AN13338

KM35Z512 based Three-Phase Smart Power Meter Reference Design

Rev. 0 — 25 November 2021 Application Note

Contents

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

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

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 [1]
• Normal mode (powered from mains)	2.2 mA
• Standby mode (powered from battery)	12 μA (both covers closed, no tampering)
• Power-down mode (powered from battery)	

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

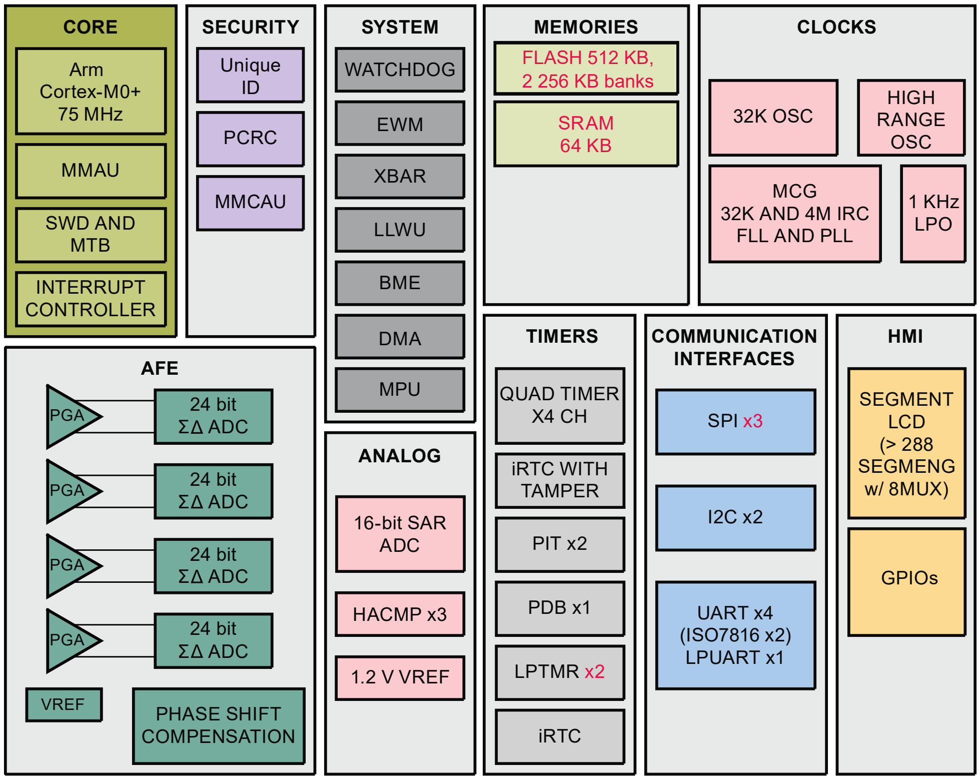

Figure 1. KM35Z512 MCUs block diagramKM35Z512 MCUs block diagram

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.

$$Wh = \int_0^{\infty} \left(u(t) i(t) \right) dt \quad \text{Eq. 3-1}$$

3.2 Reactive energy

The reactive energy is given by the integral (with respect to time) of the product of voltage and current, and the sine of the phase angle between them. The reactive energy is measured in the unit of Volt-Ampere-Reactive Hours (VARh). The reactive energy in a typical three-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.

$\boldsymbol{VARh} = \int_0^{\infty} \boldsymbol{u}(\boldsymbol{t} - 90°)\boldsymbol{i}(\boldsymbol{t})\boldsymbol{dt}$	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.

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

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

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

$S = IRMS * URMS$	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

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.

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.

$\cos(\varphi) = \frac{P}{S}$	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 nose 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.

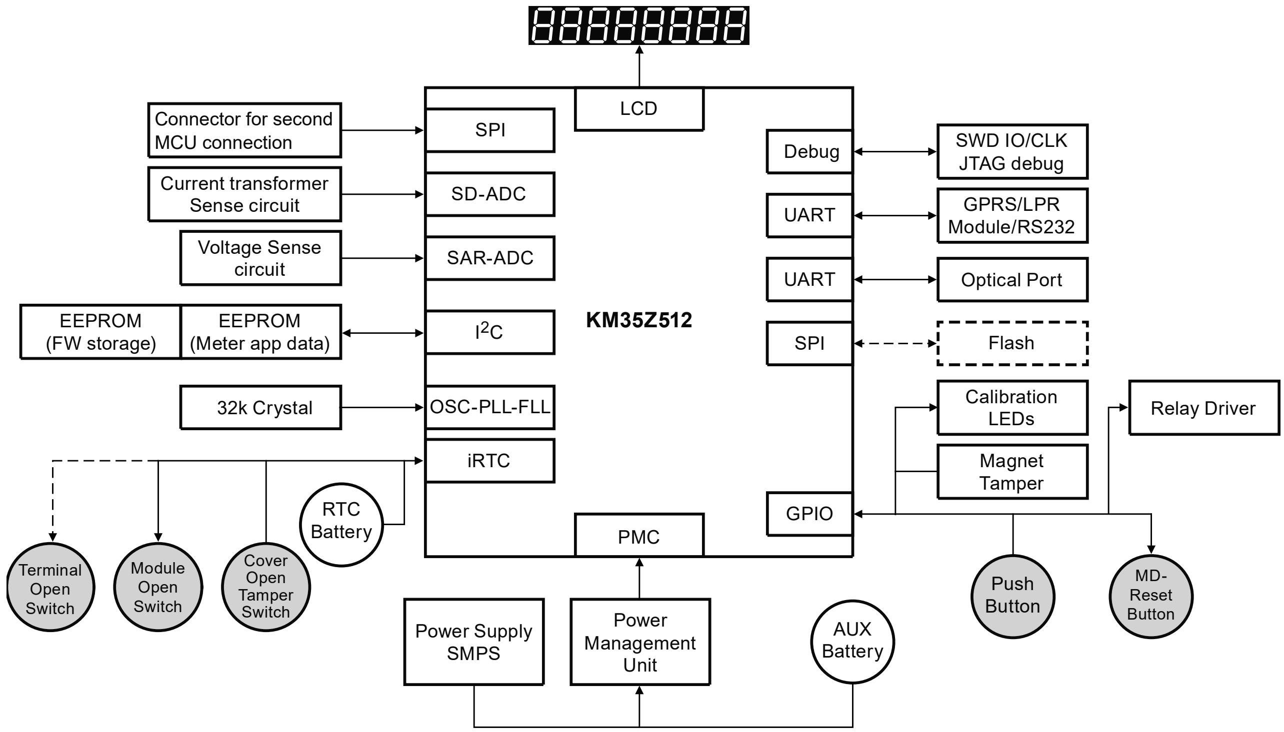

Figure 2. KM35Z512 usage for three-phase smart meter

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-SOCl$_2$ 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.

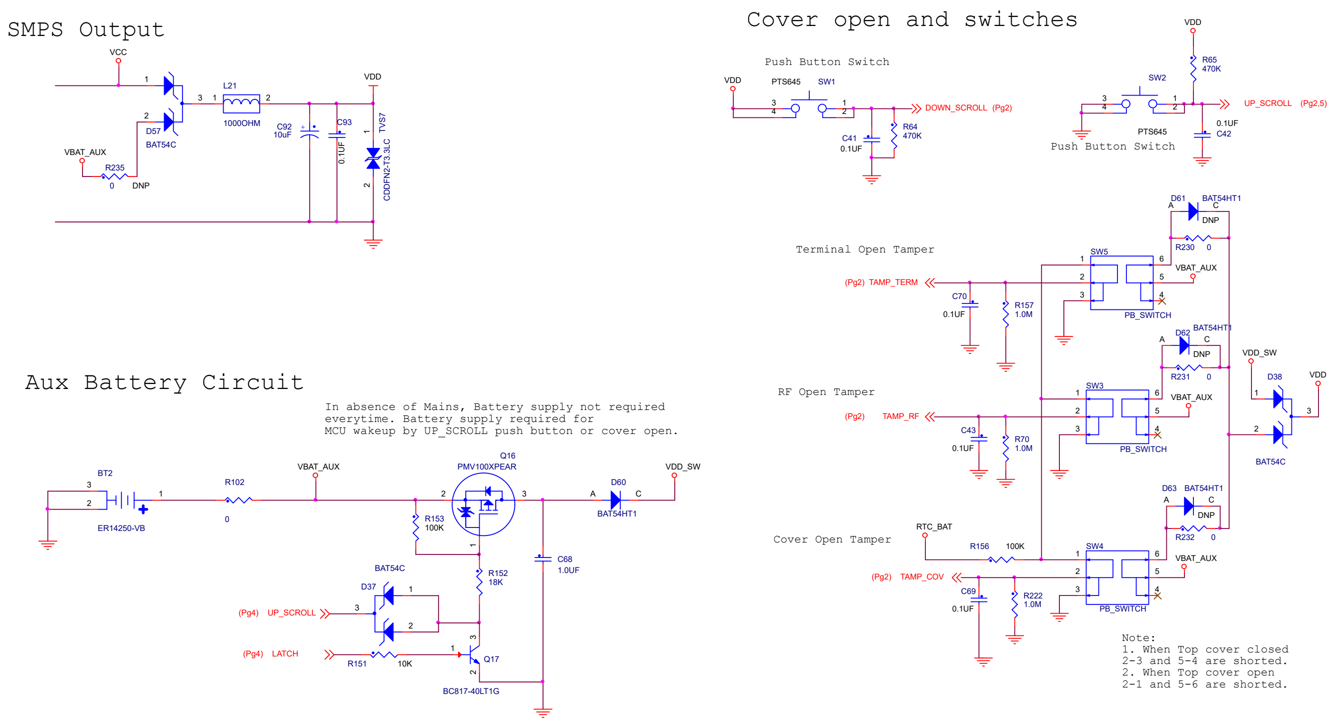

Figure 3. Voltage source for the MCU in meter

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.

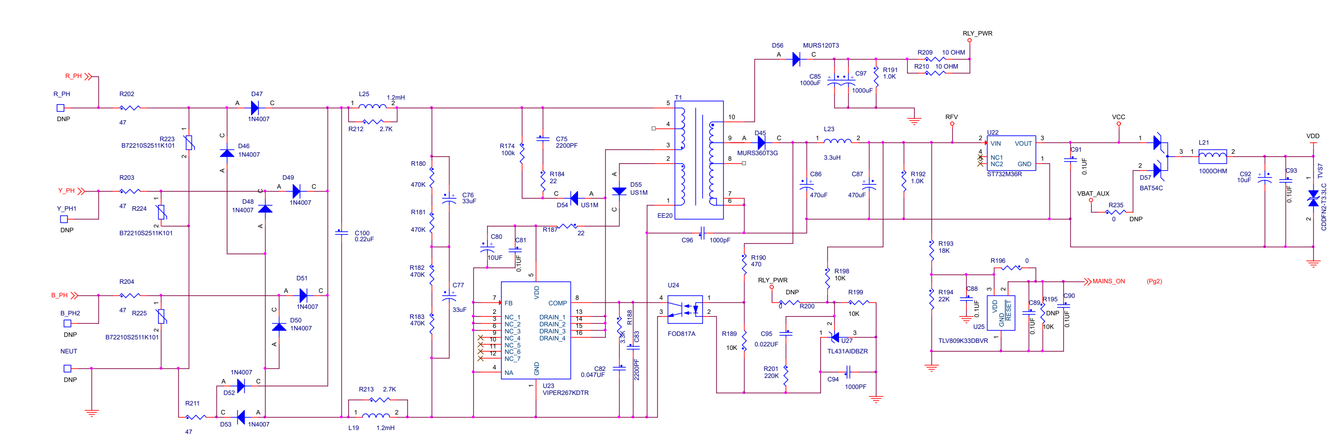

Figure 4. SMPS power supply

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-$SOCl_2$ 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.

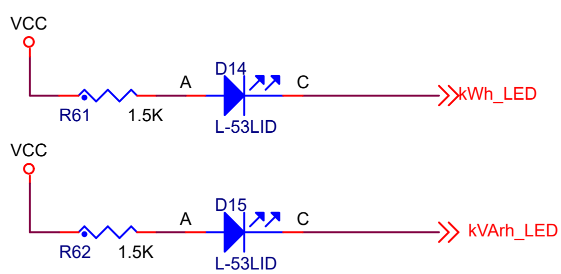

Figure 5. Output LEDs control

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.

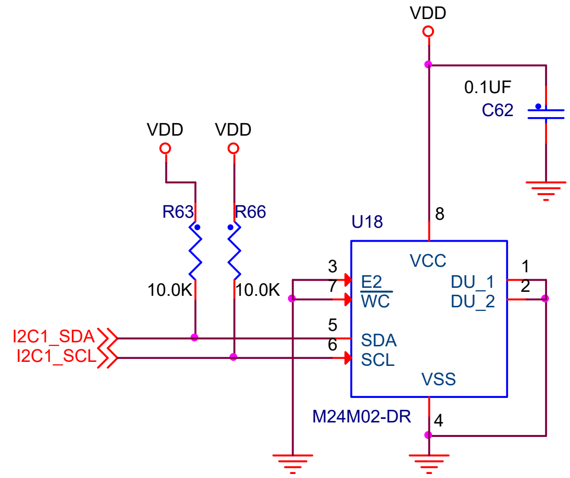

Figure 6. 256 KB I2C EEPROM control

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.

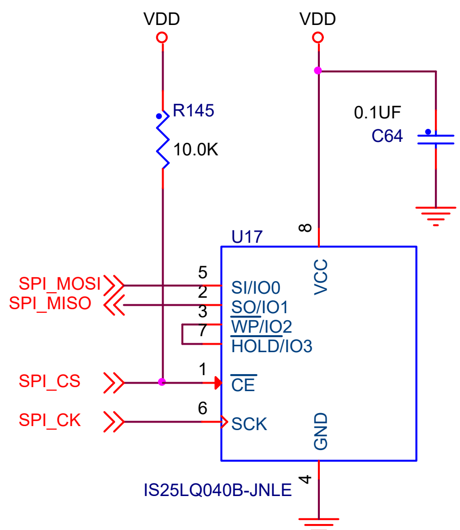

Figure 7. 512 KB SPI flash control

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

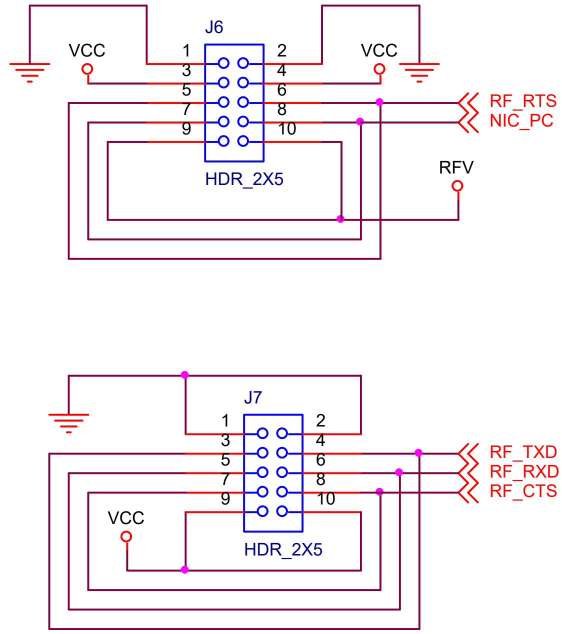

Figure 8. GPRS control

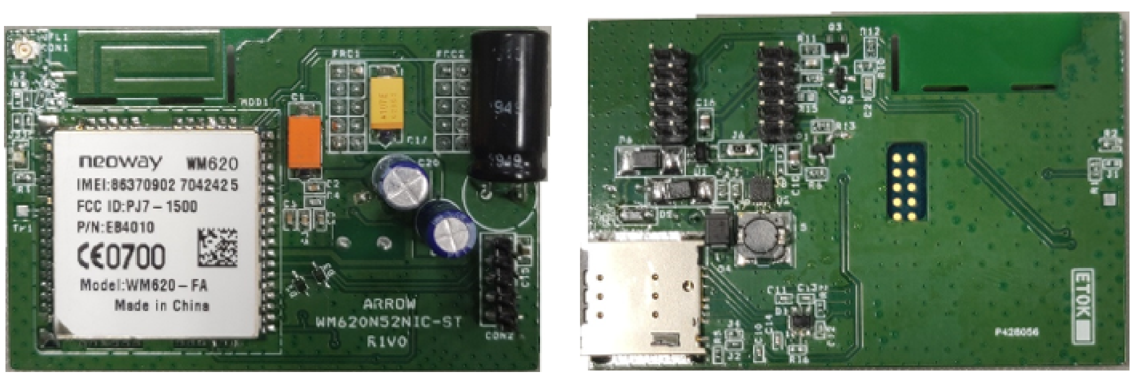

Figure 9. Extension for the GPRS communication

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.

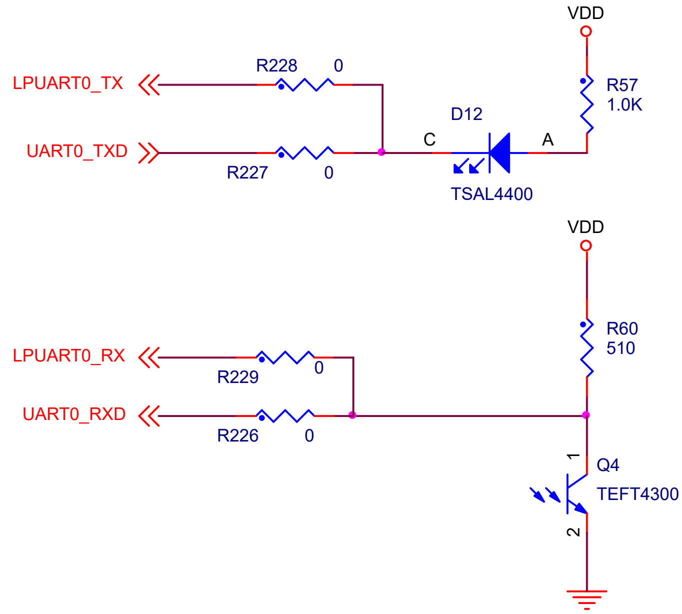

Figure 10. IR control

NOTE

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.

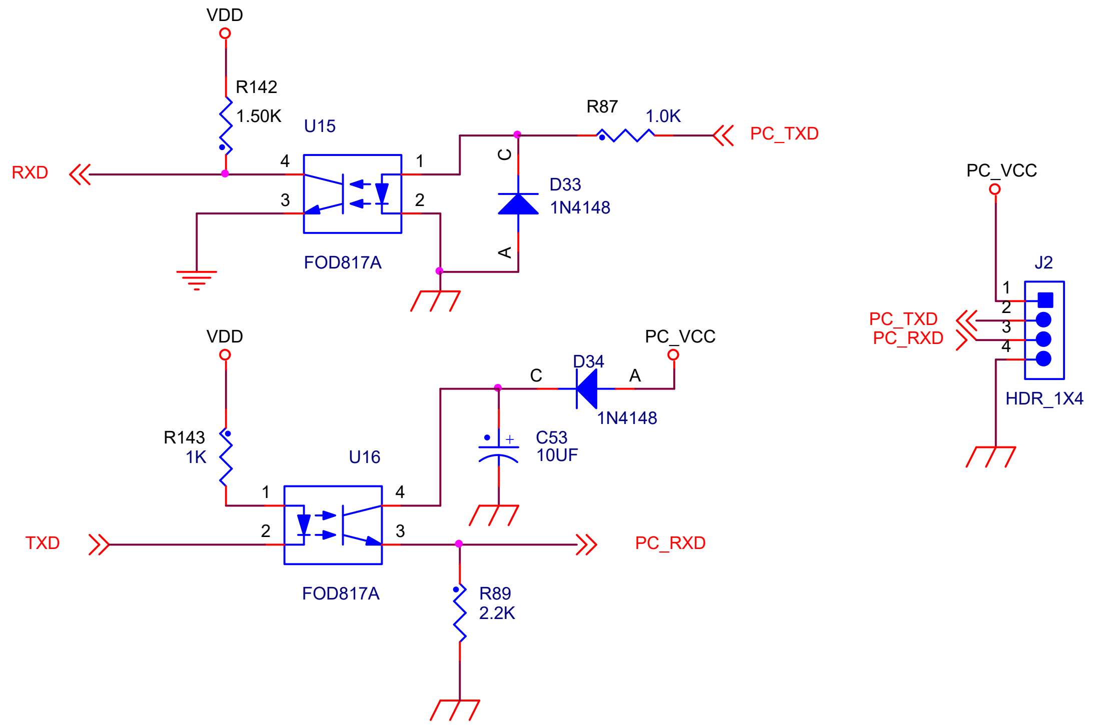

Figure 11. RS-232 control

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.

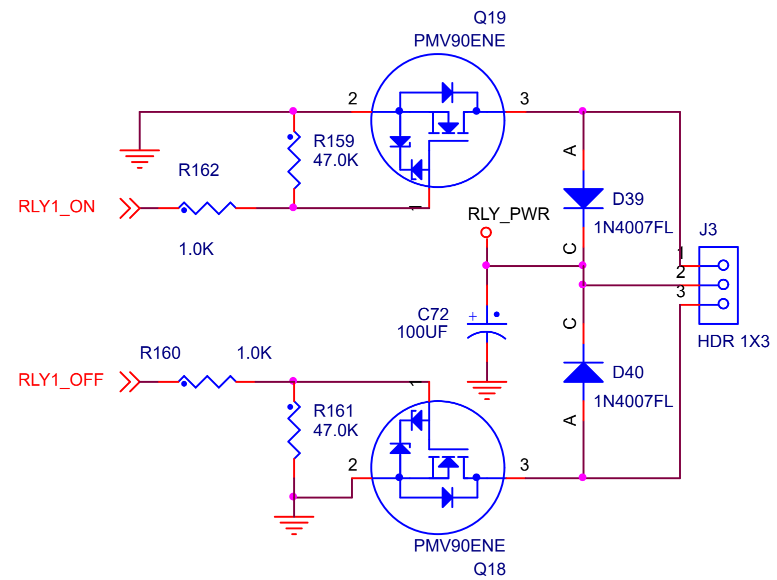

Figure 12. Relay control

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.

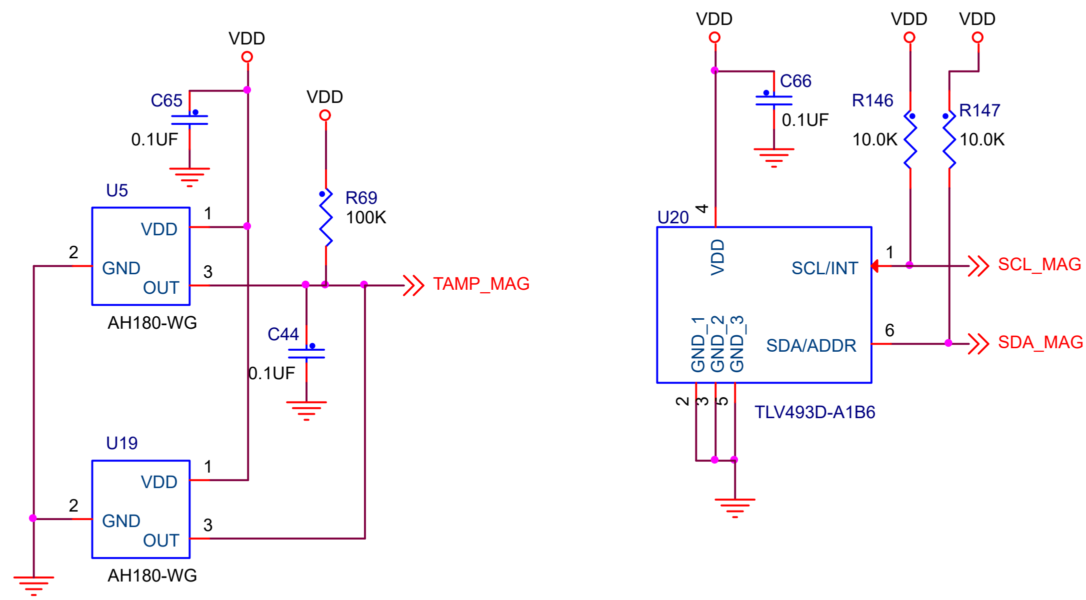

Figure 13. Magnetic tamper sense circuit

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.

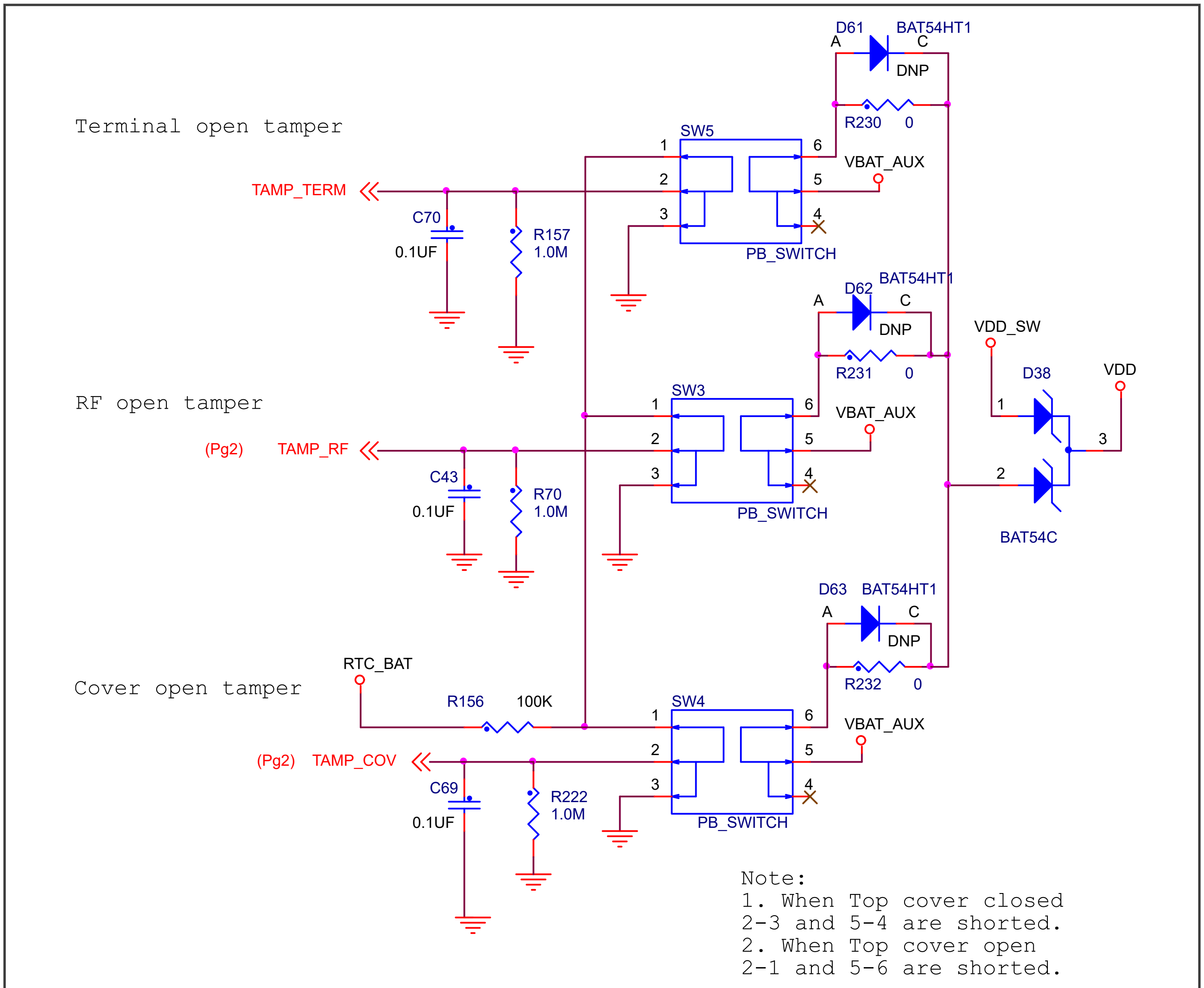

Figure 14. Tamper sense circuit

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.

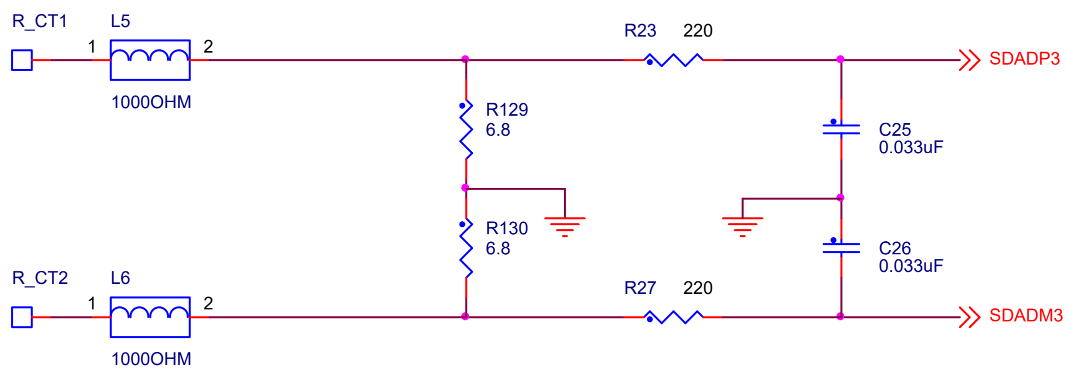

Figure 15. Phase current signal conditioning circuit

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.

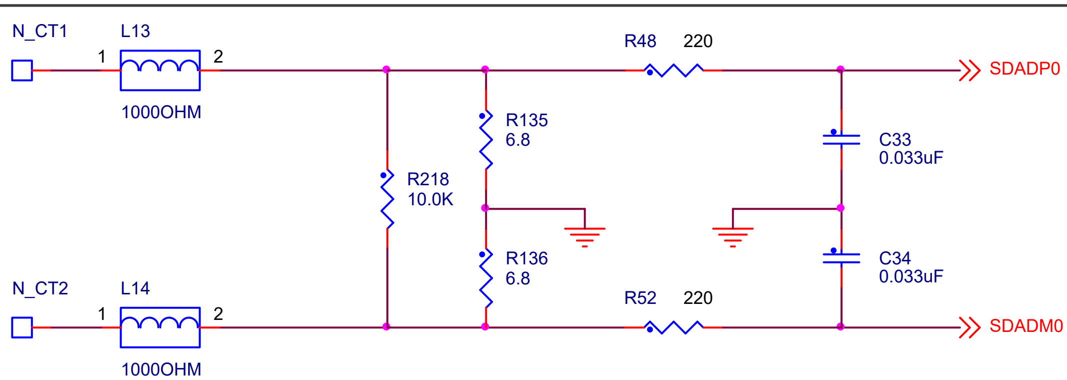

Figure 16. Neutral current signal conditioning circuit

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 diver 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.

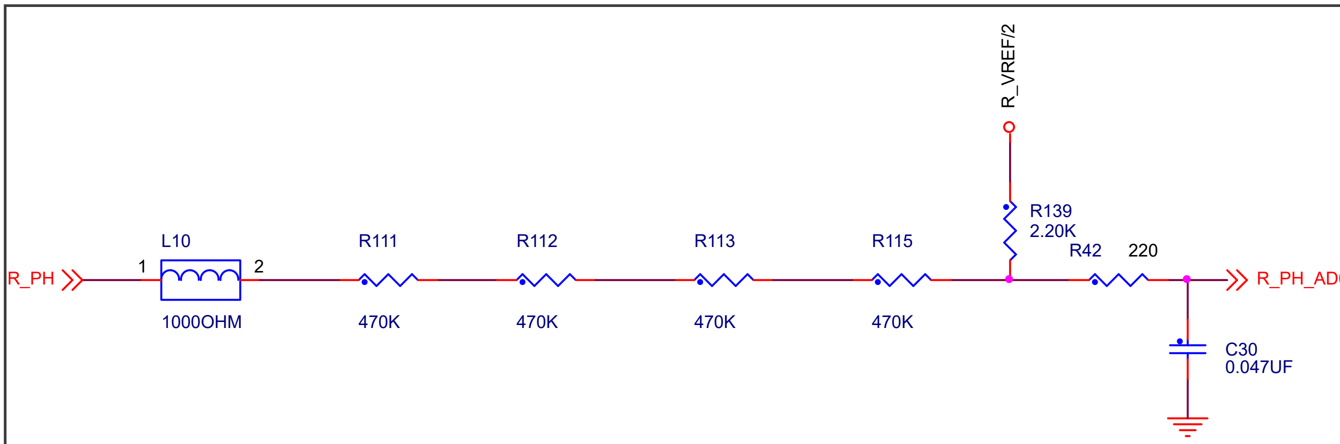

Figure 17. Phase voltages signal conditioning circuit

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.

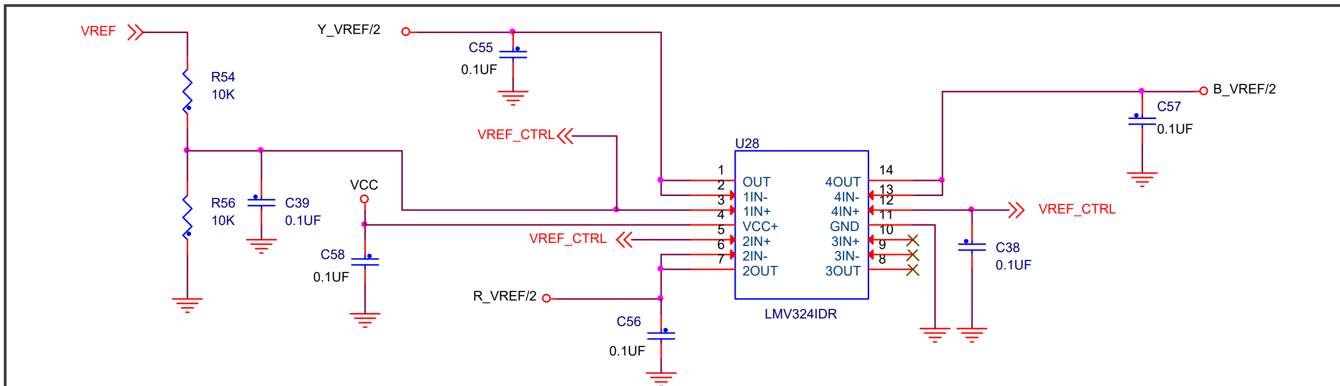

Figure 18. Half reference voltage level generator

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.

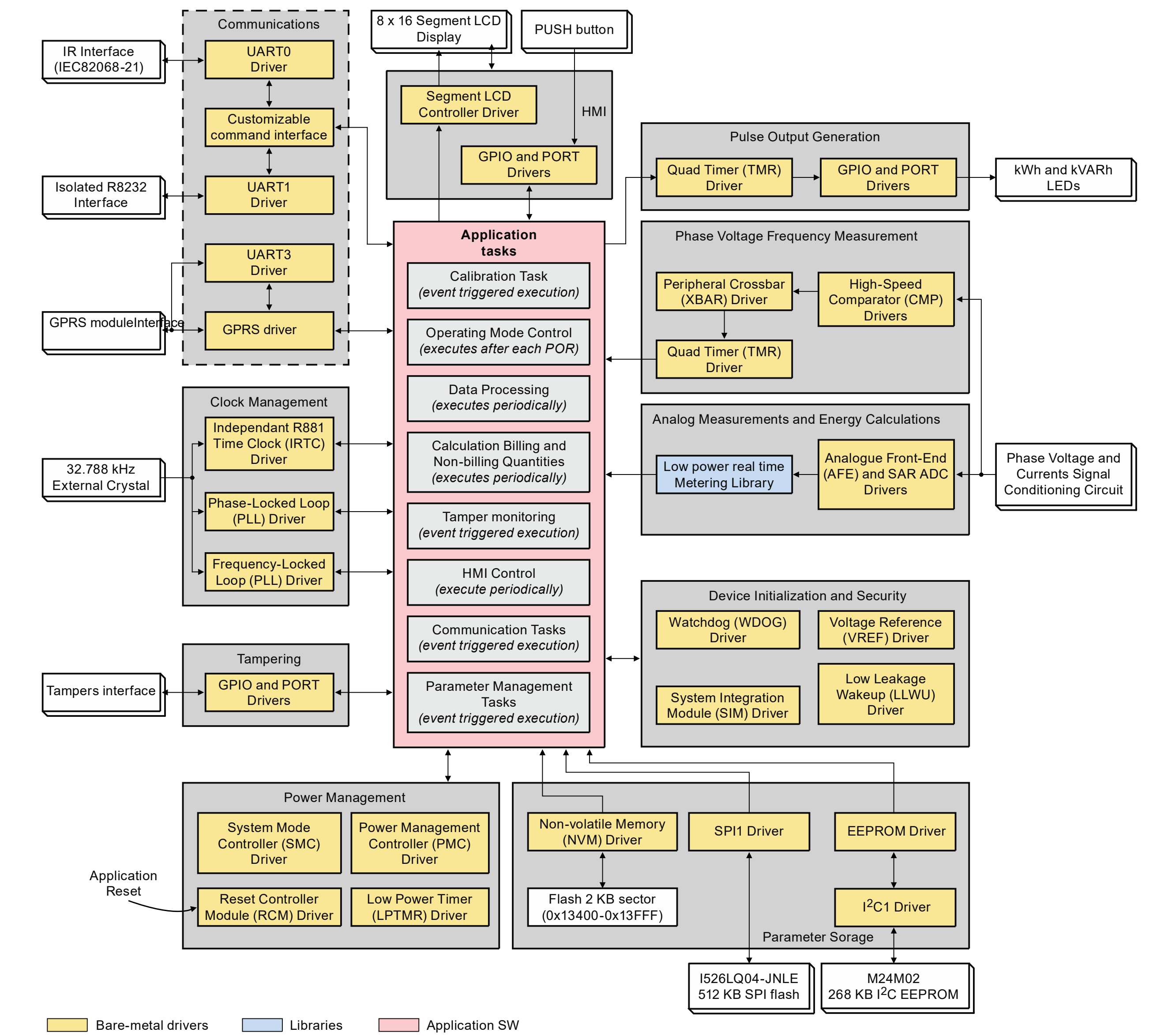

Figure 19. Software architecture

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 2. List of software tasks

Task name	Description	Source file(s)	Function(s) name	Trigger source	IRQ priority	Calling period
Operating mode control	Controls transitioning between power meter operating modes	IOControls.c IOControls.h	AppGPIOInit	device reset	–	after every device reset
HMI control	Updates LCD	UserInterface.c	Display	QTMR interrupt	Level 3 (lowest)	periodic 1 sec
	Reads user button state	Timer.c	GPTimerEventHandler	QTMR interrupt	Level 3 (lowest)	asynchronous
Data processing	Reads digital values from the SAR ADC	libmeterliblprt_cmp0p.a, meterlprtlib_cm0p_iar.a, meterlprtlib_cm0p_mdk.lib, MeteringISR.c, MeteringLPRT.h	SARADCCallback	SAR ADC CH0,1,2 conversion complete IRQ	Level 1	periodic 166.67 µs
Calculation	Zero-cross detection	MeteringISR.c	TMR2callback	QTMR interrupt (CMP2 o/p triggering QTMR through XBAR)	Level 2	periodic 20 msec (50 Hz)
Calculation	Calculation billing and non-billing quantities	libmeterliblprt_cmp0p.a, meterlprtlib_cm0p_iar.a, meterlprtlib_cm0p_mdk.lib, MeteringLPRT.h	DoMetering3Ph	–	–	Periodic 1 sec
Pulse generation	LEDs dynamic pulse output generation	MeteringISR.c	DoPulsing3Ph	LPTMR0 compare flag	Level 0 (highest)	Periodic every 1 msec
Tamper monitoring	Reads tampers state	RTCDriver.c, RTCDriver.h	RTCEventHandler	TAMPER1 active high, TAMPER2 both edges	Level 3 (lowest)	asynchronous
Power meter calibration	Performs power meter calibration	libmeterliblprt_cmp0p.a,	DoCalibration3Ph	UART interface	–	Command through

Table continues on the next page...

Table 2. List of software tasks (continued)

Task name	Description	Source file(s)	Function(s) name	Trigger source	IRQ priority	Calling period
		meterlprtlib_cm0p_iar.a, meterlprtlib_cm0p_mdk.lib, Calibration3Ph.h				UART interface
Parameter management	Reads parameters from the Flash and from the external EEPROM	MeteringRunInit.c, Calibration3Ph.h	InitCalibration	device reset	–	after every device reset
	Writes parameters to the Flash and to the external EEPROM		UpdateFlashCalib, ReadVerifyFlashCalib, ReadVerifyCalib	after successful calibration, controlled by user, or switching off	–	asynchronous

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:

$gain_U = 240.0/U_{RMS}$	Eq. 5-1
$gain_I = 10.0/I_{RMS}$	Eq. 5-2
$\theta = 60^o - tan^{-1}(Q/P)$	Eq. 5-3

where:

$gain_U$ and $gain_I$ are calibrated gains

θ 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.

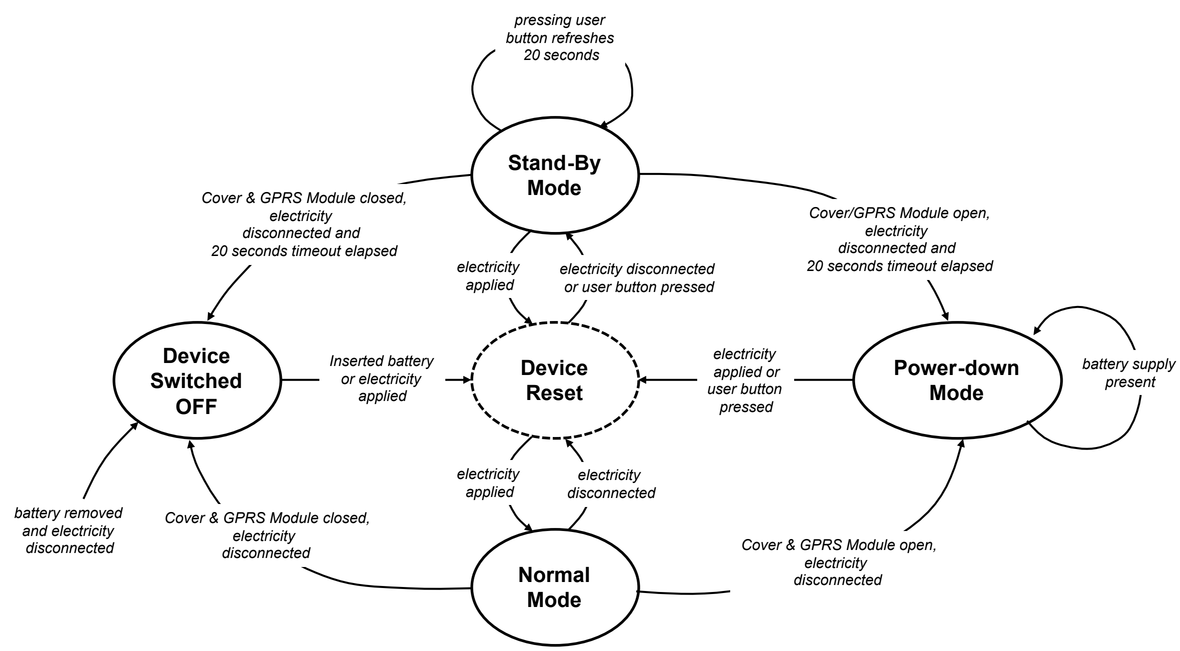

Figure 20. Operating modes

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 3. Memory requirements

Function	Description	Flash size [KB]	RAM size [KB]
Application framework	Complete application without all libraries and communication	44.214	4.174
Low-power real time metering library	Low-power real time metering algorithm library	6.037	2.262
EEPROM driver	EEPROM driver	1.1202	0.0136
Proprietary communication	Proprietary protocol and serial communication driver	6.182	1.334
Grand total		**57.564**	**7.784**

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.

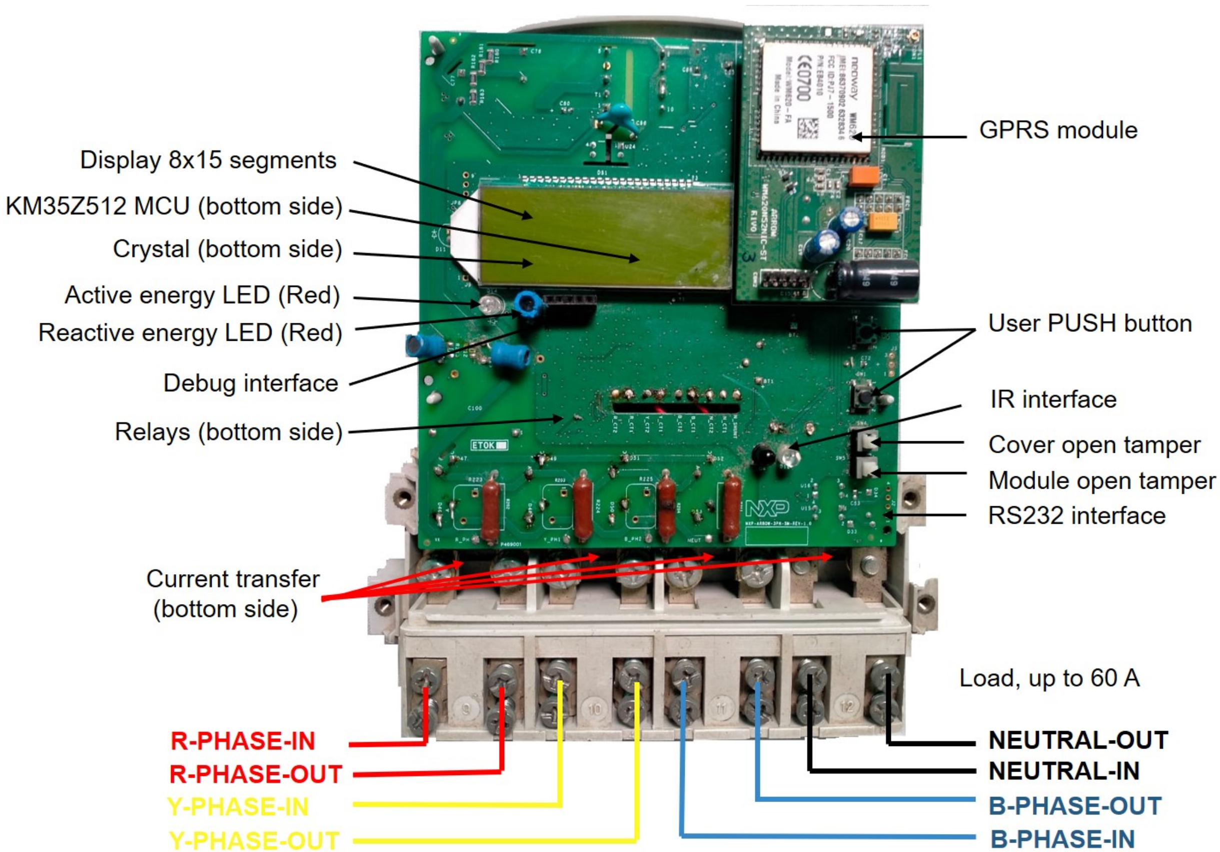

Figure 21. MKM35Z512 three-phase power meter wiring diagram

Table 4. The LCD menu item list

Value	Unit	Format	Auxiliary symbols
Line voltage	VRMS	###.##	V
Phase line current	ARMS	###.##	A
Neutral line current	ARMS	###.##	A
Signed active power P	W	#.## (+ forward, – reverse)	W
Signed reactive power Q	VAr	#.## (+ lag, – lead)	VA, r
Apparent power S	VA	#.##	VA
Power factor	–	#.###	PF
Frequency	Hz	#.###	Hz

Table continues on the next page...

Table 4. The LCD menu item list (continued)

Value	Unit	Format	Auxiliary symbols
Date	–	DD:MM:YY	–
Time	–	HH:MM:SS	–
Meter serial number	–	########	–

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.

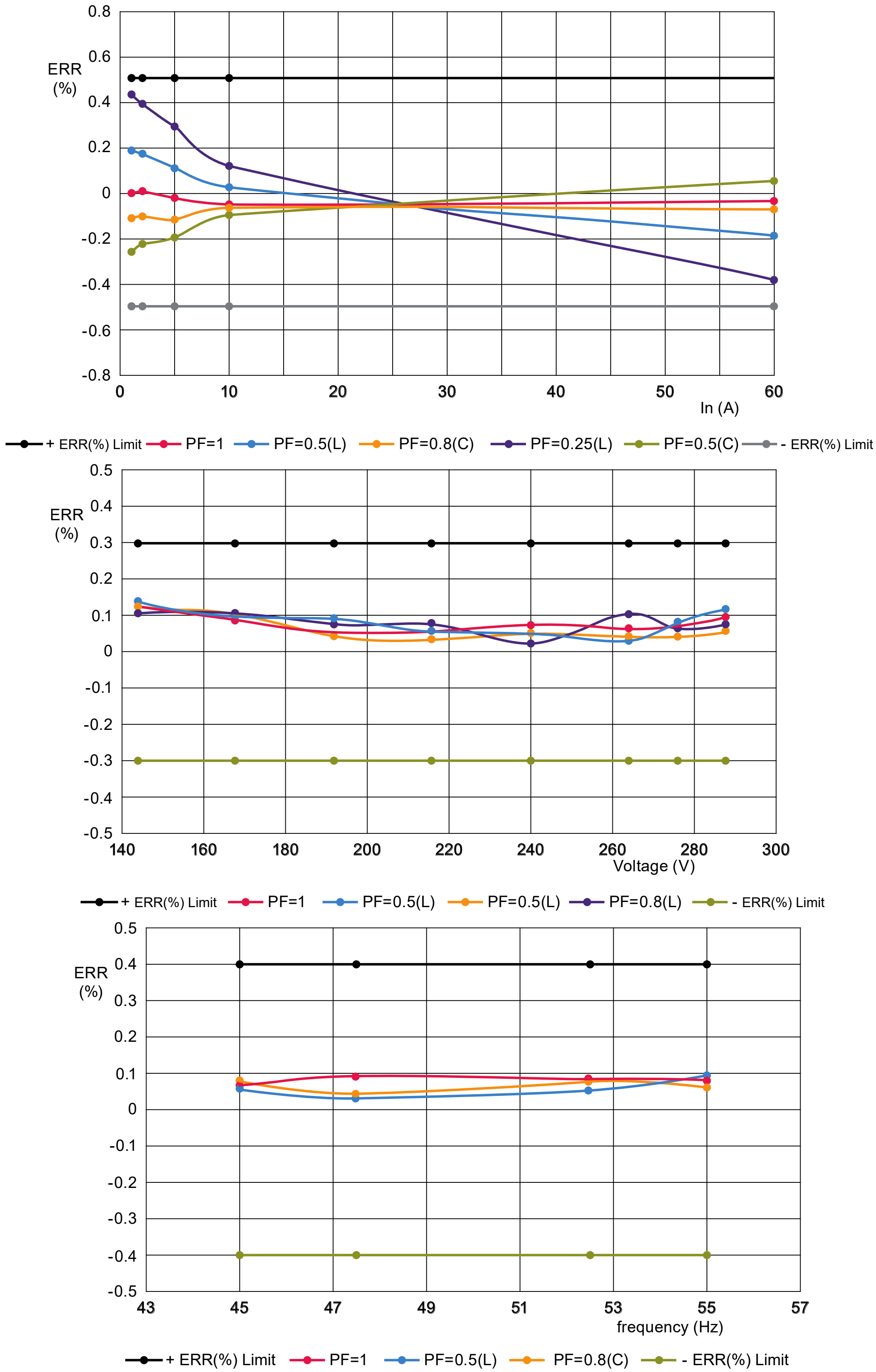

Figure 23. Accuracy results at 25°C

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.

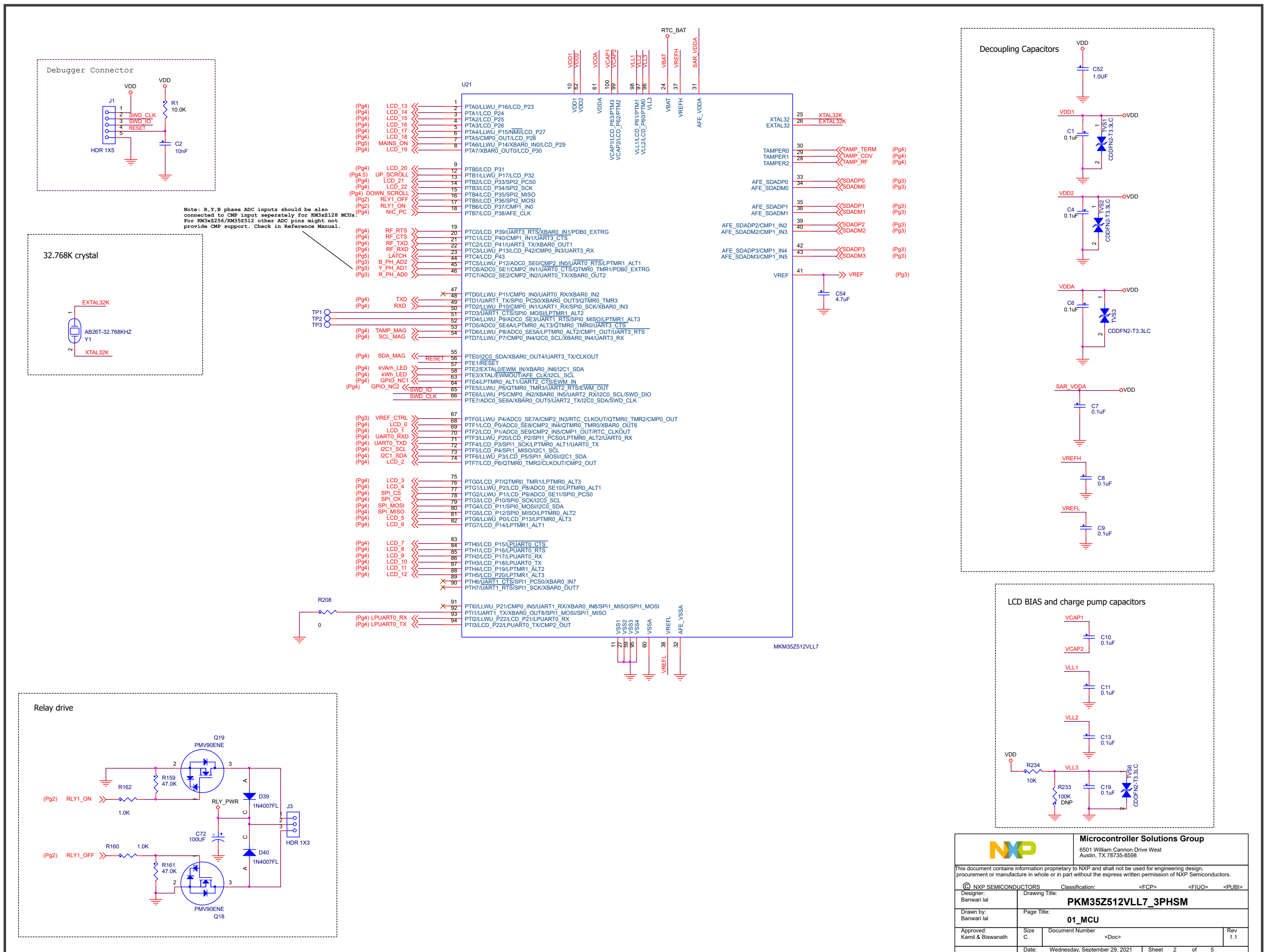

Figure 24. Schematic diagram of the metering board - MCU

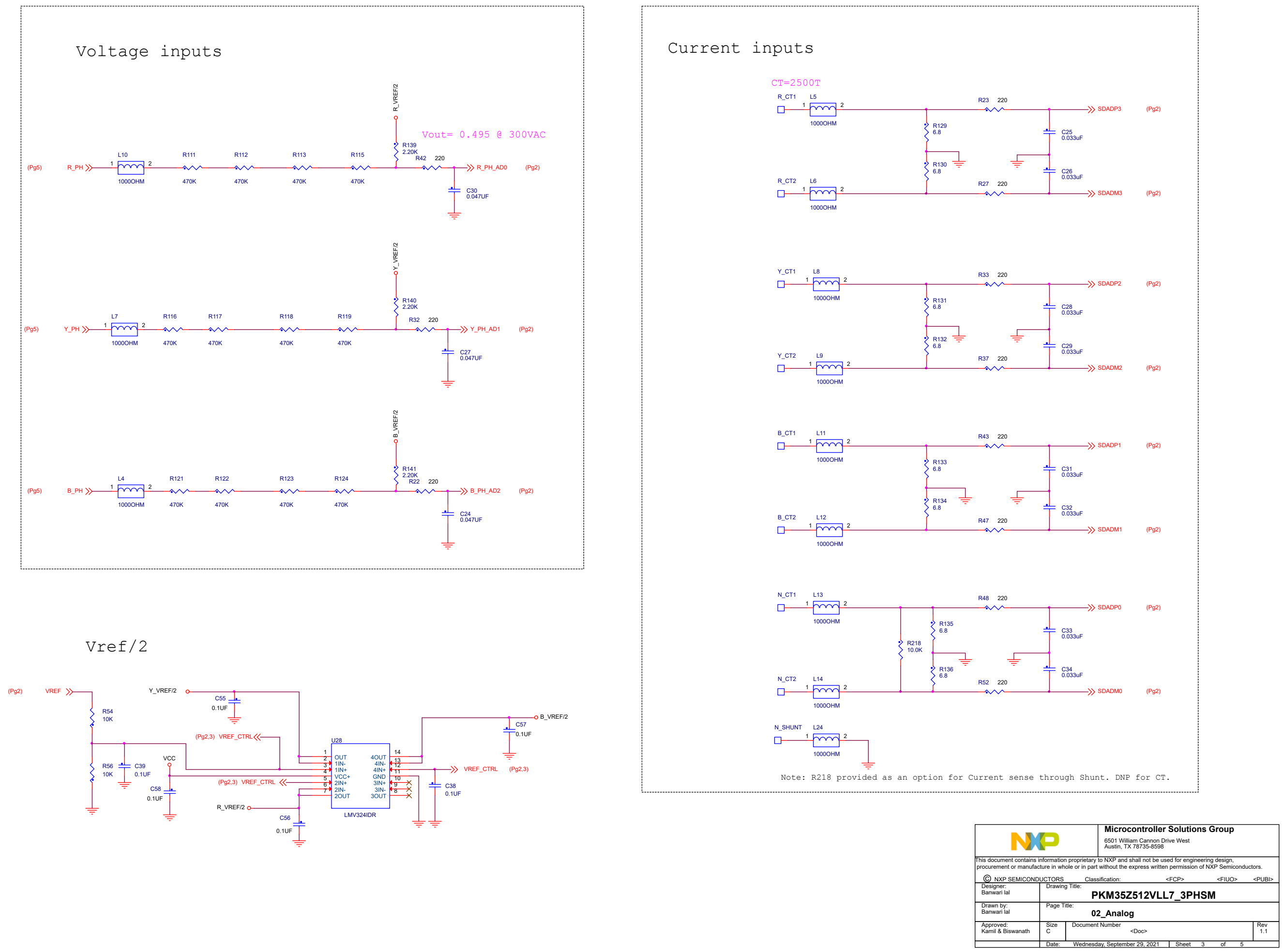

Figure 25. Schematic diagram of the metering board - Analog sensing

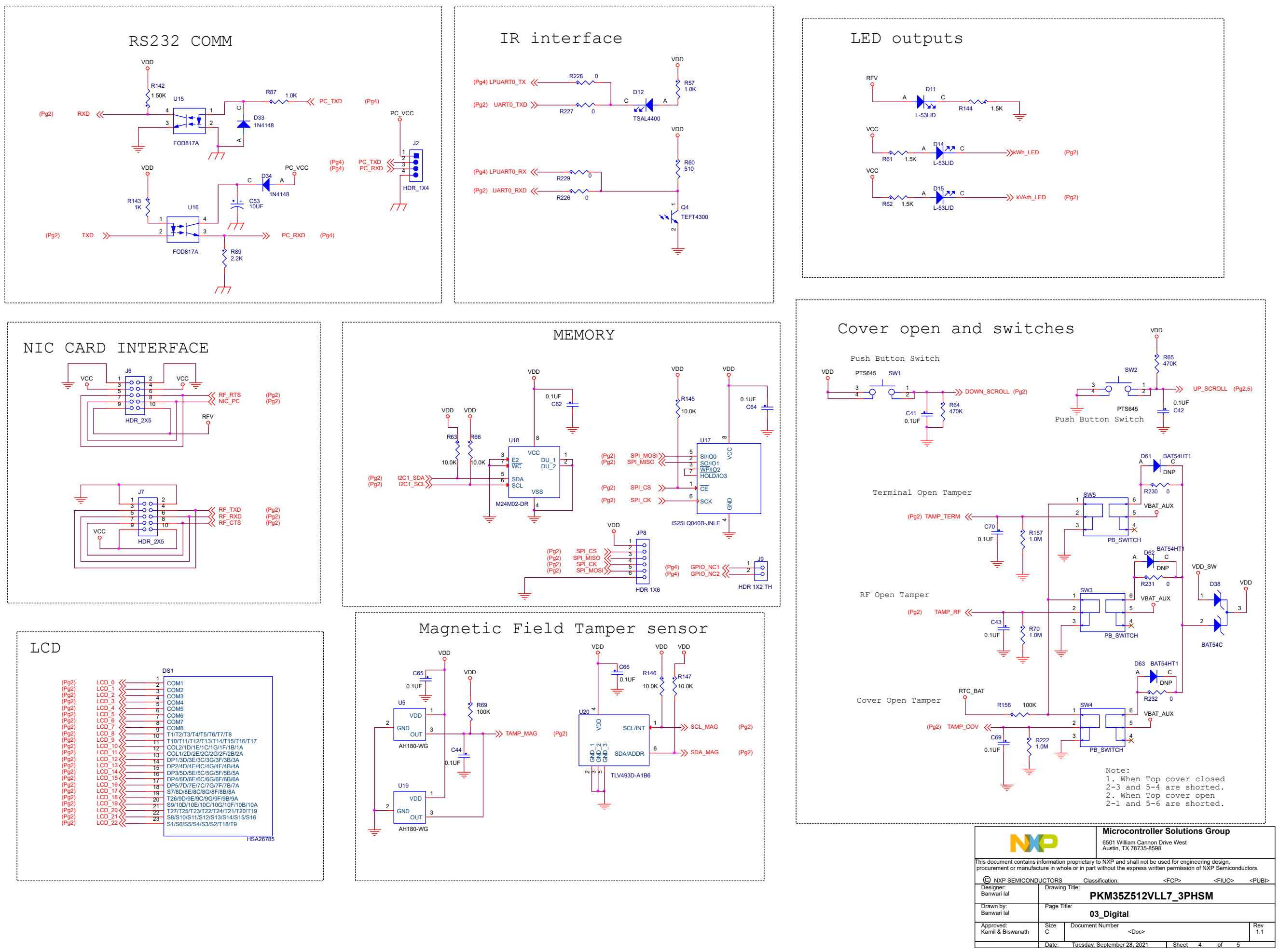

Figure 26. Schematic diagram of the metering board - user interface

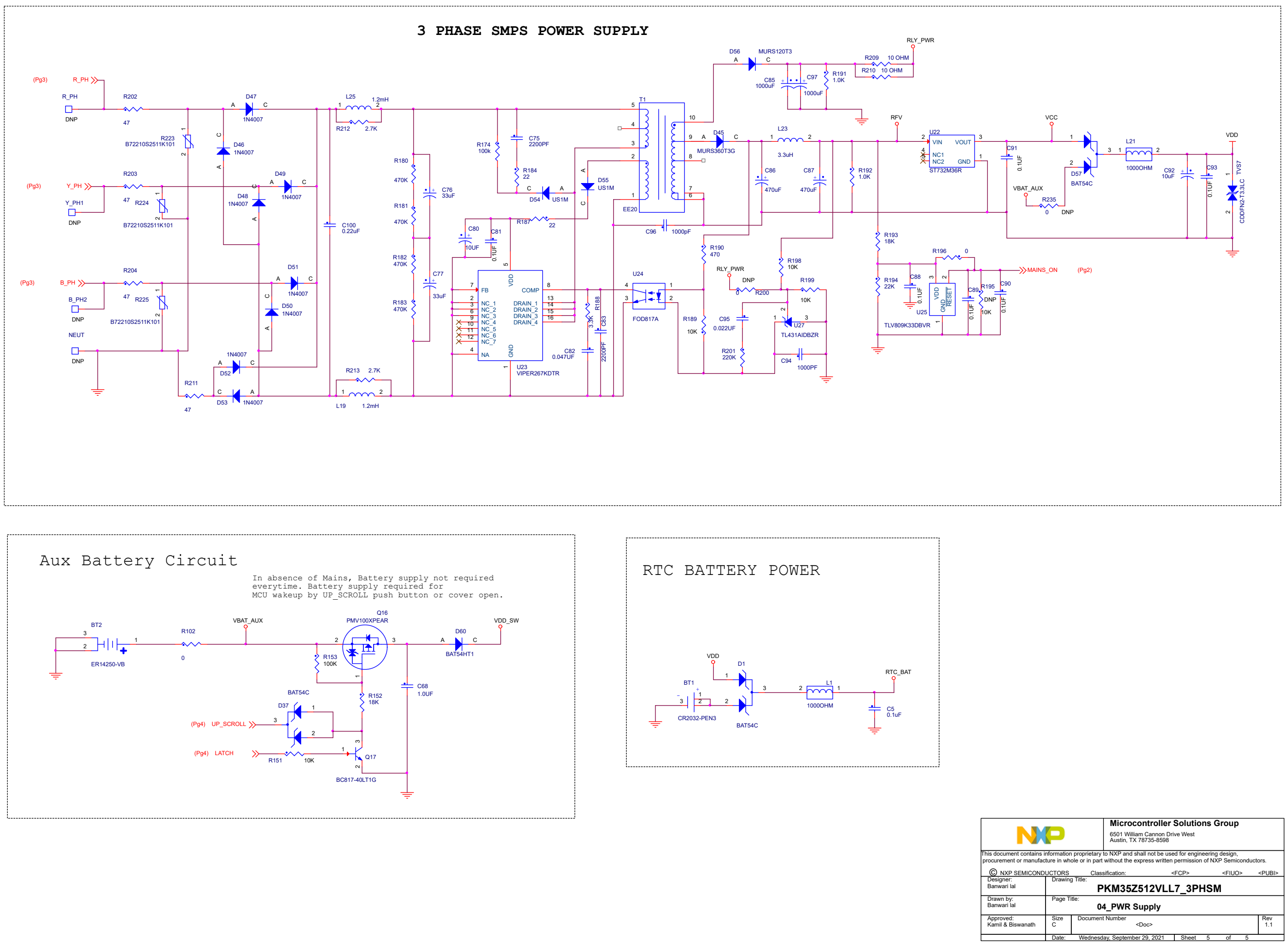

Figure 27. Schematic diagram of the metering board - power supply

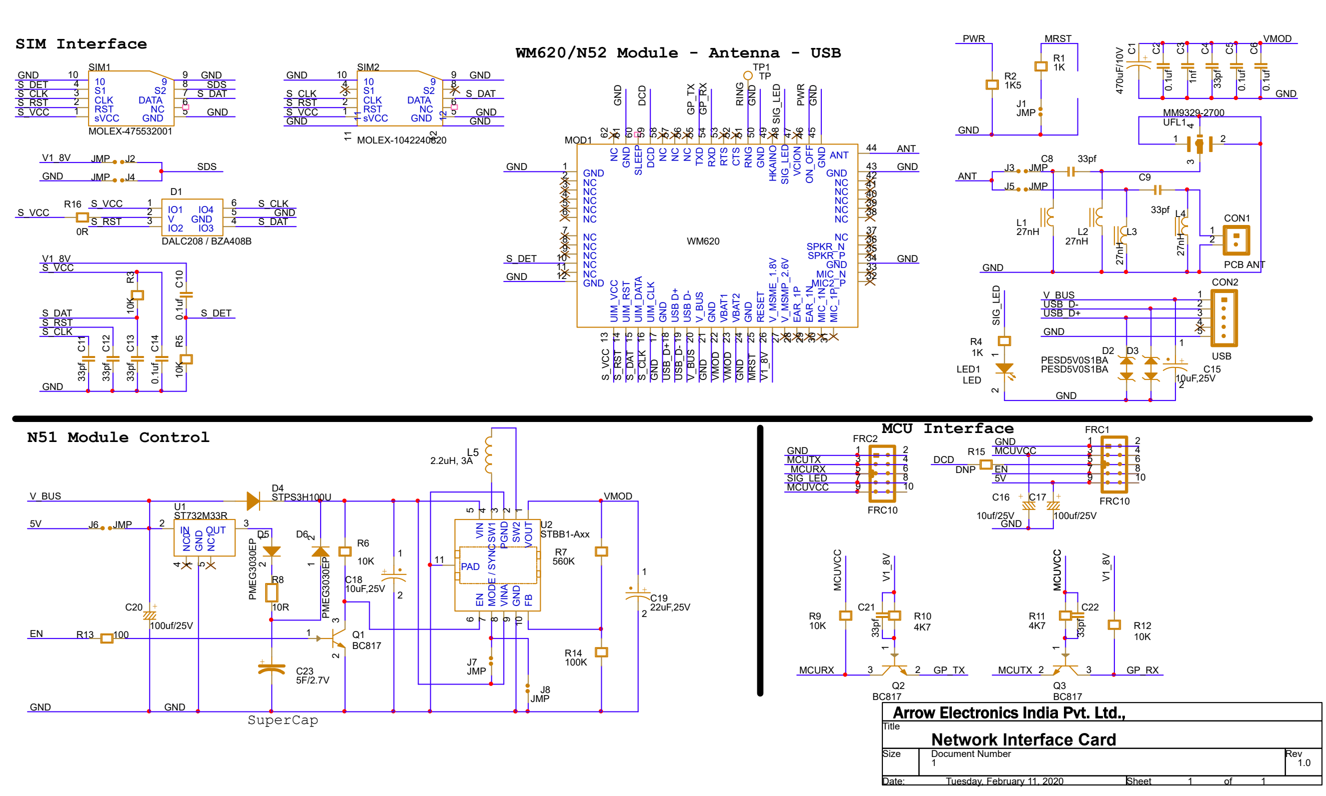

Figure 28. Schematic diagram of the GPRS expansion board

10 Metering board layout

Three-phase power meter top-side view of the metering board is shown in Figure 29.

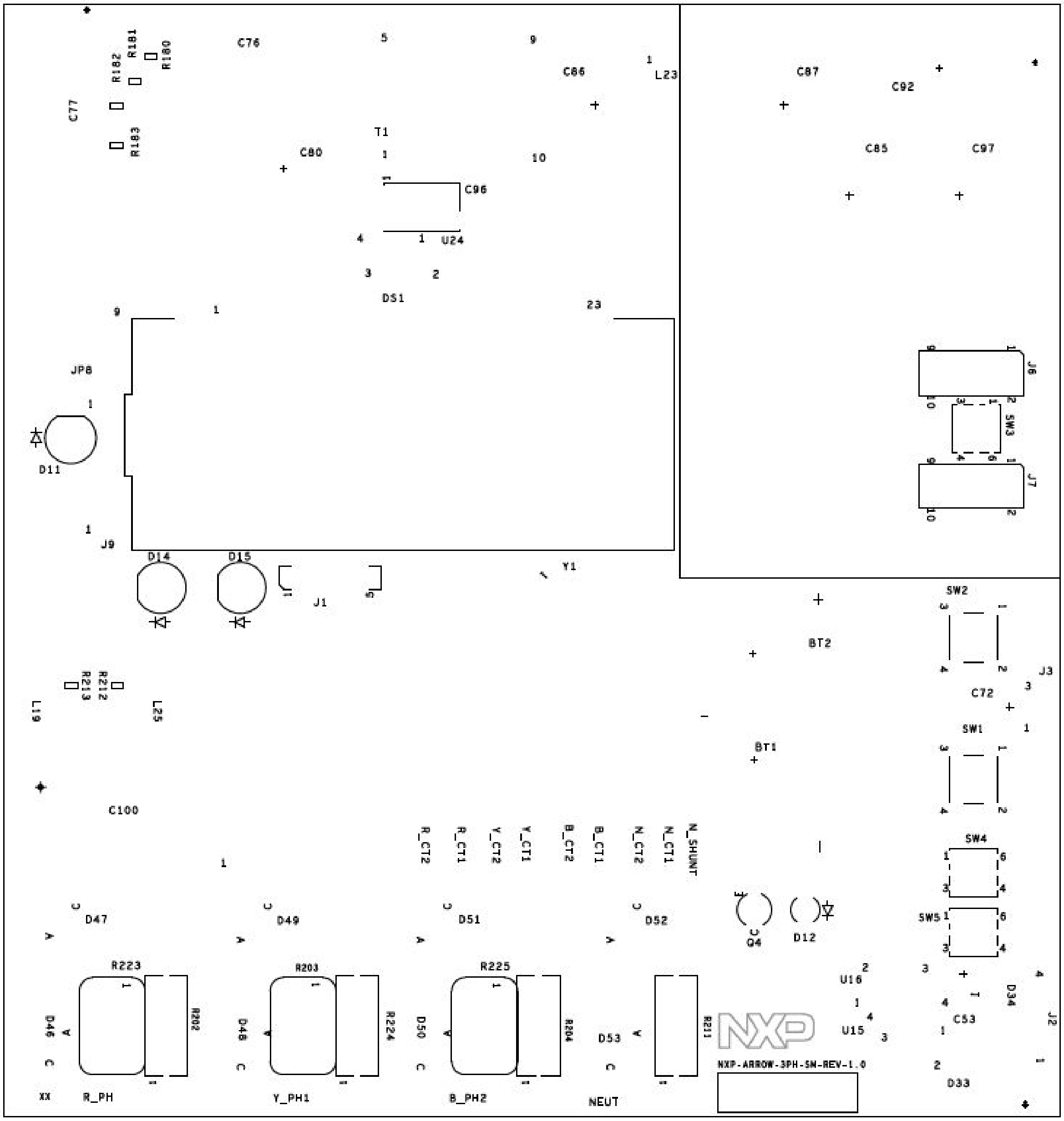

Figure 29. Top-side view of the metering board (not scaled)

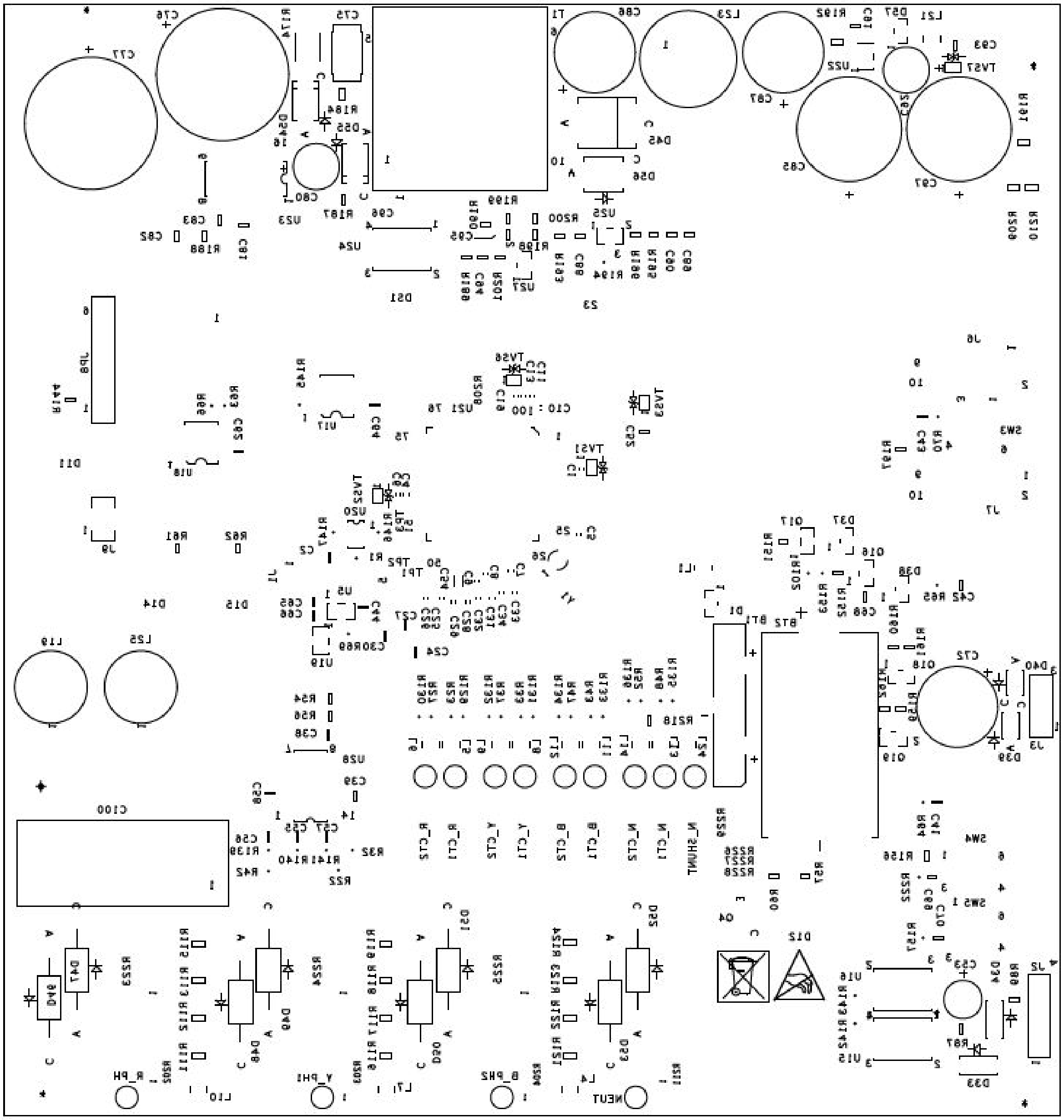

Figure 30. Bottom-side view of the metering board (not scaled)

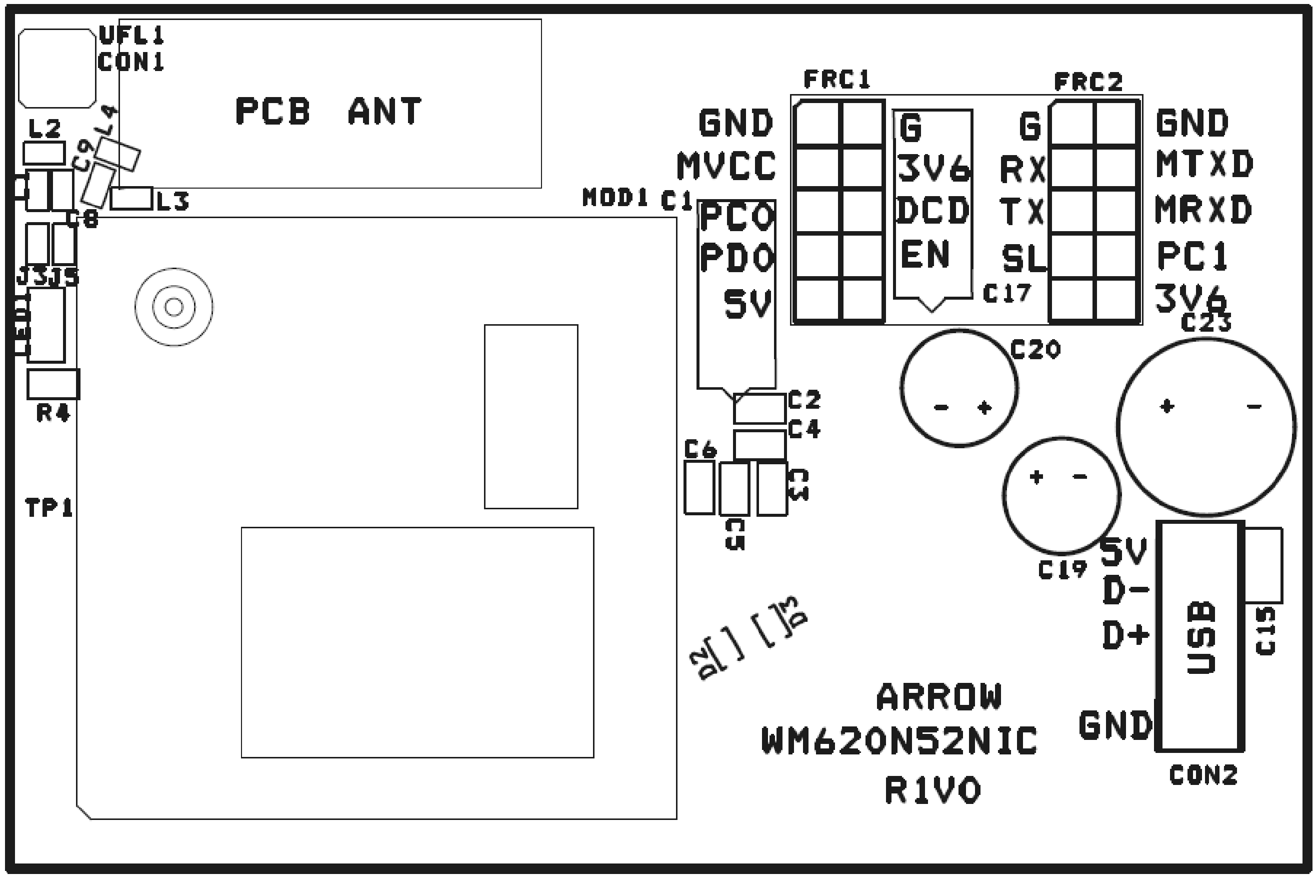

Figure 31. Top-side view of the GPRS module board (not scaled)

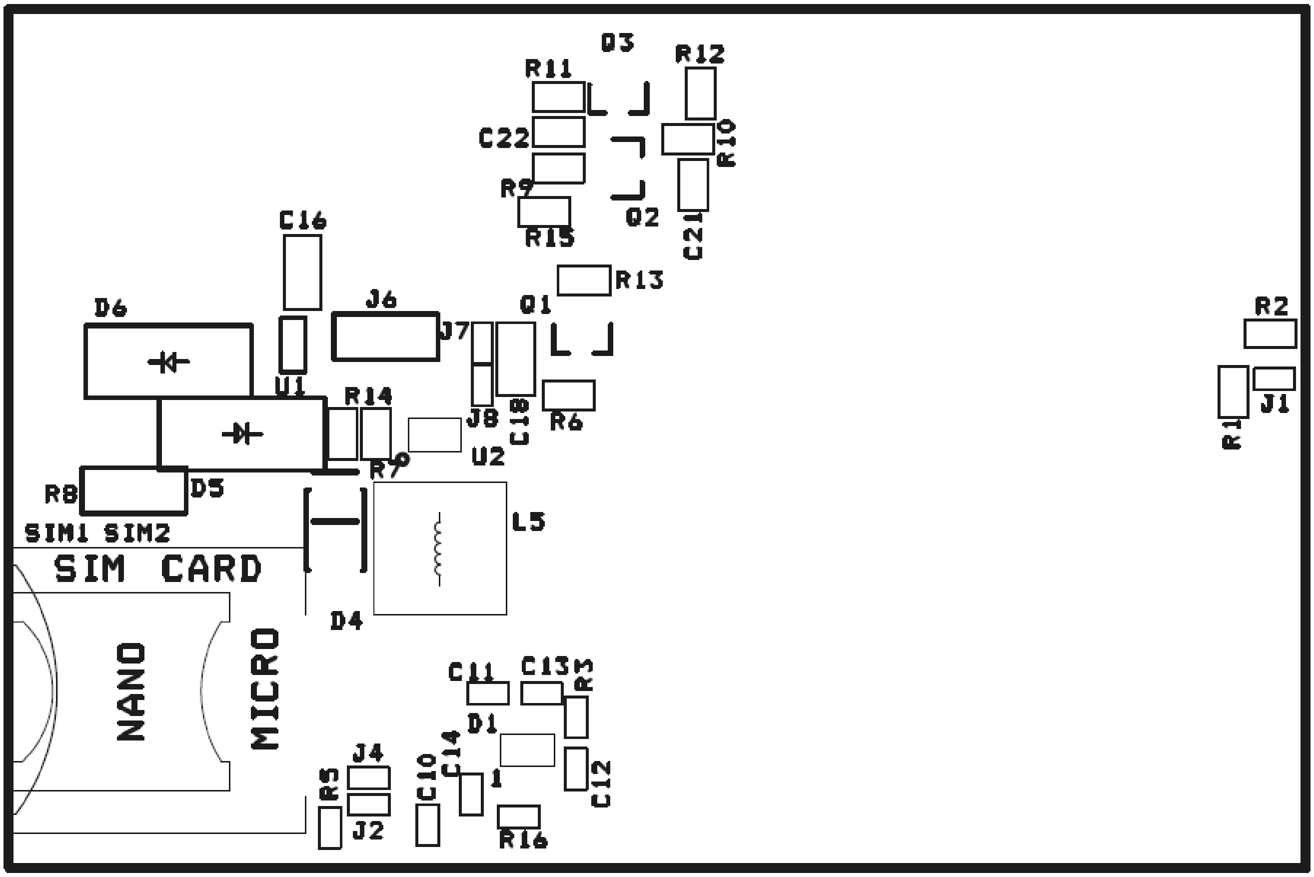

Figure 32. Bottom-side view of the GPRS module board (not scaled)

11 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

Sr. No	Quantity	Reference	Description	Value	Mfg Name	Mfg Part Number
1	1	BT1	BATTERY LI-MNO2 2032 3V 210mAh TH	CR2032-PEN3	EEMB	CR2032-PEN3
2	1	BT2	BATTERY LITHIUM 1/2AA 3.6V 1200mAh TH	ER14250-VB	EEMB	ER14250-VB
3	9	Y_CT1,R_CT1,N_CT1,B_CT1,Y_CT2,R_CT2,N_CT2,B_CT2,N_SHUNT	TEST POINT PIN 0.062X0.086 TH, NO PART TO ORDER	TP	N/A	N/A
4	4	Y_PH1,B_PH2,R_PH,NEUT	TEST POINT PIN 0.062X0.086 TH, NO PART TO ORDER	TP	N/A	N/A
5	11	C1,C4,C5,C6,C7,C8,C9,C10,C11,C13,C19	CAP CER 0.1uF 16V 10% X7R AEC-Q200 0402	0.1uF	MURATA	GCM155R71C104KA55D
6	1	C2	CAP CER 0.01UF 50V 5% X7R 0603	10nF	AVX	06035C103JAT2A
7	3	C24,C27,C30	CAP CER 0.047UF 50V 10% X7R 0603	0.047UF	AVX	06035C473KAT2A
8	8	C25,C26,C28,C29,C31,C32,C33,C34	CAP CER 0.033UF 50V 10% X7R AEC-Q200 0402	0.033uF	TDK	CGA2B3X7R1H333K050BB
9	6	C38,C39,C55,C56,C57,C58	CAP CER 0.1UF 50V 10% X7R 0603	0.1UF	WURTH ELEKTRONIK EISOS GMBH & CO. KG (ELECTRONIC & ELECTROMEHANICAL COMP)	8.85012E+11
10	10	C41,C42,C43,C44,C62,C64,C65,C66,C69,C70	CAP CER 0.10UF 25V 10% X7R 0603	0.1UF	KEMET	C0603C104K3RAC
11	2	C52,C68	CAP CER 1.0UF 10V 10% X7R 0805	1.0UF	SMEC	MCCB105K2NRTF
12	1	C53	CAP ALEL 10UF 16V 20% -- TH RADIAL	10UF	PANASONIC	ECEA1CKS100
13	1	C54	CAP CER 4.7UF 6.3V 20% X5R 0402	4.7uF	TDK	C1005X5R0J475M
14	1	C72	CAP ALEL 100UF 50V 20% -- TH RADIAL	100UF	NICHICON	UPJ1H101MPD6
15	1	C75	CAP CER 2200PF 2KV 10% X7R 1812	2200PF	TDK	C4532X7R3D222K130KA
16	2	C76,C77	CAP ALEL 33uF 450V 20% -- RADIAL	33uF	NICHICON	UVR2W330MHD
17	1	C80	CAP ALEL 10uF 35V 20% -- RADIAL	10UF	CORNELL DUBILIER	SK100M035ST
18	6	C81,C88,C89,C90,C91,C93	CAP CER 0.1UF 25V 10% X7R 0805	0.1UF	SMEC	MCCC104K2NRTF
19	1	C82	CAP CER 0.047UF 50V 10% X7R 0805	0.047UF	VENKEL COMPANY	C0805X7R500-473KNE
20	1	C83	CAP CER 2200PF 50V 5% X7R 0805	2200PF	SMEC	MCCE222J2NRTF
21	2	C85,C97	CAP ALEL 1000uF 25V 20% -- RADIAL	1000uF	LELON ELECTRONICS CORP	REA102M1ETAF1316
22	2	C86,C87	CAP ALEL 470UF 25V 20% -- RADIAL	470uF	PANASONIC	EEUFC1E471
23	1	C92	CAP ALEL 10UF 16V 20% -- RADIAL	10uF	NICHICON	UVR1C100MDD
24	1	C94	CAP CER 1000PF 50V 5% C0G 0805	1000PF	VENKEL COMPANY	C0805C0G500-102JNE
25	1	C95	CAP CER 0.022UF 50V 10% X7R 0805	0.022UF	KEMET	C0805C223K5RACTU
26	1	C96	CAP CER 1000pF 760VAC (X1) / 500VAC (Y1) 20% Y5U RADIAL	1000pF	VISHAY INTERTECHNOLOGY	440LD10-R
27	1	C100	CAP PLYP 0.22UF 1KV 10% -- RADIAL	0.22uF	EPCOS - TDK Electronics	B32913B5224K
28	1	DS1	LCD DISPLAY 64Hz 3V TH	HSA26785	JIAGNXI HOLITECH TECHNOLOGY CO.	HSA26785-DYTSP-01
29	4	D1,D37,D38,D57	OBSOLETE USE 480-77657	BAT54C	FAIRCHILD	BAT54C
30	1	D11	LED RED SGL 2MA TH	L-53LID	KINGBRIGHT	L-53LID
31	1	D12	LED IR SGL 100MA TH	TSAL4400	VISHAY INTERTECHNOLOGY	TSAL4400
32	2	D14,D15	LED RED SGL 2MA TH	L-53LID	KINGBRIGHT	L-53LID
33	2	D33,D34	DIODE SS 100V 500MW AXIAL	1N4148	FAIRCHILD	1N4148
34	2	D39,D40	DIODE RECT 1A 1000V SOD-123FL	1N4007FL	SMC DIODE SOLUTIONS LLC	1N4007FLTR
35	1	D45	DIODE PWR RECT 3A 600V SMT	MURS360T3G	ON SEMICONDUCTOR	MURS360T3G
36	8	D46,D47,D48,D49,D50,D51,D52,D53	DIODE RECT 1A 1KV DO41	1N4007	DIODES INC	1N4007-T
37	2	D54,D55	DIODE RECT FAST RECOVERY 1A 1000V SMA	US1M	DIODES INC	US1M-13-F
38	1	D56	DIODE PWR RECT 1A 200V SMB SMT	MURS120T3	ON SEMICONDUCTOR	MURS120T3G
39	1	D60	DIODE SCH 30V 200MA -- SOD323	BAT54HT1	ON SEMICONDUCTOR	BAT54HT1G
40	3	D61,D62,D63	DIODE SCH 30V 200MA -- SOD323	BAT54HT1	ON SEMICONDUCTOR	BAT54HT1G
41	1	JP8	HDR 1X6 TH 100MIL SP 330H AU 100L	HDR 1X6	SAMTEC	TSW-106-07-S-S
42	1	J1	HDR 1X5 TH 100MIL SP 336H SN 118L	HDR 1X5	GREENCONN CORPORATION	GPHA114-0501A01
43	1	J2	HDR 1X4 TH 100MIL SP 336H AU 100L	HDR_1X4	SAMTEC	TSW-104-07-G-S
44	1	J3	HDR 1X3 TH 2.54MM SP 344H AU 118L	HDR 1X3	WURTH ELEKTRONIK EISOS GMBH & CO. KG (ELECTRONIC & ELECTROMEHANICAL COMP)	61300311121
45	2	J6,J7	HDR 2X5 TH 100MIL CTR 330H AU	HDR_2X5	SAMTEC	TSW-105-08-G-D
46	1	J9	HDR 1X2 TH 100MIL SP 339H AU 98L	HDR 1X2 TH	SAMTEC	TSW-102-07-G-S
47	14	L1,L4,L5,L6,L7,L8,L9,L10,L11,L12,L13,L14,L21,L24	IND FER BEAD 1000OHM@100MHZ 1.5A 25% 0805	1000OHM	TDK	MPZ2012S102A
48	2	L19,L25	IND PWR 1.2mH@100KHZ 280MA 10% RADIAL	1.2mH	COILCRAFT	RFB0807-122L
49	1	L23	IND CHK 3.3uH@1KHz 3A 20% 10mOHM TH	3.3uH	Prismatic	122001
50	1	Q4	TRAN NPN PHOTO 50MA 70V TH	TEFT4300	VISHAY INTERTECHNOLOGY	TEFT4300
51	1	Q16	TRAN PMOS SW 2.4A 20V AEC-Q101 SOT-23	PMV100XPEAR	NEXPERIA	PMV100XPEAR
52	1	Q17	TRAN NPN GEN 45V 0.5A SOT-23	BC817-40LT1G	ON SEMICONDUCTOR	BC817-40LT1G
53	2	Q18,Q19	TRAN NMOS 30V 3.7A SOT23	PMV90ENE	NEXPERIA	PMV90ENER
54	6	R1,R63,R66,R145,R146,R147	RES MF 10.0K 1/10W 1% 0603	10.0K	YAGEO AMERICA	RC0603FR-0710KL
55	11	R22,R23,R27,R32,R33,R37,R42,R43,R47,R48,R52	RES MF 220 OHM 1/10W 1% 0603	220	BOURNS	CR0603-FX-2200ELF

Sr. No	Quantity	Reference	Description	Value	Mfg Name	Mfg Part Number
56	6	R54,R56,R151,R189,R198,R199	RES MF 10K 1/8W 5% 0805	10K	VENKEL COMPANY	CR0805-8W-103JT
57	1	R57	RES MF 1.0K 1/8W 5% AEC-Q200 0805	1.0K	ROHM	MCR10EZPJ102
58	1	R60	RES MF 510 OHM 1/10W 1% 0805	510	SMEC	RC73A2A5100FTF
59	3	R61,R62,R144	RES MF 1.5K 1/8W 1% 0805	1.5K	BOURNS	CR0805-FX-1501ELF
60	2	R64,R65	RES MF 470K 1/10W 1% 0603	470K	BOURNS	CR0603-FX-4703ELF
61	1	R69	RES MF 100K 1/10W 1% 0603	100K	BOURNS	CR0603-FX-1003ELF
62	3	R70,R157,R222	RES MF 1.0M 1/10W 1% 0603	1.0M	WALSIN TECHNOLOGY CORP.	WR06X1004FTL
63	1	R87	RES MF 1.0K 1/10W 1% 0805	1.0K	MULTICOMP	MC 0.1W 0805 1% 1K
64	1	R89	RES MF 2.2K 1/8W 1% 0805	2.2K	PANASONIC	ERJ-6ENF2201V
65	4	R102,R230,R231,R232	RES MF ZERO OHM 1/10W -- 0603	0	YAGEO AMERICA	RC0603FR-070RL
66	16	R111,R112,R113,R115,R116,R117,R118,R119,R121,R122,R123,R124,R180,R181,R182,R183	RES MF 470K 1/4W 5% 1206	470K	VENKEL COMPANY	CR1206-4W-474JT
67	8	R129,R130,R131,R132,R133,R134,R135,R136	RES MF 6.8 OHM 1/8W 1% AEC-Q200 0603	6.8	KOA SPEER	RK73H1JTTD6R80F
68	3	R139,R140,R141	RES MF 2.20K 1/10W 1% 0603	2.20K	BOURNS	CR0603-FX-2201ELF
69	1	R142	RES MF 1.50K 1/10W 1% 0603	1.50K	VISHAY INTERTECHNOLOGY	CRCW06031K50FKEA
70	1	R143	RES 1.0K OHM 1/10W 5% 0603	1K	YAGEO AMERICA	RC0603JR-071KL
71	2	R152,R193	RES MF 18.0K 1/8W 1% 0805	18K	VISHAY INTERTECHNOLOGY	CRCW080518K0FKEA
72	2	R153,R156	RES MF 100K 1/8W 1% 0805	100K	VENKEL COMPANY	CR0805-8W-1003FSNT
73	2	R159,R161	RES MF 47.0K 1/10W 1% 0805	47.0K	SMEC	RC73A2A4702FTF
74	2	R160,R162	RES MF 1.00K 1/8W 1% ACE-Q200 0805	1.0K	VISHAY INTERTECHNOLOGY	CRCW08051K00FKEA
75	1	R174	RES MF 100k 1/2W 5% AEC-Q200 1210	100k	PANASONIC	ERJ-14YJ104U
76	1	R184	RES MF 22 OHM 1/4W 5% 1206	22	BOURNS	CR1206-JW-220ELF
77	1	R187	RES MF 22 OHM 1/8W 5% 0805	22	BOURNS	CR0805-JW-220ELF
78	1	R188	RES MF 3.3K 1/8W 5% 0805	3.3K	BOURNS	CR0805-JW-332ELF
79	1	R190	RES MF 470 OHM 1/8W 1% 0805	470	BOURNS	CR0805-FX-4700ELF
80	2	R191,R192	RES MF 1.0K 1/4W 5% 1206	1.0K	BOURNS	CR1206-JW-102ELF
81	1	R194	RES MF 22K 1/4W 1% AEC-Q200 0805	22K	KOA Speer Electronics, Inc.	SG73S2ATTD2202F
82	1	R195	RES MF 10K 1/8W 5% 0805	10K	VENKEL COMPANY	CR0805-8W-103JT
83	1	R196	RES MF ZERO 1/8W AEC-Q200 0805	0	ROHM	MCR10EZPJ000
84	1	R200	RES MF ZERO 1/8W AEC-Q200 0805	0	ROHM	MCR10EZPJ000
85	1	R201	RES TF 220K 1/8W 5% 0805	220K	PANASONIC	ERJ6GEYJ224V
86	4	R202,R203,R204,R211	RES WW 47 OHM 3W 5% AXL	47	YAGEO AMERICA	PNP300JR-73-47R
87	1	R208	RES MF ZERO OHM 1/16W 5% 0402	0	YAGEO AMERICA	RC0402JR-070RL
88	2	R209,R210	RES MF 10 OHM 1/4W 1% 1206	10 OHM	YAGEO	RC1206FR-0710RL
89	2	R212,R213	RES MF 2.7K 1/4W 1% 1206	2.7K	YAGEO AMERICA	RC1206FR-072K7L
90	1	R218	RES MF 10.0K 1/8W 1% 0805	10.0K	VENKEL COMPANY	CR0805-8W-1002FT
91	3	R223,R224,R225	VARISTOR 510VRMS 0.4W 10% TH	B72210S2511K101	TDK	B72210S2511K101
92	4	R226,R227,R228,R229	RES MF ZERO OHM 1/10W -- 0402	0	PANASONIC	ERJ-2GE0R00X
93	1	R233	RES MF 100K 1/16W 1% 0402	100K	VISHAY INTERTECHNOLOGY	CRCW0402100KFKEDC
94	1	R234	RES MF 10K 1/16W 1% 0402	10K	VISHAY	CRCW040210K0FKEDC
95	1	R235	RES MF ZERO OHM 1/10W -- 0603	0	YAGEO AMERICA	RC0603FR-070RL
96	2	SW1,SW2	OBSOLETE SW SPST MOM NO PB 12V 50MA SMT	PTS645	ITT CANNON	PTS645SL50SMTR LFS
97	3	SW3,SW4,SW5	SW DPDT PB 2A 500V TH	PB_SWITCH	C&K COMPONENTS	PS221605FNS
98	3	TP1,TP2,TP3	TEST POINT PAD .035 SMT, no part to order	TP_35MIL		
99	5	TVS1,TVS2,TVS3,TVS6,TVS7	OBSOLETE DIODE TVS BIDIR -- 3.3V SMD	CDDFN2-T3.3LC	BOURNS	CDDFN2-T3.3LC
100	1	T1	BOBBIN EE20 HORIZONTAL TH	EE20	WURTH ELEKTRONIK EISOS GMBH & CO. KG (ELECTRONIC & ELECTROMEHANICAL COMP)	070-4989
101	2	U5,U19	IC SW SENSOR OMNIPOLAR HALL-EFFECT 2.5-5.5V SC59	AH180-WG	DIODES INC	AH180-WG-7
102	3	U15,U16,U24	TRAN NPN PHOTO 50MA 70V DIP4	FOD817A	ON Semiconductor	FOD817A
103	1	U17	IC MEM FLASH 4MB SPI 104MHz 2.7-3.6V SOIC8	IS25LQ040B-JNLE	ISSI	IS25LQ040B-JNLE
104	1	U18	IC MEM EEPROM 2Mb I2C 1MHZ 1.8-5.5V SO8	M24M02-DR	ST MICROELECTRONICS	M24M02-DRMN6TP
105	1	U20	IC MAGNETIC SENSOR 3D 2.7-3.5V TSOP6-6	TLV493D-A1B6	Infineon Technologies	TLV493DA1B6HTSA2
106	1	U21	IC MCU FLASH 512KB SRAM 75MHZ 1.71-3.6V LQFP100	MKM35Z512VLL7	NXP SEMICONDUCTORS	MKM35Z512VLL7
107	1	U22	IC VREG LDO 3.6V 300mA 2.5-28V SOT23-5	ST732M36R	ST MICROELECTRONICS	ST732M36R
108	1	U23	IC HIGH VOLTAGE CONVERTER 1050V 60kHz 11.5-23.5V SO16	VIPER267KDTR	ST MICROELECTRONICS	VIPER267KDTR
109	1	U25	IC VOLTAGE MONITOR 2-6V SOT-23-3	TLV809K33DBVR	TEXAS INSTRUMENTS	TLV809K33DBVR
110	1	U27	IC VREG SHUNT 100MA ADJ 36V 1% AEC-Q100 SOT23-3	TL431AIDBZR	NEXPERIA	TL431AIDBZR,215
111	1	U28	IC LIN OPAMP QUAD 2.7-5.5V SOIC14	LMV324IDR	Texas Instruments	LMV324IDR
112	1	Y1	XTAL 32.768KHZ RSN -- TH	AB26T-32.768KHZ	ABRACON CORP	AB26T-32.768KHZ

12 Bill of materials of the GPRS board

Electronics components used to develop GPRS module are mentioned in the table below.

Table 7. BOM report of GPRS module

Item	Qty	Reference	Description	Part Number	Manufacturer	Value
1	1	CON1	PCB PAD	NA	NA	NA
2	1	CON2	Headers & Wire Housings BERGSTIK	10119333-103A05LF	Amphenol FCI	BERG STICK
3	1	C1	Tantalum Capacitors - Solid SMD 470uF 10volts 10%	T495X477K010ATE100	KEMET	470uf/16v
4	3	C2,C5,C6	Multilayer Ceramic Capacitors MLCC - SMD/SMT 0.1uF 50V X7R 10%	CC0603KRX7R9BB104	YAGEO	0.1uf
5	1	C3	Multilayer Ceramic Capacitors MLCC - SMD/SMT 1.0nF 50V X7R 10%	CC0603KRX7R9BB102	YAGEO	1nf
6	2	C10,C14	Multilayer Ceramic Capacitors MLCC - SMD/SMT 0.1uF 50V X7R 10%	CC0402KRX7R9BB104	YAGEO	0.1uf
7	3	C11,C12,C13	Multilayer Ceramic Capacitors MLCC - SMD/SMT 33pF 50V NPO 10%	CC0402JRNPO8BN330	YAGEO	33pf
8	3	C4,C21,C22	Multilayer Ceramic Capacitors MLCC - SMD/SMT 33pF 50V NPO 10%	CC0603JRNPO8BN330	YAGEO	33pf
9	2	C8,C9	Multilayer Ceramic Capacitors MLCC - SMD/SMT / DNP	CC0402JRNPO8BN330/ DNP	YAGEO	33pf/DNP
10	3	C15,C18,C16	Multilayer Ceramic Capacitors MLCC - SMD/SMT 10uF 10% 25V		YAGEO	10uf
11	1	C17	Tantalum Capacitors - Solid SMD 100uF 25volts 20%	T495E107M025AHE100	KEMET	100uf
12	2	C19,C20	100uf/25v Aluminum case, electrolytic capacitor	UVR1E101MED1TD	NICHICON	100uf
13	1	C23	Supercapacitors / Ultracapacitors 5F 2.7V	505DCN2R7Q	illinoiscapacito	5F/2.7V
14	1	D1	ESD Suppressors / TVS Diodes DIODE ARRAY TAPE-7	BZA408B,115 / DALC208	Nexperia	TVS Diode
15	2	D2,D3	ESD Suppressors / TVS Diodes TRANS BIPOLAR	PESD5V0S1BAF	Nexperia	PESD5V0S1BAF
16	1	D4	Schottky Diodes & Rectifiers 100V Vrrm 3A IF Schottky Barrier	STPS3H100U	STMicroelectronics	STPS3H100U
17	2	D5,D6	Schottky Diodes & Rectifiers SCHOTTKY RECT 30V 3A	PMEG3030EP,115	Nexperia	PMEG3030EP,115
18	2	FRC1,FRC2	Headers & Wire Housings BERGSTIK	10119333-103A05LF	Amphenol FCI	BERG STICK
19	8	J1,J2,J3,J4,J5,J6,J7,J8	PCB PAD	RC0402FR-070L	YAGEO	0R
20	1	LED1	Standard LEDs - SMD WL-SMCW SMDMono TpVw Waterclr 0805 Red	150080RS75000 / QTLP630C-2TR	Wurth Elektronik / EVERLIGHT	LED
21	4	L1,L2,L3,L4	Fixed Inductors WE-KI 0402 27nH 400mA DCR=298mOhms5%	744765127A / CW100505-27NJ / DNP	Wurth Elektronik / BOURNS	27nH
22	1	L5	Fixed Inductors 2.2 ohms 20% High Temp AEC-Q200	IHLP1212BZEV2R2M5A	VISHAY	2.2uH
23	1	MOD1	WM620 Module	WM620	Neoway Technology	WM620
24	3	Q1,Q2,Q3	Bipolar Transistors - BJT BC817K-40H/SOT23/TO-236AB	BC817K-40HVL	Nexperia	BC817
25	2	R1,R4	Thick Film Resistor	RC0603FR-071KL	YAGEO	1K
26	1	R2	Thick Film Resistor	RC0603FR-071K5L	YAGEO	1K5
27	2	R3,R5	Thick Film Resistor	RC0402FR-0710KL	YAGEO	10K
28	3	R6,R9,R12	Thick Film Resistor	RC0603FR-0710KL	YAGEO	10K
29	2	R10,R11	Thick Film Resistor	RC0603FR-074K7L	YAGEO	4K7
30	1	R7	Thick Film Resistor	RC0603FR-07560KL	YAGEO	560k
31	1	R14	Thick Film Resistor	RC0603FR-07100KL	YAGEO	100K
32	1	R13	Thick Film Resistor	RC0603FR-07100RL	YAGEO	100R
33	2	R15,R16	Thick Film Resistor	RC0603FR-070RL / DNP	YAGEO	0R
34	1	R8	Thick Film Resistor	RC1206FR-0710RL	YAGEO	10R
35	1	SIM1	Memory Card Connectors ASSY FOR PUSH PUSH 6 PIN SIM CONN.	47553-2001	Molex	SIM Holder
36	1	SIM2	Memory Card Connectors ASSY FOR PUSH PUSH 6 PIN SIM CONN.	104224-0820 / DNP	Molex	SIM Holder
37	1	TP1	Testpoint	NA	NA	NA
38	1	UFL1	RF Connectors / Coaxial Connectors 2/2.55MM STD SMT ULTRA MINI RF JACK	1909763-1	TE Connectivity	RF Connector
39	1	U1	LDO Voltage Regulators 300mA, 28V low-dropout voltage regulator	ST732M28R	STMicroelectronics	ST732M28R
40	1	U2	Switching Voltage Regulators 1A High EFF DC DC 1.5MHz 2.0V to 5.5V	STBB1-APUR	STMicroelectronics	STBB1-APUR

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

Revision number	Date	Substantive changes
0	25 November 2021	Initial release

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Date of release: 25 November 2021
Document identifier: AN13338