 5.0/IRMS \qquad \text{Eq. 5-2}$$

$$\theta_{comp} = 45° - \tan^{-1}\left(\frac{Q}{P}\right) \qquad \text{Eq. 5-3}$$

where $gain_U$, $gain_I$ are calibration gains, θ_{comp} is the calculated phase shift caused by parasitic inductance of the shunt resistor, and $URMS$, $IRMS$, Q, P are quantities measured by the non-calibrated meter.

Contrary to the gain and phase shift calculations that are based on RMS values, the calibration offsets are calculated from instantaneous measured samples, as follows:

$$offset_U = \frac{max(\sum_{k=0}^{n} u(k)) - min(\sum_{k=0}^{n} u(k))}{2}$$ **Eq. 5-4**

$$offset_I = \frac{max(\sum_{k=0}^{n} i(k)) - min(\sum_{k=0}^{n} i(k))}{2}$$ **Eq. 5-5**

where $offset_U$, $offset_I$ are calculated calibration offsets, $u(k)$, $i(k)$ are respectively the instantaneous phase voltage and phase current samples in measurement steps $k = 0, 1, \ldots n$.

The calibration task terminates by storing calibration gains, offsets and phase shift into the flash and by resetting the microcontroller device. The recalibration of the power meter can also be initiated from FreeMASTER.

5.2.2 Operating mode control

The transitioning of the power meter electronics between operating modes helps maintain a long battery lifetime. The power meter software application supports the following operating modes:

- **Normal** (electricity is supplied, causing the power meter to be fully-functional)
- **Standby** (electricity is disconnected, and the user lists through the menus)
- **Power-down** (electricity is disconnected, but there is no user interaction)

Figure 5-2 shows the transitioning between supported operating modes. After a battery or the mains is applied, the power meter transitions to the Device Reset state. If the mains has been applied, then the software application enters the normal mode and all software tasks including calibration, measurements, calculations, HMI control, parameter storage, and communication are executed. In this mode, the MKM34Z128MCLL5 device runs in RUN mode. The system clock frequency is generated by the PLL and is 12.288 MHz. The power meter electronics consume 10.88 mA.

If the mains hasn't been applied, then the software application enters the standby mode. In this mode, the power meter runs from battery. All software tasks are stopped except HMI control. In this mode, the MKM34Z128MCLL5 device executes in VLPR mode. The system clock frequency is downscaled to 125 kHz from the 4 MHz internal relaxation oscillator. Because of the slow clock frequency, the limited number of enabled on-chip peripherals, and the flash module operating in a low power run mode, the power consumption of the power meter electronics is 245 µA.

Finally, when the power meter runs from battery but the user doesn't list through the menus, then the software transitions automatically to the power-down mode. The MKM34Z128MCLL5 device is forced to enter VLLS2 mode, where recovery is only possible when either the user button is pressed or the mains is supplied. The power-down mode is characterized by a current consumption of 5.6 µA.
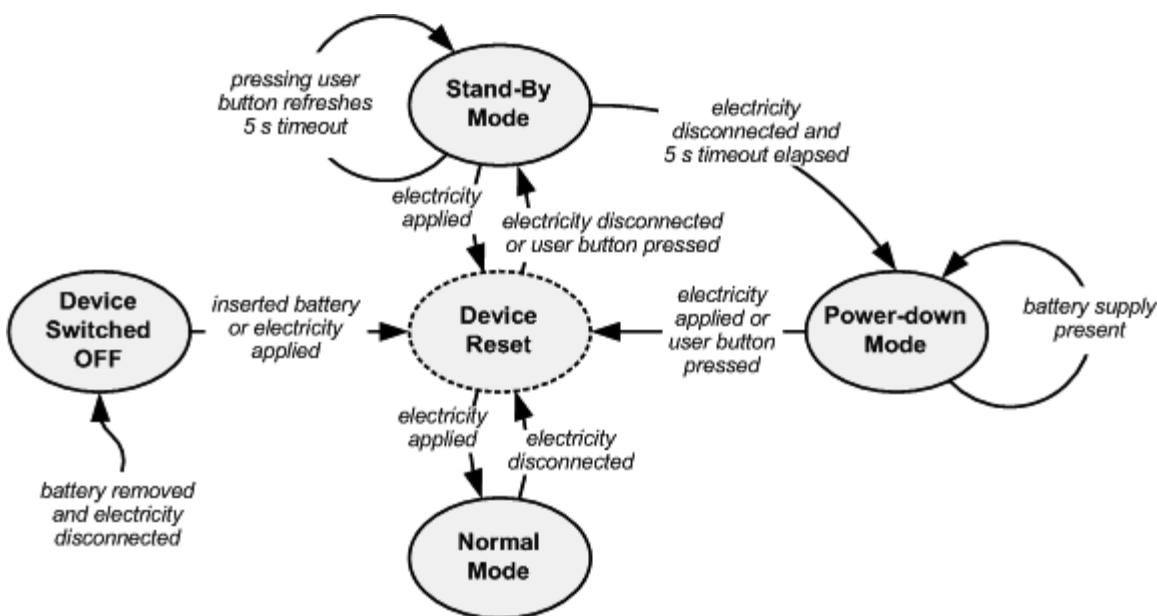
Figure 5-2. Operating modes

5.2.3 Data processing

Reading the phase voltage and phase current samples from the analog front-end (AFE) occurs periodically every 166.6 μs. This task runs on the highest priority level (Level 0) and is triggered asynchronously when the AFE result registers receive new samples. The task reads the phase voltage and phase current samples from the AFE result registers, scales the samples to the full fractional range, and writes the values to the temporary variables for use by the calculation task.

5.2.4 Calculations

The execution of the calculation task is carried out periodically every 833.3 μs. The calculation task scales the samples using calibration offsets and calibration gains obtained during the calibration phase:

$$u\_sample_{scaled} = gain_U(u\_sample - offset_U)$$ **Eq. 5-6**

$$i\_sample_{scaled} = gain_I(i\_sample - offset_I)$$ **Eq. 5-7**

where u_sample, i_sample are measured samples, $offset_U$, $offset_I$, $gain_U$, and $gain_I$ are calibration parameters.

The scaled samples are then used by the metering algorithm.

NOTE

We found experimentally that increasing the calculation update rate beyond 1200 Hz doesn't improve the accuracy of the measurement and calculations.

5.2.5 HMI control

The Human Machine Interface (HMI) control task executes in a 250 ms loop and on the lowest priority (Level 3). It reads the real-time clock, battery voltage, calculates the mains frequency, and formats data into a string that is displayed on the LCD. The interaction with the user is arranged through an asynchronous event, which occurs when the user button is pressed. By pressing the user button, you may scroll through menus and display all measured and calculated quantities (see **Table 6-1**).

5.2.6 FreeMASTER communication

FreeMASTER establishes a data exchange with the PC. The communication is fully driven by the UART0 Rx/Tx interrupts, which generate interrupt service calls with priority Level 2. The power meter acts as a slave device answering packets received from the master device (PC). The recorder function is called by the calculation task every 833.3 μs. The priority setting guarantees that data processing and calculation tasks are not impacted by the communication. For more information about using FreeMASTER, refer to **Subsection 5.2.6-FreeMASTER communication**.

5.2.7 Parameter management

The current software application uses the last 1024 bytes sector of the internal flash memory of the MKM34Z128MCLL5 device for parameter storage. By default, parameters are written after a successful calibration and read after a device reset. In addition, storing and reading parameters can be initiated through FreeMASTER.

5.3 Performance

Table 5-2 shows the memory requirements of the Kinetis-M one-phase power meter software application[2].

Table 5-2. Memory requirements

Function	Description	Flash size [KB]	RAM size [KB]
Application framework	Complete application without the metering library and FreeMASTER	19.0	0.1
Filter-based metering algorithm library	Filter-based metering algorithm library	6.8	2.3
FreeMASTER	FreeMASTER protocol and serial communication driver	4.1	4.2
Total:		**29.9**	**6.6**

The software application reserves the 4.0 KB RAM for the FreeMASTER recorder. If the recorder is not required, or a fewer number of variables will be recorded, you may reduce the size of this buffer by modifying the FMSTR_REC_BUFF_SIZE constant (refer to the freemaster_cfg.h header file, line 72).

---

[2] Application compiled using the IAR Embedded Workbench for ARM (version 6.50.6) with full optimization for execution speed.

The system clock of the device is generated by the PLL. In the normal operating mode, the PLL multiplies the clock of an external 32.768 kHz crystal by a factor of 375, hence generating a low-jitter system clock with a frequency of 12.288 MHz. Such a system clock frequency is sufficient for executing the fully functional software application.

NOTE

The filter-based metering algorithm configuration tool estimates the minimum system clock frequency for the ARM Cortex-M0+ core to calculate billing and non-billing quantities with an update rate of 1200 Hz to approximately 8.4 MHz. As shown in the following figure, by slowing down the update rate of the non-billing calculations from 1200 to 600 Hz and further by reducing the Hilbert-filter length from 49 to 39-taps, the required performance will even decrease by 32.14% to 5.7 MHz.
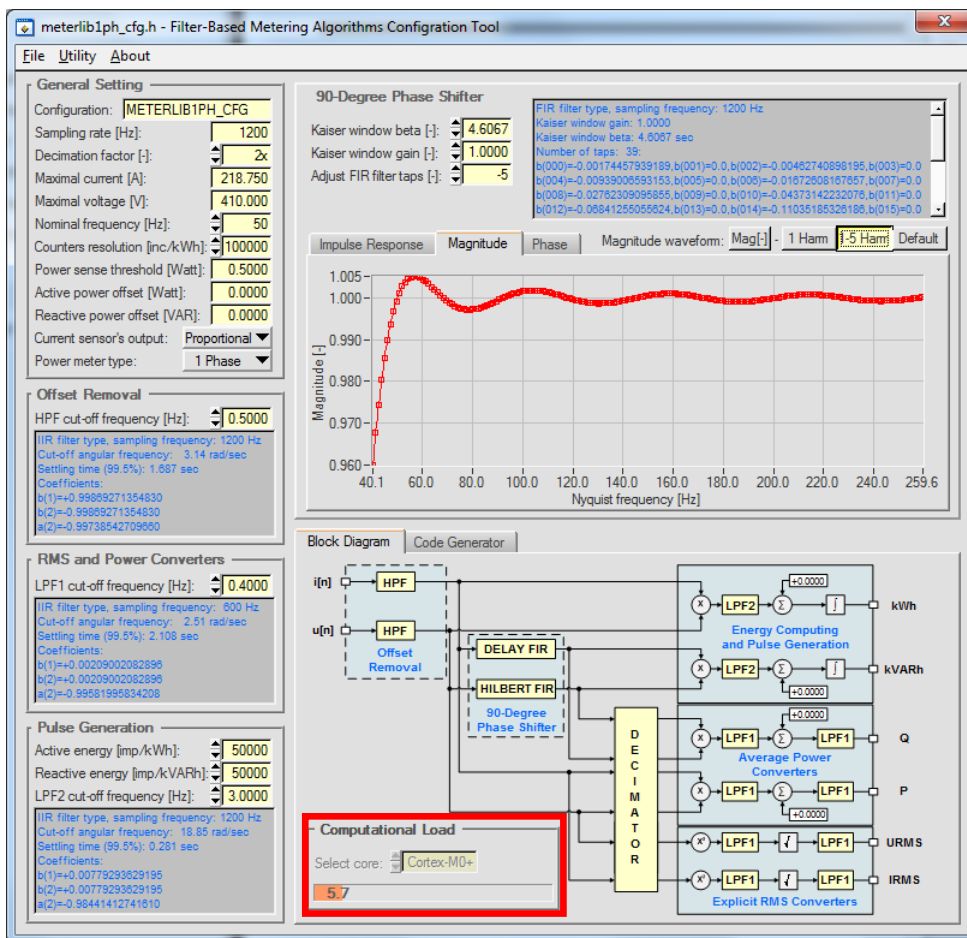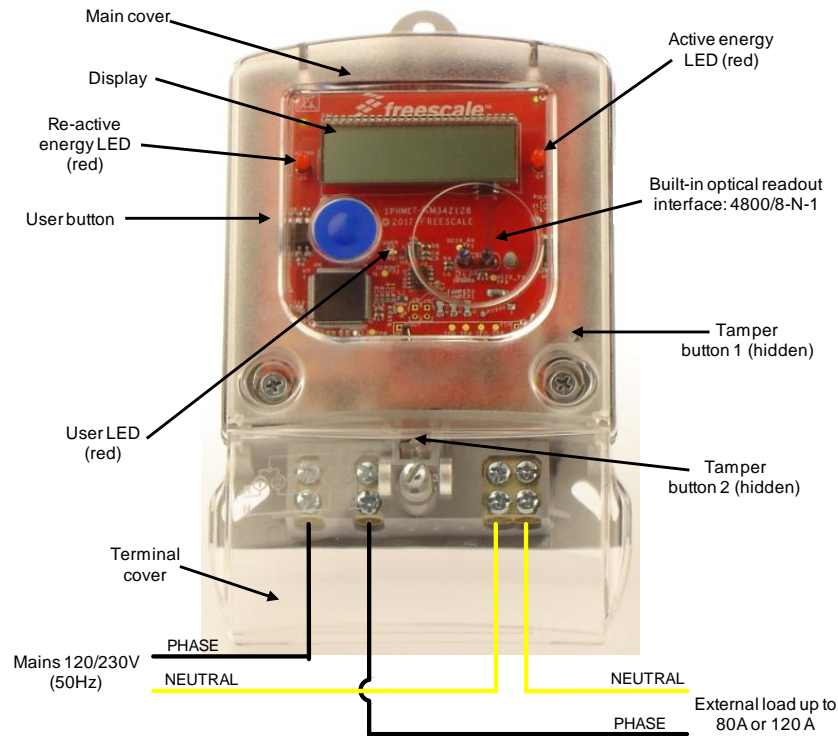

Figure 5-3. Minimum system clock requirements for the filter-based metering algorithm

6 Application set-up

Figure 6-1 shows the wiring diagram of the Kinetis-M one-phase power meter.

Figure 6-1. Kinetis-M one-phase power meter – wiring diagram

Among the main capabilities of the power meter, is registering the active and reactive energy consumed by an external load. After connecting the power meter to the mains, or when you press the user button, the power meter transitions from the power-down mode to either the normal mode or standby mode, respectively. In normal and standby modes, the LCD is turned on and shows the last quantity. The user can list through the menus and display other quantities by pressing the user button. All configuration and informative quantities accessible through the LCD are summarized in the following table:

Table 6-1. Quantities shown on the LCD

Value	Units	Format	OBIS code
Date	year, month, day	YYYY:MM:DD	0.9.2
Time	hour, min, sec	HH:MM:SS	0.9.1
Line voltage	V_{RMS}	#.# V	
Line current	I_{RMS}	#.### A	
Signed active power	W	#.### W (+ forward, - reverse)	1.6.0
Signed reactive power	VAr	#.### VAr (+ lag, - lead)	
Apparent power	VA	#.### VA	
Signed active energy	kWh	#.### kWh (+ import, - export)	1.9.0
Signed reactive energy	kVArh	#.### kVArh (+ import, - export)	

Frequency	Hz	##.# Hz	
Battery voltage	V	#.## V	
Active energy pulse number	Imp/kWh	###### (default 50000)	
Reactive energy pulse number	Imp/kVARh	###### (default 50000)	
Software revision-product serial number	-	#.#.# - ### (revision – meter serial number)	
Class according to EN50470-3	-	C # #-###A (example C 5-120A)	

7 FreeMASTER visualization

The FreeMASTER data visualization and calibration software is used for data exchange [**5**]. The FreeMASTER software running on a PC communicates with the Kinetis-M one-phase power meter over an optical head attached to the **IR interface (IEC1107)**. The communication is interrupt driven and is active when the power meter is powered from the mains. The FreeMASTER software allows remote visualization, parameterization and calibration of the power meter. It runs visualization scripts which are embedded into a FreeMASTER project file.

Before running a visualization script, the FreeMASTER software must be installed on your PC. After installation, a visualization script may be started by double-clicking on the *monitor.pmp* file. Once started, the following visualization script will appear on your computer screen.
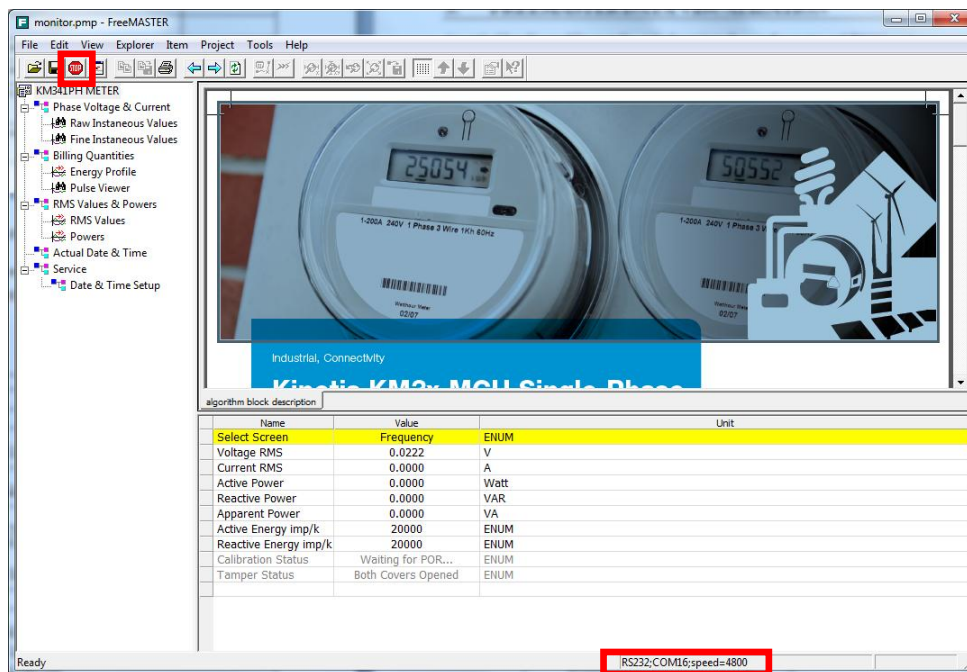

Figure 7-1. FreeMASTER visualization software

Now, you should set the proper serial communication port and communication speed in the Project/Option menu (see **Figure 7-2**). After communication parameters are properly set and the "Stop"

button is released, the communication is initiated. A message on the status bar signalizes the communication parameters and successful data exchange.
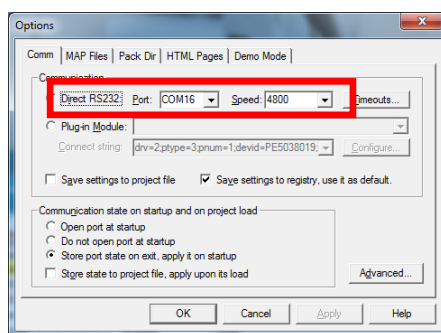
Figure 7-2. Communication port setting

Now you can see the measured phase voltages, phase current, active, reactive and apparent powers, pulse numbers and additional status information in FreeMASTER. You may also visualize some variables in a graphical representation by selecting the respective scope or recorder item from the tree.

The visualization script allows you to monitor and parameterize the majority of the power meter features. To eliminate inappropriate and unwanted changes, some key parameters are protected by a 5-digit system password. These key parameters are as follows:

- Set Calendar
- Set Imp/kWh
- Set Imp/kVARh
- Recalibration

All the remaining parameters and commands can be executed anytime, without the need for entering the system password:

- LCD Screen Select
- Software Reset
- Clear Energy Counters
- Clear Tampers

Most of all, FreeMASTER will be used for monitoring the power meter operation and analyzing the phase voltages and phase currents waveforms in real-time. The visualization script file contains the following visualization objects:

- **Recorders** (833 µs update rate, the number of samples optional but limited to 4096 bytes)
  - Raw instantaneous phase voltage and current samples
  - High-pass filtered instantaneous phase voltage and current samples
- **Scopes** (10 ms update rate, the number of samples unlimited)
  - Energy profile (kWh and kVARh counters with resolution 10^{-5})
  - RMS voltage, RMS current, active power, reactive power, and apparent power.
  - Power meter's actual date and time
  - Mains frequency
- **Variables and Enumerations** (shown in text form)

- Password set-up
- Tamper status
- Remote command

Figure 7-3 shows the high-pass filtered phase voltage and phase current waveforms with shorted input terminals. The waveform samples are captured every 833 µs and stored in a dedicated buffer of the MKM34Z128MCLL5 device. When the buffer is full, the data is sent to the PC via the optical port interface. The FreeMASTER visualization tool then displays the data on the PC screen.
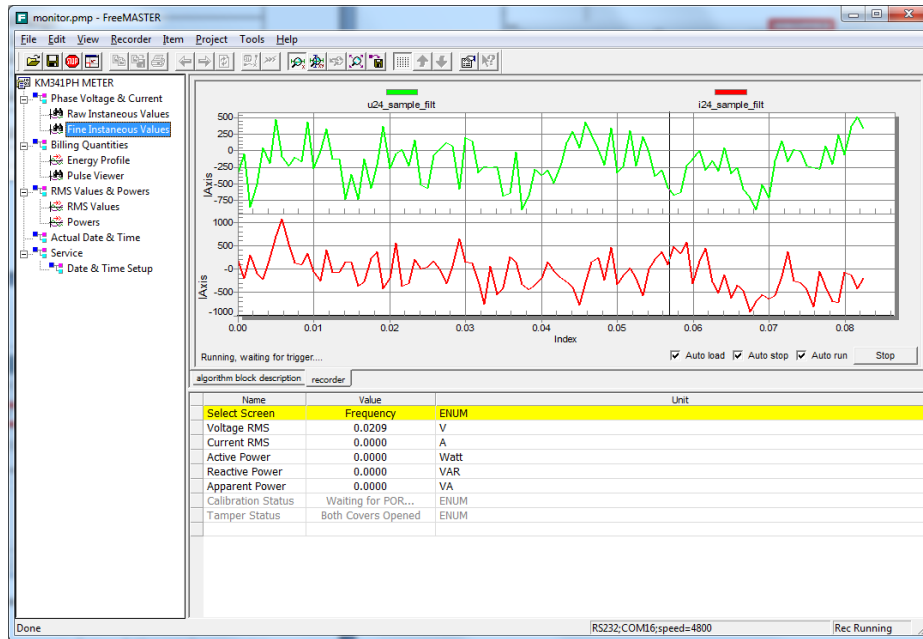
Figure 7-3. Recorded phase voltage and phase current waveforms

Then advanced users can benefit from FreeMASTER's built-in an active-x interface that serves for exchanging data with other signal processing and programming tools, such as Matlab, Excel, LabView, and LabWindows.

8 Accuracy and performance

As already indicated, the Kinetis-M one-phase reference designs have been calibrated using the test equipment ELMA8303 [**1**]. All power meters were tested according to the EN50470-1 and EN50470-3 European standards for electronic meters of active energy classes B and C, the IEC 62053-21 and IEC 62052-11 international standards for electronic meters of active energy classes 2 and 1, and the IEC 62053-23 international standard for static meters of reactive energy classes 2 and 3.

During accuracy calibration and testing, the power meter measured electrical quantities generated by the test bench, calculated active and reactive energies, and generated pulses on the output LEDs; each generated pulse was equal to the active and reactive energy amount kWh (kVARh)/imp[3]. The deviations between pulses generated by the power meter and reference pulses generated by test equipment defined the measurement accuracy.

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[3] The active and reactive energy LED impulse numbers were set to 50,000 pulses per kWh and kVARh respectively.

8.1 Room temperature accuracy testing

Figure 8-1 shows the calibration protocol of the power meter S/N: 35. The protocol indicates the results of the power meter calibration performed at 25 °C. The accuracy and repeatability of the measurement for various phase currents and angles between phase current and phase voltage are shown in these graphs.

The first graph (on the top) indicates the accuracy of the active and reactive energy measurement after calibration. The x-axis shows variation of the phase current, and the y-axis denotes the average accuracy of the power meter computed from five successive measurements; the gray lines define the Class C (EN50470-3) accuracy margins.

The second graph (on the bottom) shows the measurement repeatability; i.e. standard deviation of error of the measurements at a specific load point. Similarly to the power meter accuracy, the standard deviation has also been computed from five successive measurements.
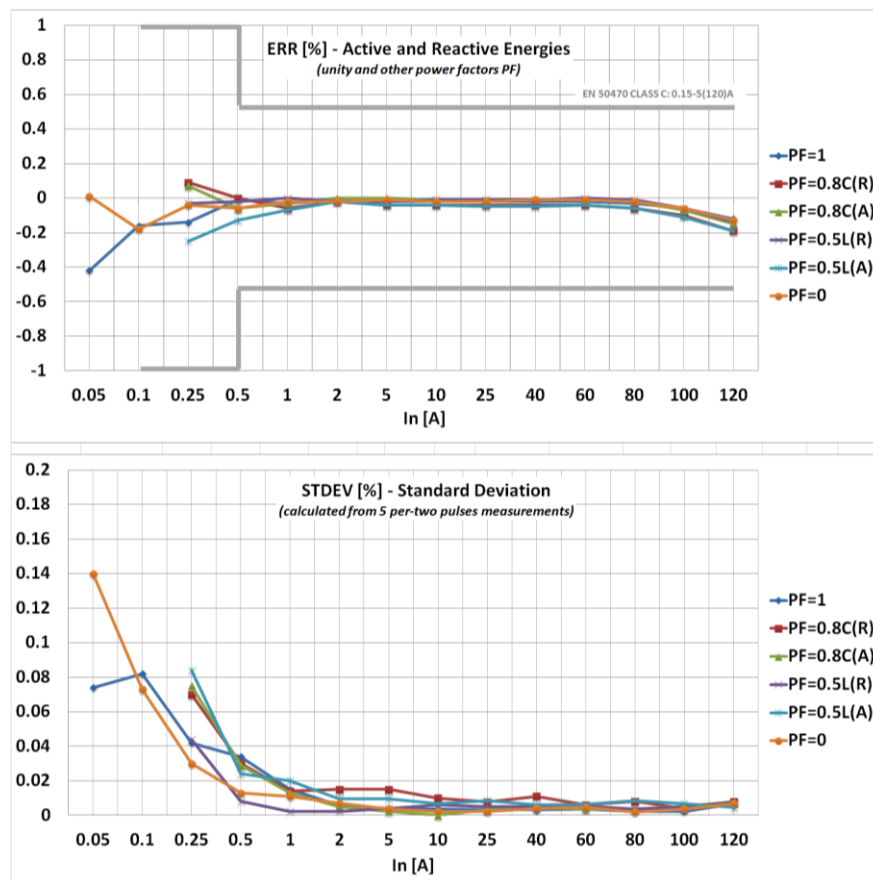
Figure 8-1. Calibration protocol at 25°C

By analyzing the protocols of several Kinetis-M one-phase power meters, it can be said that this equipment measures active and reactive energies at all power factors, a 25 °C ambient temperature, and in the current range 0.25-120 A[4], more or less with an accuracy range ±0.25%.

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[4] The current and voltage measurements were scaled to I_MAX= 152 A and U_MAX= 286 V.

8.2 Extended temperature accuracy testing

In addition to room temperature testing, the Kinetis-M one-phase power meter has been evaluated over the whole operating temperature range (-40 °C to 85 °C). This testing was carried out with the power meter placed in a heat chamber (see **Figure 8-2**). In order to speed up the measurement, only active energy accuracy has been evaluated. The isolated open-collector pulse output interface has been used instead of the output LED to provide active energy pulses to the test equipment for accuracy evaluation.

Figure 8-2. Power meter inside a heat chamber – temperature controlled to -40 °C

Figure 8-3 shows the accuracy of the power meter evaluated at an extended temperature range. The accuracy margins defined by EN50470-3 for Class C power meters and the extended temperature range are denoted by gray lines. As you can see, the active energy measured by the power meter at all temperatures fits within accuracy margins mandated by the standard.
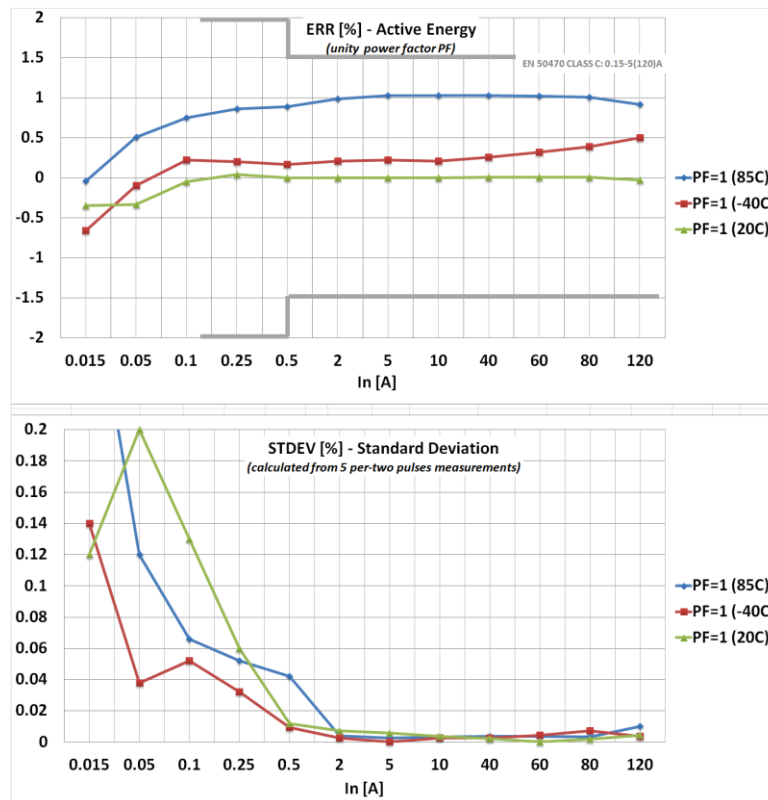
Figure 8-3. Calibration protocol for -40 °C, 20 °C, and 85 °C

8.3 EMC testing

The calibrated power meter has also been inspected with regards to EMC according to EN 61326-1:2007 for usage in industrial environments. The tested power meter operated at a nominal voltage of 230 V AC ± 5%, frequency of 50 ± 0.5 Hz, and under a resistive load of 60 W. The power meter immunity has been evaluated against the following acting phenomena:

- Electrostatic discharge (ESD) according to EN 61000-4-2
- Magnetic field of the network with intensity 30 A/m according to EN 61000-4-8
- Short-time supply voltage dips (DIPS) according to EN 61000-4-11
- Short-time interruptions of supply voltage (INTERRUPT) according to EN 61000-4-11
- Fast transients (BURST) according to EN EN61000-4-4
- Voltage surge (SURGE) according to EN61000-4-5
- Injected currents according to EN61000-4-6

The failure modes for equipment are classified into one of three categories as specified in EN 61326-1. The classification is determined by the performance degradation of the equipment in the presence of the acting phenomena. The applicable functional criteria and their characteristic performance degradations are as follows:

- **Functional criteria A:** during testing the normal properties remain within specified limits.
- **Functional criteria B:** during testing, a transient degradation or loss of function or activity occurs, but they automatically recover to the original state.
- **Functional criteria C:** during testing, a transient degradation or loss of function or activity occurs, which demands intervention by personnel or a resetting of the system.

The acting phenomena, basic standards, test values, requirements of minimum immunity, and also the performance of the power meter concerning EMC, are all summarized in the following table:

Table 8-1. EMC performance of the Kinetis-M one-phase power meter

Input / output	Acting phenomenon	Basic standard	Test value	Required criterion	Test result	Comments
Through enclosure	Electrostatic discharge (ESD)	EN 61000-4-2	4kV contact	B	A	No degradation of the function occurred.
			8 kV air	B	A	
			15 kV indirect application	B	A	
	Magnetic field of network frequency 50 Hz	EN 61000-4-8	30 A/m	A	A	
AC supply	Voltage dip (DIPS)	EN 61000-4-11	0 % -0.02 s (1 period)	B	A	
			20 % -0.2 s (10 period)	C	A	
			70 % -0.5 s (25 period)	C	A	
	Short voltage interruption (INTERRUPT)	EN 61000-4-11	0 % -5 s (250 period)	C	B	At the time of voltage interruption, the unit was switched off, and after regeneration of voltage, the automatic starting operation is in the mode of the previous set-up.

	Burst of pulses (BURST)	EN 61000-4-4	± 2 kV Tr/Th=5/50 ns 5 kHz	**B**	**A**	
AC supply	Voltage surge (SURGE)	EN 61000-4-5	± 2 [1] / ±1 [2] kV Tr/Th=1.2/50 (8/20) µs	**B**	**A**	No degradation of the function occurred.
	Radio frequency electromagnetic asymmetrical disturbance	EN 61000-4-6	3 V (0.15 - 80 MHz)	**A**	**A**	
[1] Line to earth　　　[2] Line to line						

The records of individual tests show that the Kinetis-M one-phase power meter has a proven exceptional EMC performance exceeding the functional criteria required by the standard. The first and last pages of the power meter's EMC test report are provided by agreement of the TÜV SÜD Czech s.r.o. in **Appendix D-EMC test report**.

9 Summary

This design reference manual describes a solution for a one-phase electronic power meter based on the MKM34Z128CLL5 microcontroller.

Freescale semiconductor offers Filter and FFT based metering algorithms for use in customer applications. The former calculates metering quantities in the time domain, the latter in the frequency domain. The reference manual explains the basic theory of power metering and lists all the equations to be calculated by the power meter.

The hardware platform of the power meter is algorithm independent, so application firmware can leverage any type of metering algorithm based on customer preference. In order to extend the power meter uses, the hardware platform comprises a 128 KB SPI flash for firmware upgrade, 4 KB SPI EEPROM for data storage, an MMA8491Q 3-axis multifunction digital accelerometer for enhanced tampering, and UMI and RF MC1323x-IPB interfaces for AMR communication and monitoring.

The application software has been written in C-language and compiled using the IAR Embedded Workbench for ARM (version 6.50.6), with full optimization for the execution speed. It is based on the Kinetis-M bare-metal software drivers [7] and filter-based metering library [2]. The application firmware automatically calibrates the power meter, calculates all metering quantities, controls active and reactive energy pulse outputs, runs the HMI (LCD and button), stores and retrieves parameters from flash memory, and allows monitoring the application, including recording selected waveforms through the FreeMASTER. An application software of such complexity requires 29.9 KB of flash and 6.6 KB of RAM. The system clock frequency of the MKM34Z128CLL5 device must be 12.288 MHz or higher to calculate all metering quantities with an update rate of 1200 Hz.

The power meter is designed to transition between three operating modes. It runs in the so-called normal mode when it is powered from the mains. In this mode, meter electronics consume 10.88 mA. The second mode, the so-called standby mode, is entered when the power meter runs from the battery and the user lists through the menus. In this particular mode, the 3.6V Li-SOCI$_2$ (1.2Ah) battery is discharged by 245 µA, resulting in 4,100 hours of operation (0.47 year battery lifetime). Finally, when the power meter runs from the battery but no interaction with the user occurs, the power meter electronics automatically transition to the power-down mode. The power-down mode is characterized by a current consumption as low as 5.6 µA, which results in 143,000 hours of operation (16.3 year battery lifetime).

The application software allows you to monitor measured and calculated quantities through the FreeMASTER application running on your PC. All internal static and global variables can be monitored and modified using the FreeMASTER. In addition, some variables, for example phase voltages and phase currents, can be recorded in the RAM of the MKM34Z128CLL5 device and sent to the PC afterwards. This power meter capability helps you to understand the measurement process.

The Kinetis-M one-phase power meters were tested according to the EN50470-1 and EN50470-3 European standards for electronic meters of active energy classes B and C, the IEC 62053-21 and IEC 62052-11 international standards for electronic meters of active energy classes 2 and 1, and the IEC 62053-23 international standard for static meters of reactive energy classes 2 and 3. After analyzing several power meters, we can state that this equipment measures active and reactive energies at all power factors, a 25 °C ambient temperature, and in the current range 0.25-120 A, more or less with an accuracy range ±0.25%. Further accuracy testing has been carried out on one power meter in a heat chamber. This particular testing revealed that the temperature coefficient of the complete measurement chain of this equipment is approximately 80 ppm/°C. In addition to accuracy testing, the power meter has been inspected with regards to EMC according to EN 61326-1:2007 for usage in industrial environments. The power meter passed all tests easily.

In summary, the Kinetis-M one-phase power meter has undergone thorough intensive accuracy and EMC testing. It demonstrated excellent measurement accuracy, a low temperature coefficient and robust EMC performance. In reality, the capabilities of the Kinetis-M one-phase power meter fulfill the most demanding European and international standards for electronic meters.

10 References

1. *Electricity Meter Test Equipment ELMA 8x01*, available on www.appliedp.com.

2. *Filter-Based Algorithm for Metering Applications* (document AN4265), available on freescale.com.

3. FFT-Based Algorithm for Metering Applications (document AN4255), available on freescale.com.

4. *AN37 – LinkSwitch-TN Family Design Guide*, April 2009, available on www.powerint.com.

5. *FreeMASTER Data Visualization and Calibration Software*, available on freescale.com.

6. *UMI-S-001 - Main UMI specification*, available on umi.cambridgeconsultants.com.

7. *Kinetis M Bare-metal Software Drivers* (document KMSWDRVAPI), available on freescale.com.

8. *Using an FFT on the Sigma-Delta ADCs* (document AN4847), available on freescale.com.

11 Revision history

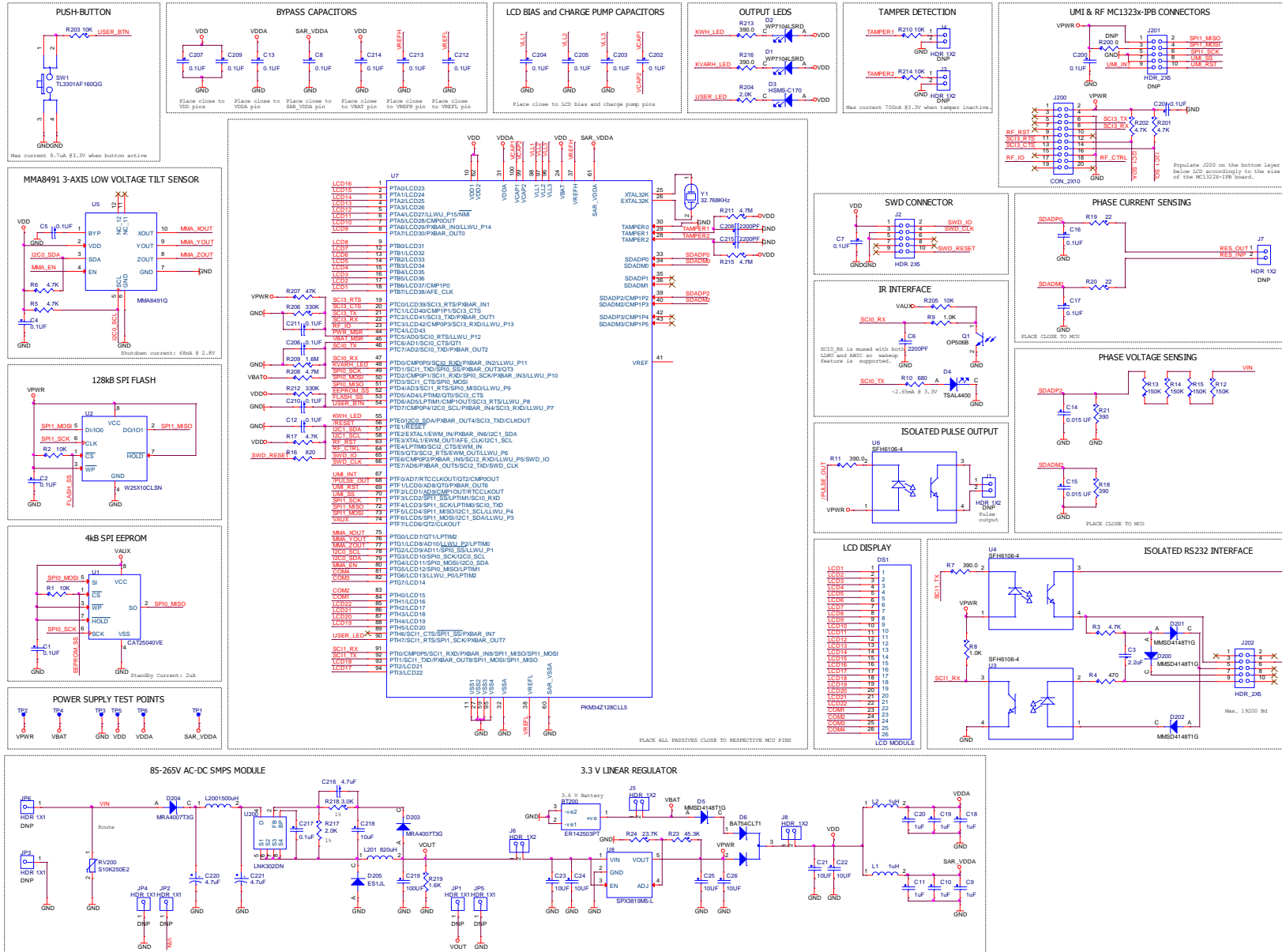| Revision Number	Date	Substantial Changes
0	10/2013	Initial release
1	12/2013	Updated Section 10 - References

Appendix A.   Board Electronics

Figure A-1. Schematic diagram
Kinetis-M One-Phase Power Meter Reference Design, Rev. 1, 12/2013
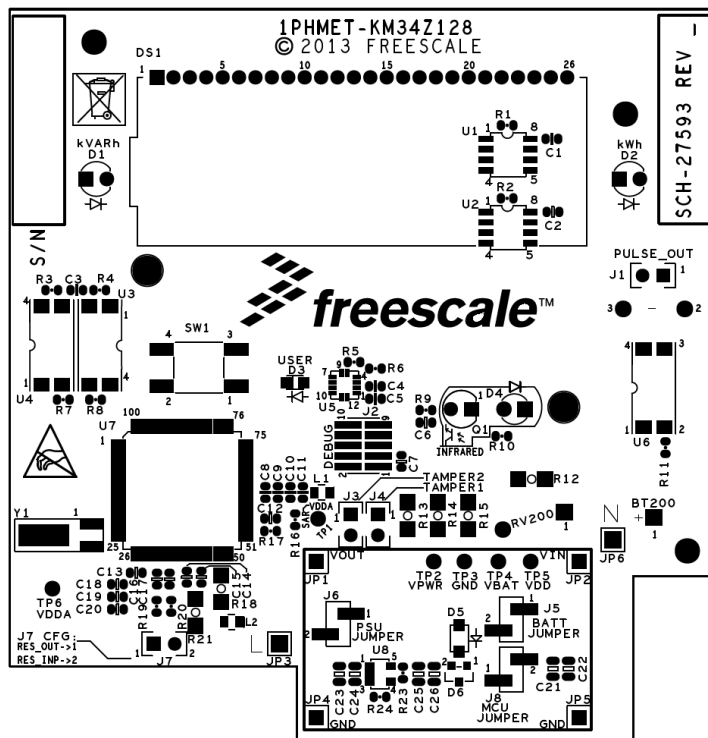
Appendix B.   Board layout

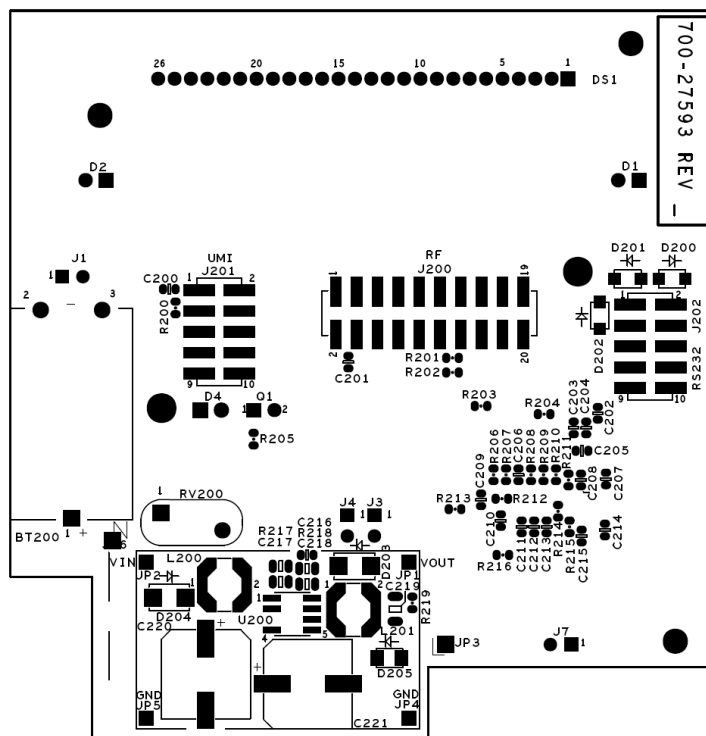

Figure B-1. Top side view (not to scale)

Figure B-2. Bottom side view (not to scale)

Appendix C.   Bill of materials

Table C-1. BOM report

Part Reference	Quantity	Description	Manufacturer	Part Number
BT200	1	BATTERY 1/2AA LI-SOCl2 3.6V 1200MAH	EVE ENERGY CO., LTD	ER142503PT
C1,C2,C4,C5,C7,C8,C12,C13,C16,C17,C200,C201,C202,C203,C204,C205,C206,C207,C209,C210,C211,C212,C213,C214,C3	24	CAP CER 0.10UF 25V 10% X7R 0603	KEMET	C0603C104K3RAC
C3	1	CAP CER 2.2UF 16V 10% X5R 0603	MURATA	GRM188R61C225KE15D
C6,C208,C215	3	CAP CER 2200PF 50V 5% X7R 0603	KEMET	C0603C222J5RACTU
C9,C10,C11,C18,C19,C20	6	CAP CER 1UF 25V 10% X7R 0603	CAPAX TECHNOLOGIES INC.	0603X105K250SNT
C14,C15	2	CAP CER 0.015UF 50V 5% X7R 0603	KEMET	C0603C153J5RACTU
C21,C22,C23,C24,C25,C26	6	CAP CER 10UF 16V 10% X5R 0805	AVX	0805YD106KAT2A
C216	1	CAP CER 4.7uF 16V 10% X5R 0603	TDK	C1608X5R1C475K
C217	1	CAP CER 0.10UF 50V 5% X7R 0805	SMEC	MCCE104J2NRTF
C218	1	CAP CER 10uF 25V 10% X5R 0805	TDK	C2012X5R1E106K
C219	1	CAP CER 100UF 6.3V 20% X5R 1206	Murata	GRM31CR60J107ME39L
C220,C221	2	CAP ALEL 4.7uF 400V 20% -- SMT	NIC COMPONENTS CORP	NACV4R7M400V10x10.8TR13F
DS1	1	LCD DISPLAY POWER METER 4BPx22FP 3V TH	Yes Optoelectronics Display Co., Ltd	YDDC41919AATDRPN
D1,D2	2	LED RED SGL 30mA TH	Kingbright	WP7104LSRD
D3	1	LED HER SGL 2.1V 20MA 0805	AVAGO TECHNOLOGIES	HSMS-C170
D4	1	LED IR SGL 100MA TH	VISHAY INTERTECHNOLOGY	TSAL4400
D5,D200,D201,D202	4	DIODE SW 100V SOD-123	ON SEMICONDUCTOR	MMSD4148T1G
D6	1	DIODE SCH DUAL CC 200MA 30V SOT23	ON SEMICONDUCTOR	BAT54CLT1G
D203,D204	2	DIODE PWR RECT 1A 1000V SMT 403D-02	ON SEMICONDUCTOR	MRA4007T3G
D205	1	DIODE RECT 1A 600V SMT	TAIWAN SEMICONDUCTOR	ES1JL
JP1,JP2,JP3,JP4,JP5,JP6	6	HDR 1X1 TH -- 330H SN 115L	Samtec	TSW-101-23-T-S
J1,J3,J4,J7	4	HDR 1X2 TH 100MIL SP 338H AU 150L	SAMTEC	HMTSW-102-24-G-S-230
J2	1	HDR 2X5 SMT 1.27MM CTR 175H AU	SAMTEC	FTS-105-01-F-DV-P-TR
J5,J6,J8	3	HDR 1X2 SMT 100MIL SP 380H AU	SAMTEC	TSM-102-01-SM-SV-P-TR

J200	1	CON 2X10 SKT SMT 100MIL CTR 390H AU	SAMTEC	SSW-110-22-F-D-VS-N
J201,J202	2	HDR 2X5 SMT 100MIL CTR 380H AU	SAMTEC	TSM-105-01-S-DV-P-TR
L1,L2	2	IND CHIP 1UH@10MHZ 220MA 25%	TDK	MLZ2012A1R0PT
L200	1	IND PWR 1500UH@100KHZ 130MA 20% SMT	Coilcraft	LPS6235-155ML
L201	1	IND PWR 820UH@100kHz 0.18A 20% SMT	COILCRAFT	LPS6235-824ML
Q1	1	TRAN PHOTO NPN 250mA 30V TH	OPTEK TECHNOLOGY INC	OP506B
RV200	1	VARISTOR 250VRMS 10% 0.4W RADIAL	EPCOS	B72210S2251K101
R1,R2,R203,R205,R210,R214	6	RES MF 10K 1/10W 5% 0603	KOA SPEER	RK73B1JTTD103J
R3,R5,R6,R17,R201,R202	6	RES MF 4.7K 1/10W 5% 0603	VISHAY INTERTECHNOLOGY	CRCW06034K70JNEA
R4	1	RES MF 470 OHM 1/10W 1% 0603	KOA SPEER	RK73H1JTTD4700F
R7,R11,R213,R216	4	RES MF 390.0 OHM 1/10W 1% 0603	KOA SPEER	RK73H1JTTD3900F
R8,R9	2	RES MF 1.00K 1/10W 1% 0603	KOA SPEER	RK73H1JTTD1001F
R10	1	RES MF 680 OHM 1/10W 5% 0603	BOURNS	CR0603-JW-681ELF
R12,R13,R14,R15	4	RES MF 150K 1/4W 1% 50PPM MELF0204	WELWYN COMPONENTS LIMITED	WRM0204C-150KFI
R16	1	RES MF 820 OHM 1/10W 5% 0603	BOURNS	CR0603-JW-821ELF
R18,R21	2	RES MF 390 200V 0.1% 15PPM MELF0204	WELWYN COMPONENTS LIMITED	WRM0204Y-390RBI
R19,R20	2	RES MF 22.0 OHM 1/10W 1% 0603	KOA SPEER	RK73H1JTTD22R0F
R23	1	RES MF 45.3K 1/10W 1% 0603	KOA SPEER	RK73H1JTTD4532F
R24	1	RES MF 23.7K 1/10W 1% 0603	KOA SPEER	RK73H1JTTD2372F
R200	1	RES MF ZERO OHM 1/10W -- 0603	VISHAY INTERTECHNOLOGY	CRCW06030000Z0EA
R204	1	RES MF 2.0K 1/10W 5% 0603	BOURNS	CR0603-JW-202ELF
R206,R212	2	RES MF 330K 1/10W 1% 0603	KOA SPEER	RK73H1JTTD3303F
R207	1	RES MF 47K 1/10W 5% 0603	VENKEL COMPANY	CR0603-10W-473JT
R208,R211,R215	3	RES MF 4.7M 1/10W 1% 0603	KOA SPEER	RK73H1JTTD4704F
R209	1	RES MF 1.6M 1/10W 1% 0603	KOA SPEER	RK73H1JTTD1604F
R217	1	RES MF 2.00K 1/10W 1% 0805	SPC TECHNOLOGY	MC0805WAF2001T5E-TR
R218	1	RES MF 3.00K 1/10W 1% 0805	SPC TECHNOLOGY	MC0805WAF3001T5E-TR

R219	1	RES MF 1.6K 1/10W 1% 0603	KOA SPEER	RK73H1JTTD1601F
SW1	1	SW SPST MOM NO PB SMT 50V 50MA GULL_WING	E SWITCH	TL3301AF160QG
U1	1	IC MEM EEPROM SPI 4Kb 1.8-5.5V SOIC8	ON SEMICONDUCTOR	CAT25040VE-G
U2	1	IC MEM FLASH SPI 1MBIT 2.3-3.6V SOIC8	WINBOND ELECTRONICS CORP	W25X10CLSNIG
U3,U4,U6	3	IC OPTOCOUPLER 100MA 70V SMD	VISHAY INTERTECHNOLOGY	SFH6106-4
U5	1	IC 3-AXIS LOW VOLTAGE TILT SENSOR 1.95-3.6V QFN12	FREESCALE SEMICONDUCTOR	MMA8491QR1
U7	1	IC MCU FLASH 128K 16K 50MHZ 1.71-3.6V LQFP100	FREESCALE SEMICONDUCTOR	PKM34Z128CLL5
U8	1	IC VREG LDO ADJ 500MA 2.5-16V SOT23-5	Exar	SPX3819M5-L
U200	1	IC VREG LINKSWITCH 65MA/80MA 85-265VAC/700V S0-8C	POWER INTEGRATIONS	LNK302DN
Y1	1	XTAL 32.768KHZ PAR 20PPM -- SMT	Citizen	CMR200T32.768KDZF-UT

Appendix D. EMC test report

Test report concerning EMC
(Inspection report according to EN ISO/IEC 17020)

registration number 06.752.285

Customer:	Freescale Polovodiče, Česká republika s.r.o., 1. máje 1009, 756 61 Rožnov pod Radhoštěm
Order number of:	130913 z 13.09.2013
Order of TÜV SÜD Czech s.r.o.:	5401305971

for specimen/type:

Name:	**Single-phase electricity meter**
Type:	**KM34Z128**
Supply voltage:	230 V
Frequency:	50 Hz
Current:	120 A max.
Class appliance:	II
Manufacturer:	Freescale Polovodiče, Česká republika s.r.o., 1. máje 1009, 756 61 Rožnov pod Radhoštěm
ČSN EN 61326-1:	class A
Testing according to: The test procedure:	ČSN EN 61326-1:2007 (idt EN 61326-1:2006),: instruction I 540-015-6, ČSN EN 61326-1

Testing - test results:
- ČSN EN 61000-4-2 ed.2:2009 (idt EN 61000-4-2:2009) – IS IN COMPLIANCE WITH
- ČSN EN 61000-4-8 ed.2:2010 (idt EN 61000-4-8:2010) – IS IN COMPLIANCE WITH
- ČSN EN 61000-4-11 ed.2:2005 (idt EN 61000-4-11:2004) – IS IN COMPLIANCE WITH
- ČSN EN 61000-4-4 ed.2:2005+A1:10 (idt EN 61000-4-4:2004+A1:10) – IS IN COMPLIANCE WITH
- ČSN EN 61000-4-5 ed.2:2007 (idt EN 61000-4-5:2006) – IS IN COMPLIANCE WITH
- ČSN EN 61000-4-6 ed.3:2009 (idt EN 61000-4-6:2009) – IS IN COMPLIANCE WITH.

Date of acceptance of the tested subject:	2013-03-05 and 3013-09-20
The tests executed by:	**TÜV SÜD Czech s.r.o.**

F 540 – 040 – 1 (2011-01-01) (Protokol EMC_odolnost_en)   page 1 of 11

Figure D-1. EMC test report – front page.

Test report reg. No. 06.752.285

2. EVALUATION OF THE TESTS:

2.1 The results of individual tests are recorded in the above presented tables separately for each tested discipline.

2.2 The records of the individual tests show the statement that the submitted device fulfils the functional criterion required by the standard in all performed tests.

Annexes:

Without annexes.

On the basis of the performed test we declare the following

conclusion:

The device is accordance with requirements of the harmonized standard ČSN EN 61326-1 for usage in industrial environments.

The tested equipment was not damaged during testing and remains after testing in a functional state

The above given conclusion is valid under these conditions:

Without conditions.

The test results given in this report apply only to the tested product.

Without the agreement of TÜV SÜD Czech s.r.o. the report shall be reproduced only as a whole.

At Ostrava, dated 2013-09-20

Tests carried out by the inspector of TÜV SÜD Czech s.r.o.: Ing. Josef Struška

Head of the office TÜV SÜD Czech s.r.o. : Ing. Roman Prášek, Ph.D.

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Figure D-2. EMC test report – conclusion

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