Freescale Semiconductor
Design Reference Manual

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Kinetis-M Two-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 one percent accuracy or better in the typical dynamic range of power measurement of 1000:1, whereas electro-mechanical meters have 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 two-phase electronic power meter based on the MKM34Z128CLL5 microcontroller. This microcontroller is part of the Freescale Kinetis-M series of MCUs. The Kinetis-M series 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 two-phase power meter reference design is intended for the measurement and registration of active and reactive energies in two-phase networks. It is targeted specifically at the American and Japanese regions. Depending on the target region, it is pre-certified according to different standards; the ANSI C12.20-2002, accuracy classes 0.2 and 0.5 for the U.S., and the international standard IEC 62053-22, accuracy classes 0.2S and 0.5S for Japan.

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, two low-power digital 3-axis Xtrinsic sensors for electronic tamper detection, and a Radio Frequency (RF) communication module for Automatic Meter Reading (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. The meter has no mechanical tampers, only electronic ones. One tamper event may be generated by an ultra-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 second tamper event may be generated by a low-power 3-axis Xtrinsic magnetometer, which can detect a magnetic field caused by an external strong magnet. This magnetic field may negatively affect the current transformers used inside the meter.

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 collection.

1.1 Specification

As previously indicated, the Kinetis-M two-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 two-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 two following tables according to the target version (U.S. or Japan):

Table 1-1. Kinetis-M two-phase power meter specification (U.S. version)

Type of meter	Two-phase residential active and reactive energy meter
Type of measurement	4-quadrant
Metering algorithm	Fast Fourier Transform or Filter based
Accuracy	ANSI C12.20-2002 Class 0.2 (for active and reactive energy)
Nominal Voltage	120 VAC ± 20%
Current Class	CL200
Test Current	30 A
Staring Current	50 mA
Nominal Frequency	60 Hz ± 6%
List of impulse numbers for FFT-based algorithm (imp/kWh, imp/kVArh)	500, 1000, 2000, 5000[2)], 10000[2)], 20000[2)], 50000[2)], 100000[2)]
List of impulse numbers for Filter-based algorithm (imp/kWh, imp/kVArh)	100, 200, 500, 1000, 2000, 5000, 10000, 20000, 50000[2)], 100000[2)], 200000[2)], 500000[2)], 1000000[2)]

Default Watt-hour (VAr-hour) constant	K_h=0.2 (Filter-based algorithm) or K_h=0.5 (FFT-based algorithm)
Functionality	V, A, kW, VAr, VA, kWh (import/export), kVArh (import/export), Hz, power factor, time, date, serial number and SW version
Voltage sensor	Voltage divider (VTR 2000:1)
Current sensor	Current Transformer (CTR 2000:1), type CHEM 9912192
Energy output pulse interface	Two super bright red LEDs (active and reactive energy)
Optoisolated pulse output (optional only)	Optocoupler (active or reactive energy)
User interface (HMI)	160-segment LCD, one user red LED
Electronic tamper detection	3-axis magnetometer MAG3110, 3-axis accelerometer MMA8491Q
Infrared interface[1)]	According to ANSI C12.18-2006
Isolated RS232 serial interface (optional only)	19200 Bd, 8 data bits, 1 stop bit, no parity
RF interface (the 1st option)	MC1322x-IPB radio module based on 2.4GHz IEEE® 802.15.4
RF interface (the 2nd option)	HAN/NAN radio modules based on 900MHz RF Mesh IEEE 802.15.4g/e and 6loWPAN/IPv6 connectivity
Internal battery (for RTC)	1/2AA, 3.6 V Lithium-Thionyl Chloride (Li-SOCI2) 1.2 Ah
Service type	Form 12S
Enclosure	According to ANSI C12.10-2004
Power consumption @3.3V and 22°C: • Normal mode (powered from mains) • Standby mode (powered from battery) • Power-down mode (powered from battery)	 16.0 mA [3)] (measurement mode) 192 μA (transition from normal to power-down, duration only 2.5 seconds) 2.6 μA [4)] (MCU only)

Table 1-2. Kinetis-M two-phase power meter specification (Japan version)

Type of meter	Two-phase residential active and reactive energy meter
Type of measurement	4-quadrant
Metering algorithm	Fast Fourier Transform or Filter based
Accuracy	Class 0.5S, IEC 62053-22, IEC 62052-11 (for active and reactive energy)
Nominal Voltage	100 VAC ± 20%
Maximum Current	60 A
Nominal Current	5 A
Staring Current	20 mA
Nominal Frequency	50 Hz ± 8%
List of impulse numbers (FFT-based algorithm) (imp/kWh, imp/kVArh)	500, 1000, 2000, 5000, 10000, 20000[2)], 50000[2)], 100000[2)]
List of impulse numbers (Filter-based algorithm) (imp/kWh, imp/kVArh)	100, 200, 500, 1000, 2000, 5000, 10000, 20000, 50000[2)], 100000[2)], 200000[2)], 500000[2)], 1000000[2)]
Default Watt-hour (VAr-hour) impulse number	50000 (Filter based algorithm) or 10000 (FFT based algorithm)
Functionality	V, A, kW, VAr, VA, kWh (import/export), kVArh (import/export), Hz, power factor, time, date, serial number and SW version
Voltage sensor	Voltage divider (VTR 2000:1)
Current sensor	Current Transformer (CTR 2000:1), type CHEM 9912192
Energy output pulse interface	Two super bright red LEDs (active and reactive energy)
Optoisolated pulse output (optional only)	Optocoupler (active or reactive energy)
User interface (HMI)	160-segment LCD, one user red LED
Electronic tamper detection	3-axis magnetometer MAG3110, 3-axis accelerometer MMA8491Q
Infrared interface[1)]	According to IEC1107
Isolated RS232 serial interface (optional only)	19200 Bd, 8 data bits, 1 stop bit, no parity

Internal battery (for RTC)	1/2AA, 3.6 V Lithium-Thionyl Chloride (Li-SOCl2) 1.2 Ah
Enclosure	According to ANSI C12.10-2004
Power consumption @3.3V and 22°C: • Normal mode (powered from mains) • Standby mode (powered from battery) • Power-down mode (powered from battery)	 16.0 mA [3] (measurement mode) 192 µA (transition from normal to power-down, duration only 2.5 seconds) 2.6 µA [4] (MCU only)

[1] *This functionality is not implemented in the current SW (Rev. 2.0.0.2).*
[2] *These impulse numbers are applicable only for low current measurement*
[3] *Valid for CORECLK=47.972352 MHz and without any RF communication module*
[4] *Magnetometer, accelerometer, EEPROM and IR interface are switched off (VAUX is not applied)*

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.

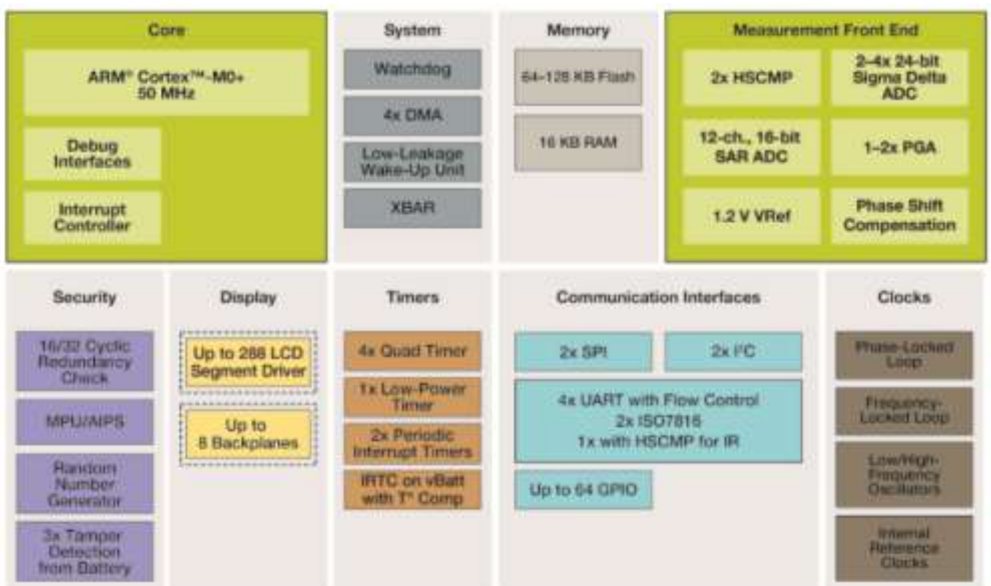

Figure 2-1. Kinetis-M block diagram

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. Currently, 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 to as non-billing. Further follows a description of the 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.

$$Wh = \int_{0}^{\infty} u(t)\, i(t) dt$$

Eq. 3-1

NOTE

The total active energy in a typical two-phase power meter application is computed as a sum of two individual active energies.

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.

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

NOTE

The total reactive energy in a typical two-phase power meter application is computed as a sum of two individual reactive energies.

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.

$$P = \frac{1}{T}\int_0^\infty u(t)\, i(t)dt$$ **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.

$$Q = \frac{1}{T}\int_0^\infty u(t - 90°)\, i(t)dt$$ **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:

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

$$URMS = \sqrt{\frac{1}{T}\int_0^T [u(t)]^2\, dt}$$ **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 two-phase power meter reference design uses an FFT-based metering algorithm [**2**] [**3**]. This particular algorithm calculates the billing and non-billing quantities according to formulas given in this section. The algorithm requires only instantaneous voltage and current samples to be provided at constant sampling intervals. This sampling process should provide a power-of-two number of samples during one input signal period. After a modification of the application software, it is also possible to use the Filter-based metering algorithm, whose computing process is completely different [**4**].

4 Hardware design

This section describes the power meter electronics, which are divided into four separate parts:

- Power supply
- Digital circuits
- Optional communication interfaces
- Analog signal conditioning circuits

The power supply part is comprised of 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 60 Hz (50 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, see subsection **4.1 Power supply**.

The digital part can be configured to support both basic and advanced features. The basic configuration is comprised of only the circuits necessary for power meter operation; i.e. microcontroller (MKM34Z128MCLL5), debug interface, LCD interface, and LED interface. 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 and 3-axis digital magnetometer, both for electronic tamper detection. For more information, see subsection **4.2 Digital circuits**.

The design also supports several types of optional communication interfaces, such as an RF 2.4GHz IEEE® 802.15.4 for AMR communication and remote monitoring, isolated open-collector pulse output for auxiliary energy measurement, an isolated RS232 interface as an optional communication interface, and an infrared interface for a basic utility provider communication. For more information, see subsection **4.3 Optional communication interfaces**.

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 **4.4 Analog circuits**).

The power meter electronics have been realized using a double-sided (two copper layers) printed circuit board (PCB). It is a very good compromise, compared to a more expensive multi-layer PCB, in order to validate the accuracy of the 24-bit SD ADC on the metering hardware optimized for measurement accuracy. **Figure C-1** and **Figure C-2** show the top and bottom views of the power meter PCB respectively.

4.1 Power supply

The user can use the 85-265 V AC-DC SMPS, which is directly populated on the PCB (see **Figure A-1)**, 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 JP3, JP4, JP5 and the DC (output) side to JP6, JP7. The output voltage of the suitable AC-DC power supply module must be 4.0 V ±5%.

As previously noted, the reference design is pre-populated with an 85-265 V AC-DC SMPS power supply based on the LNK302DN. This SMPS is non-isolated and capable of delivering a continuous current of up to 80 mA at 4.125 V [**5**]. When using the HAN/NAN radio communication modules (support for 900MHz RF Mesh IEEE 802.15.4g/e), the board's current consumption is much higher. In this case, there must be a more powerful type of this SMPS used, e.g. the LNK306DN with a proper L2 inductor (470 µH). The output current rating is extended to 360 mA in this case. The SMPS supplies the SPX3819 low dropout adjustable linear regulator, which regulates the output voltage (VPWR) by using two resistors (R53 and R54) according to the formula:

$$\boldsymbol{VPWR = 1.235\left[1 + \frac{R54}{R53}\right]} \quad \textbf{Eq. 4-1}$$

The resistor values R54=45.3 kΩ and R53=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 a bit higher current consumption: 128 KB SPI flash (U8), and potential external RF modules attached to an expansion header J2. All these circuits operate only 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 D19 and D20 diodes. When the power meter is connected to the mains, then the electronics are supplied through the bottom D20 diode from the regulated output voltage (VPWR). If the power meter is disconnected from the mains, then the D20 and upper D19 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 L3 and L4, and the small capacitors next to the power pins (C43…C48). 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 L3 and L4 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.

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), which is backed up by the 1/2AA 3.6 V Li-$SOCl_2$ battery (BT1), is active even if the power meter electronics are disconnected from the mains. It supplies the microcontroller device (U5) and 3 LEDs. The regulated output voltage (VPWR) supplies the digital circuits that can be switched off during the standby and power-down operating modes. This is only 128KB SPI Flash memory (U8) in this section. For other circuits supplied by the VPWR voltage, see **Subsection 4.3-Optional communication interfaces**. In order to optimize power consumption of the meter electronics in standby and power-down modes, the auxiliary voltage (VAUX) is sourced from the PTF2 pin of the microcontroller. The microcontroller uses this pin to power the 4KB SPI EEPROM (U4), IR Interface (Q1), the 3-axis digital accelerometer (U7), and the 3-axis digital magnetometer (U6), if in use.

4.2.1 MKM34Z128MCLL5

The MKM34Z128MCLL5 microcontroller (U5) 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 C13…C19
- LCD charge pump capacitors C25…C28
- External reset filter C24 and R42
- 32.768 kHz crystal Y1

An indispensable part of the power meter is the LCD (DS1). Connector J5 is the SWD interface for MCU programming.

CAUTION

The debug interface (J5) is not isolated from the mains supply. Use only galvanic isolated debug probes for programming the MCU when the power meter is supplied from the mains supply.

4.2.2 Output LEDs

The microcontroller uses two timer channels to control two super-bright LEDs (see **Figure 4-1**), D13 for active energy and D14 for reactive energy. These LEDs are used at the time of the meter's calibration or verification. The timers' outputs are routed to the respective device pins. 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.

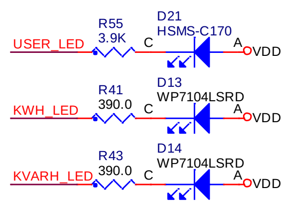

Figure 4-1. Output LEDs control

The SMD user LED (D21) is driven by software through output pin PTF0. It blinks when the power meter enters the calibration mode, and turns solid after the power meter is calibrated and is operating normally. All output LEDs can work only in the normal operation mode. These LEDs may be also seen as a simple unidirectional communication interface.

4.2.3 MMA8491Q 3-axis digital accelerometer

This sensor can be used for advanced tamper detection. In the schematic diagram, the MMA8491Q 3-axis digital accelerometer is marked as U7 (see **Figure 4-2**). The accelerometer communicates with the microcontroller through the I2C data lines; therefore, the external pull-ups R45 and R46 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. Because of the very small supply current of this sensor, it is powered directly by the PTF2 pin of the microcontroller (VAUX). The sensor can work in all three operating modes. 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.

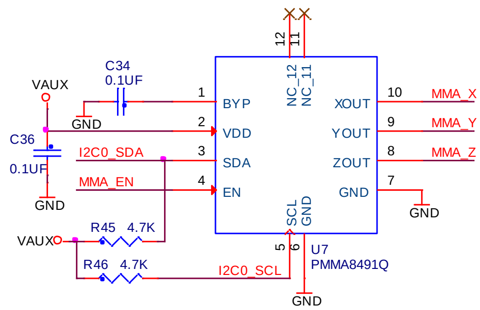

Figure 4-2. MMA8491Q sensor control

4.2.4 MAG3110 3-axis digital magnetometer

This sensor can be used for advanced tamper detection as well. In the schematic diagram, the MAG3110 3-axis digital magnetometer is marked as U6 (see **Figure 4-3**). The magnetometer communicates with the microcontroller through the I2C data lines and uses the same pull-ups resistors as the accelerometer, i.e. R45 and R46. Similarly to the accelerometer, the magnetometer is also powered directly by the PTF2 pin of the microcontroller (VAUX). Theoretically, it can work in all operating modes, but in practice there is no reason to run it in the standby or power-down modes. This sensor can detect an external magnetic field caused by a strong magnet, which may influence a measurement because of the sensitive current transformers (CT) used inside the meter.

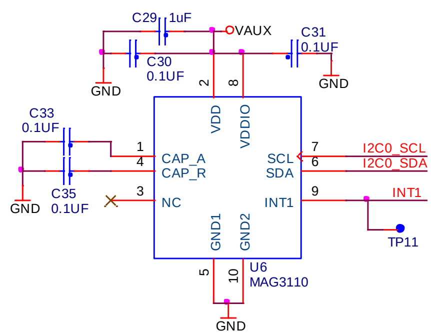

Figure 4-3. MAG3110 sensor control

4.2.5 128 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 4-4**.

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 (normal operation mode).

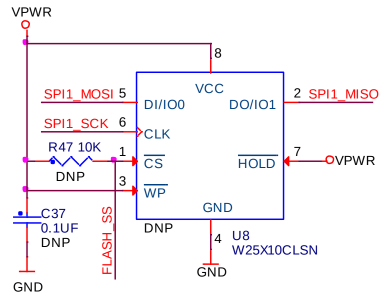

Figure 4-4. 128 KB SPI flash control

4.2.6 4 KB SPI EEPROM

The 4 KB SPI EEPROM (CAT25040VE) can be used for parameter storage (backup of the calibration parameters). The connection of the EEPROM memory to the microcontroller is made through the SPI0 module, as shown in **Figure 4-5**. Because of the very small supply current of this memory, it is powered directly by the PTF2 pin of the microcontroller (VAUX). Powering from the pin allows the microcontroller to switch off the memory, and thus minimize current consumption in the standby mode. The maximum communication throughput is limited by the CAT25040VE device to 10 Mbit/s. The memory is prepared to work in normal and standby operation modes.

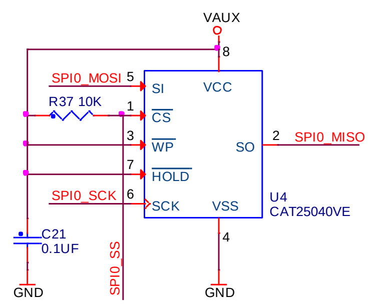

Figure 4-5. 4 KB SPI EEPROM control

4.3 Optional communication interfaces

Apart from the main unidirectional communication interface (see subsection **4.2.2-Output LEDs**), the meter also supports several types of optional communication interfaces that extend its usage. The main components of these interfaces are: isolated RS232 interface (U2, U3), isolated open-collector pulse output interface (U1), an expansion header (J2) for some RF daughter card, and an infrared interface. All of these communication interfaces are intended to run in the normal operation mode only.

4.3.1 RF interfaces

The expansion header J2 (see **Figure 4-6**) is intended to interface the power meter with two types of Freescale's ZigBee small factor radio modules. Firstly, it supports an RF MC1323x-IPB radio module based on 2.4GHz IEEE 802.15.4. Secondly, it supports the K11 expansion board (for a schematic, see

Appendix B), which is used for connecting two HAN/NAN small radio sub-modules based on 900MHz RF Mesh IEEE 802.15.4g/e and 6loWPAN/IPv6 connectivity (not included in the schematic in **Appendix B**). The J2 expansion header provides the regulated output voltage VPWR to supply these RF communication modules. Therefore, all modules should accept a supply voltage of 3.6 V with a continuous current of up to 60 mA (MC1323x-IPB) or up to 150 mA (K11 HAN/NAN board with two RF sub-modules). Both RF daughter cards need different MCU peripherals, therefore the J2 expansion header supports connections to SPI1, SCI3 and the I2C1 peripherals, as well as to several I/O lines for modules reset, handshaking, and control.

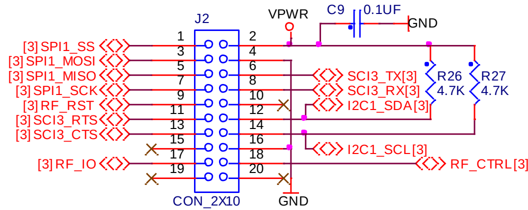

Figure 4-6. RF interfaces control

NOTE

Only one RF daughter card can be operated at one time inside the meter, that is, the MC1323x-IPB or the K11 HAN/NAN with two RF sub-modules.

4.3.2 Isolated open-collector pulse output interface

Figure 4-7 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_OUT7) 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 J3.

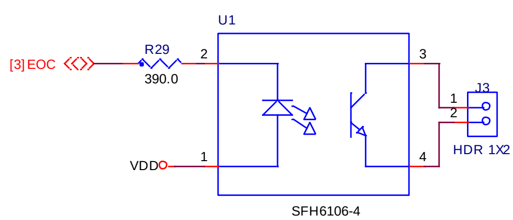

Figure 4-7. Open-collector pulse output control

NOTE

The J3 output connector is not bonded to the meter’s enclosure. Therefore, the described interface is primarily used at the time of development (uncovered equipment).

4.3.3 IR interface

The power meter has a galvanic isolated optical communication port, as per IEC 1107 (Japan version) or ANSI C12.18 (U.S. version), so that it can be easily connected to a hand-held common meter reading instrument for data exchange. The IR interface is driven by the SCI0. The IR interface schematic part is shown in the **Figure 4-8**. Because of the very small supply current of the NPN phototransistor (Q1), it is powered directly by the PTF2 (PTF7) pin of the microcontroller. Powering from the pin allows the microcontroller to switch off the phototransistor circuit, and thus minimize current consumption in the standby mode.

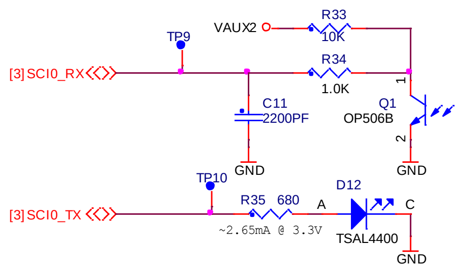

Figure 4-8. IR control

NOTE

Alternatively, this interface can be also used for waking up the meter (from power-down to standby mode) by an external optical probe. This feature has impact of increasing the current consumption in both operation modes.

4.3.4 Isolated RS232 interface

This communication interface is used primarily for real-time visualization using FreeMASTER [**6**]. The communication is driven by the SCI1 module of the microcontroller. Communication is optically isolated through the optocouplers U2 and U3. 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 U2 and the primary side of the U3 optocouplers. The communication interface, including the D9…D11, C10, R30, and R32 components, required to supply the optocouplers from the transition control signals, is shown in **Figure 4-9**.

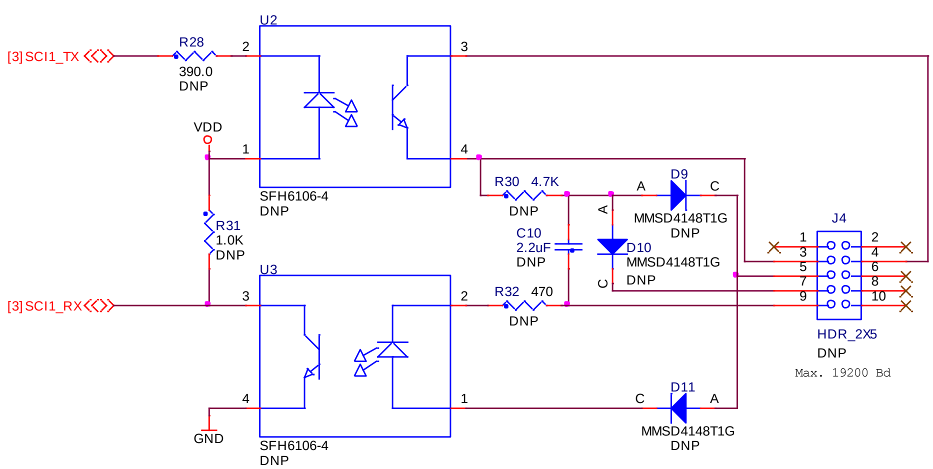

Figure 4-9. RS232 control

NOTE

The J4 output connector is not bonded to the meter's enclosure. Therefore, the described interface is primarily used at the time of development (uncovered equipment).

4.4 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 (typically 2000:1) and the relatively low input signal range (from microvolts to several tens of millivolts). All analog circuits are described in the following subsections.

4.4.1 Phase current measurement

The Kinetis-M two-phase power meter reference design is optimized primarily for current transformers measurement. Alternatively, the Rogowski coils can be also used. Unfortunately, the shunt resistors cannot be used here due to a strict requirement for the galvanic isolation between each phase. The interface of a current sensor to the MKM34Z128MCLL5 device is very simple. Because of the two-phase meter, this part of the interface is doubled (see **Figure 4-10)**. Firstly, there are burden resistors (R15+R18 and R21+R24) which transform currents from both the CT sensors to voltages. The values of these burden resistors are adjusted to have a ±0.25 V peak on each individual AFE input. This is due to using the whole AFE range for the maximum phase current (see the tables in **Section 1.1** for the meter's specification). Secondly, there are anti-aliasing low-pass first order RC filters attenuating signals with frequencies greater than the Nyquist frequency. The cut-off frequency of each individual analog filter implemented on the board is 33.863 kHz; such a filter has an attenuation of 39.15 dB at the Nyquist frequency of 3.072 MHz.

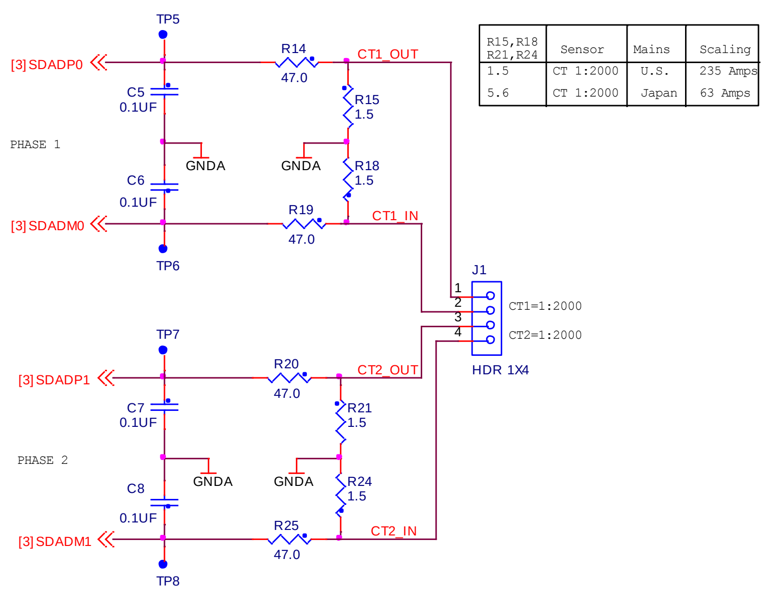

Figure 4-10. Phase currents signal conditioning circuit

4.4.2 Phase voltage measurement

A simple voltage divider is used for the line voltage measurement. Because of the two-phase meter, this voltage divider is doubled for the second phase (see **Figure 4-11)**. In a practical implementation, it is better to design each particular divider from several resistors connected serially due to the power dissipation. Let us analyze a situation for line L2 for example. One half of this total resistor consists of R1, R2, R3, and R4, the second half consists of resistor R8. The resistor values were selected to scale down the 339.4 V peak input line voltage (240 V_{RMS}*√2) to the 0.2204 V peak input signal range of the 24-bit SD ADC. The voltage drop and power dissipation on each of the R1…R4 MELF0204[1] resistors are below 60 V and 24 mW, respectively. The anti-aliasing low-pass filter of the phase voltage measurement circuit is set to a cut-off frequency of 34.029 kHz. Such an anti-aliasing filter has an attenuation of 39.11 dB at the Nyquist frequency of 3.072 MHz.

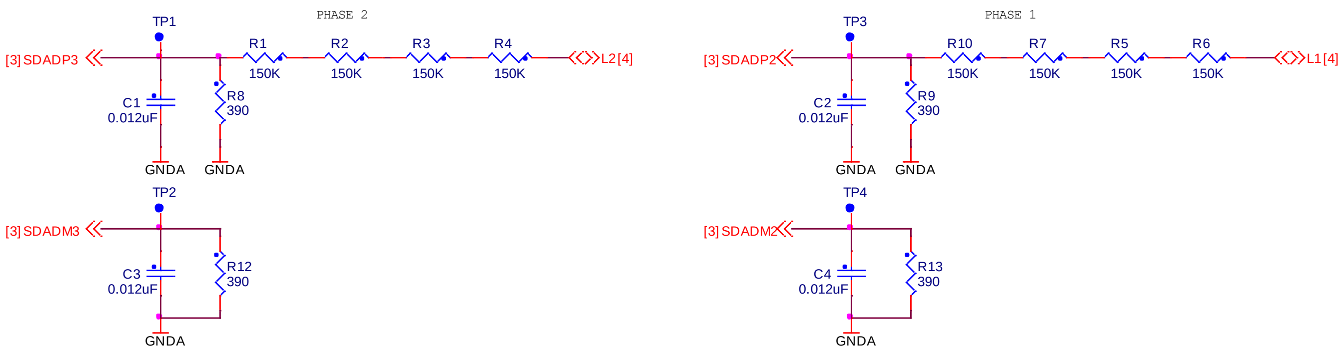

Figure 4-11. Phase voltages signal conditioning circuit

NOTE

Both phase voltage inputs are scaled to 240 V_{RMS} (prepared for Form 2S configuration), although the standard voltage range is 100/120 V_{RMS} (Form 12S).

4.4.3 Auxiliary measurements

Figure 4-12 shows the part of 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 R39=1.6 MΩ and R40=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.

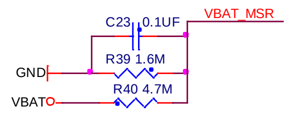

Figure 4-12. Battery voltage divider circuit

[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.

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 (see the following figure) 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.

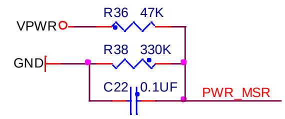

Figure 4-13. Supply voltage divider circuit

5 Software design

This section describes the software application of the Kinetis-M two-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 6.40.2) with high optimization for execution speed (except for loop unrolling). The software application is based on the Kinetis-M bare-metal software drivers [**7**] and the FFT-based metering algorithm library [**2**] [**3**].

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, controls the LCD, stores and retrieves parameters from the NVMs, and allows application remote monitoring and control. The application monitoring and control is performed through FreeMASTER.

The following figure shows the software architecture of the power meter including interactions of the software peripheral drivers and application libraries with the application kernel. All tasks executed by the Kinetis-M two-phase power meter software are briefly explained in the following subsections.

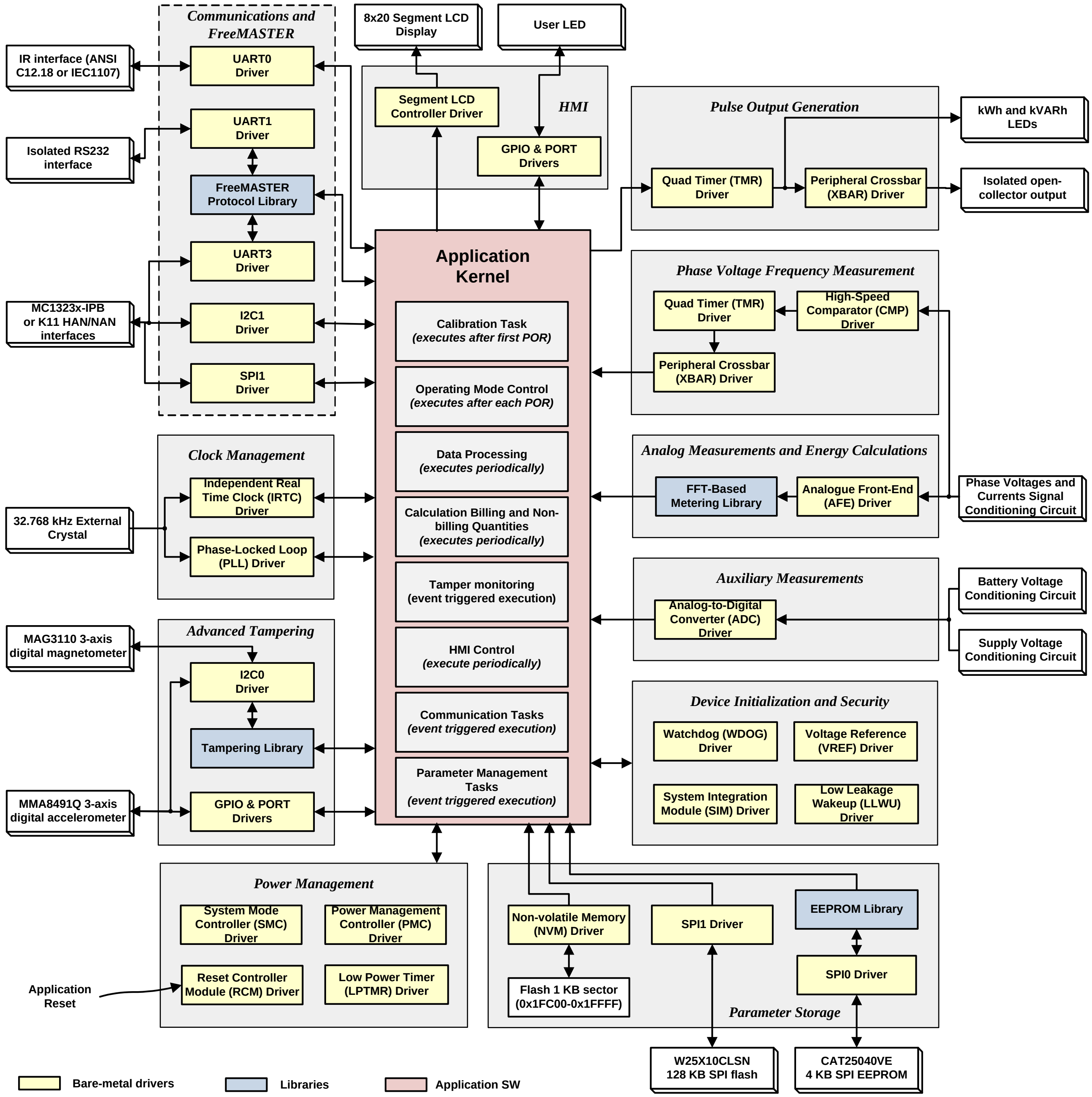

Figure 5-1. Software architecture

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(s) name	Trigger source	IRQ priority	Calling period
Power meter calibration	Performs power meter calibration	2phmet.c 2phmet.h	calib_AFE	device reset	-	after the first device reset[1]
Operating mode control	Controls transitioning between power meter operating modes		norm_mode_hw_init stby_mode_hw_init	device reset	-	after every device reset
HMI control	Updates LCD with new values and transitions to new LCD screen		lptmr_callback	LPTMR interrupt	Level 3 (lowest)	periodic 250 ms
Data processing	Reads digital values from the AFE		afechX_callback	AFE CHx conversion complete IRQ[2]	Level 1	periodic 166.6 µs
	Zero-cross detection		cmp_callback	CMP1 interrupt (rising edge)	Level 1	periodic 20 or 16.6 ms (50 or 60 Hz)
Calculation billing and non-billing quantities	Calculates billing (*kWh, kVArh*) and non-billing (*U, I, P, Q, S, cos φ*) quantities and performs scaling	2phmet.c 2phmet.h metering2.c metering2.h	swint0_callback	SW0 interrupt	Level 3 (lowest)	periodic 20 or 16.6 ms (50 or 60 Hz)
	LEDs dynamic pulse output generation		qtim1_callback qtim2_callback	TMR1 or TMR2 IRQ compare flag	Level 0 (highest)	asynchronous
Tamper monitoring	Performs advanced electronic tampering	tamperlib.c tamperlib.h	MMA8491_GetTamperEvent MAG3110_GetTamperEvent	PORTD rising edge IRQ (MAG3110 new data ready)	Level 3 (lowest)	periodic 200 ms
Communication tasks	K11 HAN/NAN communication	IIC_Zigbee_SE10.c IIC_Zigbee_SE10.h	Slave_IIC_Data_Read_CB Slave_IIC_Data_Write_CB	I2C1 Rx/Tx interrupt	Level 1	asynchronous
	FreeMASTER application monitoring and control	freemaster_*.c freemaster_*.h	FMSTR_Init	UART1 or UART3 Rx/Tx interrupt	Level 2	asynchronous
	FreeMASTER Recorder		FMSTR_Recorder	AFE CHx conversion complete IRQ[2]	Level 2	periodic 166.6 µs
Parameter management	Reads parameters from the flash or from the external EEPROM	config.c config.h cat25.c cat25.h	CONFIG_Read CAT25_Read	device reset	-	-
	Writes parameters to the flash and to the external EEPROM	2phmet.c 2phmet.h	power_down	after successful calibration or switching-off	-	-
	Writes parameters to the external EEPROM	cat25.c cat25.h	CAT25_Write	LPTMR interrupt	Level 3 (lowest)	periodic 2 minutes

1) In addition, a special load point must be applied by the test equipment (see **Table 5-2**).
2) CHx = CH1, CH2, CH3 or CH4.

5.2.1 Power meter calibration

The power meter is calibrated with the help of the special test equipment [**1**]. The calibration task runs whenever a non-calibrated power meter is connected to the mains. The user LED flashes periodically at this time. The running calibration task measures the phase voltage and phase current signals generated by the test equipment; it scans for a defined phase voltage and phase current waveforms with a 45-degree phase shift. The voltage and current signals should be the first harmonic only and should be applied on both pairs of phases, i.e. U1, I1, U2, and I2. These absolutely correct values depend on the power meter version (see **Table 5-2**). All these values should be precise and stable during the calibration itself; the power meter final precision strongly depends on it.

Table 5-2. List of calibration load points

Power meter version	Current range $I_{NOM}(I_{MAX})$ [A]	Voltage load point U_{NOM} [V]	Current load point I_{NOM} [A]	Frequency [Hz]	U to I phase shift [degree]
U.S.: ANSI C12.20 (Form 12S)	30(200)	120	30	60 (50)	45
Japan: IEC62053-22	5(60)	100	5	50 (60)	45

Each voltage and current load point is applied with two different frequencies (50 and 60 Hz) independently. It is not mandatory, but thanks to this, the calibrated power meter is prepared for working with different mains around the world. If the calibration task detects such a load point, then the calibration task calculates the calibration gains, and phase shift using the following formulas:

$$u\_gain_j = U_{NOM} * u\_gain_j / U_{RMS_j} \qquad \text{Eq. 5-1}$$

$$p\_gain_j = I_{NOM} * p\_gain_j / I_{RMS_j} = I_{NOM} * p\_gain_j * U_{RMS_j} / S_j \qquad \text{Eq. 5-2}$$

$$u\_delay_j = (P_j - Q_j)/p_{DIV} \qquad \text{Eq. 5-3}$$

Where:

u_gain, p_gain are unsigned 16-bit values of both the voltage and power gains for a known frequency; these are used in the *scaling_power* function after calibration,

u_delay is the signed 16-bit value of the calculated phase shift caused by parasitic inductance of the current transformer for a known frequency; it is used in the AFE channel delay register after calibration (in the *afe_chan_init* function),

j-index is the number of the phase (0=Phase 1, 1=Phase 2),

U_{NOM}, I_{NOM} are calibration (load) points (see **Table 5-2**),

U_{RMS}, P, Q are scaled non-billing quantities measured by the non-calibrated meter,

I_{RMS}, S are scaled computed quantities: $S = \sqrt{P^2 + Q^2}$; $I_{RMS} = S / U_{RMS}$,

p_{DIV} is the divide factor (4 for the U.S. meter and 1 for the Japan meter).

NOTE

The AFE offsets are not calibrated due to the metering algorithm used, which ignores this phenomenon for power computing [**2**].

The calibration task terminates by storing the calibration gains and phase shifts into two non-volatile memories; the internal flash memory and the external EEPROM memory (backup storage). The whole calibration process is terminated by resetting the microcontroller device finally. The recalibration of the power meter can be re-initiated later from the FreeMASTER tool by rewriting the *Calibration status* flag.

NOTE

The user LED is permanently turned off after successful calibration.

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 can see the latest kWh value on the LCD for a limited time, 2.5 seconds)
- **Power-down** (electricity is disconnected with no user interaction)

The following figure 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 electricity 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, core and flash clock frequency is generated by the FLL and is 47.972 MHz. The AFE clock frequency is generated by the PLL and is 12.288 MHz. The power meter electronics consume 16.0 mA in the normal mode[2].

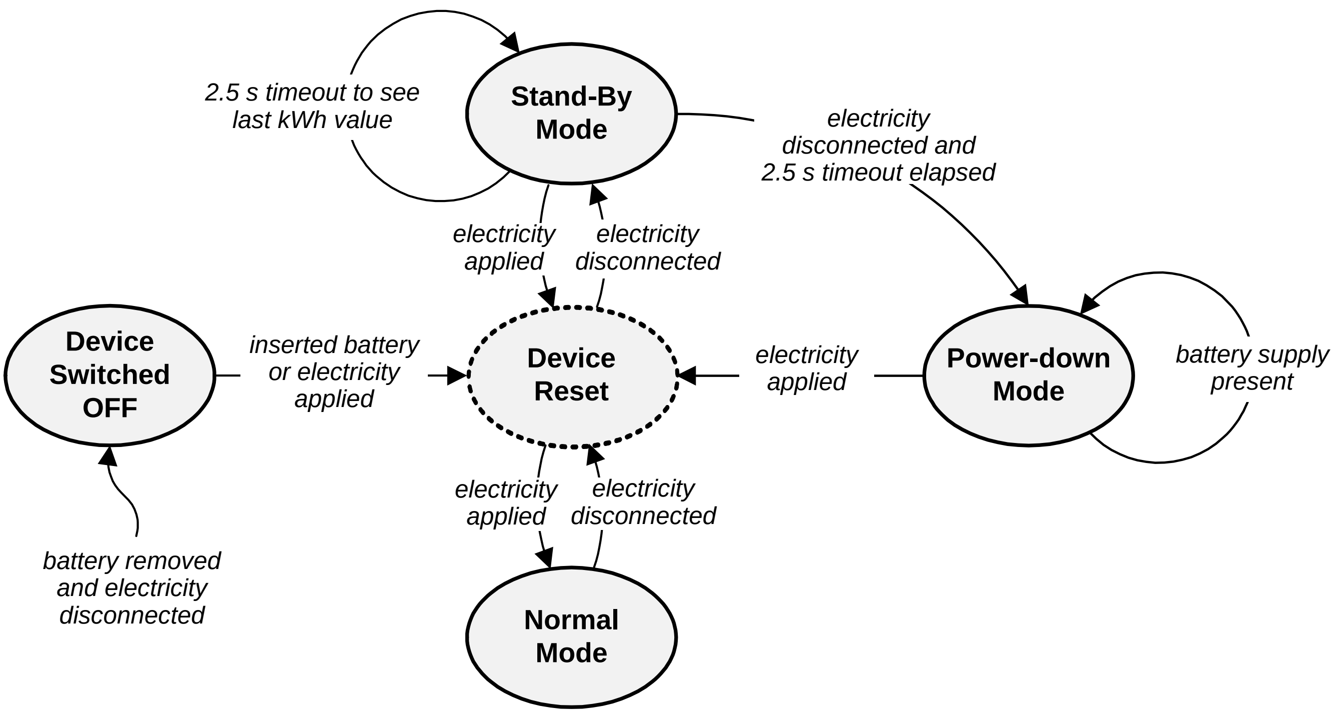

Figure 5-2. Operating modes

If the electricity is not applied, then the software application enters the standby mode firstly. This mode performs a transition between the normal mode and the power-down mode with duration of only 2.5 seconds. The power meter runs from the battery during this mode and the user can see the latest value of the import active energy on the LCD (the most important value for the user or utility). All software tasks are stopped except for the LCD 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 192 µA approximately. This current is discharged from the 3.6V Li-$SOCl_2$ (1.2Ah) battery, resulting in 4,400 hours of operation approximately (0.5 year battery lifetime).

[2] This is valid for CORECLK=47.972352 MHz and without any RF communication module.

Finally, when the duration of the standby mode has elapsed, the power meter goes into the power-down mode. The MKM34Z128MCLL5 device is forced to enter VLLS0 mode, where recovery is only possible when the mains is supplied. The power meter runs from the 3.6V Li-$SOCI_2$ (1.2Ah) battery during this mode. The power-down mode is characterized by a battery current consumption of 2.6 μA, which results in 270,000 hours of operation approximately (more than 20 year battery lifetime).

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 high priority level and is triggered asynchronously when the AFE result registers receive new samples. The task reads the phase voltage and phase current samples from four AFE result registers (two voltages and two currents), and writes these values to the buffers for use by the calculation task.

Another separate task monitors the mains zero-crossings, which is necessary for starting the main calculation process by a software interrupt (one complete calculation process per one signal period). This task also backs up the buffers with current AFE results to prevent an overwrite of these values by new AFE results.

5.2.4 Calculations

The execution of the calculation task is carried out when the SW0 interrupt is generated. This interrupt is caused by a zero-crossing of the input signal. This is done periodically at the beginning of each signal period. At this time, all circle buffers are filled up with the AFE results from the previous signal period. Therefore, the execution period of the calculation task depends on the input signal frequency. The calculation task performs the power computation by the *PowerCalculation* function, according to the metering algorithm used ([**2**] [**3**]), and also scales the results by the *scaling_power* function, using the calibration gains obtained during the calibration phase:

$$U_{RMS_j} = u\_gain_j * U_{FFT_j} / u_{DIV} \qquad \text{Eq. 5-4}$$

$$P_j = p\_gain_j * P_{FFT_j} / p_{DIV} \qquad \text{Eq. 5-5}$$

$$Q_j = p\_gain_j * Q_{FFT_j} / p_{DIV} \qquad \text{Eq. 5-6}$$

$$S_j = p\_gain_j * S_{FFT_j} / p_{DIV} \qquad \text{Eq. 5-7}$$

Where: U_{RMS}, P, Q, S are scaled non-billing values,
u_gain, p_gain are calibration parameters (see **Section 5.2.1**),
$U_{FFT}, P_{FFT}, Q_{FFT}, S_{FFT}$ are FFT outputs; not scaled, and non-billing values,
u_{DIV}, p_{DIV} are voltage and power divide constants for rough basic scaling,
j-index is the number of the phase (0=Phase 1, 1=Phase 2).

These scaled non-billing values are used for computing the billing values (energies) by the *EnergyCalculation* function consecutively, and also for producing a low-jitter, high dynamic range pulse output waveform for two energy LEDs (kWh and KVArh).

NOTE

I_{RMS} and $cos\ \varphi$ values are computed indirectly in the HMI task (see **Section 5.2.5**).

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, calculates the mains frequency, runs the calibration task (see **Section 5.2.1**), computes any remaining non-billing quantities (I_{RMS}, $cos\ \varphi$), and formats data into a string that is displayed on the LCD. Because there is no user push-button in the meter, this task also deals with scrolling the values on the LCD every 5 seconds (see **Table 6-1**). This task also provides both the phase and gains compensation according to the measured frequency (u_gain, p_gain, and u_delay parameters).

5.2.6 Tamper monitoring

Because there isn't any mechanical push-button used for tamper detection, the meter uses an advanced electronic version. This includes two types of 3-axis sensor, one for cover opening detection (MMA8491Q) and the other for magnetic tamper detection (MAG3110). The application software supports a full tamper library for controlling these sensors. The communication with these sensors is based on an interrupt, which comes periodically from the MAG3110 sensor when new data is ready. The relevant interrupt service routine is not only used for reading the MAG3110 output, but also for scanning the MMA8491Q sensor, which doesn't generate any interrupt.

5.2.7 Communication tasks

5.2.7.1 FreeMASTER communication task

The FreeMASTER establishes a data exchange with the PC. The communication is fully driven by the UART1 or UART3 Rx/Tx interrupts, which generate interrupt service calls with priority Level 2. The priority setting guarantees that data processing and calculation tasks are not impacted by the communication. Assigning the right UART port is selected by the *SCIx_PORT* program constant in the *freemaster_cfg.h* file. For using the FreeMASTER on the RF 2.4 GHz interface (see **Subsection 4.3.1-RF interfaces**), the *SCIx_PORT* constant should be set to 3, whereas for using on a basic isolated RS232 interface (see **Subsection 4.3.4-Isolated RS232 interface**), this constant should be set to 1. The power meter acts as a slave device answering packets received from the master device (PC). The recorder function is called inside the *afechX_callback* interrupt service routine every 166.6 µs. For more information about using FreeMASTER, refer to **Subsection 7- FreeMASTER visualization**.

5.2.7.2 HAN/NAN communication task

This task is used for Home Area Network (HAN) and Neighborhood Area Network (NAN) communication. The task is fully driven by the I2C1 Rx/Tx interrupt, which generates interrupt service calls with priority Level 1. These are asynchronous interrupts. The HAN/NAN communication concept is based on a wired communication between the metering MCU (MKM34Z128MCLL5), which is the master, and the K11 HAN/NAN expansion board, which is the slave (from the I2C point of view). The K11 expansion board contains the ZigBee IP Smart Energy 2.0 Profile stack for directly driving two small RF radio modules, which are part of the K11 board. For more information, refer to **Section 8- HAN/NAN visualization**.

5.2.8 Parameter management

The current software application uses the last 1024 bytes sector of the internal flash memory of the MKM34Z128MCLL5 device for parameter storage. There is also an external 4 kB EPROM used for the same purpose, but as a backup storage. The main purpose for using these NV memories is to save all the calibration parameters. By default, parameters are written after a successful calibration and read after each device reset. In addition, storing and reading parameters can be also initiated through the FreeMASTER independently (see also **Subsection 7- FreeMASTER visualization**).

5.3 Performance

Table 5-3 shows the memory requirements of the Kinetis-M two-phase power meter software application[3].

Table 5-3. Memory requirements

Function	Description	Flash size [KB]	RAM size [KB]
Application framework	Complete application without all libraries and FreeMASTER	25.882	5.871
FFT-based metering library	FFT-based metering algorithm library	6.484	-
Tamper library	MAG3110 and MMA8491Q tamper library	1.524	0.02
EEPROM library	CAT25040VE EEPROM library	0.738	-
FreeMASTER	FreeMASTER protocol and serial communication driver	2.328	4.309
Grand Total		**36.956**	**10.200**

The software application reserves about 4 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 81).

The system clock of the device is generated by the FLL (except for the AFE clock). In the normal operating mode, the FLL multiplies the clock of an external 32.768 kHz crystal by a factor of 1464, hence generating a low-jitter system clock with a frequency of 47.972352 MHz. Such a system clock frequency is absolutely sufficient for executing the fully functional software application.

6 Application set-up

The following figures show both the front panel description and the 12S connection wiring diagram of the Kinetis-M two-phase power meter.

Among the main capabilities of the power meter, is the registering of the active and reactive energy consumed by an external load. After connecting the power meter to the mains, the power meter

[3] Application is compiled using the IAR Embedded Workbench for ARM (version 6.40.2) with high optimization for execution speed (except for Loop unrolling). Memory requirements are valid for S/W Rev. 2.0.0.2. (December 2013).

transitions from the power-down mode to the normal mode. In the normal operation mode, the LCD is turned on and firstly shows the last quantity (value). Because there is no user push-button in the meter, the next value is shown periodically every 5 seconds. There is the list of all values shown on the meter's display in the correct order in the **Table 6-1**. After disconnecting the power meter from the mains, the power meter goes from the normal mode to the standby mode which is active only for several seconds. During this time, the meter is powered from the battery and shows only the latest active imported energy quantity (kWh) without any other functionality. Most of the peripherals are asleep at this time. After this short time, the LCD is switched off and the meter goes into the deeper power-down mode. The meter is powered from the battery in this mode until its next connection to the mains.

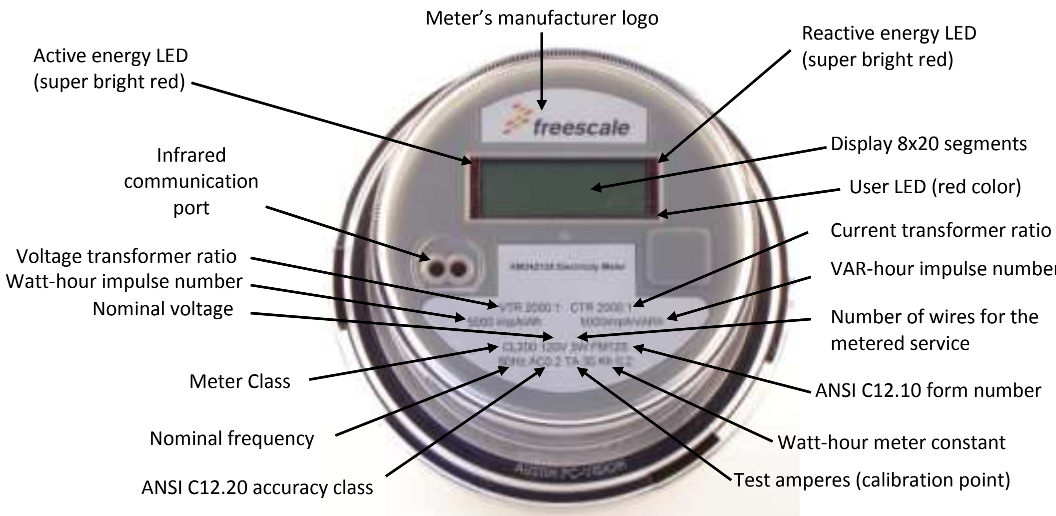

Figure 6-1. Kinetis-M two-phase power meter front panel description

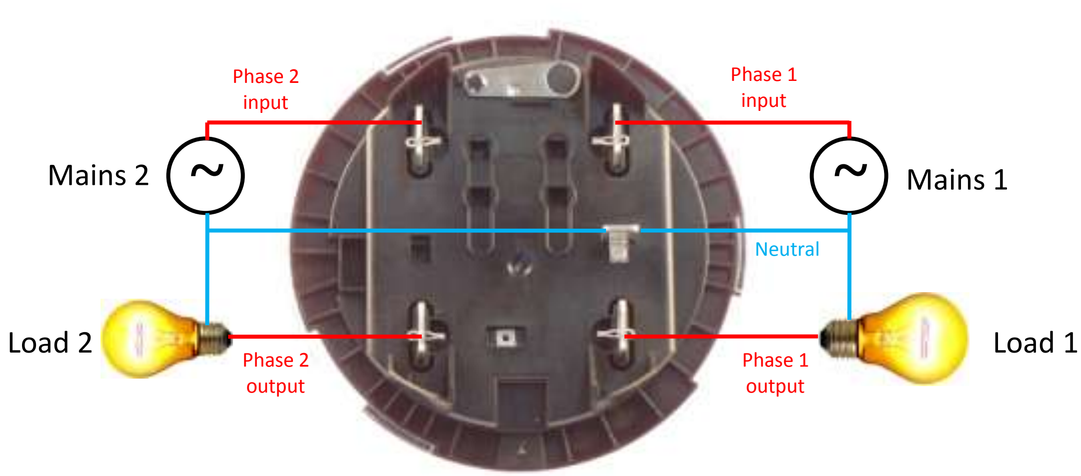

Figure 6-2. Kinetis-M two-phase power meter wiring diagram

NOTE

This power meter can work in purely single-phase installations too. In this case, use only the Phase 1 and Neutral inputs on the meter.

Table 6-1. The menu item list

Value	Unit	Format	OBIS code	Auxiliary symbols
Line voltage (phase 1)	V_{RMS}	#.## V	32.7.0	L1
Line voltage (phase 2)			52.7.0	L2
Line current (phase 1)	A_{RMS}	#.### A	31.7.0	I1
Line current (phase 2)			51.7.0	I2
Signed active power P (phase 1) [4]	kW	#.### kW (+ import, - export)	1.7.0	I1, L1, →, ←
Signed active power P (phase 2) [4]			1.7.0	I2, L2, →, ←
Signed reactive power Q (phase 1) [4]	VAr	#.## VAr (+import, - export)	3.7.0	I1, L1, +Q, -Q
Signed reactive power Q (phase 2) [4]			3.7.0	I2, L2, +Q, -Q
Apparent power S (phase 1)	VA	#.## VA	9.7.0	I1, L1
Apparent power S (phase 2)			9.7.0	I2, L2
Signed power factor (phase 1)	-	#.### (+motor mode, - generator mode)	33.7.0	I1, L1, cos φ, I, C
Signed power factor (phase 2)			53.7.0	I2, L2, cos φ, I, C
Frequency[1]	Hz	#.### Hz	14.7.0	-
Active energy imported[2] (ph 1+ph 2)	kWh	#.### kWh	1.8.0	L1, L2
Active energy exported[2] (ph 1+ph 2)			2.8.0	L1, L2
Reactive energy imported[3] (ph 1+ph 2)	kVArh	#.### kVArh	3.8.0	L1, L2
Reactive energy exported[3] (ph 1+ph 2)			4.8.0	L1, L2
Date	-	MMM.DD.YYYY	-	🕒
Time	-	HH.MM.SS + WDAY	-	🕒
Serial number and SW version	-	SN: #### + #.#.#.# (SW)	-	-

[1] Frequency is measured when phase 1 (or both phases) is connected to the meter
[2] Total active energy (import + export) is computed in the case of the Filter-based metering algorithm
[3] Total reactive energy (import + export) is computed in the case of the Filter-based metering algorithm
[4] The sign of both powers (P and Q) provide information about the energy flow direction (see the following table).

Table 6-2. Energy flow direction

Quadrant	Power factor	Powers	Mode	I to U phase shift
I	cos φ, I	+P, +Q	Motor mode with inductive load	Lagging current
II	-cos φ, I	-P, +Q	Inductive acting generator mode	Leading current
III	-cos φ, C	-P, -Q	Capacitive acting generator mode	Lagging current
IV	cos φ, C	+P, -Q	Motor mode with capacitive load	Leading current

There are two Freescale electronic tamper detection sensors inside the meter. Firstly, there is a magnetometer sensor, which can detect a magnetic field caused by a strong external magnet. This sensor works only in the normal operation mode. Secondly, there is an accelerometer sensor, which can detect some unexpected movements of the meter itself or some parts of the meter, e.g. the front cover due to tamper detection. When some tampering occurs, the applicable symbol appears on the LCD for a short time. See also **Figure 6-3** for description of the meter's entire display.

NOTE

The information about the tamper event is deliberately not saved into the non-volatile memory due to repeated customer's evaluation.

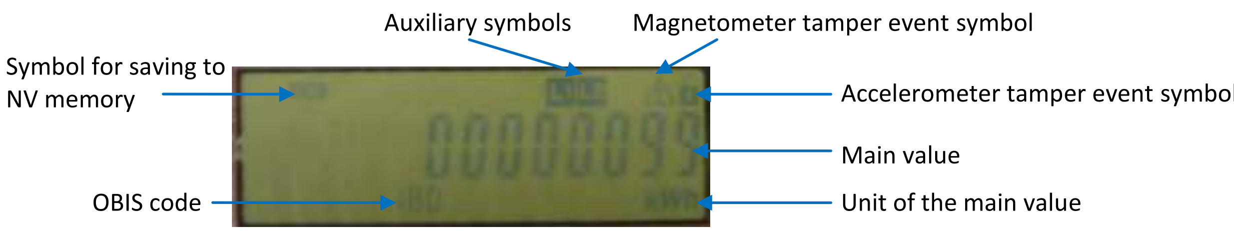

Figure 6-3. Power meter display description

Both energy LEDs (kWh and kVArh) flash simultaneously with the internal energy counters during the normal operation mode. LED kWh is the sum of both active energies (imported and exported) and LED kVArh is the sum of both reactive energies (imported and exported). All these active and reactive energy counters are periodically saved every 2 minutes into the external EEPROM memory (backup storage). An applicable symbol for data saving flashes on the LCD at this time. These energy quantities remain in the memory after resetting the Power Meter. To remotely clear these energy counters, you should use the FreeMASTER application (see **section 7-FreeMASTER visualization**) and apply the *REMOTE COMMAND/CLEAR ENERGY COUNTERS* command.

7 FreeMASTER visualization

The FreeMASTER data visualization software is used for data exchange [**6**]. The FreeMASTER software running on a PC communicates with the Kinetis-M two-phase power meter over a defined interface. This 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.

There can be several types of defined interfaces used for communication between the meter itself and the remote PC:

- 2.4GHz RF interface based on the IEEE 802.15.4 standard (default interface),
- An isolated RS232 interface (not bonded to the meter's enclosure, for development only),
- An infrared interface (optional only).

For the hardware formation of the communication based on the 2.4GHz RF interface, an internal MC1322x-IPB daughter card should be connected inside the meter to the J2 connector (see **Figure 7-1**) and the USB Dongle to the PC. The FreeMASTER software running on the PC side shall be used for the data exchange.

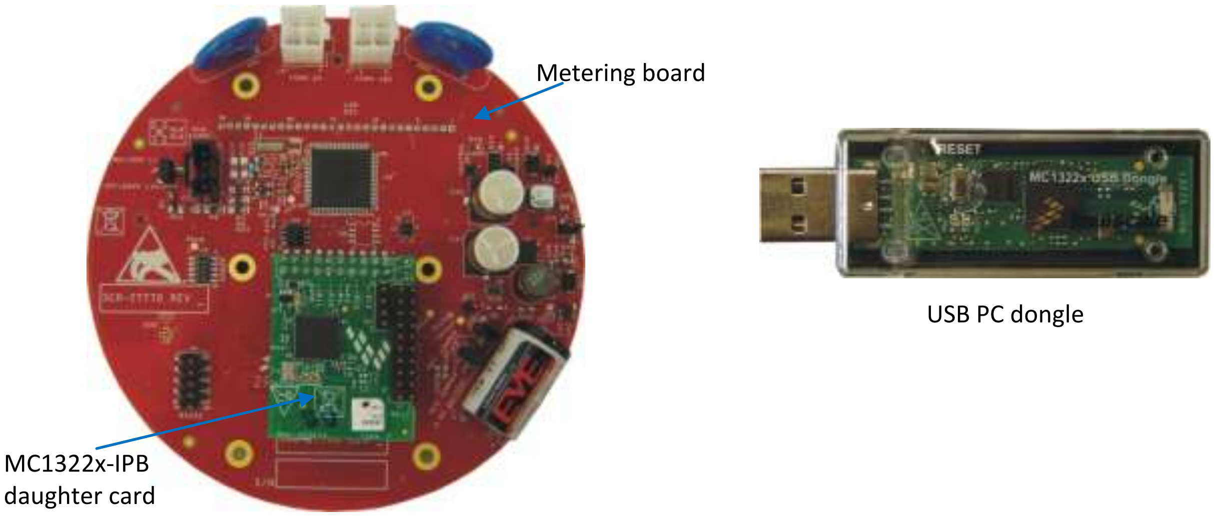

Figure 7-1. Extension for the 2.4 GHz IEEE 802.15.4 communication

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 *2phmonitor.pmp* file in the current directory. Following this, a visualization script will appear on your PC (see the following figure).

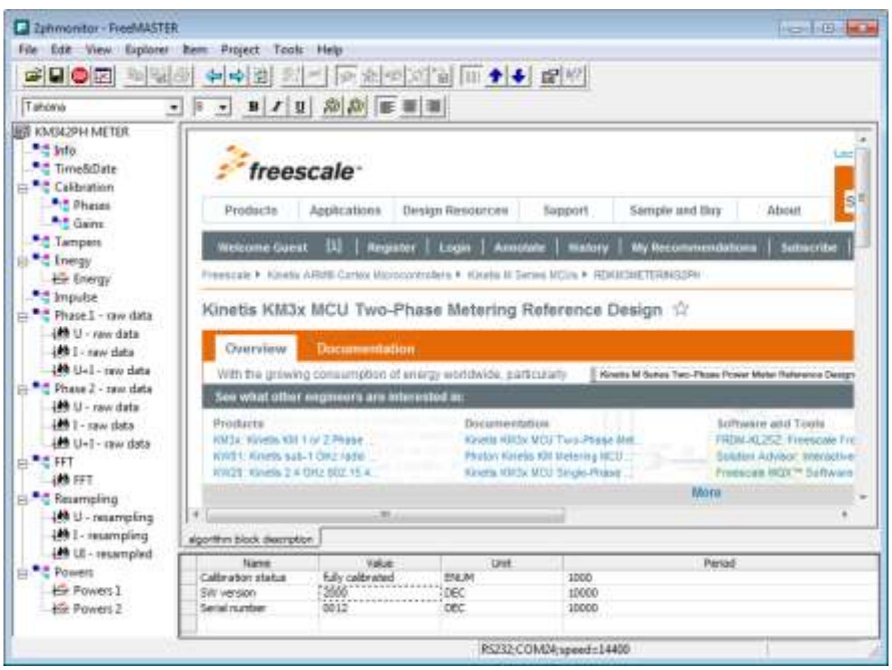

Figure 7-2. FreeMASTER graphical user interface (GUI)

Now, you should set the proper PC serial communication port where the USB Dongle is connected, in the menu *Project/Option/Comm* (see **Figure 7-3**). The communication speed of 38400Bd must be used. A message on the status bar signalizes the communication parameters and successful data exchange. After that, you should set the proper *2phmet.out* project file in menu *Project/Option/MAP Files* (see **Figure 7-4**). Originally, this file is accessible in the subdirectory called *Release**Exe*. If all previous settings are correctly done, the communication between the power meter and the PC may be initiated.

To do this, you should click on the *Start/Stop* Communication button (the third ‘red’ icon on the upper left side in the GUI). Alternatively, CTRL+K keys may be used.

Figure 7-3. FreeMASTER communication port settings

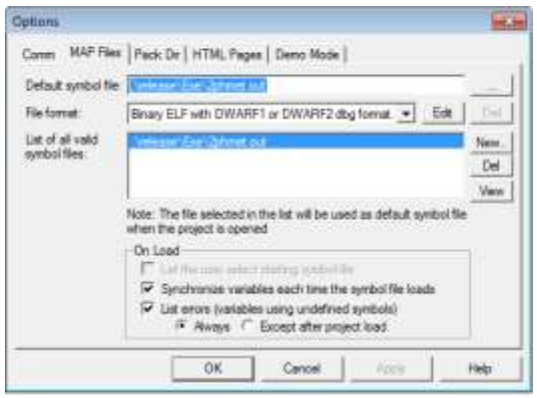

Figure 7-4. FreeMASTER project file settings

If communication fails the first time, try to switch the power meter off and unplug the USB PC dongle from the PC. After that, connect both devices again in this order: USB dongle to the PC firstly, and the power meter to the mains secondly. After several seconds, try to restore the communication by clicking on the *Start/Stop* button in the GUI.

At this time you may watch measured phase voltages, phase currents, active, reactive and apparent powers, energies and additional status information of the power meter appearing on the PC. You may also visualize some variables in a graphical representation by selecting the respective scope or recorder item from the **KM342PH METER** tree (see the following figure).

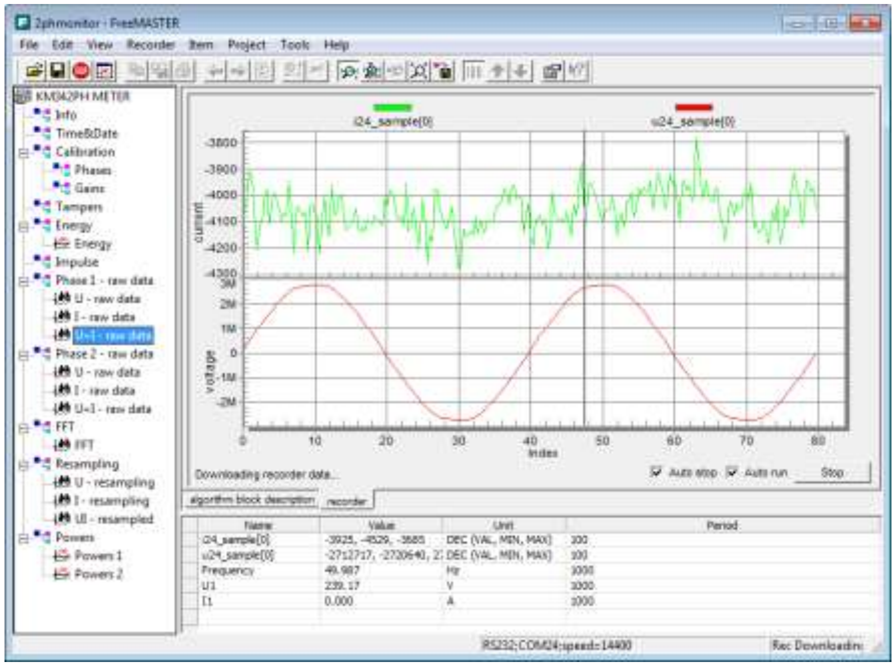

Figure 7-5. FreeMASTER recorder screen

Alternatively, you may set some values, such as impulse number, clock and date, clear the energy counters and also the tamper flags. After setting an appropriate value in the FreeMASTER GUI, use the correct command for transferring this changed value to the power meter. For example, changing the kWh impulse number should be done by selecting an appropriate number between 100 and 1000000 (according to the metering algorithm used) followed by the *REMOTE COMMAND/IMPULSE NUMBER SETTINGS* command (see the following figure).

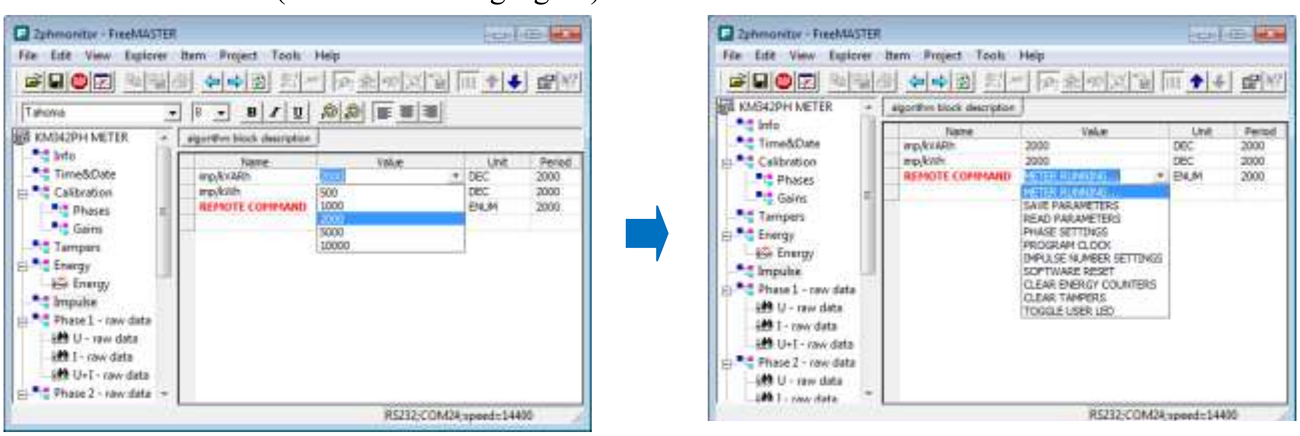

Figure 7-6. FreeMASTER impulse number settings procedure

After applying these commands, it is also suitable to save the changed value into the non-volatile memory of the MCU by applying the *REMOTE COMMAND/SAVE PARAMETERS* command. Alternatively, this operation is done automatically after disconnecting the power meter from the mains – there is a power failure detection logic which saves all necessary settings before losing the power supply inside the meter.

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

CAUTION

The user is not allowed to change any 'red-marked decimal calibration values' in the *Calibration* section.

8 HAN/NAN visualization

This Power Meter also supports an extension for Home Area Network (HAN) and Neighborhood Area Network (NAN) communication. To do this, a K11 expansion daughter card with both Nivis and Coconino radio sub-modules must be connected to the main metering board (see the following figure). The K11 expansion board works as a mediator between the metering engine and both RF modules ("sandwich concept"). Both radio modules, housed on the K11 daughter board, are RF-based, therefore these require an antenna. The Coconino radio module has its own integrated antenna as part of the printed circuit board, whereas the Nivis radio module needs an external, small and flexible antenna, connected to the respective connector placed on its front side. This antenna perfectly fits into the meter's enclosure. A software installation for the HAN/NAN communication procedure, connection with the remote station, and description of its graphical user interface is not included in the content of this document. It can be found in a separate document through the Freescale support [**8**].

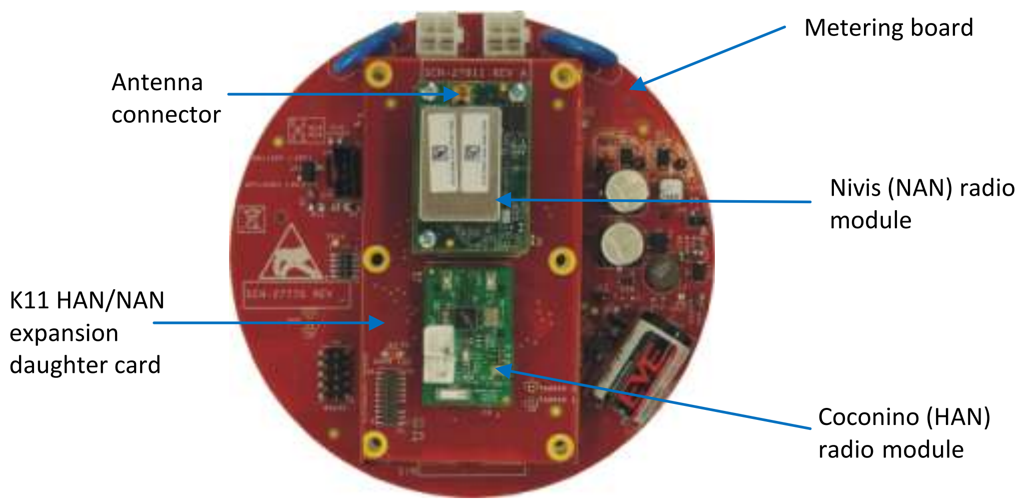

Figure 8.1 Extension for the HAN/NAN connectivity

9 Accuracy and performance

As already indicated, the Kinetis-M two-phase reference designs have been fully calibrated using the test equipment ELMA8303 [**1**], which comprises of a reference meter with a precision of 0.01 %. The U.S. power meters were tested according to the ANSI C12.20-2002 American national standards for Electricity Meters 0.2 and 0.5 accuracy classes, whereas the Japan power meters were tested according to the IEC 62053-22 international standards for electronic meters of active energy classes 0.2S and 0.5S, the IEC 62053-23 international standard for static meters of reactive energy classes 2 and 3, and the IEC 62052-11 international standards for electricity metering equipment.

During the calibration and testing process, the power meter measured electrical quantities generated by the test bench ELMA8303, calculated the 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. The deviations between pulses generated by the power meter and reference pulses generated by test equipment defined the measurement accuracy.

9.1 Room temperature accuracy testing

The following figure shows the calibration protocol of the typical Freescale two-phase ANSI (U.S.) power meter. 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 the 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. Two bold red lines define the ANSI C12.20-2002 Class 0.2 accuracy margins for active energy measurement for power factor 1.

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. The standard deviation is approximately ten-times lesser than the meter's accuracy (compare the top and bottom graphs).

By analyzing the protocols of several Kinetis-M two-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 0.9-200 A[4], more or less with an accuracy range ±0.1%.

[4] The current range was scaled to $I_{MAX} = 235$ A. It is valid for the ANSI (U.S.) version meter.

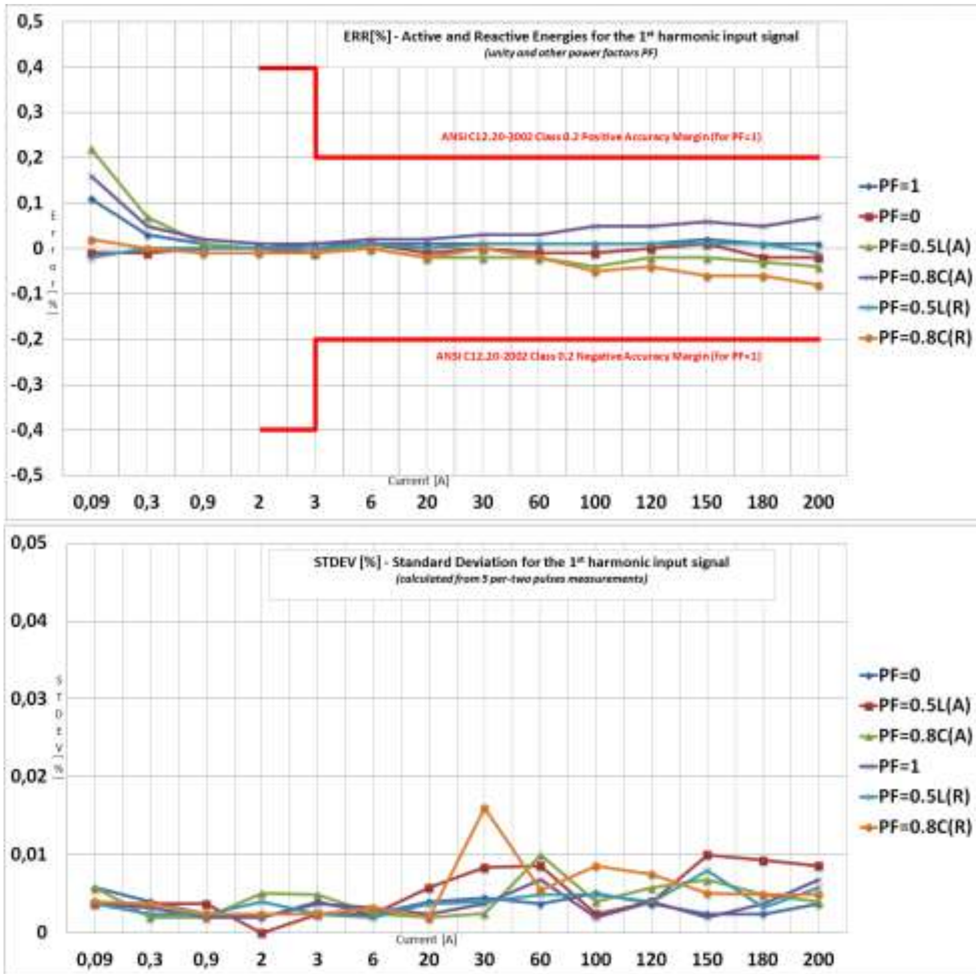

Figure 9.1 Calibration protocol at 25°C according to the ANSI C12.20-2002 class 0.2

9.2 Extended temperature accuracy testing

In addition to room temperature testing, the Kinetis-M two-phase power meter has been evaluated over the extended operating temperature range (0 °C to 80 °C). This testing was carried out with the power meter placed in a heat chamber. 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.

The following figure shows the accuracy of the power meter evaluated at an extended temperature range. The temperature test was done on the Japan version of the two-phase power meter, therefore the accuracy margins are defined by the IEC62053-22 Class 0.5 S. The extended accuracy margins are denoted by respective bold lines for each temperature. The color of each margin is the same as the color of each particular error curve. The calibration protocol shows that the active energy measured by the power meter at all temperatures for a unity power factor fits within the accuracy margins mandated by the standard with a temperature coefficient approximately ±40 ppm/°C.

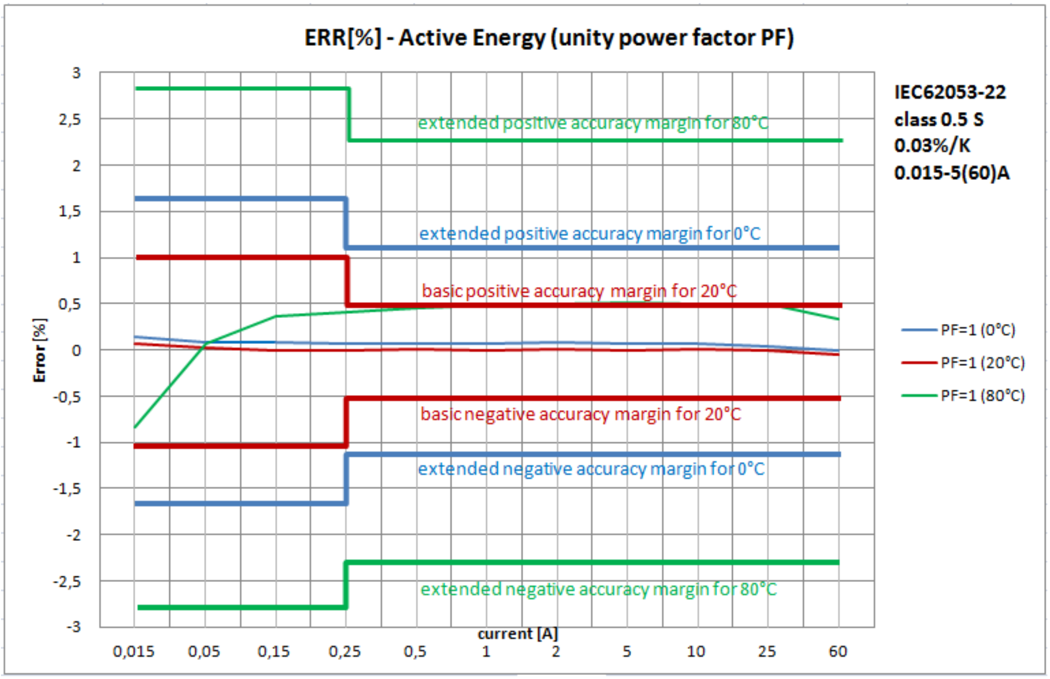

Figure 9.2 Calibration protocol for extended temperature range according to the IEC 62053-22 class 0.5S

10 Summary

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

Freescale semiconductor offers both FFT and Filter based metering algorithms for use in customer applications. The former calculates metering quantities in the frequency domain, the latter in the time 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, two Xtrinsic 3-axis digital sensors for enhanced tamper detection, and an expansion header for two types of the RF daughter boards for AMR communication and monitoring.

The application software has been written in C-language and compiled using the IAR Embedded Workbench for ARM (6.40 and higher), with optimization for the execution speed. It is based on the Kinetis-M bare-metal software drivers [**7**] and the FFT-based metering library [**2**] [**3**] as default. Alternatively, the Filter-based metering library can be also used [**4**]. The application firmware automatically calibrates the power meter, calculates all metering quantities, controls active and reactive energy pulse outputs, the LCD, stores and retrieves parameters from flash memory, and allows monitoring the application, including recording selected waveforms through the FreeMASTER. The application software of such complexity requires 36.9 KB of flash and 10.2 KB of RAM approximately. The system clock frequency of the MKM34Z128CLL5 device must be 23.986176 MHz or higher to calculate all metering quantities with an update rate of 6 kHz and with the 32 FFT points (16 harmonics in total) consecutively.

This power meter can be produced in two H/W versions: the U.S. version according to the ANSI C12.20 standard, and the Japan version according to the IEC 62053-22 standard. The main H/W difference between both versions is in the input current range, the S/W is the same.

The power meter is designed to transition between three operating modes. Firstly, in the normal operating mode, the power meter is powered from the mains. The second mode, the so-called standby mode, is a transition between the normal mode and the power-down mode with a duration of only several seconds. The power meter runs from the battery during this mode and the user can see the latest value of the import active energy on the LCD (the most important value). Finally, when the power meter electronics automatically transitions from the standby mode to the power-down mode with the slowest current consumption, the power meter runs from the battery with no user interaction.

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.

Depending on the H/W version (U.S. or Japan), the Kinetis-M two-phase power meters were tested according to the ANSI C12.20-2002 American national standards for Electricity Meters 0.2 and 0.5 accuracy classes, the IEC 62053-22 international standards for electronic meters of active energy classes 0.2S and 0.5S, 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 this equipment measures active and reactive energies at all power factors, a 25 °C ambient temperature, and in the current range 0.9-200 A, more or less with an accuracy range ±0.1%. Further accuracy testing has been carried out on one power meter in a heat chamber with very good results.

In summary, the Kinetis-M two-phase power meter demonstrates excellent measurement accuracy with a low temperature coefficient. In reality, the capabilities of the Kinetis-M two-phase power meter fulfill the most demanding American and international standards for electronic meters.

11 References

1. Applied Precision s.r.o, "Electricity Meter Test Equipment ELMA 8x01", www.appliedp.com/en/elma8x01.htm

2. "AN4255 – FFT-Based Algorithm for Metering Applications", Freescale Semiconductor, Rev.1, 10/2013, www.freescale.com/files/32bit/doc/app_note/AN4255.pdf

3. "AN4847 – Using an FFT on the Sigma-Delta ADCs", Freescale Semiconductor, Rev.0, 12/2013, www.freescale.com/files/32bit/doc/app_note/AN4847.pdf

4. "AN4265 – Filter-Based Algorithm for Metering Applications", Freescale Semiconductor, Rev.0, 08/2013, www.freescale.com/files/32bit/doc/app_note/AN4265.pdf

5. Power Integrations, "AN37 – LinkSwitch-TN Family Design Guide, April 2009, www.powerint.com/sites/default/files/product-docs/an37.pdf

6. FreeMASTER Data Visualization and Calibration Software, Freescale Semiconductor, www.freescale.com/webapp/ sps/site/prod_summary.jsp?code=FREEMASTER

7. Freescale Semiconductor, “Kinetis-M Bare-metal Software Drivers”, September 2013, www.freescale.com/webapp/Download?colCode=KMSWDRV_SBCH
8. “Nivis - Smart Object Development Kit”, Quick Start Guide

12 Revision history

Revision Number	Date	Substantial Changes
0	04/2014	Initial release

Appendix A. Metering Board Electronics

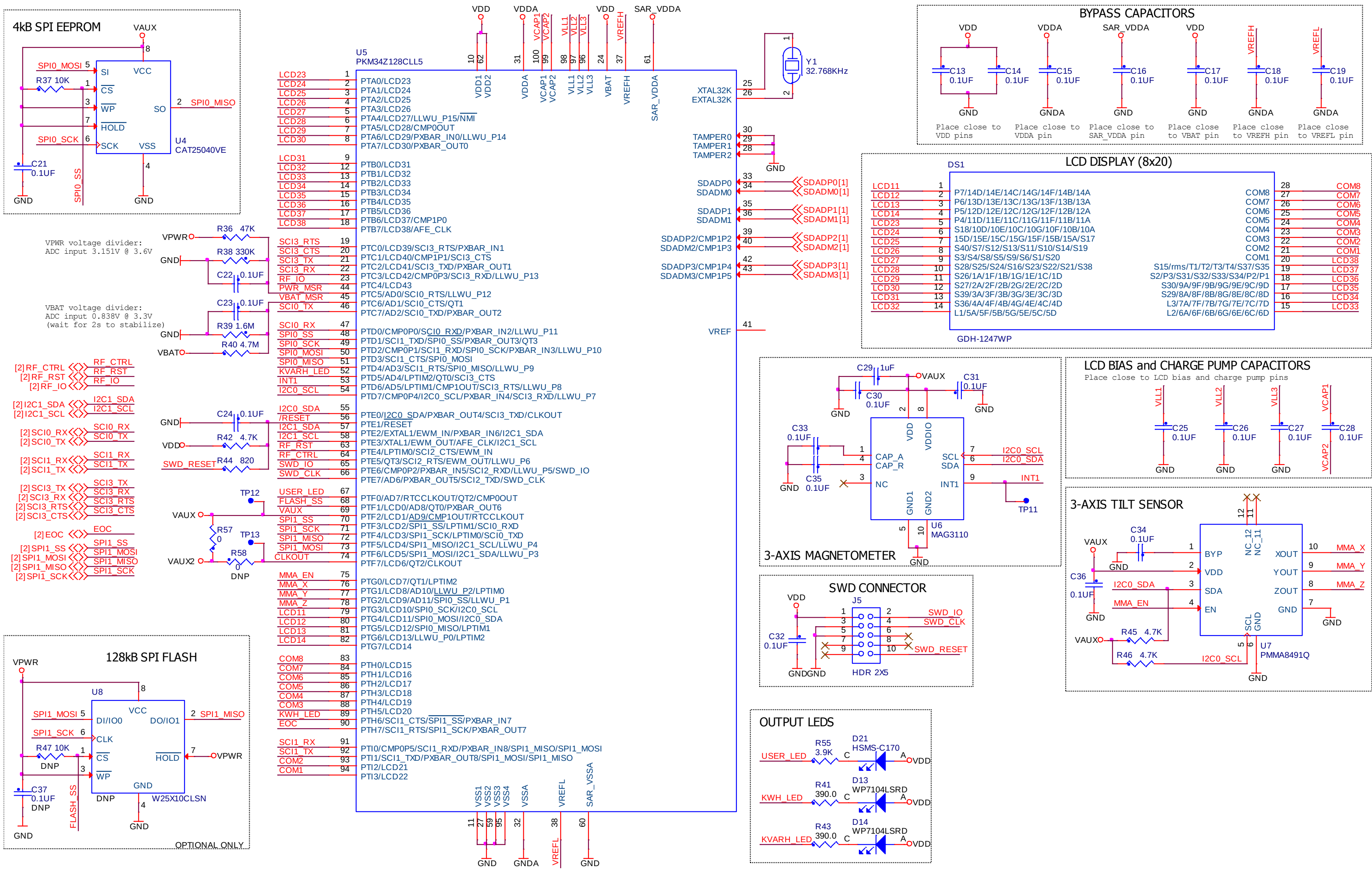

Figure A-1. Schematic diagram of the metering board (sheet 1 of 4 - MCU section)

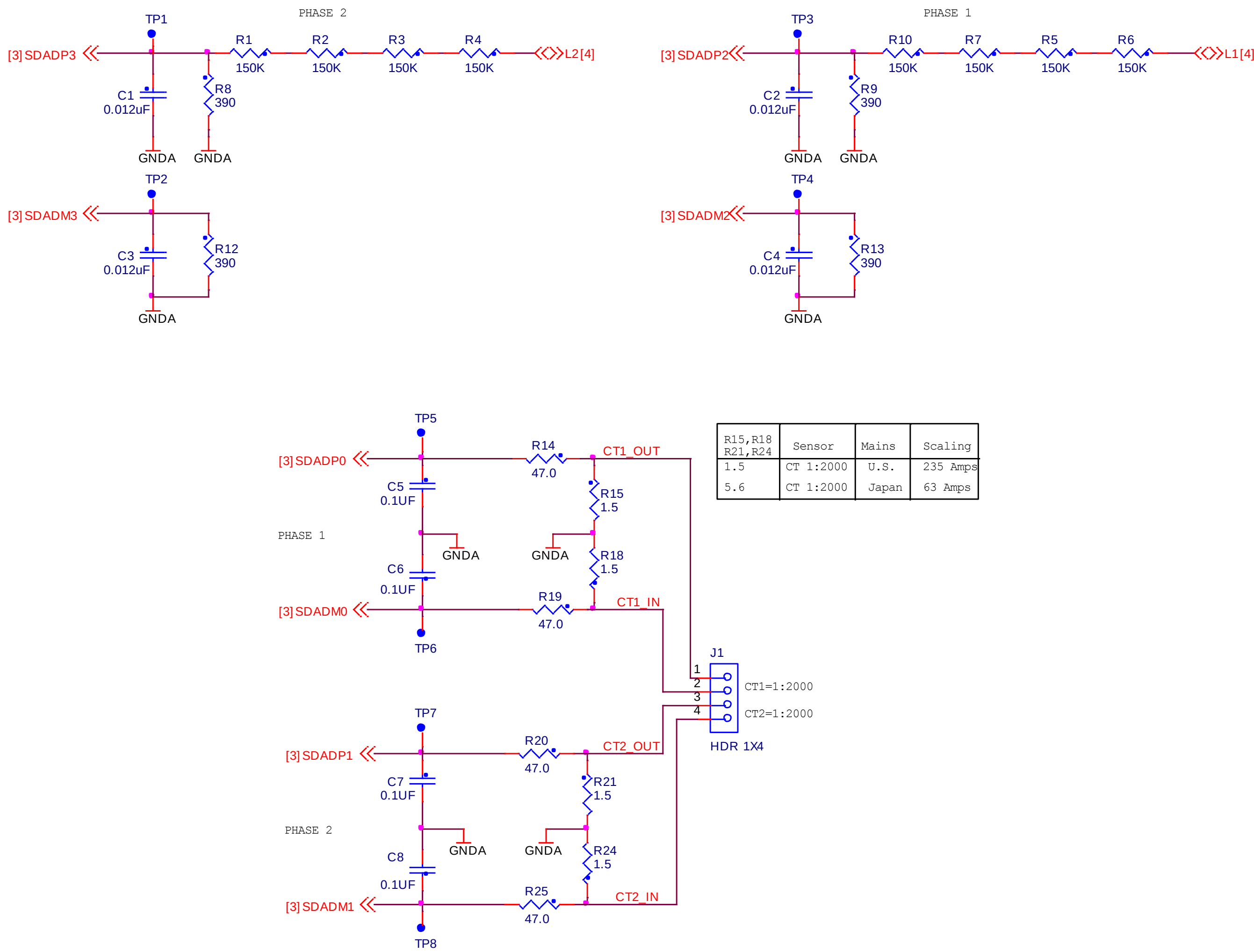

Figure A-2. Schematic diagram of the metering board (sheet 2 of 4 - Analog Front-End section)

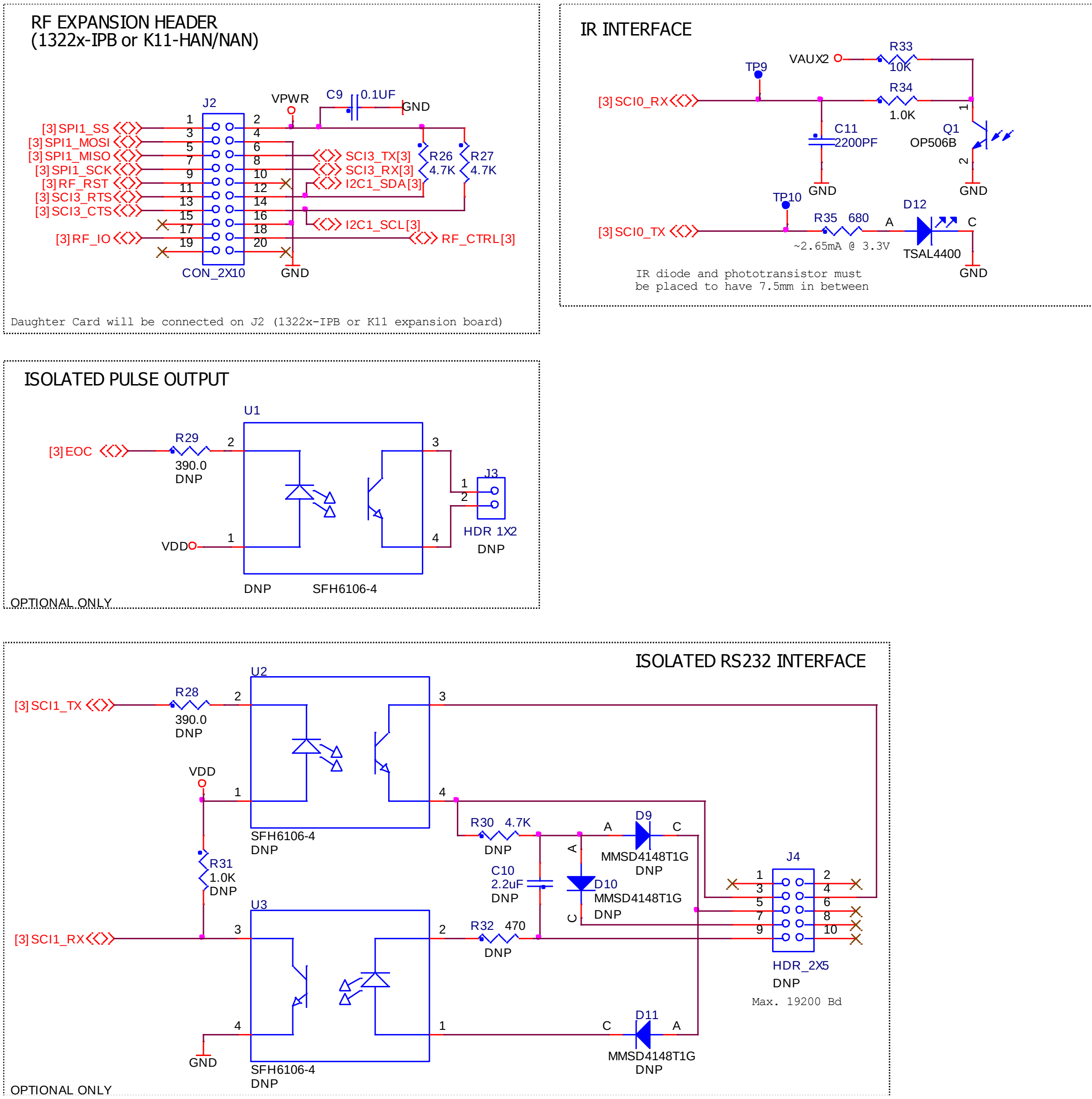

Figure A-3. Schematic diagram of the metering board (sheet 3 of 4 – Interface section)

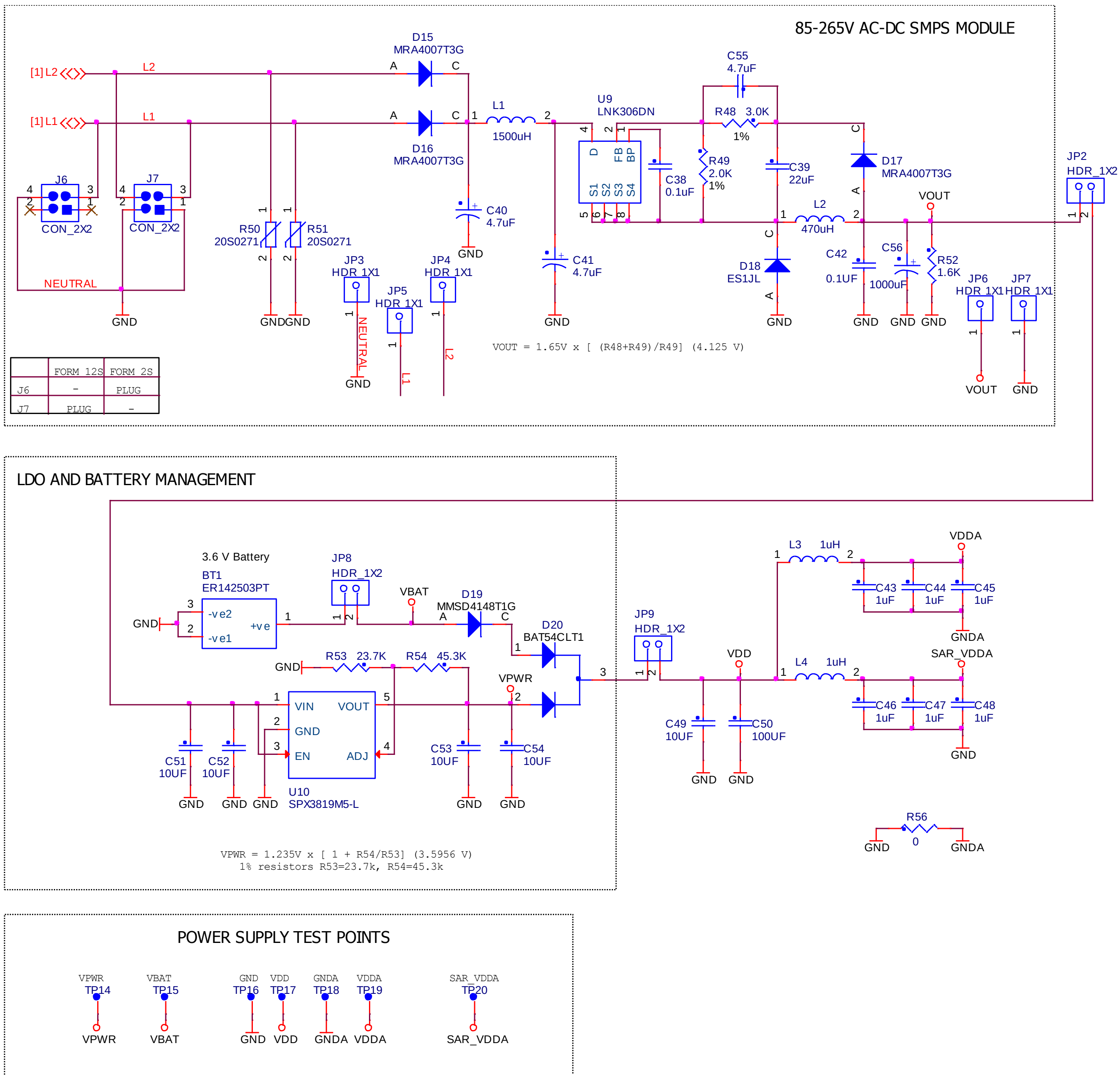

Figure A-4. Schematic diagram of the metering board (sheet 4 of 4 - Power Supply section)

Appendix B. Expansion Board Electronics

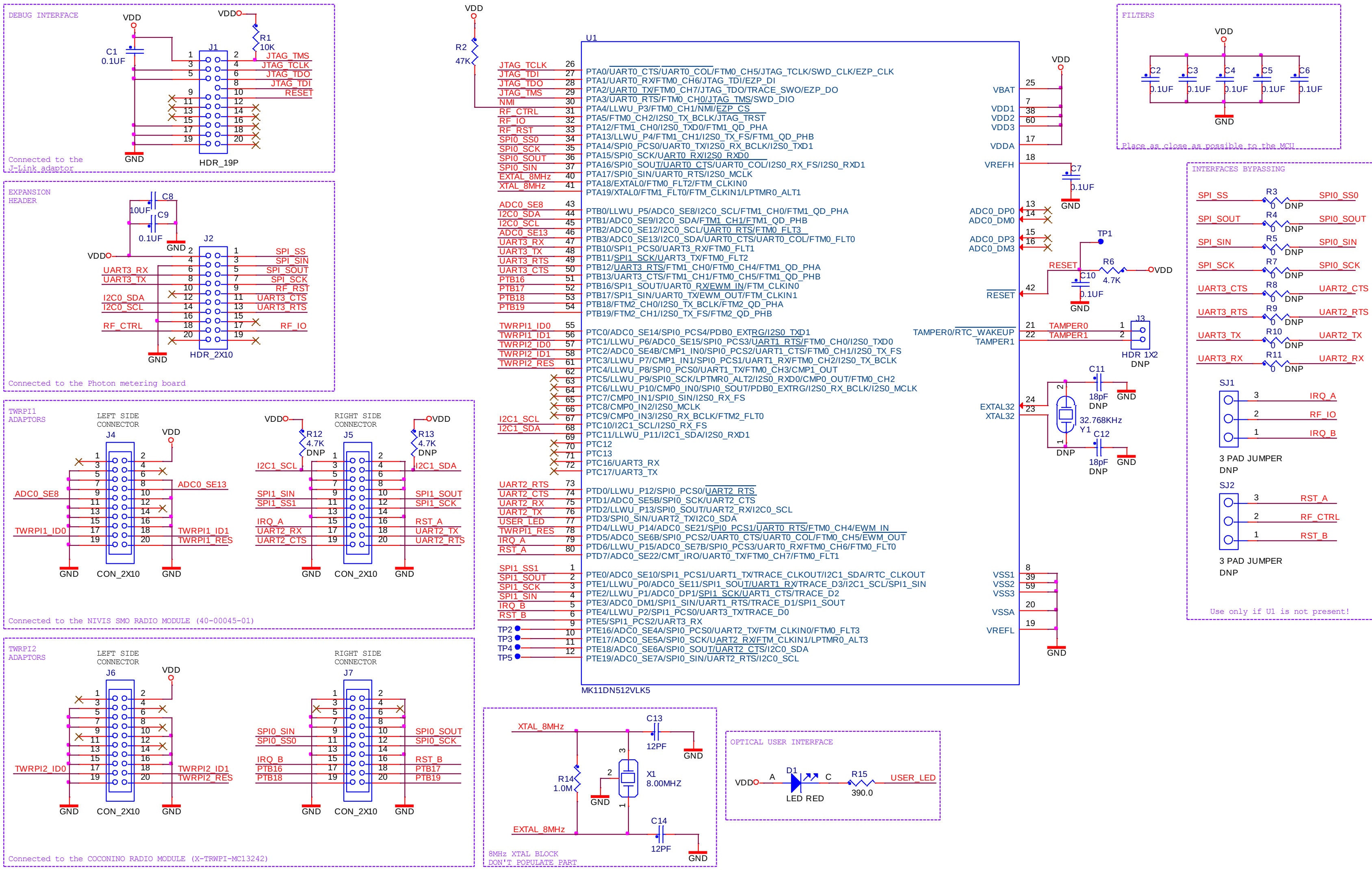

Figure B-1. Schematic diagram of the K11 expansion board (sheet 1 of 1)

Appendix C. Metering board layout

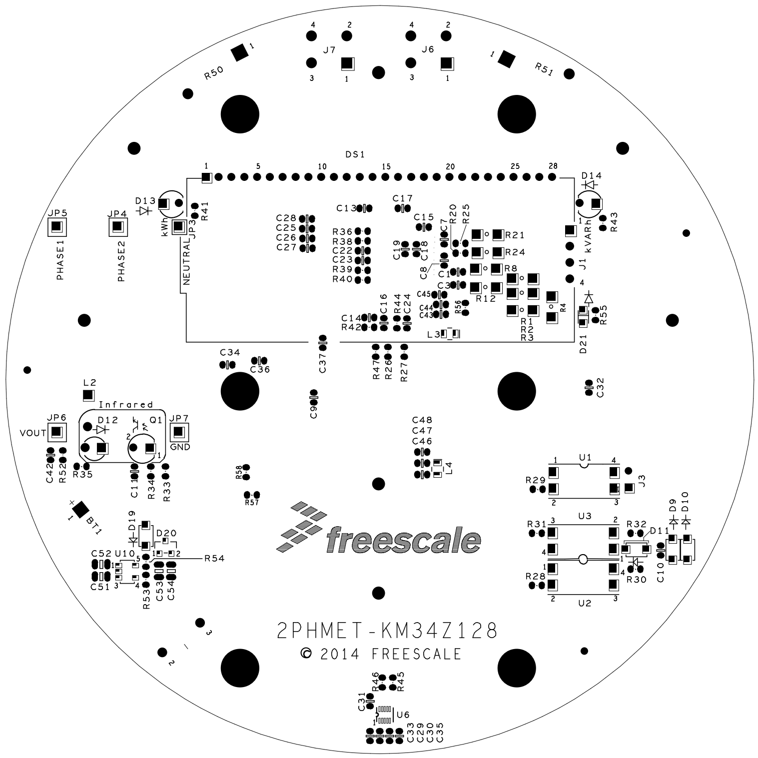

Figure C-1. Top side view of the metering board (not scaled)

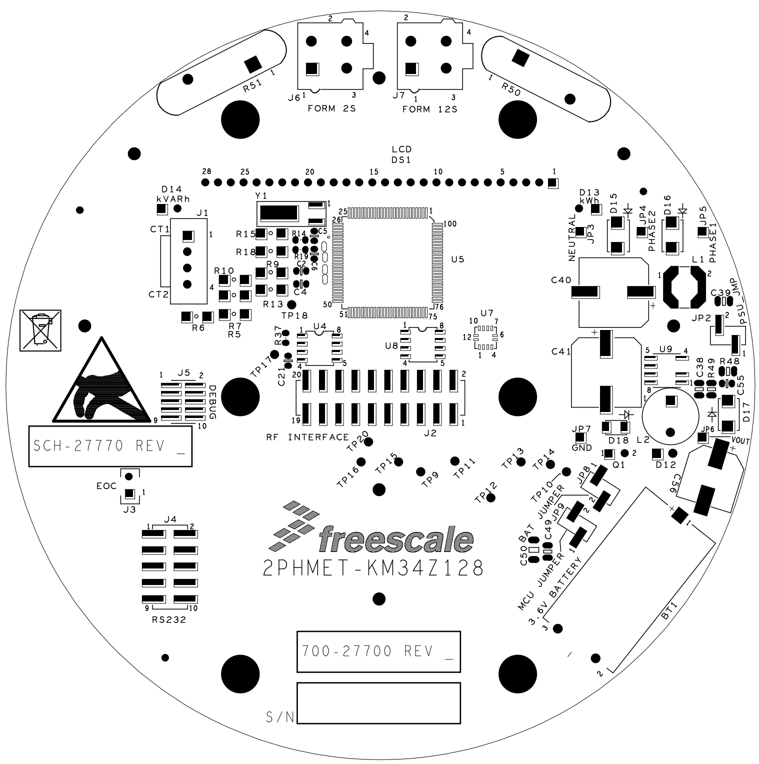

Figure C-2. Bottom side view of the metering board (not scaled)

Appendix D. Expansion board layout

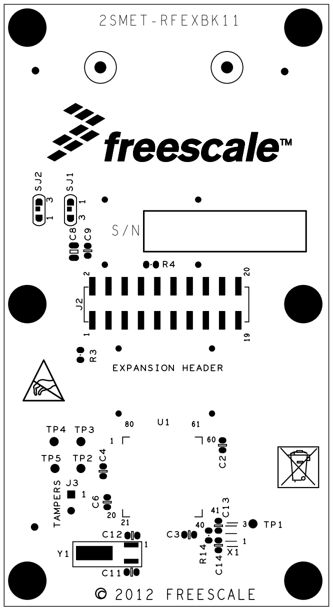

Figure D-1. Top side view of the K11 expansion board (not scaled)

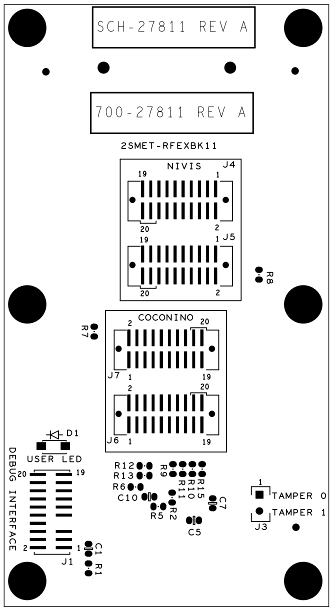

Figure D-2. Bottom side view of the K11 expansion board (not scaled)

Appendix E. Bill of materials of the metering board

Table E-1. BOM report

Part Reference	Qty	Description	Manufacturer	Part Number
BT1	1	BATTERY 1/2AA LI-SOCl2 3.6V 1200MAH	EVE ENERGY CO., LTD	ER142503PT
C1,C2,C3,C4	4	CAP CER 0.012uF 50V 5% X7R 0603	AVX	06035C123JAT2A
C5,C6,C7,C8,C9, C13,C14,C15,C16, C17,C18,C19,C21, C22,C23,C24,C25, C26,C27,C28,C30, C31,C32,C33,C34, C35,C36, C42	28	CAP CER 0.10UF 25V 10% X7R 0603	KEMET	C0603C104K3RAC
C10	1	CAP CER 2.2UF 16V 10% X5R 0603	MURATA	GRM188R61C225KE15D
C11	1	CAP CER 2200PF 50V 5% X7R 0603	KEMET	C0603C222J5RACTU
C29,C43,C44,C45, C46,C47,C48	7	CAP CER 1UF 25V 10% X7R 0603	CAPAX TECHNOLOGIES Inc.	0603X105K250SNT
C37	1	CAP CER 0.10UF 25V 10% X7R 0603	KEMET	C0603C104K3RAC
C38	1	CAP CER 0.10UF 50V 5% X7R 0805	SMEC	MCCE104J2NRTF
C39	1	CAP CER 22UF 16V 10% X5R 0805	TDK	C2012X5R1C226K
C40,C41	2	CAP ALEL 3.3uF 400V 20% -- SMT	PANASONIC	PCE3441CT-ND
C50	1	CAP CER 100UF 6.3V 20% X5R 1206	Murata	GRM31CR60J107ME39L
C56	1	CAP ALEL 1000uF 6.3V 20%, Low ESR -- SMT	PANASONIC	EEEFP0J102AP
C49,C51,C52,C53, C54	5	CAP CER 10UF 16V 10% X5R 0805	AVX	0805YD106KAT2A
C55	1	CAP CER 4.7uF 16V 10% X5R 0603	TDK	C1608X5R1C475K
DS1	1	LCD DISPLAY 3.3V TH	S-TEK Inc.	GDH-1247WP
D9,D10,D11	3	DIODE SW 100V SOD-123	ON SEMICONDUCTOR	MMSD4148T1G
D12	1	LED IR SGL 100MA TH	VISHAY INTERTECHNOLOGY	TSAL4400
D13,D14	2	LED RED SGL 30mA TH	KINGBRIGHT	WP7104LSRD
D15,D16,D17	3	DIODE PWR RECT 1A 1000V SMT 403D-02	ON SEMICONDUCTOR	MRA4007T3G
D18	1	DIODE RECT 1A 600V SMT	TAIWAN SEMICONDUCTOR	ES1JL
D19	1	DIODE SW 100V SOD-123	ON SEMICONDUCTOR	MMSD4148T1G
D20	1	DIODE SCH DUAL CC 200MA 30V SOT23	ON SEMICONDUCTOR	BAT54CLT1G
D21	1	LED HER SGL 2.1V 20MA 0805	AVAGO Technologies	HSMS-C170
JP1,JP2,JP8,JP9	4	HDR 1X2 SMT 100MIL SP 380H AU	SAMTEC	TSM-102-01-SM-SV-P-TR

JP3,JP4,JP5,JP6, JP7	5	HDR 1X1 TH -- 330H SN 115L	SAMTEC	TSW-101-23-T-S
J1	1	HDR 1X4 SHRD TH 100MIL SP 475H SN	MOLEX	70543-0038
J2	1	CON 2X10 SKT SMT 100MIL CTR 390H AU	SAMTEC	SSW-110-22-F-D-VS-N
J3	1	HDR 1X2 TH 100MIL SP 338H AU 150L	SAMTEC	HMTSW-102-24-G-S-230
J4	1	HDR 2X5 SMT 100MIL CTR 380H AU	SAMTEC	TSM-105-01-S-DV-P-TR
J5	1	HDR 2X5 SMT 1.27MM CTR 175H AU	SAMTEC	FTS-105-01-F-DV-P-TR
J6,J7	2	CON 2X2 PLUG SHRD TH 4.2MM SP 516H SN 138L	MOLEX	39-29-3046
L1	1	IND PWR 1500UH@100KHZ 130MA 20% SMT	COILCRAFT	LPS6235-155ML
L2	1	IND PWR 1.2mH@100KHZ 280MA 10% RADIAL	COILCRAFT	RFB0807-122L
		IND PWR 0.47mH@100KHZ 400MA 10% RADIAL		RFB0807-471L
L3,L4	2	IND CHIP 1UH@10MHZ 220MA 25%	TDK	MLZ2012A1R0PT
Q1	1	TRAN PHOTO NPN 250mA 30V TH	OPTEK TECHNOLOGY	OP506B
R1,R2,R3,R4,R5, R6,R7,R10	8	RES MF 150K 1/4W 1% MELF0204	WELWYN COMPONENTS LIMITED	WRM0204C-150KFI
R8,R9,R12,R13	4	RES MF 390 OHM 1/4W 1% MELF0204	WELWYN COMPONENTS LIMITED	WRM0204C-390RFI
R14,R19,R20,R25	4	RES MF 47.0 OHM 1/10W 1% 0603	KOA SPEER	RK73H1JTTD47R0F
R15,R18,R21,R24	4	RES MF 1.5 OHM 1/4W 1% MELF0204	WELWYN COMPONENTS LIMITED	WRM0204C-1R5FI
		RES MF 5.6 OHM 1/4W 1% MELF0204		WRM0204C-5R6FI
R26,R27,R42,R45, R46	5	RES MF 4.7K 1/10W 5% 0603	VISHAY INTERTECHNOLOGY	CRCW06034K70JNEA
R28,R29	2	RES MF 390.0 OHM 1/10W 1% 0603	KOA SPEER	RK73H1JTTD3900F
R41,R43	2	RES MF 390.0 OHM 1/10W 1% 0603	KOA SPEER	RK73H1JTTD3900F
R30	1	RES MF 4.7K 1/10W 5% 0603	VISHAY INTERTECHNOLOGY	CRCW06034K70JNEA
R31	1	RES MF 1.00K 1/10W 1% 0603	KOA SPEER	RK73H1JTTD1001F
R32	1	RES MF 470 OHM 1/10W 1% 0603	KOA SPEER	RK73H1JTTD4700F
R34	1	RES MF 1.00K 1/10W 1% 0603	KOA SPEER	RK73H1JTTD1001F
R35	1	RES MF 680 OHM 1/10W 5% 0603	BOURNS	CR0603-JW-681ELF
R36	1	RES MF 47K 1/10W 5% 0603	VENKEL COMPANY	CR0603-10W-473JT
R33,R37	2	RES MF 10K 1/10W 5% 0603	KOA SPEER	RK73B1JTTD103J
R38	1	RES MF 330K 1/10W 5% 0603	YAGEO	RC0603JR-07330KL
R39	1	RES MF 1.6M 1/10W 1% 0603	KOA SPEER	RK73H1JTTD1604F
R40	1	RES MF 4.7 MOHM 1/10W 5% 0603	VENKEL COMPANY	CR0603-10W-475JT

R44	1	RES MF 820 OHM 1/10W 5% 0603	BOURNS	CR0603-JW-821ELF
R47	1	RES MF 10K 1/10W 5% 0603	KOA SPEER	RK73B1JTTD103J
R48	1	RES MF 3.00K 1/10W 1% 0805	SPC TECHNOLOGY	MC0805WAF3001T5E-TR
R49	1	RES MF 2.00K 1/10W 1% 0805	SPC TECHNOLOGY	MC0805WAF2001T5E-TR
R50,R51	2	RES VARISTOR 275VRMS 10% 4.5kA 151J TH	EPCOS	B72220S0271K101
R52	1	RES MF 1.6K 1/10W 1% 0603	KOA SPEER	RK73H1JTTD1601F
R53	1	RES MF 23.7K 1/10W 1% 0603	KOA SPEER	RK73H1JTTD2372F
R54	1	RES MF 45.3K 1/10W 1% 0603	KOA SPEER	RK73H1JTTD4532F
R55	1	RES MF 3.9K 1/10W 5% 0603	BOURNS	CR0603-JW-392ELF
R56,R57	2	RES MF ZERO OHM 1/10W 0603	VISHAY INTERTECHNOLOGY	CRCW06030000Z0EA
R58	1	RES MF ZERO OHM 1/10W 0603	N/A	N/A
TP1....TP20	20	ROUND TEST PAD SMT; NO PART TO ORDER	N/A	N/A
U1,U2,U3	3	IC OPTOCOUPLER 100MA 70V SMD	VISHAY INTERTECHNOLOGY	SFH6106-4
U4	1	IC MEM EEPROM SPI 4Kb 1.8-5.5V SOIC8	ON SEMICONDUCTOR	CAT25040VE-G
U5	1	IC MCU FLASH 128K 16K 50MHZ 1.71-3.6V LQFP100	FREESCALE SEMICONDUCTOR	PKM34Z128CLL5
U6	1	IC 3-AXIS DIGITAL MAGNETOMETER 1.95-3.6V DFN10	FREESCALE SEMICONDUCTOR	MAG3110FC
U7	1	IC 3-AXIS LOW VOLTAGE TILT SENSOR 1.95-3.6V QFN12	FREESCALE SEMICONDUCTOR	MMA8491Q
U8	1	IC MEM FLASH SPI 1MBIT 2.3-3.6V SOIC8	WINBOND ELECTRONICS CORP	W25X10CLSNIG
U9	1	IC VREG LINKSWITCH 63MA/80MA 85-265VAC/700V S0-8C	POWER INTEGRATIONS	LNK302DN
		IC VREG LINKSWITCH 225MA/360MA 85-265VAC/700V S0-8C		LNK306DN
U10	1	IC VREG LDO ADJ 500MA 2.5-16V SOT23-5	EXAR	SPX3819M5-L
Y1	1	XTAL 32.768KHZ PAR 20PPM -- SMT	CITIZEN	CMR200T32.768KDZF-UT

Legend:

- Optional only
- Without K11 expansion board
- With K11 expansion board
- U.S. version
- Japan version

Appendix F. Bill of materials of the expansion board

Table F-2. BOM report

Part Reference	Qty	Description	Manufacturer	Part Number
C1,C2,C3,C4,C5, C6,C7,C9,C10	9	CAP CER 0.10UF 25V 10% X7R 0603	KEMET	C0603C104K3RAC
C8	1	CAP CER 10UF 16V 10% X5R 0805	AVX	0805YD106KAT2A
C11,C12	2	CAP CER 18PF 25V 10% C0G 0603	AVX	06033A180KAT2A
C13,C14	2	CAP CER 12PF 25V 10% C0G 0603	AVX	06033A120KAT2A
D1	1	LED RED SGL 30MA SMT	KINGBRIGHT	KPT-3216ID
J1	1	HDR 19P SMT 1.27MM SP 285H AU	SAMTEC	ASP-159234-02
J2	1	HDR 2X10 SMT 100MIL CTR 380H AU	SAMTEC	TSM-110-01-SM-DV-P-TR
J3	1	HDR 1X2 TH 100MIL SP 338H AU 150L	SAMTEC	HMTSW-102-24-G-S-230
J4,J5,J6,J7	4	CON 2X10 PLUG SHRD SMT 50MIL CTR 237H AU	SAMTEC	TFC-110-02-L-D-A-K
R1	1	RES MF 10K 1/10W 5% 0603	KOA SPEER	RK73B1JTTD103J
R2	1	RES MF 47K 1/10W 5% 0603	VENKEL COMPANY	CR0603-10W-473JT
R3,R4,R5,R7,R8, R9,R10,R11	8	RES MF ZERO OHM 1/10W 1% 0603	MULTICOMP	MC0603SAF0000T5E
R6	1	RES MF 4.7K 1/10W 5% 0603	VISHAY INTERTECHNOLOGY	CRCW06034K70JNEA
R12,R13	2	RES MF 4.7K 1/10W 5% 0603	VISHAY INTERTECHNOLOGY	CRCW06034K70JNEA
R14	1	RES MF 1.0M 1/10W 5% 0603	BOURNS	CR0603-JW-105ELF
R15	1	RES MF 390.0 OHM 1/10W 1% 0603	KOA SPEER	RK73H1JTTD3900F
SJ1,SJ2	2	JUMPER 3 PAD 40MIL SQUARE SMT - NO PART TO ORDER	N/A	N/A
TP1,TP2,TP3,TP4, TP5	5	TEST PAD 70MIL ROUND SMT; NO PART TO ORDER	N/A	N/A
U1	1	IC MCU 512KB FLASH 64KB RAM 50MHZ 1.71-3.6V LQFP80	FREESCALE SEMICONDUCTOR	MK11DN512VLK5
X1	1	XTAL 8.00MHZ RSN CERAMIC -- SMT	MURATA	CSTCE8M00G55-R0
Y1	1	XTAL 32.768KHZ PAR 20PPM -- SMT	CITIZEN	CMR200T32.768KDZF-UT

Legend:

Don’t need to be populated

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