1 Introduction

This document describes the design of a Three-Phase Smart Power Meter reference design based on NXP KM35Z512 microcontroller. This microcontroller is a part of NXP Kinetis-M microcontroller family. Kinetis-M microcontroller family designed for power metering applications. Therefore, the Kinetis-M family offers a high-performance Analog Front-End (24-bit AFE) combined with an embedded Programmable Gain Amplifier (PGA). In addition to high-performance analog peripherals, such as an auxiliary 16-bit SAR ADC, these new devices integrate memories, input-output ports, digital blocks, and various communication options. The Arm® Cortex®-M0+ core and Memory-Mapped Arithmetic Unit (MMAU), with support for 64-bit math, enable fast execution of metering algorithms. The three-phase power meter reference design is intended for the measurement and registration of active and reactive energies in three-phase four-wire networks. This design is made to be compliant with IS14697:1999 for class 0.5 accuracy for a dynamic range of 10-60 A.

The main purpose of a three-phase meter implementation on the KM3x devices is based on the signal's dynamic range analysis. The current signal in metering is typically from 50 mA to 120 A, therefore the current must be digitalized by a very precise and linear ADC with wide dynamic range, typically 24 bits. The SD method is an ideal solution to solve current dynamic range requirements. On the other hand, the voltage signal in metering is in the range of 80 V to 280 V. So the voltage dynamic range is approximately 60 times smaller than current dynamic range. The voltage requirements can be easily solved by a high-resolution SAR converter.

The common reason for using six or seven independent ADC channels is for easier converter synchronization—that is, all channels are able to begin precisely at the defined time. The KM3x devices solve this problem by the peripheral called XBAR. The XBAR is an internal connection matrix among the peripherals. Internal signals, such as conversion complete from the SD converter can be used for starting SAR conversion. So the complete signal sampling process based on the combination of three or four SDs and one SAR with an input multiplexer is fully supported by the device’s hardware and only the conversion results must be read by the microcontroller core or by DMA.

The three-phase power meter reference design is intended for the measurement and registration of active and reactive energies in three-phase four-wire networks. It is pre certified according to the European EN50470-1, EN50470-3, classes B and C, and to the IEC 62053-21 and IEC 62052-11 international standards for electronic meters of active energy classes 2, 1, and 0.5.

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 magnetic field 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-SOCI2 battery when disconnected from the power 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 magnetometer sensor. The 3-axis magnetometer is useful to check for magnetic field changes which is important because current sensing is widely used with current transformers. This type of sensor guarantees the static magnetic field generated by the permanent magnet.

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.
This design is a reference for designing Smart Power Meter or Electricity Meter, which measures and displays Active Energy (kWh), Reactive Energy (kVArh) and Apparent Energy (kVAh). It also measures and displays Voltage, Current, frequency, Power factor, Active Power (kW), Reactive Power (kVAr), Apparent Power (kVA), Maximum demand in kW. It displays date and time.

### 1.1 Specification

The MKM35Z512 three-phase power meter reference design is intended for use in a real application. Its metrology portion has undergone thorough laboratory testing. Thanks to intensive testing, accurate 24-bit AFE, and continual algorithm improvements, the three-phase power meter calculates active, reactive, and apparent energies more accurately and over a higher dynamic range than what is required by common standards. All information, including accuracies, operating conditions, and optional features, are summarized in the following Table 1.

#### Table 1. MKM35Z512 three-phase power meter specification

<table>
<thead>
<tr>
<th>Type of meter</th>
<th>Three-phase AC static watt-hour smart meter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of measurement</td>
<td>Four-quadrant</td>
</tr>
<tr>
<td>Metering algorithm</td>
<td>Low-power real time based</td>
</tr>
<tr>
<td>Accuracy</td>
<td>IS14697 class 0.5 (0.5 %)</td>
</tr>
<tr>
<td>Nominal voltage</td>
<td>240 VAC ± 20 %</td>
</tr>
<tr>
<td>Current range</td>
<td>0 – 60 A (10 A is nominal current, dynamic range is up to 72 A)</td>
</tr>
<tr>
<td>Nominal frequency</td>
<td>50 Hz ± 5 %</td>
</tr>
<tr>
<td>Meter constant (imp / kWh, imp / kVArh)</td>
<td>1600</td>
</tr>
<tr>
<td>Functionality</td>
<td>V, A, kW, VAr, VA, kWh (import / export), kVArh (import / export), Hz, power factor, time, date</td>
</tr>
<tr>
<td>Voltage sensor</td>
<td>Voltage divider</td>
</tr>
<tr>
<td>Current sensors</td>
<td>Current Transformer (CT) with 2500:1 turn ratio</td>
</tr>
<tr>
<td>Energy output pulse interface</td>
<td>Two red LEDs (active and reactive energy)</td>
</tr>
<tr>
<td>User interface (HMI)</td>
<td>8 x 15 segment LCD, one pushbutton</td>
</tr>
<tr>
<td>Tamper detection</td>
<td>Two hidden buttons (module area and main cover)</td>
</tr>
<tr>
<td>IEC62056-21 infrared interface</td>
<td>9600 / 8-N-1 IR interface</td>
</tr>
<tr>
<td>Remote communication modules (optional only)</td>
<td>GPRS modules with 1 x SIM card slot, IPv6 capable module</td>
</tr>
<tr>
<td>- GPRS</td>
<td></td>
</tr>
<tr>
<td>External NVMs</td>
<td>M240M2, 256 KB</td>
</tr>
<tr>
<td>- EEPROM</td>
<td>IS25LQ040B, 512 KB</td>
</tr>
<tr>
<td>- Flash (optional only)</td>
<td></td>
</tr>
<tr>
<td>Internal battery</td>
<td>1/2AA, 3.6 V Lithium-Thionyl Chloride (Li-SOCI2) 1.2 Ah</td>
</tr>
</tbody>
</table>

*Table continues on the next page...*
Table 1. MKM35Z512 three-phase power meter specification (continued)

| Power consumption @ 3.3 V and 22°C: | 11.0 mA  
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal mode (powered from mains)</td>
<td>1</td>
</tr>
<tr>
<td>Standby mode (powered from battery)</td>
<td>2.2 mA</td>
</tr>
<tr>
<td>Power-down mode (powered from battery)</td>
<td>12 μA (both covers closed, no tampering)</td>
</tr>
</tbody>
</table>

1. Valid for CORECLK = 23.986176 MHz and without any plugin communication module

2 MKM35Z512 series MCU

NXP’s MKM35Z512 series MCU is based on the 90 nm process technology. It has on-chip peripherals, computational performance, and power capabilities to enable the development of a low-cost and highly integrated power meter (see Figure 1). It is based on the 32-bit Arm® Cortex®-M0+ core, with CPU clock rated up to 75 MHz. The analog measurement 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, a high-speed analog comparator which allows to compare external signal with internal reference, a peripheral crossbar (XBAR), programmable delay block (PDB), and a memory-mapped arithmetic unit (MMAU). The XBAR module acts as a programmable switch matrix, enabling multiple simultaneous connections of internal and external signals. An accurate Independent Real-Time Clock (IRTC) with passive tamper detection capabilities is also available on all devices.

In addition to high-performance analog and digital blocks, the MKM35Z512 series MCU was 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 MKM35Z512 devices are highly capable and fully programmable MCUs, with application software driving the differentiation of the product. Currently, the necessary SDK 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 the MKM35Z512 MCUs integrate a high-performance analog front end, communication peripherals, hardware blocks for software separation, and are capable of executing various 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 an MCU 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. A description of the billing and non-billing metering quantities and calculation formulas follows.

#### 3.1 Active energy

Active energy is the energy which is consumed or utilized in an AC Circuit is called true energy or Active Energy or real energy. The active energy is measured in the unit of Watt Hours (Wh). In electric power, real work is performed for the portion of the current which is in phase with the voltage. No real work will result, from the portion where the current is not in phase with the voltage. The active energy in a typical three-phase power meter application is computed as an infinite integral of the unbiased instantaneous phase voltage \(u(t)\) and phase current \(i(t)\) waveforms.

\[
Wh = \int_0^\infty (u(t)i(t))dt \tag{3-1}
\]
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 three-phase power meter is computed as an infinite integral of the unbiased instantaneous shifted phase voltage \( u(t-90^\circ) \) and phase current \( i(t) \) waveforms.

\[
VARh = \int_0^\infty u(t-90^\circ) i(t) \, dt
\]

Eq. 3-2

3.3 Active power

The active power (P) is measured in Watts (W), and it is expressed as a product of the voltage and the in-phase component of the alternating current. The average power of any whole number of cycles is the same as the average power value of just one cycle. Therefore, 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 \( T \).

\[
P = \frac{1}{T} \int_0^T u(t) i(t) \, dt
\]

Eq. 3-3

3.4 Reactive power

The reactive power (Q) is measured in units of volt-amperes-reactive (VAR), and it is a 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 the active power, but, in the reactive power, the voltage input waveform is shifted 90 degrees with respect to the current input waveform.

\[
Q = \frac{1}{T} \int_0^T u(t-90^\circ) i(t) \, dt
\]

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 a straightforward computation of the RMS current and RMS voltage from the signal function are as follows:

\[
IRMS = \sqrt{\frac{1}{T} \int_0^T [i(t)]^2 \, dt}
\]

Eq. 3-5

\[
URMS = \sqrt{\frac{1}{T} \int_0^T [u(t)]^2 \, dt}
\]

Eq. 3-6

3.6 Apparent power

The total power in an AC circuit (both absorbed and dissipated) is referred to as the 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.
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.

$S = IRMS \cdot URMS$  \hspace{1cm} Eq. 3-7

For a better accuracy, 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 provide the same results.

$S = \sqrt{P^2 + Q^2}$  \hspace{1cm} Eq. 3-8

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 ranging from –1 to 1.

$\cos(\varphi) = \frac{P}{S}$  \hspace{1cm} Eq. 3-9

where angle $\varphi$ 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 on) 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.

4 Hardware design

Hardware design and stability are very important to achieve high accuracy and repeatability in power meter. High level hardware block diagram of power meter is shown in Figure 2. This section describes the power meter electronics, which are divided into three separate parts:

- Power supply
- Digital circuits
- Analog signal-conditioning circuits

An active power source (Switch Mode Power Supply – SMPS) is chosen for this design. The power supply is designed to operate from three phases as well as single phase universal input mains voltage with secondary side regulation. Secondary side regulation provides stable and well-regulated output voltage with minimal noise with respect to input voltage and output load variations. A low-noise 3.6 V linear regulator, and a power management block is placed at power supply output to further reduce the noise. Total capacity of power supply output is 10 W max. The simple power management block works autonomously—that is, it supplies stable power source to the power meter electronics from either the 50 Hz (60 Hz) mains or the 3.6 V Li-SOCI2 battery, which is also integrated.

The basic configuration is comprised of only the circuits necessary for power meter operation; that means MCU (MKM35Z512VLL7), debug interface, LCD interface, LED interface, Ir (IEC62056-21), GPRS module connector, relays, pushbutton, 256 KB I2C EEPROM and tamper detection. In contrast to the basic configuration, all the advanced features are optional, and require the following additional components to be populated: 512 KB SPI Flash for firmware upgrade and/or data storage. For more information, see 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 sensors' hardware interfaces. The phase voltage signal is connected to the SAR multiplexer, however, the external biasing circuits must be added externally.

Digital and analog circuit of the reference design is based on peripheral usage of the MCU and a block diagram is shown below.

Figure 2. KM35Z512 usage for three-phase smart meter

The power meter electronics were created using a two-layer printed circuit board (PCB). Two-layer PCB is cheaper and cost-effective. Figure 29 and Figure 30 show the top and bottom views of the power meter PCB, respectively.

4.1 Power supply

Switched Mode Power Supply (SMPS) has been developed using an offline high-voltage converter which features a 1050 V avalanche-rugged power section, PWM operation at 60 kHz with frequency jittering for lower EMI, as shown in Figure 4. The power supply provides 12 V for Latching relay operation and 5 V (2 A Max) for GPRS/RF module and other digital and analog circuit. For stable and well-regulated output with low ripple SMPS is designed with secondary side feedback from 5 V. 5 V output is followed by 3.6 V LDO for further reduction in output ripple and maintained very high regulation for input and output variation. 3.6 V generated from LDO is used for energy measurement block and other digital circuit.

The following supply voltages are all derived from the regulated output voltage of the SMPS-LDO and auxiliary battery:

- RFV – 5 V supply used to supply GPRS module and backlight in the meter
- VCC – Fixed 3.6 V supply from SMPS-LDO that powers the GPRS modem or other types of wireless communication modules
- VDD is supported by VCC and VBAT_AUX (auxiliary 3.6 V Li-SOCl₂ battery) – provides supply to digital and analog voltage for the MCU and digital/analog circuits in case of VDD failure. MCU power pins VDD, VDDA, SAR_VDDA all are powered through this.
The analog circuits within the MCU usually require decoupled power supplies for the best performance. The analog voltages (VDDA and SAR_VDDA) are supplied through VDD only and bypass capacitors C6, C7 are put close to the MCU analog voltage pins for better performance. Chip inductor L21 is placed between VDD and VCC to suppress the noise and provide clean voltage for digital and analog measurement circuit.

MCU will not have any VDD when there is no AC mains. Auxiliary battery (VBAT_AUX) will provide VDD to MCU through D38 whenever any switch SW3, SW4, and SW5 become active. MCU also gets VDD whenever switch SW2 (UP_SCROLL) is pressed. When SW2 switch is pressed, MCU software can activate the LATCH pin to latch the VBAT_AUX to MCU VDD.

The analog circuits within the MCU usually require decoupled power supplies for the best performance. The analog voltages (VDDA and SAR_VDDA) are supplied through VDD only and bypass capacitors C6, C7 are put close to the MCU analog voltage pins for better performance. Chip inductor L21 is placed between VDD and VCC to suppress the noise and provide clean voltage for digital and analog measurement circuit.

NOTE
The digital and analog voltages MCU VDD, VDDA, and SAR_VDDA are lower than the regulated output voltage VCC, due to a voltage drop on the diode D57 (0.35 V).
4.2 Digital circuits

All the digital circuits are supplied from the VDD, and VCC voltages. The digital/analog common MCU voltage (VDD), which is backed up by the 1/2AA 3.6 V Li-SOCI₂ battery (BT2), is active even when the power meter electronics are disconnected from the mains. It powers the MCU (U21), LEDs, isolated optical communication interface (U15, U16). The regulated output voltage (VCC) powers the digital circuits that can be switched off during the Standby and Power-down operating modes anyway. These are the communication modules which can be connected on connectors (J6, J7).

4.2.1 MKM35Z512VLL7

The MKM35Z512VLL7 MCU (U1) is the most noticeable component on the metering board (see ). The following components are required for proper operation of this MCU:

- Filtering ceramic capacitors C1, C4, C6, C7, C8, C9, C52, C54
- LCD charge pump capacitors C10, C11, C13, C19
- External reset filters C2 and R1
- 32.768 kHz crystal Y1

The LCD (DS1) is an indispensable part of the power meter used to display billing and non-billing quantity. Debugger Connector J1 is the SWD interface for MCU programming and debugging.

CAUTION:

The debug interface (J1) 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.

4.2.2 Output LEDs

The MCU uses a timer and GPIO pins to control two bright red LEDs D14 and D15 (see Figure 5; D14 for active energy, and D15 for reactive energy. These LEDs are used at the time of the meter calibration or verification as well as indication of energies calculations.

![Output LEDs control](image)

**Figure 5. Output LEDs control**

4.2.3 KB I2C EEPROM memory

The 256 KB I2C EEPROM memory (M24M02) can be used for parameter storage (backup of the calibration parameters) and other application purposes, for example, load profiles, billing, and even to store new application firmware. The connection of the EEPROM memory to the MCU is made through the I2C1 module, as shown in Figure 6. The maximum communication throughput is limited by the M24M02 device. The memory can work in both the Normal and Standby operation modes.
4.2.4 KB SPI flash

The 512 KB SPI Flash (IS25LQ040B-JNLE) can be used to store a new firmware application, and/or to store load profiles. The connection of the Flash memory to the MCU is made through the SPI0 module, as shown in Figure 7.

The SPI0 module of the MKM35Z512VLL7 device supports communication speed of up to 12.5 Mbit/s. The memory can work in both the Normal and Standby operation modes.

4.2.5 GPRS module interface

The expansion headers J6 and J7 (see Figure 8) are used to interface the power meter to the GPRS modules. Currently, they support only the WM620 based GPRS module (see Figure 9). In the future, they will also support other types of modules, for example, the 6 LowPAN LPR modules and so on. Header RFC4 provides the interconnection, while header RFC1 provides power supply from the SMPS supply to the module itself. All of these modules accept supply voltage of 3.6 V or 5.0 V with a maximum continuous current of up to 2000 mA. Currently, these module connectors support below signals apart from power/ground pins:

- UART Tx, Rx data lines, RTS, CTS flow controls
- Low voltage 3.6 V, High voltage 5 V
• NIC enable pin to enable/disable GPRS module resident power supply

![GPRS control diagram](image1)

**Figure 8. GPRS control**

![GPRS extension diagram](image2)

**Figure 9. Extension for the GPRS communication**

### 4.2.6 IR interface (IEC62056-21)

The power meter has a galvanically isolated optical communication port, as per IEC62056-21 so that it can be easily connected to a common handheld meter-reading instrument for data exchange. The IR interface is driven by the UART. Power to the IR interface is provided by VDD. The IR interface schematic part is shown in Figure 10.
Alternatively, this interface can be also used for waking up the meter (from the Power-down to the Standby mode) by an external optical probe. However, this feature has an impact on increasing the current consumption in both operation modes.

### 4.2.7 Isolated RS-232 interface

This communication interface can be used primarily for real-time visualization using the FreeMASTER tool [6] or other means. The communication is driven by the UART1 module of the MCU. The communication is optically isolated using the optocouplers U15 and U16. As there is a fixed voltage level on these control lines generated by the PC, it is used to power the secondary side of the U15 optocoupler and the primary side of the U16 optocoupler. The communication interface, including the R87, R89, R142, R143, C53 components, are required to power the optocouplers from the transition control signals, is shown in Figure 11.
Figure 11. RS-232 control

NOTE
The J2 output connector is not bonded to the meter's enclosure. Therefore, the described interface is primarily used at the time of development (uncovered equipment).

4.2.8 Relay driver
Relays are present in smart meter to cutoff the load from source input. Two PMV90ENE N channel trench MOSFETs are used to drive the relays that are connected through J3 placed at the meter PCB. Relays are driven by MCU GPIO pins configured as output. Relay connectors are shown in Figure 12.
4.2.9 Magnetic tamper

There are two magnetic tamper sensors in the meter PCB. The first one is a hall-effect sensor which is used to sense any presence of DC magnet near the meter. MCU interface is a GPIO pin input configuration. The second one is the 3D magnetic sensor and is not placed in the meter PCB and can be populated if required. This sensor is interfaced to MCU using I2C. Magnetic tamper sense circuit is shown in Figure 13.

4.2.10 Cover, module and terminal open tampers

There are options for 3 tampers detection in the meter PCB. Cover open tamper occurs when the cover of the meter is opened. MCU is signaled through tamper pin which is available in RTC battery power domain. The second one is the module open tamper
and is signaled when the GPRS module of the meter is removed or replaced. The third one is optional and called terminal open tamper and is detected when terminal of the meter is opened or closed. Tamper sense circuit is shown in Figure 14.

![Tamper sense circuit](image)

**Figure 14. Tamper sense circuit**

### 4.3 Analog circuits

An excellent performance of the metering AFE, including external analog signal conditioning, is crucial for the power meter application. Due to the high dynamic range of the current measurement (typically 700:1) and the relatively low input signal range (from microvolts to several tens of millivolts), the phase current measurement is utmost critical. All analog circuits are described in the following subsections.

#### 4.3.1 Phase and neutral current measurement

The Kinetis-M three-phase power meter reference design is optimized for current transformers, but various Rogowski coils can also be used. The only limitations are that the sensor output signal range must be within ±0.5 V peak and within the dimensions of the enclosure. The interface of a current sensor to the MKM35Z512VLL7 device is very straightforward; a burden resistor for current-to-voltage conversion and anti-aliasing low-pass filters attenuating signals with frequencies greater than the Nyquist frequency must be populated on the board (see Figure 15). The cutoff frequency of the analog filters implemented on the board is 72.3 kHz; such a filter has an attenuation of -33.3 dB at Nyquist frequency of 3.072 MHz. The burden resistor is a composite formed by two resistors with the same value. The middle point of this is connected to ground.
Figure 15. Phase current signal conditioning circuit

In addition to phase current measurement, due to the need to identification of current related tampers, such as earth tamper, the neutral current is also measured with a current transformer sensor. The current transformer gives isolation to the MCU AFE circuit as the ground of the circuit is referenced from the mains phase voltage. The neutral current signal conditioning circuit is shown in Figure 16.

Figure 16. Neutral current signal conditioning circuit

4.3.2 Phase voltage measurement

A simple voltage divider is used for the line voltage measurement. As phase voltage is high voltage so multiple resistors are used to meet the total resistor requirement as well as meet resistor voltage and energy dissipation stress (see Figure 17). One half of this total resistor consists of R111, R112, R113, and R115, the second half consists of resistor R139 (channel 1), R116, R117, R118, R119, and R140 (channel 2) and R121, R122, R123, R124, and R141 (channel 3). The resistor values were selected to scale down the 424.2 V peak input line voltage to the 0.4964 V peak input signal range of the 16 bit SAR ADC. The SAR ADC input is unipolar different to bipolar SD ADC inputs. Hence, an external bias voltage must be added. External bias voltage is derived from the on-chip reference voltage (taken from the VREF pin) and the value is the half of reference voltage. The bias voltage is connected to the voltage divider through resistors R139, R140, and R141. The anti-aliasing low-pass filter of the phase voltage measurement circuit is set to a cutoff frequency of 27.22 kHz. Such an anti-aliasing filter has an attenuation of -41.0 dB at Nyquist frequency of 3.072 MHz.
4.3.3 Half reference voltage generator

The reference voltage half value is generated from internal voltage reference. Reference voltage 1.2 V is available on the VREF pin. This voltage is divided by two through the voltage divider R54 and R56. The half reference voltage is connected to the unity gain buffer where the optional filter capacity C39 is added. The unity gain buffer is a low cost and simple instrumentation amplifier U28 LMV324. A unity gain buffer is placed for phase voltage channel decoupling, therefore, the buffer works like an impedance transformer. Figure 18 shows the schematic diagram of the half reference voltage generator.

4.3.4 Zero crossing circuit connection

Internal comparator of MKM35Z512VLL7 is used for zero crossing detection. MKM35Z512VLL7 MCU has 3 high-speed analog comparator with an integrated 6-bit DAC and analog mux. To optimize external circuit and reduce component count, same ADC pin used for phase voltage sensing can configure to positive or negative pin of internal comparator.

5 Software design

This section describes the software application of the MKM35Z512 three-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 is written in the C language and compiled using the IAR® Embedded Workbench for Arm (version 7.50.1), with high optimization for execution speed. The software application is based on the MKM35Z512 bare-metal software drivers [5] and the RMS and power converter-based metering algorithm library.
The software transitions between operating modes, calculates all metering quantities, controls the active and reactive energy pulse output, controls the LCD, stores and retrieves parameters from the NVMs, and enables application monitoring and control. The application monitoring and control is performed using local IR interface and a remote GPRS communication interface.

Figure 19 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 MKM35Z512 three-phase power meter software are briefly explained in the following subsections.

5.2 Software tasks

The software tasks are part of the application. They are driven by events (interrupts) generated either by the on-chip peripherals or the application tasks. The list of all tasks, trigger events, and calling periods is summarized in the following table:
<table>
<thead>
<tr>
<th>Task name</th>
<th>Description</th>
<th>Source file(s)</th>
<th>Function(s) name</th>
<th>Trigger source</th>
<th>IRQ priority</th>
<th>Calling period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating mode control</td>
<td>Controls transitioning between power meter operating modes</td>
<td>IOControls.c, IOControls.h</td>
<td>AppGPIOInit</td>
<td>device reset</td>
<td>–</td>
<td>after every device reset</td>
</tr>
<tr>
<td>HMI control</td>
<td>Updates LCD</td>
<td>UserInterface.c</td>
<td>Display</td>
<td>QTMR interrupt</td>
<td>Level 3 (lowest)</td>
<td>periodic 1 sec</td>
</tr>
<tr>
<td></td>
<td>Reads user button state</td>
<td>Timer.c</td>
<td>GPTimerEventHandler</td>
<td>QTMR interrupt</td>
<td>Level 3 (lowest)</td>
<td>asynchronous</td>
</tr>
<tr>
<td>Data processing</td>
<td>Reads digital values from the SAR ADC</td>
<td>libmeterliblprt_c, meterlprtlib_cm_0p_iar.a, meterlprtlib_cm_0p_mdk.lib, MeteringISR.c, MeteringLPRT.h</td>
<td>SARADCCallback</td>
<td>SAR ADC CH0,1,2 conversion complete IRQ</td>
<td>Level 1</td>
<td>periodic 166.67 μs</td>
</tr>
<tr>
<td>Calculation</td>
<td>Zero-cross detection</td>
<td>MeteringISR.c</td>
<td>TMR2callback</td>
<td>QTMR interrupt</td>
<td>(CMP2 o/p triggering QTMR through XBAR)</td>
<td>Level 2</td>
</tr>
<tr>
<td>Calculation</td>
<td>Calculation billing and non-billing quantities</td>
<td>libmeterliblprt_c, meterlprtlib_cm_0p_iar.a, meterlprtlib_cm_0p_mdk.lib, MeteringLPRT.h</td>
<td>DoMetering3Ph</td>
<td>–</td>
<td>–</td>
<td>Periodic 1 sec</td>
</tr>
<tr>
<td>Pulse generation</td>
<td>LEDs dynamic pulse output generation</td>
<td>MeteringISR.c</td>
<td>DoPulsing3Ph</td>
<td>LPTMR0 compare flag</td>
<td>Level 0 (highest)</td>
<td>Periodic every 1 msec</td>
</tr>
<tr>
<td>Tamper monitoring</td>
<td>Reads tampers state</td>
<td>RTCDriver.c, RTCDriver.h</td>
<td>RTCEventHandler</td>
<td>TAMPER1 active high, TAMPER2 both edges</td>
<td>Level 3 (lowest)</td>
<td>asynchronous</td>
</tr>
<tr>
<td>Power meter calibration</td>
<td>Performs power meter calibration</td>
<td>libmeterliblprt_c, meterlprtlib_cm_0p.a, MeteringISR.c</td>
<td>DoCalibration3Ph</td>
<td>UART interface</td>
<td>–</td>
<td>Command through</td>
</tr>
</tbody>
</table>

*Table continues on the next page...*
### Table 2. List of software tasks (continued)

<table>
<thead>
<tr>
<th>Task name</th>
<th>Description</th>
<th>Source file(s)</th>
<th>Function(s) name</th>
<th>Trigger source</th>
<th>IRQ priority</th>
<th>Calling period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameter</td>
<td>Reads parameters from the Flash and from the external EEPROM</td>
<td>meterlprtlib_cm_0p_iar.a, meterlprtlib_cm_0p_mdk.lib, Calibration3Ph.h</td>
<td>InitCalibration</td>
<td>device reset</td>
<td></td>
<td>UART interface</td>
</tr>
<tr>
<td>management</td>
<td>Writes parameters to the Flash and to the external EEPROM</td>
<td>MeteringRunInit.c, Calibration3Ph.h</td>
<td>UpdateFlashCalib, ReadVerifyFlashCalib, ReadVerifyCalib</td>
<td>after successful calibration, controlled by user, or switching off</td>
<td></td>
<td>after every device reset</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>asynchronous</td>
</tr>
</tbody>
</table>

1. A special load point must be applied by the test equipment

#### 5.2.1 Power meter calibration

The power meter is calibrated using a special test equipment. The calibration task runs whenever a power meter is connected to the mains and a calibration command is triggered through IR communication interface. Calibration is done on fix point of voltage (240 Vac), current (10 A) and power factor (0.5L, 60 degree phase angle). The running calibration task measures the phase voltage and phase current signals generated by the test equipment, and it expects 240 V phase voltage and 10.0 A phase current waveforms with a 60 degree phase shift (lag). The voltage and current signals must be the first harmonic (fundamental) only. All these values should be precise and stable during the calibration itself; the final precision of the power meter strongly depends on it. If the calibration task detects such a load point, then the calibration task calculates the calibration gains and phase shift using the following equations:

\[
gain_U = \frac{240.0}{U_{RMS}} \quad \text{Eq. 5-1}
\]

\[
gain_I = \frac{10.0}{I_{RMS}} \quad \text{Eq. 5-2}
\]

\[
\theta = 60^\circ - \tan^{-1}\left(\frac{Q}{P}\right) \quad \text{Eq. 5-3}
\]

where:

- \(gain_U\) and \(gain_I\) are calibrated gains
- \(\theta\) is the calculated phase shift caused by the parasitic inductance of the shunt resistor or current transformer
- \(U_{RMS}, I_{RMS}, P, Q\) are quantities measured by the non-calibrated meter

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 recalibration of the power meter can be reinitiated later also. For more details on the calibration process, see AN12827.
5.2.2 Operating mode control

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

- **Normal**: Electricity is supplied and the power meter is fully functional.
- **Standby**: Electricity is disconnected. And, you can list through the menus and also can communicate with the meter using IR interface.
- **Power-down**: Electricity is disconnected with no user interaction.

Figure 20 shows the transitioning between the supported operating modes. After the battery or the mains is connected, the power meter transitions to the Device Reset state. If mains is applied, hardware generates MAINS_ON signal which is connected to MCU GPIO pin. Status change in MAINS_ON pin trigger the software application to enter into the Normal mode operation. In Normal mode all software tasks including calibration, measurements, calculations, HMI control, parameter storage, pulse generation, tamper management, and communication, are executed. In this mode, the MKM35Z512VLL7 device runs in the RUN mode. The system core and Flash clock frequency are generated by the frequency-locked loop (FLL), and it is 23.986 MHz. The AFE clock frequency is generated by the phase-locked loop (PLL), and it is 12.288 MHz. The power meter electronics consume 11.0 mA in the Normal mode.

If mains is not applied, then the software application enters the Switched OFF state. Once the mains is applied, meter enters in Normal mode. As soon as electricity is disconnected, meter switches back to Switched OFF mode provided meter cover and GPRS module is kept inserted in the meter. If either of those are open, then the meter enters in Power-down mode when the electricity is disconnected and if a battery is connected to the meter. If user button is pressed, the software then enters the standby mode. This mode transitions between the Normal mode and the Switched-off mode with a duration of only 20 seconds refresh timeout. The power meter runs from the battery during standby mode, and in this mode user can list through the menus and can also download meter billing and non-billing quantities through IR interface only. In this mode, the MKM35Z512VLL7 device functions in the RUN mode with much reduced MCU clock to save power. The system clock frequency is scaled down to 2 MHz from the 4 MHz internal relaxation oscillator. Because of the slow clock frequency, the limited number of enabled on-chip peripherals, the power consumption of the power meter electronics is approximately 2.2 mA.

When the power meter runs from the battery (standby mode) but user does not list through the menus, then the software transitions automatically to the Switched OFF mode. The MKM35Z512VLL7 device is forced to enter the Very Low Leakage Stop...
2 (VLLS2) mode, where the recovery can be triggered by pressing the user button or applying the mains. The Power-down mode is characterized by a battery current consumption of 12 μA.

5.2.3 Data processing

Reading all the phases and neutral currents samples from the analog front end (AFE) and all the phases voltages from SAR ADC periodically every 166.67 μsec. This task runs on the high priority level. AFE runs continuous conversion mode asynchronously and SAR ADC is configured in trigger conversion mode. Each AFE (assigned for taking current samples) triggered its corresponding SAR ADC channels to take voltage sample of respective phases at same time AFE sample conversion completes. Both current samples (AFE result register) and voltage samples (SAR ADC result register) of respective phases is been collected in buffers at respective SAR ADC conversion complete interrupt. Calculation task is been initiated once required number of samples of voltages and currents is been stored in buffer.

NOTE

Each phase current sample from AFE and each phase voltage from SAR ADC are taken continuously at a constant rate of 6000 samples per second. This can be achieved by setting AFE modulator clock and over sampling ratio (OSR) accordingly for example, in low-power AFE mode, setting AFE modulator clock to 768 KHz and OSR to 256. Although in normal AFE mode, higher modulator clock and OSR value can be set to achieve desired sample rate.

5.2.4 Calculations

This separate task monitors the mains zero-crossings, which is used to calculate frequency in the timer handler callback function itself. Apart from that, the main calculation process computes both the billing (energies) and the non-billing quantities. This is done periodically at the end of every one second.

At this time, all circle buffers are filled up with the AFE and SAR ADC results. Firstly, the calculation task performs the DoMetering3Ph which calculates all instantaneous parameters of all phases including Vrms, Irms, Phase angle, and Powers. This calculation process uses the calibration gains obtained during the calibration stage (see Power meter calibration).

DoCalibration3Ph function is used to do calibration of the meter depending on a user command received through IR communication interface.

Finally, the billing quantities is computed and the energy LED pulsing is done by another independent task DoPulsing3Ph.

5.2.5 HMI control

The Human Machine Interface (HMI) control task executes continuously for LCD display and pushbutton events. Using short keypress, the LCD parameters can be scrolled through a pre-defined list of billing and non-billing parameters. But after pressing the key for a longer duration once, the display mode can be changed to High resolution mode where subsequent short duration keypresses display billing and non-billing parameters with higher resolutions. The display mode reverts back to regular resolution mode after a predefined time is elapsed.

5.2.6 Main loop processing

Main loop of the application software runs all the tasks like Data processing, checking and storing tamper/events, communication tasks, checking for power mode change, reads the real-time clock and refreshes the watchdog. The interaction with the user is made through an asynchronous event, which occurs when the user button is pressed. By pressing the user button, you are able to scroll through the menus and display all measured and calculated quantities (see Figure 22).

5.2.7 Tamper monitoring

There are two hidden mechanical pushbuttons. One button is used for the main cover opening detection, and the second button is used for the GPRS module removal or insertion detection. There is an optional third pushbutton to detect the terminal cover opening. By default, this pushbutton is not populated on meter PCB. These asynchronous events are read as the IRTC interrupt, those are stored in the memory, and shown on the LCD continuously. The other tampers which are monitored are magnetic tamper and few other electrical tamper conditions the detection logic of which are beyond the scope of this document.
5.2.8 IR port communication

IR port communication is done as part of Communication task. A proprietary set of communication commands has been utilized to communicate with the meter for few tasks for example calibration of the meter, reading billing and non-billing quantities, reading or setting meter clock etc. UART0 has been used for this interface.

5.2.9 GPRS port communication

GPRS module communication is done as part of Communication task. GPRS module is connected through UART3 of the MCU. The application software utilizes AT command interface to communicate with the GPRS mode. The communication protocol for remote communication through GPRS is beyond the scope of this document. GPRS communication enables AMI (or AMR) meter reading from remote location.

5.2.10 Parameter management

The current software application uses 2048 byte sector of the internal MKM35Z512VLL7 Flash memory for parameter storage. There is also an external 256 KB EPROM memory used for the same purpose, but as a backup storage (optional only). By default, the parameters are written after a successful calibration, and they are read after each device reset. The main purpose for using these non-volatile memories like EEPROM is to save all the other meter parameters. Storing and reading of parameters can also be initiated through the IR or GPRS communication interface using proprietary tool or protocol specific standard tools used by power meter OEMs or utilities.

5.3 Performance

Table 3 shows the memory requirements of the MKM35Z512 three-phase power meter software application[1].

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
<th>Flash size [KB]</th>
<th>RAM size [KB]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Application framework</td>
<td>Complete application without all libraries and communication</td>
<td>44.214</td>
<td>4.174</td>
</tr>
<tr>
<td>Low-power real time metering library</td>
<td>Low-power real time metering algorithm library</td>
<td>6.037</td>
<td>2.262</td>
</tr>
<tr>
<td>EEPROM driver</td>
<td>EEPROM driver</td>
<td>1.1202</td>
<td>0.0136</td>
</tr>
<tr>
<td>Proprietary communication</td>
<td>Proprietary protocol and serial communication driver</td>
<td>6.182</td>
<td>1.334</td>
</tr>
<tr>
<td></td>
<td><strong>Grand total</strong></td>
<td><strong>57.564</strong></td>
<td><strong>7.784</strong></td>
</tr>
</tbody>
</table>

The device system clock 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 732, hence generating a low-jitter system clock with a frequency of 23.986176 MHz. Such system clock frequency is sufficient for executing a fully functional software application.

6 Application setup

Figure 21 shows the wiring diagram of the MKM35Z512 three-phase power meter.

Registering the active and reactive energy consumed by an external load is among the main capabilities of the power meter. When user connects the power meter to the mains or when user press the user button, the power meter transitions from the Power-down mode to either the Normal mode or the Standby mode, depends up on mains present or absent. In the Normal and Standby modes,

[1] Application is compiled using the IAR Embedded Workbench for Arm, with high optimization for execution speed.
the LCD is turned on, and it shows the last calculated quantity. 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 Table 4.

![MKM35Z512 three-phase power meter wiring diagram](image)

Table 4. The LCD menu item list

<table>
<thead>
<tr>
<th>Value</th>
<th>Unit</th>
<th>Format</th>
<th>Auxiliary symbols</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line voltage</td>
<td>VRMS</td>
<td>###.##</td>
<td>V</td>
</tr>
<tr>
<td>Phase line current</td>
<td>ARMS</td>
<td>###.##</td>
<td>A</td>
</tr>
<tr>
<td>Neutral line current</td>
<td>ARMS</td>
<td>#.###</td>
<td>A</td>
</tr>
<tr>
<td>Signed active power P</td>
<td>W</td>
<td>#.## (+ forward, – reverse)</td>
<td>W</td>
</tr>
<tr>
<td>Signed reactive power Q</td>
<td>VAr</td>
<td>#.## (+ lag, – lead)</td>
<td>VA, r</td>
</tr>
<tr>
<td>Apparent power S</td>
<td>VA</td>
<td>#.##</td>
<td>VA</td>
</tr>
<tr>
<td>Power factor</td>
<td>–</td>
<td>#.###</td>
<td>PF</td>
</tr>
<tr>
<td>Frequency</td>
<td>Hz</td>
<td>#.###</td>
<td>Hz</td>
</tr>
</tbody>
</table>
Table 4. The LCD menu item list (continued)

<table>
<thead>
<tr>
<th>Value</th>
<th>Unit</th>
<th>Format</th>
<th>Auxiliary symbols</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date</td>
<td>–</td>
<td>DD:MM:YY</td>
<td>–</td>
</tr>
<tr>
<td>Time</td>
<td>–</td>
<td>HH:MM:SS</td>
<td>–</td>
</tr>
<tr>
<td>Meter serial number</td>
<td>–</td>
<td>########</td>
<td>–</td>
</tr>
</tbody>
</table>

Figure 22 shows the values and special symbols on the power meter display. This figure displays the following display parameters – line voltage, phase current, cumulative active energy, date, time, all segment ON.

Figure 22. MKM35Z512 three-phase smart power meter display

The active energy LED flash simultaneously with the internal energy counters during the Normal operation mode. The active energy LED is the sum of both active energies (imported and exported). All these active and reactive energy counters are periodically saved every 3 minutes into the external EEPROM memory (backup storage). These energy quantities remain in the memory after resetting the power meter.

7 Accuracy and performance

The MKM35Z512 three-phase reference designs are fully calibrated using the test equipment ST6300V2. All power meters were tested according to the IS14697 class 0.5 (0.5 %) Indian standards for electronic meters.

During the calibration and testing process, the power meter measured electrical quantities generated by the test bench ST6300V2, calculated the active energy, and generated pulses on the output LED; each generated pulse was equal to the active energy amount in kWh/ imp. The deviations between the pulses generated by the power meter and the reference pulses generated by the test equipment defined the measurement accuracy.

Figure 23 shows the accuracy plot of NXP MKM35Z512 three-phase smart power meter. The figure indicates the results of the power meter accuracy performed at 25°C. The accuracy of the measurement for various phase currents, various phase voltages, various frequency values and the angles between phase current and phase voltage, are shown in the graph.

The graph (on the top) indicates the accuracy of the active energy measurement after calibration. The x-axis shows the variation of the phase current, and the y-axis denotes the average accuracy of the power meter, computed from five successive measurements. The two bold red lines define the Class 0.5 (IS14697) accuracy margins for active energy measurement for power factor 1 for this test.

The second graph shows the accuracy of the active energy after calibration. The x-axis shows the variation of the phase voltage, and the y-axis denotes the average accuracy of the power meter, computed from five successive measurements. The two bold red lines define the Class 0.5 (IS14697) accuracy margins for active energy measurement for power factor 1 for this test.

The third graph shows the accuracy of the active energy after calibration. The x-axis shows the variation of the frequency, and the y-axis denotes the average accuracy of the power meter, computed from five successive measurements. The two bold red lines define the Class 0.5 (IS14697) accuracy margins for active energy measurement for power factor 1 for this test.
By analyzing the protocols of several MKM35Z512 three-phase power meters, this equipment measures active and reactive energies at all power factors, at 25°C ambient temperature, and in the current range of 0.1 – 90 A, with the accuracy range of ±0.25 %.

**CAUTION:**
Even though the current range of the power meter is scaled to 90 A, it is not recommended to operate the power meter in the 60 – 90 A range for a longer time period, due to heating of the single turn primary winding of current transformer.
Figure 23. Accuracy results at 25°C
8 Summary

This design reference manual describes a solution for a three-phase smart electronic power meter, based on the MKM35Z512VLL7 MCU.

NXP offers Fast Fourier Transform (FFT), Filter-based and low-power and real time-based metering algorithms for use in customer applications. The FFT based metering algorithm calculates the metering quantities in the frequency domain, the latter two does the same in the time domain. This 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 the application firmware can leverage any type of metering algorithm, based on customer preference. To extend the power meter uses, the hardware platform comprises either 256 KB EEPROM for data storage and firmware upgrade and also an optional 512 KB SPI Flash for firmware upgrade, and an expansion header for GPRS module for AMI communication and monitoring.

The application software is written in the C language, and compiled using MCUXpresso, IAR Embedded Workbench for Arm and Keil tool chains, with optimization for the execution speed. It is based on the MKM35Z512 SDK driver software drivers and the Low-Power Real-Time (LPRT) metering library as default. The application firmware calibrates the power meter through IR command, calculates all metering quantities, controls active energy pulse output and the LCD, stores and retrieves parameters from the Flash and EEPROM memory. The application software of such complexity requires approximately 58 KB of Flash and 8 KB of RAM. The system clock frequency of the MKM35Z512VLL7 device must be 24.576 MHz (or higher) to calculate all metering quantities with an update rate of 6 kHz (the sample rate).

The power meter is designed to transition between three operating modes. It runs in the Normal mode when it is powered from the mains. In this mode, the meter electronics consume 11.0 mA. The Standby mode is entered when the power meter runs from the battery and the user lists through the menus. In this particular mode, the 3.6 V Li-SOCI2 (1.2 Ah) battery is being discharged by 2.2 mA as it also measures currents current channels. When the power meter runs from the battery but no interaction with the user occurs, the power meter electronics automatically transition to the Switched OFF mode.

The application software enables you to monitor the measured and calculated quantities through the proprietary application running on your PC. The IR communication interface is used for such communication. Another very important means of AMI (or AMR) communication is through GPRS communication module.

The MKM35Z512 three-phase smart power meters were tested according to the IS14697 Indian standard for static watt-hour meters for Class 0.5 accuracy. After analyzing several power meters, we can state that this smart power meter measures active energies at all power factors, at 25°C ambient temperature, in the current range of 0.1 – 72 A, with an accuracy range of ±0.25 %.

9 Metering board electronics

Three-phase power meter hardware schematic is shown in this section. schematic has four major sections: MCU, Analog sensing, user interface, and power supply.
Figure 24. Schematic diagram of the metering board - MCU
Figure 25. Schematic diagram of the metering board - Analog sensing
Figure 26. Schematic diagram of the metering board - user interface
Figure 27. Schematic diagram of the metering board - power supply
10 Metering board layout

Three-phase power meter top-side view of the metering board is shown in Figure 29.
Figure 29. Top-side view of the metering board (not scaled)
Figure 30. Bottom-side view of the metering board (not scaled)
Figure 31. Top-side view of the GPRS module board (not scaled)
Bill of materials of the metering board

Electronics components used to develop three-phase power meter are mentioned in the table below.

Table 6. BOM report of meter PCB
<table>
<thead>
<tr>
<th>Ref</th>
<th>Quantity</th>
<th>Description</th>
<th>Value</th>
<th>Manufacturer</th>
<th>Part Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1A</td>
<td>1</td>
<td>BATTERY LITHIUM 1/2AA 3.5V 1200mAH</td>
<td>1R1430P-VR</td>
<td>ULEB</td>
<td>ER14250-VB</td>
</tr>
<tr>
<td>1.1B</td>
<td>1</td>
<td>BATTERY LITHIUM 1/2AA 3.5V 1200mAH</td>
<td>1R1430P-VR</td>
<td>ULEB</td>
<td>ER14250-VB</td>
</tr>
<tr>
<td>1.2A</td>
<td>1</td>
<td>TEST POINT PIN 0.062X0.086 TH, NO PART TO ORDER</td>
<td>TP</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>1.2B</td>
<td>1</td>
<td>TEST POINT PIN 0.062X0.086 TH, NO PART TO ORDER</td>
<td>TP</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>1.3A</td>
<td>1</td>
<td>CAP CER 0.1uf 16V 10% X7R AEC-Q200 0402</td>
<td>0.1uf</td>
<td>MURATA</td>
<td>GC315SR71C04K4ASSD</td>
</tr>
<tr>
<td>1.3B</td>
<td>1</td>
<td>CAP CER 0.1uf 16V 10% X7R AEC-Q200 0402</td>
<td>0.1uf</td>
<td>MURATA</td>
<td>GC315SR71C04K4ASSD</td>
</tr>
<tr>
<td>1.4A</td>
<td>1</td>
<td>CAP CER 0.1uf 16V 10% X7R AEC-Q200 0402</td>
<td>0.1uf</td>
<td>MURATA</td>
<td>GC315SR71C04K4ASSD</td>
</tr>
<tr>
<td>1.4B</td>
<td>1</td>
<td>CAP CER 0.1uf 16V 10% X7R AEC-Q200 0402</td>
<td>0.1uf</td>
<td>MURATA</td>
<td>GC315SR71C04K4ASSD</td>
</tr>
<tr>
<td>1.5A</td>
<td>1</td>
<td>CAP CER 0.1uf 16V 10% X7R AEC-Q200 0402</td>
<td>0.1uf</td>
<td>MURATA</td>
<td>GC315SR71C04K4ASSD</td>
</tr>
<tr>
<td>1.5B</td>
<td>1</td>
<td>CAP CER 0.1uf 16V 10% X7R AEC-Q200 0402</td>
<td>0.1uf</td>
<td>MURATA</td>
<td>GC315SR71C04K4ASSD</td>
</tr>
<tr>
<td>1.6A</td>
<td>1</td>
<td>CAP CER 0.1uf 16V 10% X7R AEC-Q200 0402</td>
<td>0.1uf</td>
<td>MURATA</td>
<td>GC315SR71C04K4ASSD</td>
</tr>
<tr>
<td>1.6B</td>
<td>1</td>
<td>CAP CER 0.1uf 16V 10% X7R AEC-Q200 0402</td>
<td>0.1uf</td>
<td>MURATA</td>
<td>GC315SR71C04K4ASSD</td>
</tr>
</tbody>
</table>

**Bill of materials of the metering board**

**Component Details**

- **Diodes**
  - BAT54HT1G
  - BC817-40LT1G
  - PMV100XPEAR
  - TEFT4300

- **Capacitors**
  - 1000PF
  - 0.1UF
  - 0.01UF
  - 0.033UF

- **Resistors**
  - 10.0K
  - TRAN NMOS 30V 3.7A SOT23
  - NEXPERIA

- **Inductors**
  - 3.3uH@1KHz 3A 20%

- **Connectors**
  - HDR 1X2 TH 100MIL SP 339H AU 98L

**Application Note**

_KM35Z512 based Three-Phase Smart Power Meter Reference Design, Rev. 0, 25 November 2021_
Electronics components used to develop GPRS module are mentioned in the table below.

<table>
<thead>
<tr>
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12 Bill of materials of the GPRS board

13 References

1. Single Point Meter Calibration process (document AN12827)
2. FFT-Based Algorithm for Metering Applications (document AN4255)
3. Using FFT on the Sigma-Delta ADCs (document AN4847)
4. Filter-Based Algorithm for Metering Applications (document AN4265)
5. MKM35Z512 SDK Software Drivers (available at https://mcuxpresso.nxp.com)
6. FreeMASTER Data Visualization and Calibration Software (available at www.nxp.com/FreeMASTER)
7. KM35Z512 based one-Phase Smart Power Meter Reference Design (document AN12837)
8. Kinetis-M Three-Phase Power Meter Reference Design (document DRM147)
9. Low-Power Real-Time Algorithm for Metering Applications (document AN13259)

14 Revision history

The following table lists the substantive changes done to this document since the initial release.
Table 5. Revision history

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<th>Revision number</th>
<th>Date</th>
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<tr>
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<td>25 November 2021</td>
<td>Initial release</td>
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**Date of release:** 25 November 2021
**Document identifier:** AN13338