AN12837

KM35Z512 based One-Phase Smart Power Meter Reference Design

Rev. 1 — 21 October 2021 Application Note

Contents

1 Introduction

The electro-mechanical power meters are gradually replaced by electronic meters. Modern electronic meters have several advantages over their electro-mechanical predecessors. Their mechanical construction is more cost-effective because there are no moving parts. In addition, electronic meters have one-percent accuracy (or better) in the typical dynamic range of power measurement of 1000:1, whereas electro-mechanical meters have two-percent accuracy in the dynamic range of 80:1. The higher the accuracy and dynamic range of the measurement are, the more precise the energy bills are.

This design reference manual describes a solution for one-phase electronic power meter, based on the MKM35Z512VLL7 MCU. This MCU is a part of the NXP Kinetis-M Series. The Kinetis-M series MCUs address accuracy needs by providing a high-performance analog frontend (24-bit AFE), combined with embedded Programmable Gain Amplifier (PGA). Along with high-performance analog peripherals, 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 of 64-bit math, enable fast execution of metering algorithms. The one-phase power meter reference design is intended for the measurement and registration of active and reactive energies in one-phase two-wire networks. This design is made to be compliant with IS14697:1999 for class 0.5 accuracy for a dynamic range of 10-60 A.

The integrated Switched-Mode Power Supply (SMPS) enables efficient operation of the power meter electronics, and it provides enough power for optional modules, such as nonvolatile memories (NVM) for data logging and firmware storage, and the plugin card for wireless communication for Automatic Meter Reading (AMR)/Advance Metering Infrastructure (AMI) and remote monitoring. The power meter electronics are backed up by a 3.6 V Li-SOCI2 battery when disconnected from the mains. This battery activates the power meter, whenever the user button is pressed or a tamper event occurs.

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

1.1 Specification

The MKM35Z512 one-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 one-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:

Table 1. MKM35Z512 one-phase power meter specification

Type of meter	One-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)	3200
Functionality	V, A, kW, VAr, VA, kWh (import / export), kVArh (import / export), Hz, power factor, time, date
Voltage sensor	Voltage divider
Current sensors (Shunt, CT)	Shunt resistor down to 200 μΩ (350 μΩ used in this design), Current transformer 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 push button
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
Power consumption @ 3.3 V and 22 °C: • Normal mode (powered from mains) • Stand-by mode (powered from battery) • Power-down mode (powered from battery)	 11.0 mA [1] 2.2 mA 4.0 μA (both covers closed, no tampering)

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

2 MKM35Z512 series MCU

NXPs 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 frontend 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 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

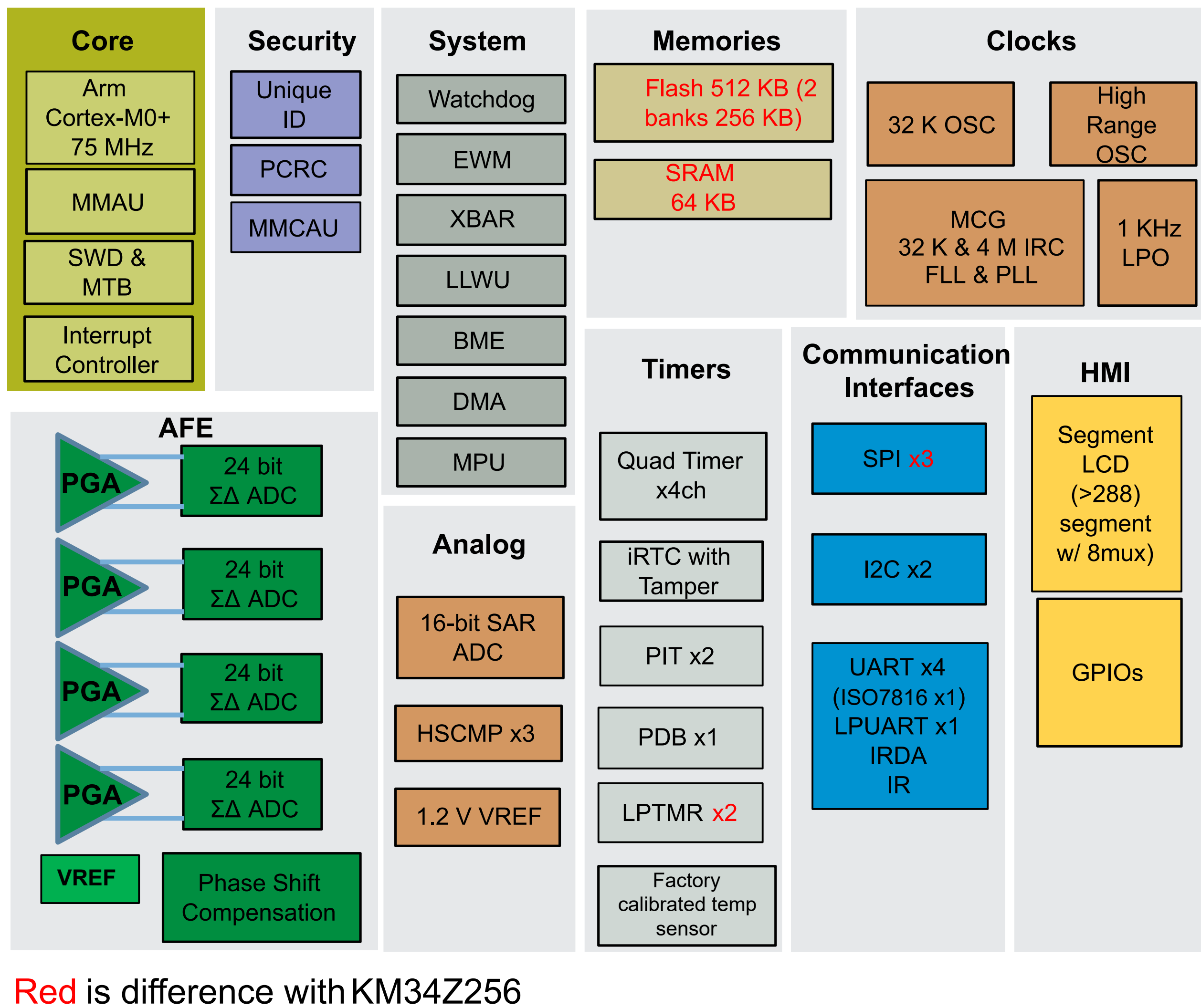


Figure 1. KM35Z512 MCUs block diagramKM35Z512 MCUs block diagram

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 frontend, 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

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

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

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 one-phase power meter is computed as an infinite integral of the unbiased instantaneous shifted phase voltage u(t-90°) and phase current i(t) waveforms.

$$VARh = \int_0^\infty u(t - 90^\circ)\, i(t) dt \quad \text{Eq. 3-2}$$

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.

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

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.

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

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:

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

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

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.

$$S = IRMS * URMS \quad \text{Eq. 3-7}$$

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.

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

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.

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

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

Circuits containing purely resistive heating elements (filament lamps, cooking stoves, and so 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

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

- Power supply

- Digital circuits
- Analog signal-conditioning circuits

The power supply is designed to operate single phase input mains from 90 VAC to 450 VAC and secondary side regulation.

Total capacity of power supply output is 10 W max. For more information, see Power supply.

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

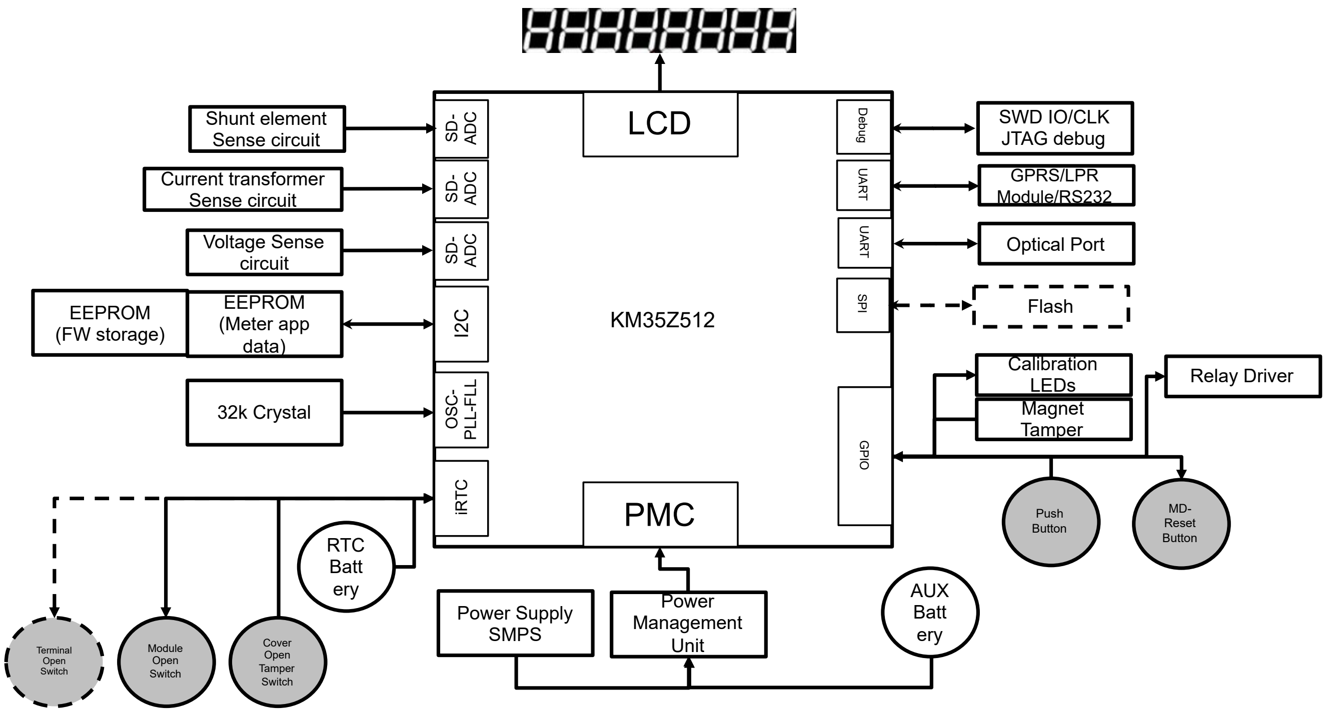


Figure 2. KM35Z512 usage for one-phase smart meter

The digital part can be configured to support both basic and advanced features. The basic configuration is composed 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 MKM35Z512 devices enable differential analog signal measurements with common mode reference of up to 0.8 V and input signal range of ±250 mV. The capability of the device to measure analog signals with negative polarity brings a significant simplification to the phase current and phase voltage sensors hardware interfaces (see Analog circuits).

The power meter electronics were created using a two-layer printed circuit board (PCB). Two-layer PCB is cheaper and cost-effective. Figure 24 and Figure 25 show the top and bottom views of the power meter PCB, respectively.

4.1 Power supply

Power supply 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. The power supply provides 12 V for Latching relay operation and 5 V (2A Max) for GPRS/RF module and energy measurement block by using 3.6 V LDO.

Output of the SMPS and LDO is LPV fixed at 3.6 V.

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
- LPV – Fixed 3.6 V supply from SMPS-LDO that powers the GPRS modem or other types of modules

- uVCC is supported by LPV and ABAT (auxiliary 3.6 V Li-SOCl$_2$ battery) – provides supply to digital and analog voltage for the MCU and digital/analog circuits. MCU power pins VDD, VDDA, SAR_VDDA all are powered through this.

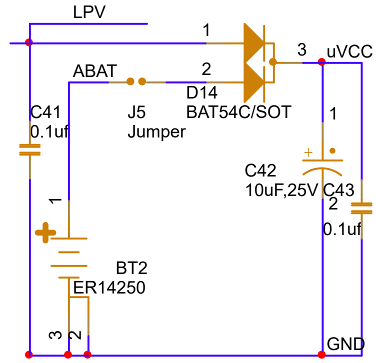


Figure 3. Power supplies for the MCU in meter

The battery voltage (ABAT) is separated from the regulated output voltage (LPV) using D14 diode. When the power meter is connected to the mains, then the electronics are powered through the top D14 diode from the regulated output voltage (LPV). If the power meter is disconnected from the mains, then the bottom D14 diode start conducting, and the MCU, including a few additional circuits operating in the Standby and Power-down modes, are supplied from the battery (ABAT). The switching between the mains and battery voltage sources is performed autonomously, with a transition time that depends on the rise and fall times of the regulated output supply (LPV).

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 uVCC only and bypass capacitors C19, C22 are put close to the MCU analog voltage pins for better performance.

NOTE

The digital and analog voltages MCU VDD, VDDA, and SAR_VDDA are lower than the regulated output voltage LPV, due to a voltage drop on the diode D14 (0.35 V).

4.2 Digital circuits

All the digital circuits are supplied from the uVCC, and uVCCB voltages. The digital/analog common MCU voltage (uVCC), 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 (U1), LEDs, isolated optical communication interface (IRLED1, PT1). The regulated output voltage (LPV) 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 (FRC1, FRC4).

4.2.1 MKM35Z512VLL7

The MKM35Z512VLL7 MCU (U1) is the most noticeable component on the metering board see Figure 25 The following components are required for proper operation of this MCU:

- Filtering ceramic capacitors C7, C8, C19, C22, C37, C13, C14
- LCD charge pump capacitors C1 – C4
- External reset filters C35 and R63
- 32.768 kHz crystal XT2

The LCD (LCD1) is an indispensable part of the power meter. Connector CON11 is the SWD interface for MCU programming.

CAUTION

The debug interface (CON11) 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 see Figure 4; LED1 for active energy, and LED2 for reactive energy. These LEDs are used at the time of the meter calibration or verification.

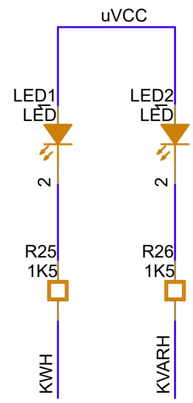


Figure 4. Output LEDs control

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 5. The maximum communication throughput is limited by the M24M02 device. The memory can work in both the Normal and Standby operation modes.

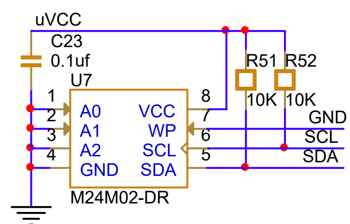


Figure 5. 256 KB I2C EEPROM control

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 SPI1 module, as shown in Figure 6.

The SPI1 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.

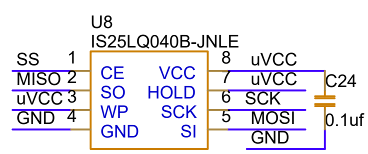


Figure 6. 512 KB SPI Flash control

4.2.5 GPRS module interface

The expansion headers FRC1, FRC4, see Figure 7 are used to interface the power meter to the GPRS modules. Currently, they support only the WM620 based GPRS module, see Figure 8. In the future, they will also support other types of modules for example, the 6LowPAN 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

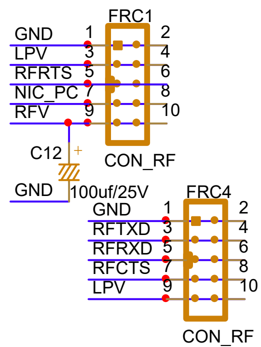


Figure 7. GPRS control

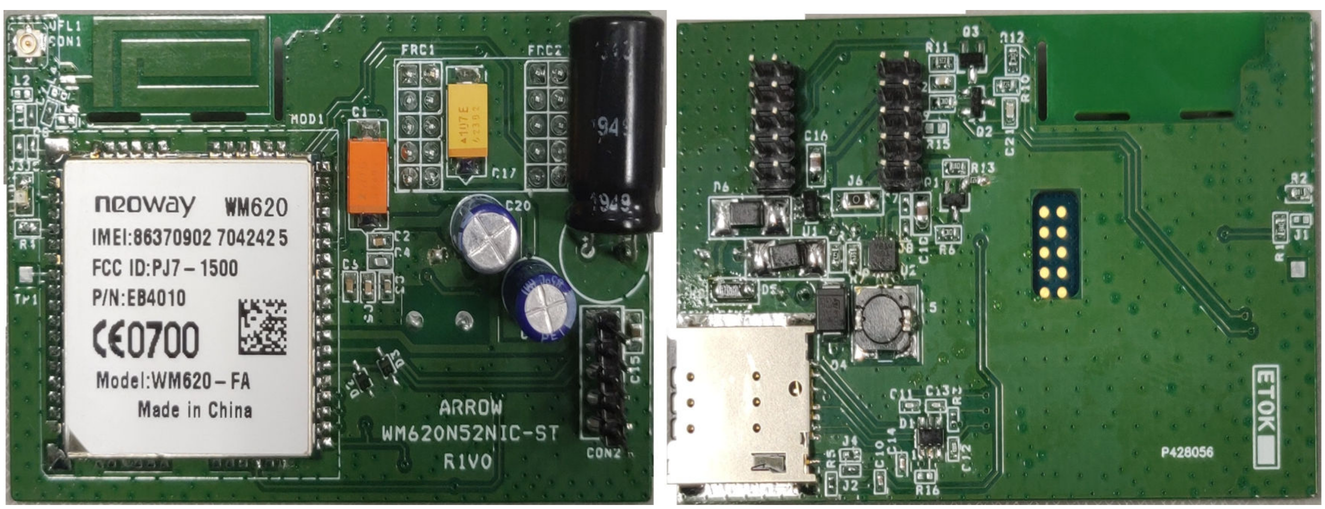


Figure 8. Extension for the GPRS communication

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 a latch MOSFET circuit so that the IR interface can be disabled during standby or low leakage stop mode of the meter, that is, when mains power supply is not available. Powering from the latch to MOSFET circuit enables the MCU to switch off the phototransistor circuit, and thus minimize current consumption in the Standby or power-down modes. The IR interface schematic part is shown in the following figure:

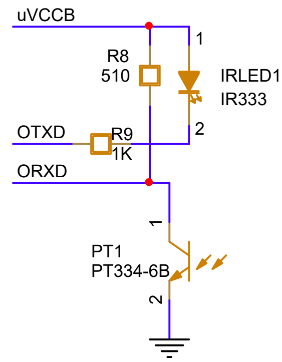


Figure 9. IR control

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 RS232 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 U2 and U6. 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 U2 optocoupler and the primary side of the U6 optocoupler. The communication interface, including the R41, R43, R44, R47, C15 components, are required to power the optocouplers from the transition control signals, is shown in Figure 10.

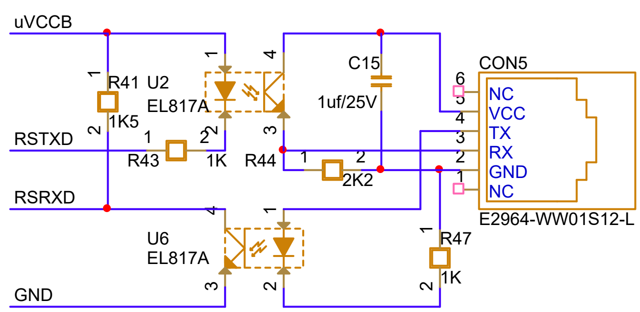


Figure 10. RS232 control

NOTE

The CON5 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 cut-off the load from source input. Two PMV90ENE N channel trench MOSFETs are used to drive the relays that are connected through CON9, CON10 placed at the meter PCB. Relays are driven by MCU GPIO pins configured as output. Relay connectors are shown Figure 11.

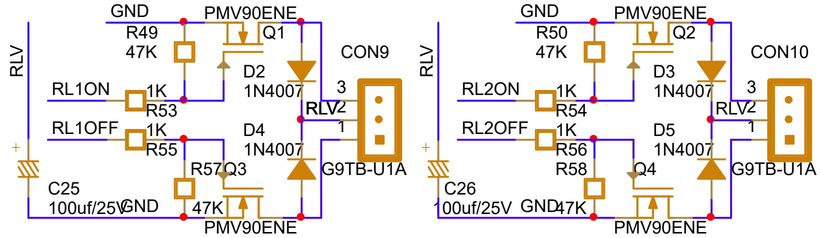


Figure 11. Relay control

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 12.

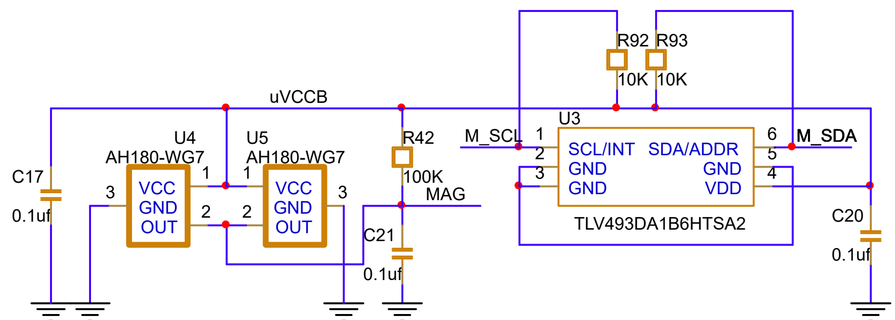


Figure 12. Magnetic tamper sense circuit

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 13.

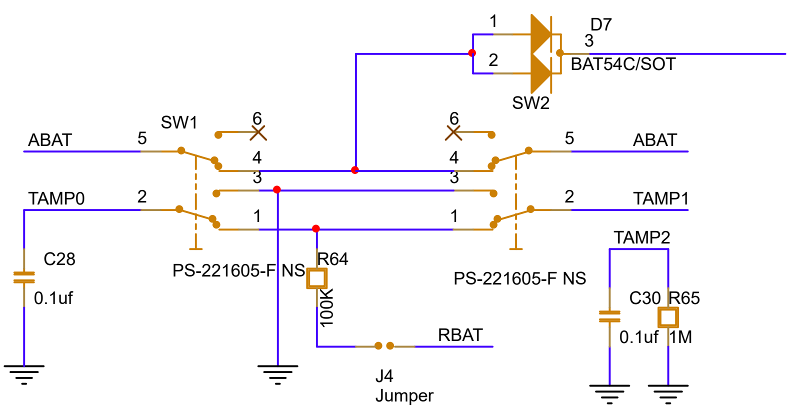


Figure 13. Tamper sense circuit

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

Although the MKM35Z512 one-phase power meter reference design is optimized for shunt resistors, various current transformers and Rogowski coils can also be used. The only limitations are the sensor output signal range (which must be within ±0.5 V peak) and the dimensions of the enclosure. The interface of a current sensor to the MKM35Z512VLL7 device is very straightforward; only the anti-aliasing low-pass filters, attenuating signals with frequencies greater than the Nyquist frequency, must be populated on the board (see Figure 14). The cut-off frequency of the analog filters implemented on the board is 15.4 kHz.

A 350 μΩ shunt resistor is used to measure phase current. This produces peak voltage of 350 μΩ x 60 A x 1.2 = 25.2 mV across the shunt resistor. So, AFE PGA gain value ‘8’ can be chosen safely to restrict under the ±250 mV for the AFE input. High value of shunt resistor is not chosen as it generates more heat across the shunt.

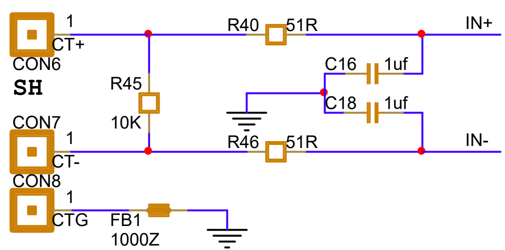


Figure 14. Phase current signal conditioning circuit

In addition to phase current measurement, due to the need to identification of current related tampers such as earth tamper etc, the neutral current is also measured but 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 15.

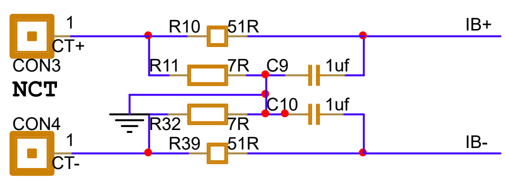


Figure 15. Neutral current signal conditioning circuit

4.3.2 Phase voltage measurement

A simple voltage divider is used for the line voltage measurement. Due to power dissipation, it is better to design this divider using several resistors connected serially. See Figure 16. One half of these resistors consists of R3, R4, R5, and R6, the second half consists of resistor R7. The resistor values were selected to scale down the 536.4 V Vrms (758.56 V Peak) which is peak input line voltage (designed as per electricity board requirement, but one can change according to their requirement) to the 0.250 V peak input signal range of the 24-bit SD ADC. The voltage drop and power dissipation on each of the R3-R6 SMD 1206/MELF0204 resistors are below 190 V and 76 mW, respectively. The anti-aliasing low-pass filter of the phase voltage measurement circuit is set to a cut-off frequency of 72.34 kHz.

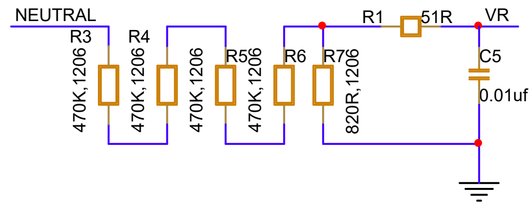


Figure 16. Phase voltages signal conditioning circuit

5 Software design

This section describes the software application of the MKM35Z512 one-phase power meter reference design. The software application consists of measurement, calculation, calibration, user interface, and communication tasks.

5.1 Block diagram

The application software is written in the C language and compiled using:

- NXP MCUXpresso
- IAR® Embedded Workbench for Arm
- Keil MDK toolchains with high optimization for execution speed

The software application is based on the MKM35Z512 SDK drivers [5] and Low Power Real Time (LPRT) metering algorithm library (AN13259).

The software transitions between operating modes, calculates all metering quantities, controls the active 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.

The following figure shows the software architecture of the power meter, including interactions of the software peripheral drivers and application libraries with the application kernel. All tasks executed by the MKM35Z512 one-phase power meter software are briefly explained in the following subsections.

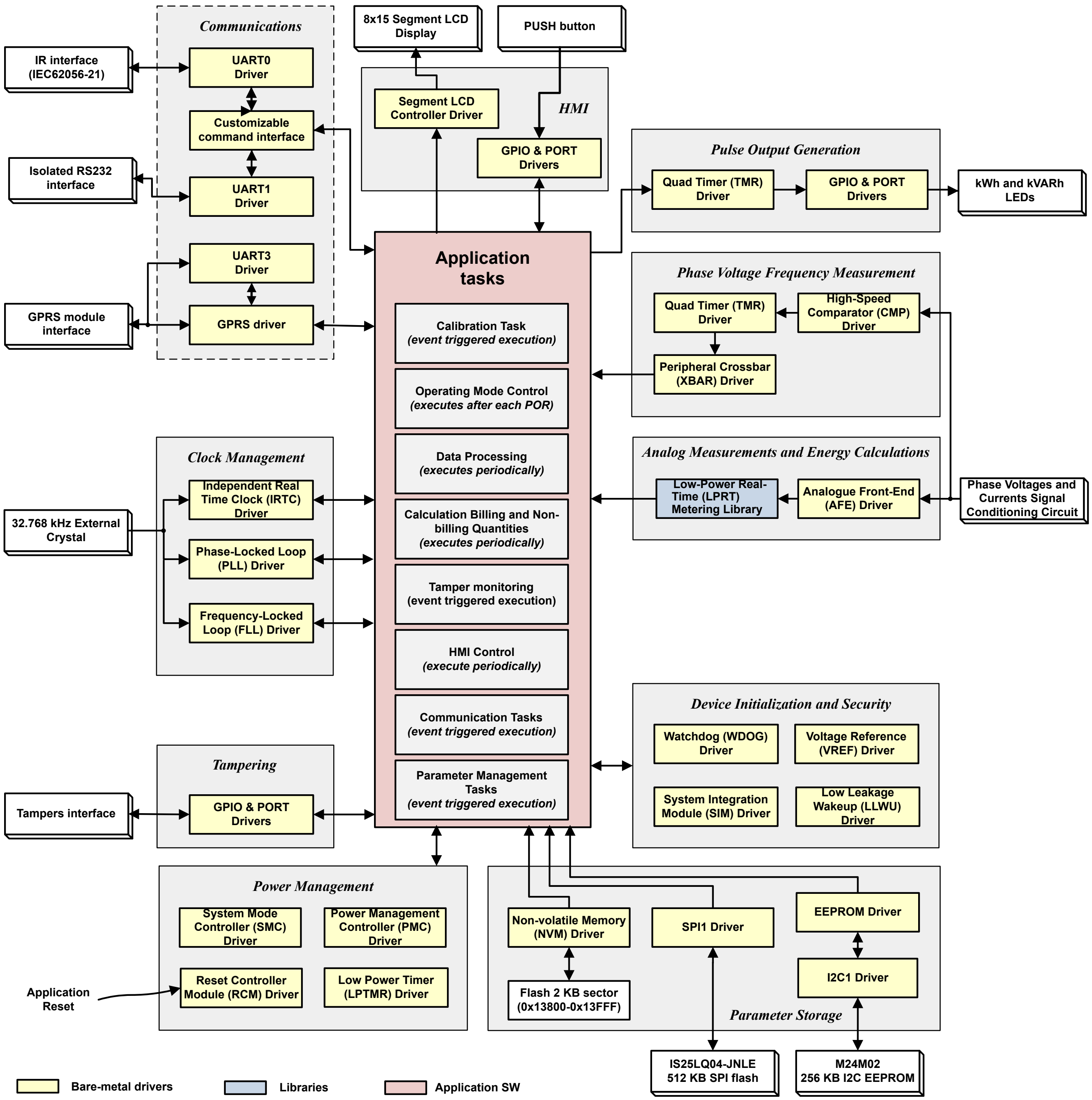


Figure 17. Software architecture

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	Meter reset	–	After every meter 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 AFE	libmeterliblprt_cmp0p.a/ meterlprtlib_cm0p_iar.a/ meterlprtlib_cm0p_mdk.lib, MeteringLPRT.h	V_Callback	AFE CH2 conversion complete IRQ	Level 2	Periodic 333.3 μs
Calculation	Zero-cross detection	libmeterliblprt_cmp0p.a/ meterlprtlib_cm0p_iar.a/ meterlprtlib_cm0p_mdk.lib, MeteringLPRT.h	TMR2callback	QTMR interrupt (CMP1 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	DoMetering1Ph		–	Periodic 1 sec
Pulse generation	LEDs dynamic pulse output generation	MeteringISR.h	DoPulsing1Ph	LPTMR0 compare flag	Level 0 (highest)	Periodic every 1 msec
Tamper monitoring	Reads tampers state	RTCDriver.c, RTCDriver.h	RTCEventHandler	TAMPER0 active high, TAMPER1 both edges	Level 3 (lowest)	Asynchronous

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
Power meter calibration	Performs power meter calibration	libmeterliblprt_cmp0p.a/ meterlprtlib_cm0p_iar.a/ meterlprtlib_cm0p_mdk.lib, Calibration1Ph.h	DoCalibration1Ph	UART interface	–	Command through UART interface
Parameter management	Reads parameters from the Flash and from the external EEPROM	MeteringRunInit.c, MeteringInterface1Ph.h	InitCalibration	Device reset	–	After every device reset
	Writes parameters to the Flash and to the external EEPROM		UpdateFlashCalib, ReadVerifyFlashCalib, ReadVerifyCalib1Ph,	After successful calibration, controlled by user, or switching off	–	Asynchronous
	Writes backup to the external EEPROM		UpdateCalib	After successful calibration, controlled by user	–	Command through UART interface

NOTE
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 power meter is connected to the mains and a calibration command is triggered through IR communication interface. The running calibration task measures the phase voltage and phase current signals generated by the test equipment; it scans for 240 V phase voltage and 10.0 A phase current waveforms with a 60 degree phase shift. The voltage and current signals must be the first harmonic 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:

$$gain_U = 240.0/U_{RMS} \quad \text{Eq. 5-1}$$

$$gain_I = 10.0/I_{RMS} \quad \text{Eq. 5-2}$$

$$\theta = 60^o - tan^{-1}(Q/P) \quad \text{Eq. 5-3}$$

$gain_U$ 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, and 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 detailed discussion of the calibration process, refer application note AN12827 Single point power meter calibration process.

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

The Figure 18 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 the electricity is applied, then the software application enters the Normal mode, and 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.

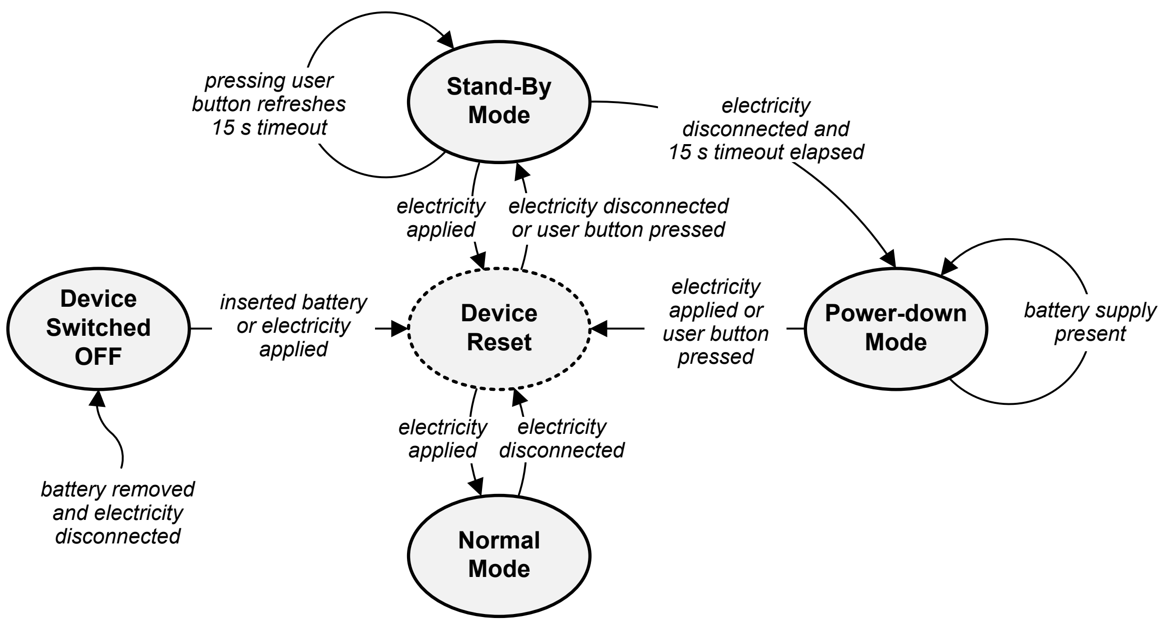


Figure 18. Operating modes

If the electricity is not applied, then the software application enters the power-down mode. Meter can exit this mode when electricity is applied, or user button is pressed. If user button is pressed, the software then enters the standby mode. This mode transitions between the Normal mode and the Power-down mode with a duration of only 15 seconds refresh timeout. The power meter runs from the battery during this mode, and you 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. 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 but you do not list through the menus, then the software transitions automatically to the Power-down 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 electricity. The Power-down mode is characterized by a battery current consumption of 4.0 µA.

5.2.3 Data processing

Reading the phase voltage, phase and neutral current samples from the analog frontend (AFE) occurs periodically every 333.3 µsec. This task runs on the high priority level, and it is triggered asynchronously when the AFE result registers receive new samples.

This task reads the phase voltage, phase, and neutral current samples from three AFE result registers, and writes these values to the buffers, to be used by the calculation task.

NOTE

AFE samples for voltage and current are taken continuously at a constant rate of 3000 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 are 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 50 signal periods, that is, 1 second.

Now, all circle buffers are filled up with the AFE results from the previous 50 signal periods. First, the calculation task performs the *DoMetering1Ph* which calculates all instantaneous parameters including Vrms, Irms, Phase angle, and Powers. This calculation process uses the calibration gains obtained during the calibration stage (see Power meter calibration). *DoCalibration1Ph* function is used to do calibration of the meter depending on a user command received through IR communication interface.

Finally, the billing quantities are computed, which helps to produce a low-jitter, high-dynamic range pulse output waveform for one or two energy LEDs (kWh and KVArh). The energy LED pulsing is done by another independent task *DoPulsing1Ph*.

5.2.5 HMI control

The Human Machine Interface (HMI) control task executes continuously for LCD display and push-button events. Using short keypress, the LCD parameters can be scrolled through a pre-defined list of billing and non-billing parameters.

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 20.

5.2.7 Tamper monitoring

There are two hidden mechanical push-buttons. 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 push button to detect the terminal cover opening. By default, this push button is not populated on meter PCB. These asynchronous events are read as the IRTC interrupt, those tamper events can be stored in the memory, and can be 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 uses 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 one-phase power meter software application, see section 5.1.

Table 3. Memory requirements

Function	Description	Flash size [KB]	RAM size [KB]
Application framework	Complete application without LPRT library, EEPROM driver, and communication	37.758	9.976
Low-power real time metering library	Low-power real time metering algorithm library	4.628	1.453
EEPROM driver	EEPROM driver	1.084	-
Proprietary communication	Proprietary protocol and serial communication driver	5.078	1.357
Grand total		48.548	12.800

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 19 shows the wiring diagram of the MKM35Z512 one-phase power meter. Registering the active and reactive energy consumed by an external load is among the main capabilities of the power meter. When you connect the power meter to the mains or when you press the user button, the power meter transitions from the Power-down mode to either the Normal mode or the Standby mode, respectively. In the Normal and Standby modes, the LCD is turned on, and it shows the last 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.

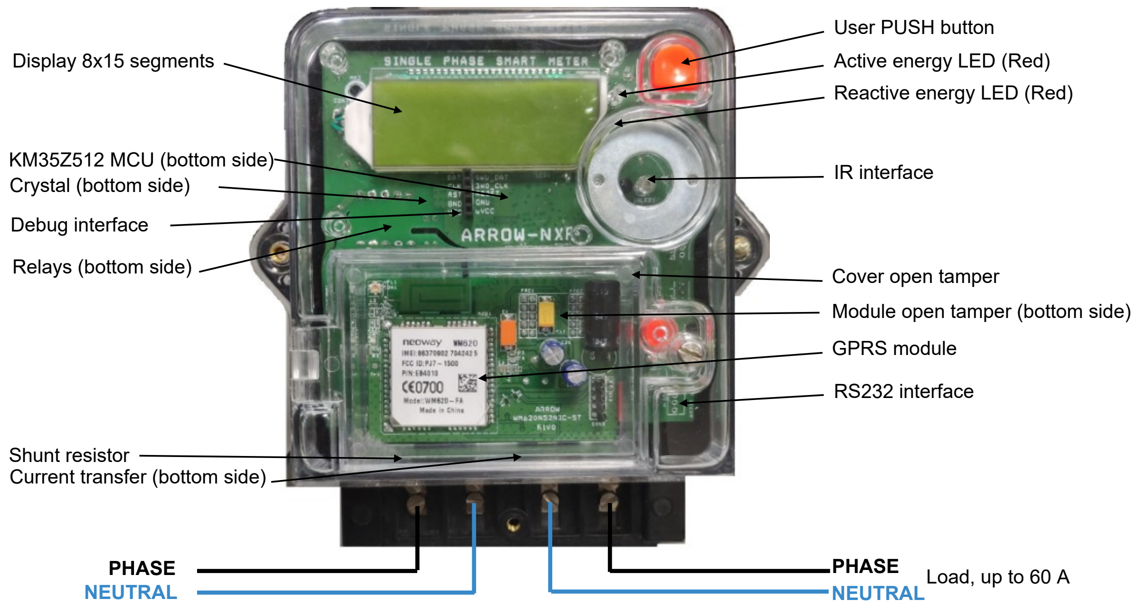


Figure 19. MKM35Z512 one-phase power meter wiring diagram

Table 4. 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
Date	–	DD:MM:YY		☐
Time	–	HH:MM:SS		☐
Meter serial number	–	########		

Figure 20 shows the values and special symbols on the power meter display. This figure displays the following display parameters – line voltage, phase current, instantaneous active power, date, time, all segment ON.

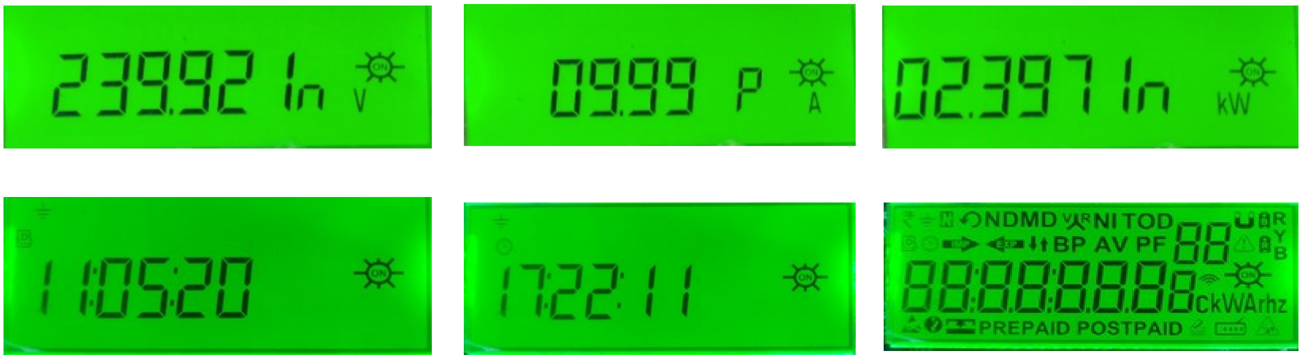


Figure 20. MKM35Z512 one-phase smart power meter display

The active energy LED flashes 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).

7 Accuracy and performance

The MKM35Z512 one-phase reference designs are fully calibrated using the test equipment MTE PTS400.3. 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 MTE PTS400.3, 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 21 shows the accuracy plot of NXP MKM35Z512 one-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.

First graph shows 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.

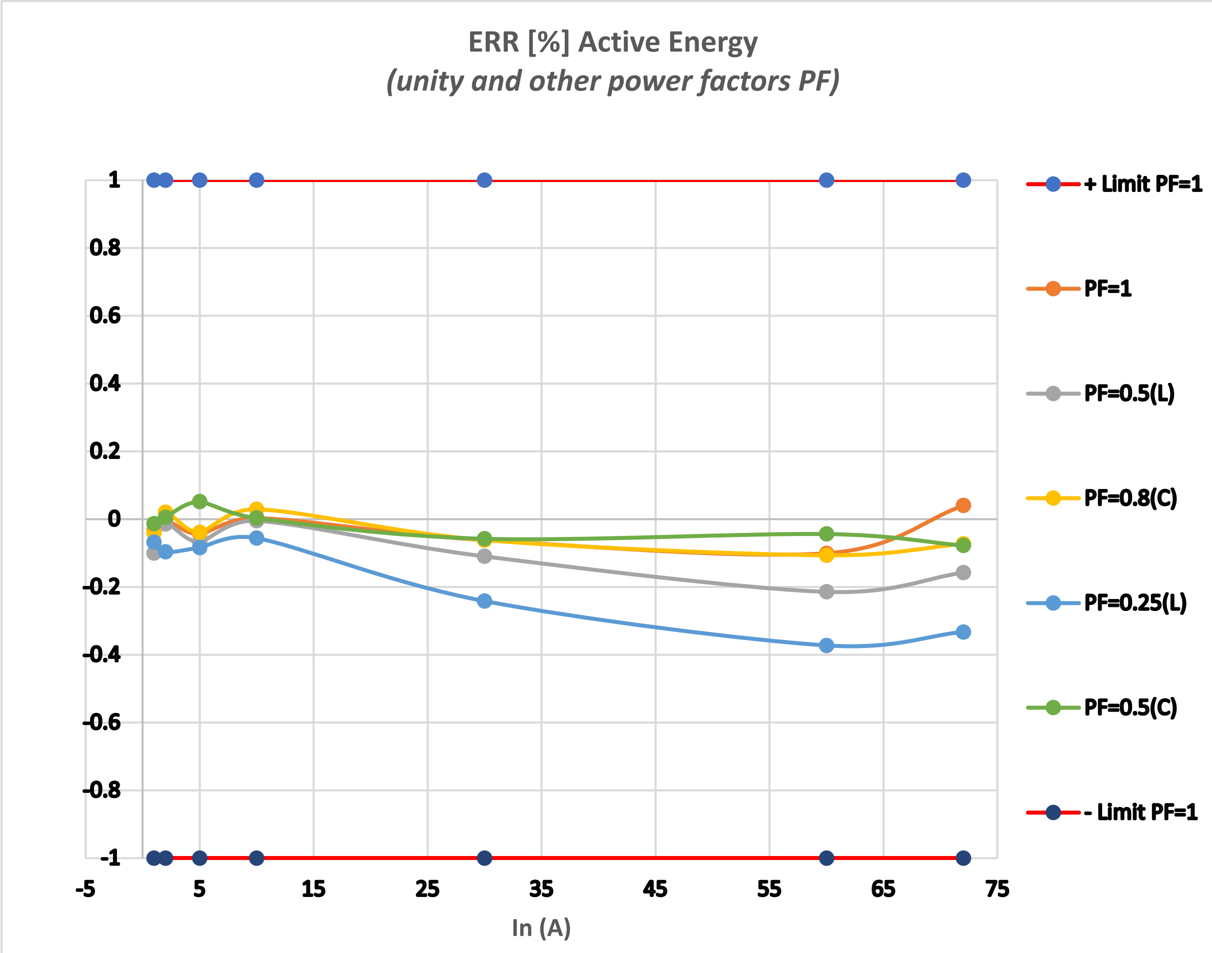
The second graph shows the accuracy of the active energy after calibration. The *x*-axis shows the variation of the phase voltage, and the *y*-axis denotes the average accuracy of the power meter, computed from five successive measurements. The two bold red lines define the Class 0.5 (IS14697) accuracy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

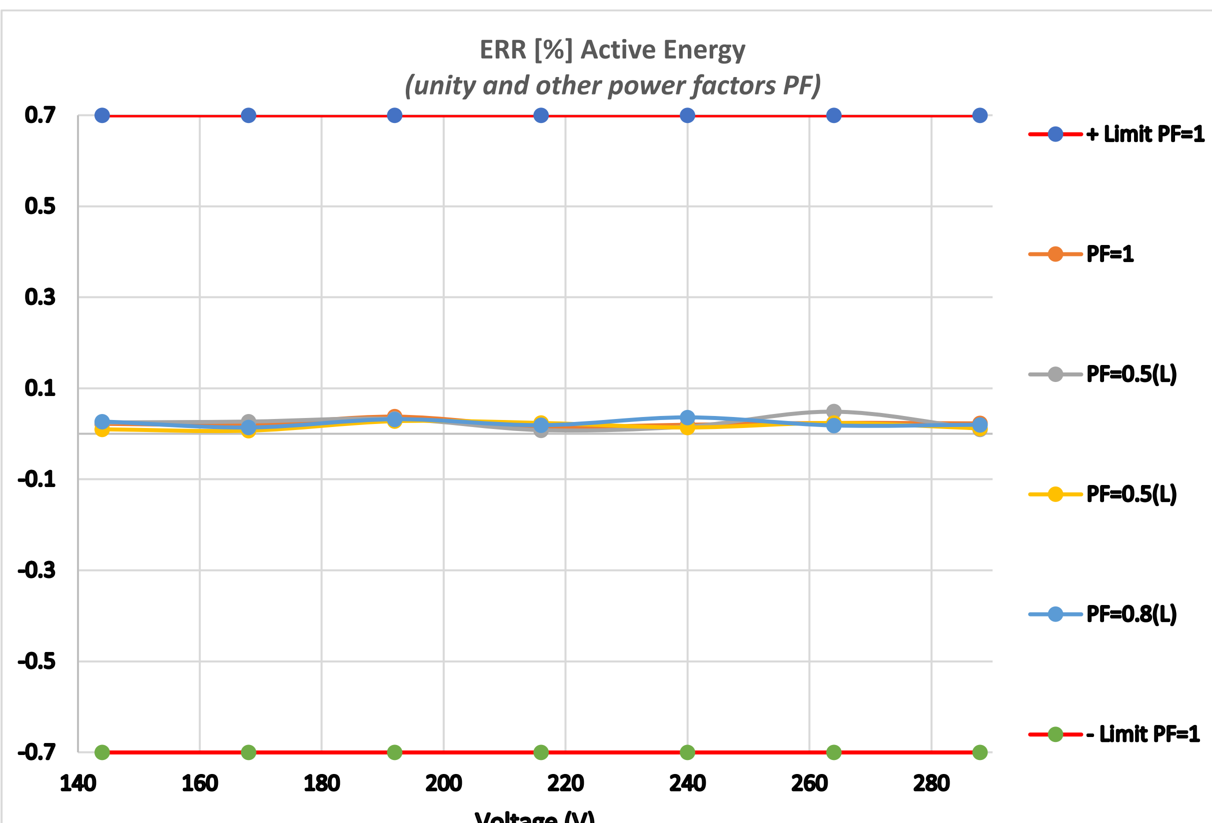
The third graph shows the accuracy of the active energy after calibration. The *x*-axis shows the variation of the frequency, and the *y*-axis denotes the average accuracy of the power meter, computed from five successive measurements. The two bold red lines define the Class 0.5 (IS14697) accuracy margins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

By analyzing the protocols of several MKM35Z512 one-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 – 72 A, with the accuracy range of ±0.5 %.

CAUTION

Even though the current range of the power meter is scaled to 72 A, it is not recommended to operate the power meter in the 60 – 72 A range for a longer time period, due to heating of the shunt resistor in this current range.


ERR [%] Active Energy
(unity and other power factors PF)
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-5
5
15
25
35
45
55
65
75
In (A)
+ Limit PF=1
PF=1
PF=0.5(L)
PF=0.8(C)
PF=0.25(L)
PF=0.5(C)
- Limit PF=1


ERR [%] Active Energy
(unity and other power factors PF)
0.7
0.5
0.3
0.1
-0.1
-0.3
-0.5
-0.7
140
160
180
200
220
240
260
280
Voltage (V)
+ Limit PF=1
PF=1
PF=0.5(L)
PF=0.5(L)
PF=0.8(L)
- Limit PF=1

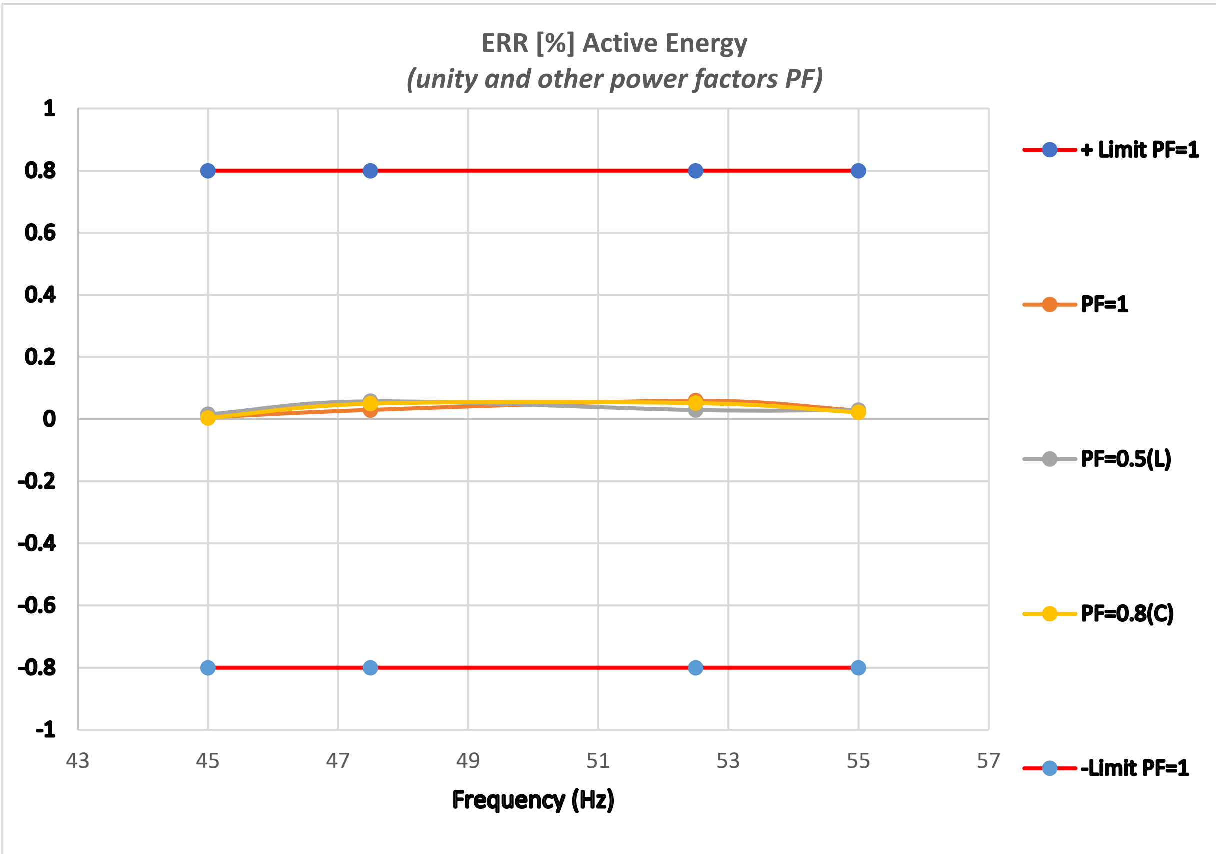


Figure 21. Accuracy results at 25 °C

8 Summary

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

NXP offers Fast Fourier Transform (FFT), Filter-based, 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. It is based on the MKM35Z512 SDK software drivers and the Low-Power Real-Time (LPRT) metrology library. 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 49 KB of Flash and 7 KB of RAM. The system clock frequency of the MKM35Z512VLL7 device must be 12.288 MHz (or higher) to calculate all metering quantities with an update rate of 3 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 on both phase and neutral 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 Power-down mode. The Power-down mode is characterized by current consumption as low as 4 μA.

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 one-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 ±0.5 %.

9 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. MKM34Z256 SDK Software Drivers (available at https://mcuxpresso.nxp.com/en/welcome).
6. FreeMASTER Data Visualization and Calibration Software (FreeMASTER).
7. Low-Power Real-Time Algorithm for Metering Applications (document AN13259).

10 Revision history

Revision number	Date	Substantive changes
0	May 2020	Initial release
1	21 October 2021	Update Class, Standard

11 Metering Board Electronics

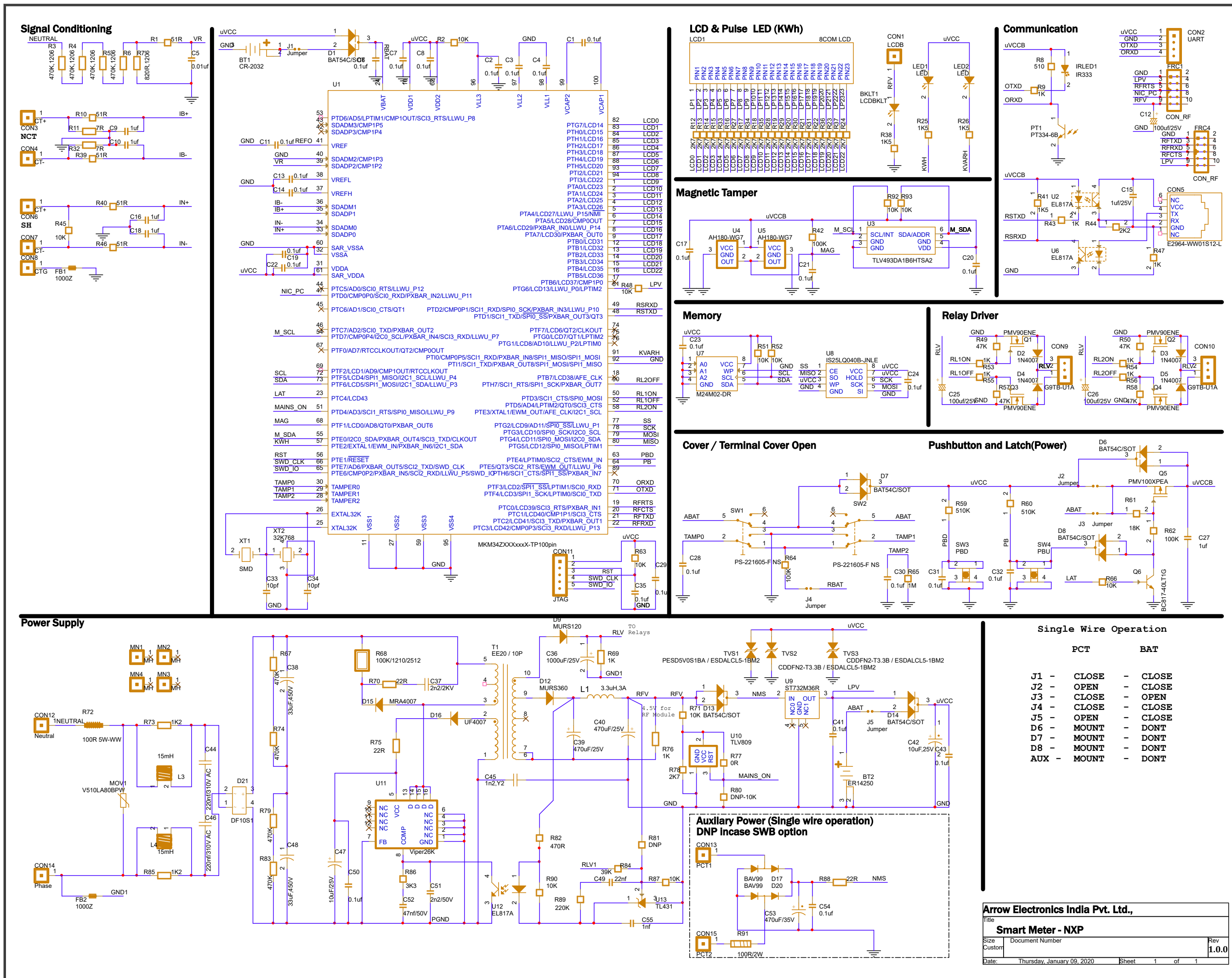


Figure 22. Schematic diagram of the metering board

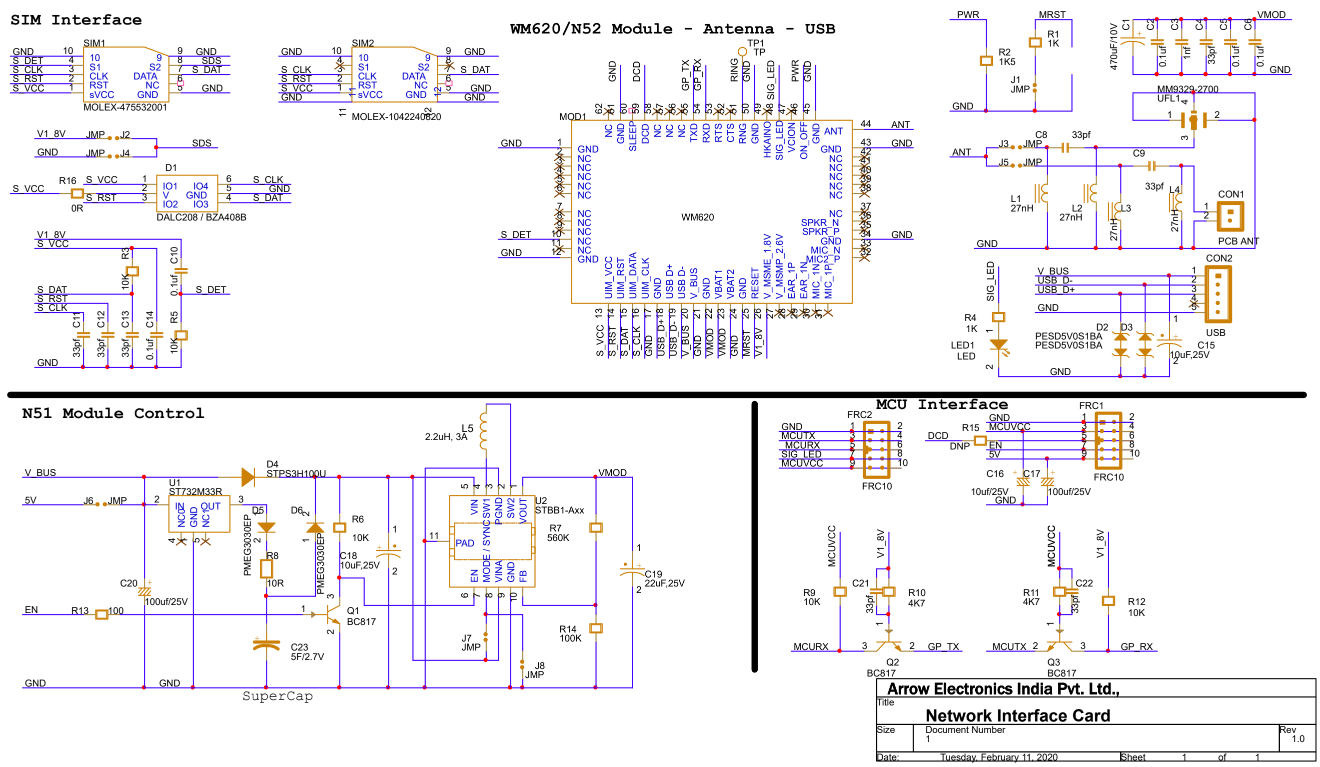


Figure 23. Schematic diagram of the GPRS daughter board

12 Appendix B: Metering board layout

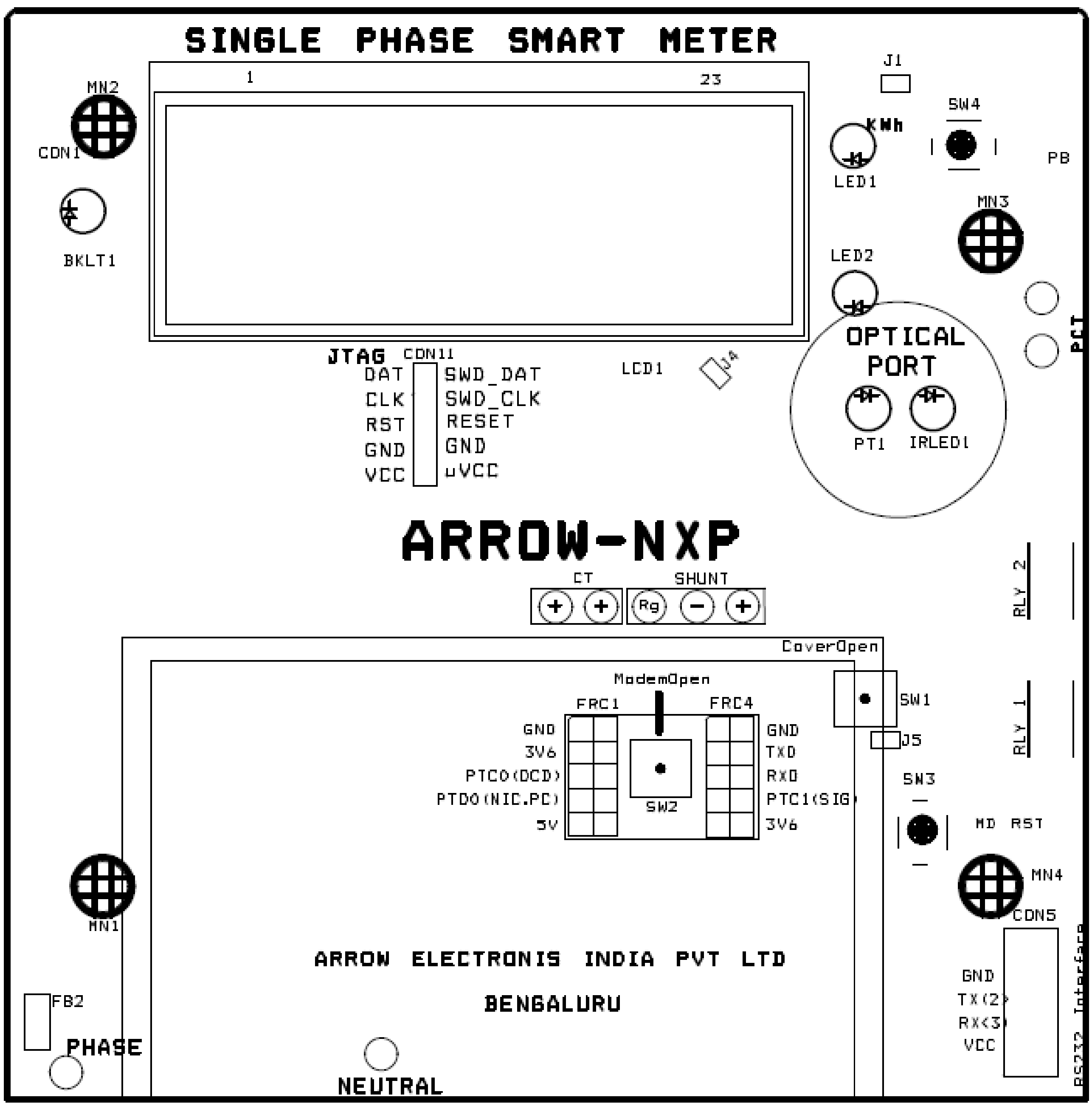


Figure 24. Top-side view of the metering board (not scaled)

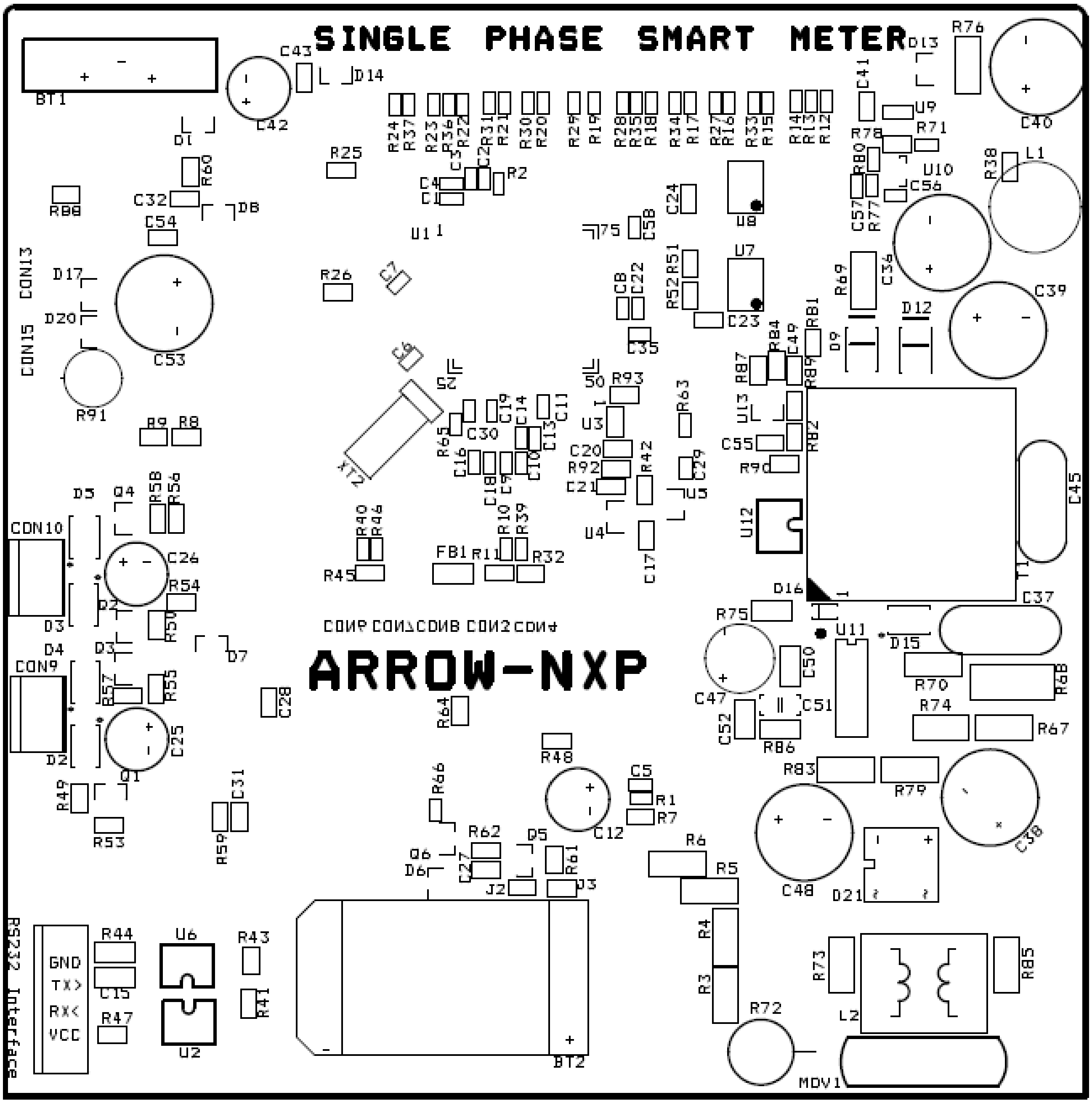


Figure 25. Bottom-side view of the metering board (not scaled)

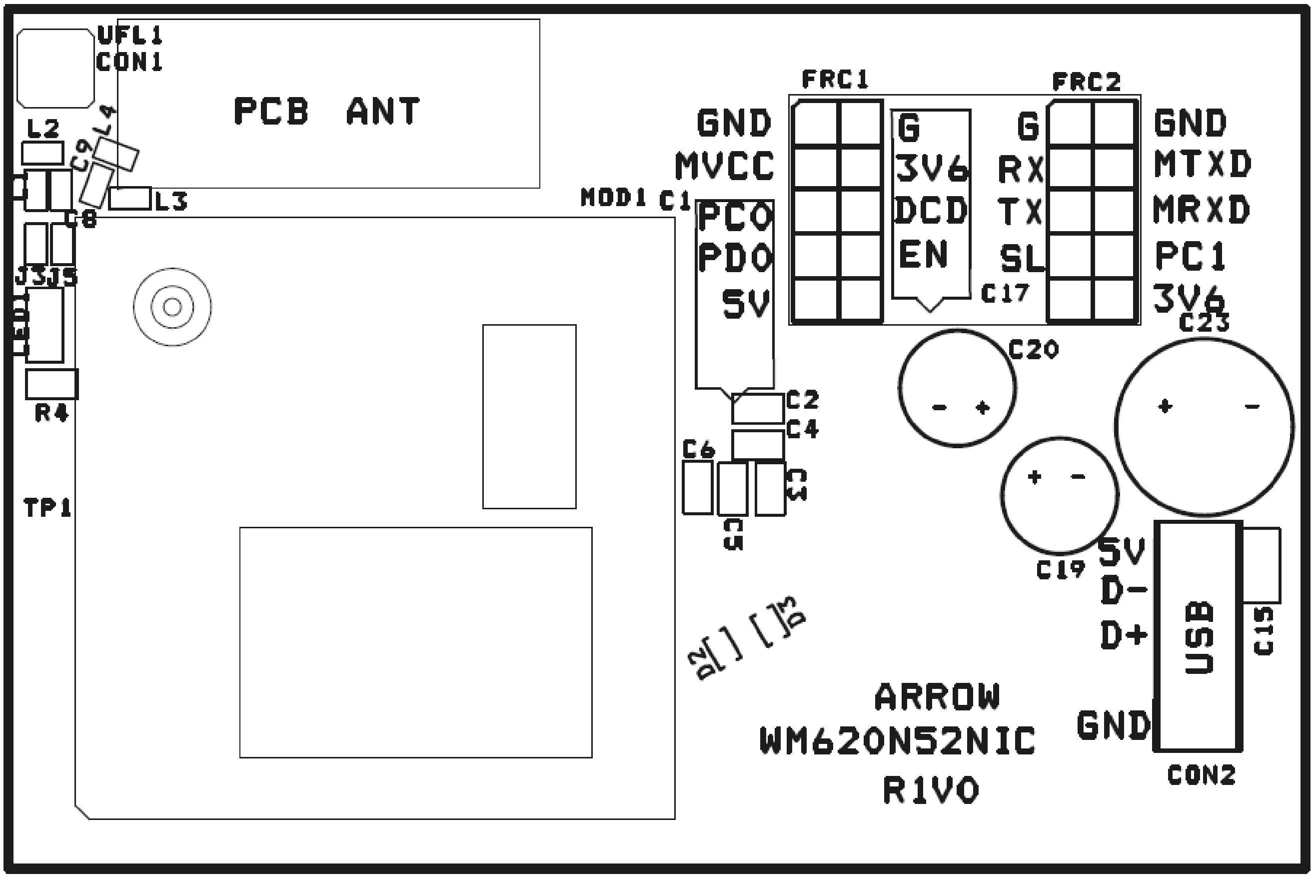


Figure 26. Top-side view of the GPRS module board (not scaled)

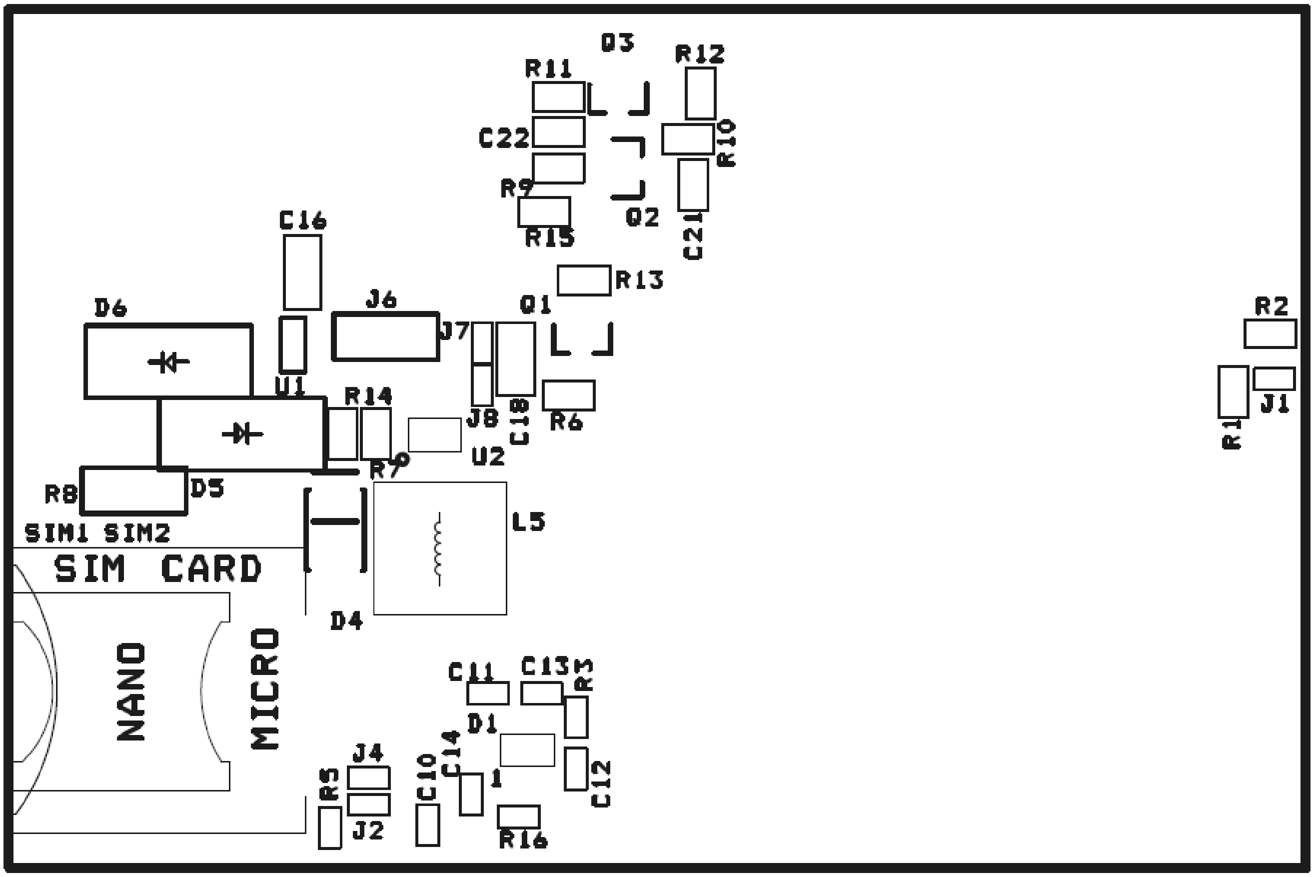


Figure 27. Bottom-side view of the GPRS module board (not scaled)

13 Appendix C: Bill of materials of the metering board

Item	Qty	Reference	Description	Part Number	Manufacturer	Value
1	1	LCD1+BKLT1	LCD with backlight	HSA26785-DYTSP-01	Jiangxi Holitech	LCD
2	1	BT1	Lithium Battery Coin 3V 210mAh	CR2032-PEN3-A10606	EEMB	3V210mAh
3	1	BT2	Lithium Battery Cylindrical 3.6V 1.2Ah 1/2AA	ER14250-VB-A09586	EEMB	3.6V 1.2Ah
4	1	CON1	PCB PAD	NA	NA	NA
5	9	CON3,CON4,CON6,CON7,CON8, CON12,CON13,CON14,CON15	PCB PAD	NA	NA	NA
6	1	CON5	Headers & Wire Housings BERGSTIK	10119333-103A05LF	Amphenol FCI	BERGSTICK
7	1	CON10	Headers & Wire Housings BERGSTIK	10119333-103A05LF	Amphenol FCI	BERGSTICK
8	1	CON9	Headers & Wire Housings BERGSTIK	10119333-103A05LF	Amphenol FCI	BERGSTICK
9	1	CON11	Headers & Wire Housings BERGSTIK	10119333-103A05LF	Amphenol FCI	BERGSTICK
10	2	C56,C57	0.1uf X7R 10% SMD0805	CC0402KRX7R9BB104 / DNP	YAGEO	0.1uF
11	15	C1,C2,C3,C4,C6,C7,C8,C11,C13, C14,C19,C22,C29,C35,C58	0.1uf X7R 10% SMD0805	CC0402KRX7R9BB104	YAGEO	0.1uF
12	1	C5	0.01uf X7R 10% SMD0805	CC0603KRX7R9BB103	YAGEO	0.01uf
13	4	C9,C10,C16,C18	1uf X7R 10% SMD0805	CC0402KRX7R9BB105	YAGEO	1uf
14	1	C26	100uf/25v Aluminum case, electrolytic capacitor	UVR1E101MED1TD / ESK107M025AE3EA / DNP	Nichicon / Kemet	100uf/25v
15	2	C12,C25	100uf/25v Aluminum case, electrolytic capacitor	UVR1E101MED1TD / ESK107M025AE3EA	Nichicon / Kemet	100uf/25v
16	1	C15	1uf X7R 10% SMD0805	CC0805KRX7R9BB105 / DNP	YAGEO	1uf
17	4	C24,C17,C20,C54	0.1uf X7R 10% SMD0805	CC0603KRX7R9BB104 / DNP	YAGEO	0.1uf
18	9	C21,C23,C28,C30,C31,C32,C41,C43, C49	0.1uf X7R 10% SMD0805	CC0603KRX7R9BB104	YAGEO	0.1uf
19	1	C27	1uf X7R 10% SMD0805	CC0603KRX7R9BB105	YAGEO	1uf
20	1	C36	1000uf/25v Aluminum case, electrolytic capacitor	UVZ1V471MPD1TD /	Nichicon / Kemet	1000uf/25v
21	1	C37	2200pF ±10% 2000V (2kV) Ceramic Capacitor X7R Radial	S222K53X7RP63K7R	VISHAY	2200pF 2KV
22	2	C38,C48	33uf/450v Aluminum case, electrolytic capacitor	UPW2W330MHD / SP450M0033B7S-1825	Nichicon / YAGEO	33uf/450v
23	1	C53	470uf/50v Aluminum case, electrolytic capacitor	UVZ1V471MPD1TD / ESK477M035AH2EA / DNP	Nichicon / Kemet	470uf/50v
24	2	C39,C40	470uf/50v Aluminum case, electrolytic capacitor	UVZ1V471MPD1TD / ESK477M035AH2EA	Nichicon / Kemet	470uf/50v
25	2	C42,C47	10uf/25v Aluminum case, electrolytic capacitor	ESK106M025AC3FA / SN025M0010AZF-0511	Kemet / YAGEO	10uf/25v
26	1	C45	AC Line Rated Disc Capacitors X1Y1	440LD10-R	VISHAY	0.001uF 400V
27	1	C50	1nf X7R 10% SMD0805	CC0805KRX7R9BB102	YAGEO	1nf
28	1	C51	2.2nf X7R 10% SMD0805	CC0805KRX7R9BB222	YAGEO	2.2nf
29	1	C52	47nf X7R 10% SMD0805	CC0805KRX7R9BB473	YAGEO	47nf
30	1	C55	1nf X7R 10% SMD0805	CC0603KRX7R9BB102	YAGEO	1nf
31	3	D6,D7,D8	Rectifier Diode Schottky 0.2A 5ns 3-Pin SOT-23 T/R	BAT54C,215 / DNP	Nexperia	BAT54C
32	3	D1,D13,D14	Rectifier Diode Schottky 0.2A 5ns 3-Pin SOT-23 T/R	BAT54C,215	Nexperia	BAT54C
33	2	D3,D5	Rectifier Diode Switching 1KV 1A 75ns 2-Pin SMA T/R	STTH110A / US1M-E3/61T / DNP	ST Micro / VISHAY	STTH110A
34	2	D2,D4	Rectifier Diode Switching 1KV 1A 75ns 2-Pin SMA T/R	STTH110A / US1M-E3/61T	ST Micro / VISHAY	STTH110A
35	2	D9,D12	Rectifier Diode Schottky 100V 3A 2-Pin SMB Flat T/R	STPS3H100UF	ST Micro	STPS3H100
36	1	D15	Rectifier Diode Switching 600V 1A 80ns 2-Pin SMA T/R	STTH1L06A	ST Micro	STTH1L06
37	1	D16	Rectifier Diode Small Signal Switching 100V 0.3A 4ns 2-Pin SOD-123 T/R	BAS16GWJ /1N4148W-13-F	Nexperia / Doide INC	1N4148
38	2	D17,D20	Rectifier Diode Switching 100V 0.215A 4ns Automotive 3-Pin SOT-23 T/R	BAV99,235 / MMBD1203 / DNP	Nexperia / ON Semi	BAV99
39	1	D21	Rectifier Bridge Diode Single 1KV 1A 4-Pin Micro DIP SMD T/R	MDB10S / MBL110S-M3/I	ON Semi / VISHAY	MDB10S
40	2	FB1,FB2	Ferrite Beads Multi-Layer High Current 1KOhm 25% 100MHz 1.6A 0.12Ohm DCR 0805 T/R	BLM21SP102SN1D	MURATA	1K Beed
41	2	FRC1,FRC4	FRC connector 10 pin- C-Grid III Interconnects	901301110	MOLEX	FRC Connector
42	1	IRLED1	Round Non-flange Infrared LED	IR313	Everlight	IR313
43	5	J1,J2,J3,J4,J5	PCB PAD	NA	NA	JUMPER
44	2	LED1,LED2	LED Uni-Color Super Red 650nm 2-Pin T-1 T/R	264-7SDRC/S530-A3	Everlight	LED
45	1	L1	DRUM Core Inductor 3.3uH@1KHz 3A 20% 10mOHM TH	122001	Prismatic	3.3uH

Figure 28. BOM report of meter PCB

Item	Qty	Reference	Description	Part Number	Manufacturer	Value
46	1	L2	common mode choke		Prismatic	15mH
47	4	MN1,MN2,MN3,MN4	PCB PAD	NA	NA	NA
48	1	MOV1	RADIAL LEAD VARISTORS 510VRMS	V510LA80BPW	Littlefuse	V510LA80
49	1	PT1	PHOTO TRANSISTOR	PT333-3C / BPV11	Everlight / VISHAY	PT333
50	2	Q1,Q3	T+D52:H54rans MOSFET N-CH 30V 3A 3-Pin SOT-23 T/R	PMV90ENER	Nexperia	PMV90ENER
51	2	Q2,Q4	T+D52:H54rans MOSFET N-CH 30V 3A 3-Pin SOT-23 T/R	PMV90ENER / DNP	Nexperia	PMV90ENER
52	1	Q5	Trans MOSFET P-CH 20V 2.4A 3-Pin SOT-23 T/R	PMV100XPEAR	Nexperia	PMV100XPEAR
53	1	Q6	Trans GP BJT NPN 45V 0.5A 345mW 3-Pin SOT-23 T/R	BC817,215 / BC817-16LT3G	Nexperia / ON Semi	BC817
54	2	R1,R45	Thick Film Resistor	RC0603FR-0751RL	YAGEO	51R
55	2	R2,R63	Thick Film Resistor	RC0603FR-0710KL	YAGEO	10K
56	8	R3,R4,R5,R6,R67,R74,R79,R83	Thick Film Resistor	RC1206FR-07470KL	YAGEO	470K
57	1	R7	Thick Film Resistor	RC1206FR-072K2L	YAGEO	2K2
58	1	R8	Thick Film Resistor	RC0603FR-0747KL	YAGEO	47K
59	4	R43,R47,R54,R56	Thick Film Resistor	RC0603FR-071KL / DNP	YAGEO	1K
60	4	R9,R53,R55,R90	Thick Film Resistor	RC0603FR-071KL	YAGEO	1K
61	4	R10,R39,R40,R46	Thick Film Resistor	RC0402FR-0751RL	YAGEO	51R
62	2	R11,R32	Thick Film Resistor	RC0603FR-077RL	YAGEO	7R
63	24	R12,R13,R14,R15,R16,R17,R18,R19, R20,R21,R22,R23,R24,R27,R28,R29, R30,R31,R33,R34,R35,R36,R37,R71	Thick Film Resistor	RC0402FR-072K7L / RC0402FR-070RL	YAGEO	2K7L / 0R
64	1	R41	Thick Film Resistor	RC0603FR-071K5L / DNP	YAGEO	1K5
65	3	R25,R26,R38	Thick Film Resistor	RC0603FR-071K5L	YAGEO	1K5
66	3	R42,R62,R65	Thick Film Resistor	RC0603FR-07100KL	YAGEO	100K
67	1	R44	Thick Film Resistor	RC0805FR-072K2L/ DNP	YAGEO	2K2
68	2	R92,R93	Thick Film Resistor	RC0603FR-0710KL	YAGEO	10K
69	9	R48,R49,R51,R52,R57,R78,R81,R87,R89	Thick Film Resistor	RC0603FR-0710KL	YAGEO	10K
70	2	R50,R58	Thick Film Resistor	RC0603FR-0710KL / DNP	YAGEO	10K
71	1	R59	Thick Film Resistor	RC0603FR-07510KL	YAGEO	510K
72	1	R60	Thick Film Resistor	RC0603FR-07510KL	YAGEO	510K
73	1	R61	Thick Film Resistor	RC0603FR-0718KL	YAGEO	18K
74	1	R64	Thick Film Resistor	RC0603FR-07100KL	YAGEO	100K
75	1	R66	Thick Film Resistor	RC0603FR-0727KL	YAGEO	27K
76	1	R68	Thick Film Resistor	RC2512FR-07100KL	YAGEO	100K
77	3	R69,R70,R76	Thick Film Resistor	RC1206FR-0722RL	YAGEO	22R
78	1	R72	Thick Film Resistor	PNP300JR-73-47R	YAGEO	47
79	2	R73,R85	Thick Film Resistor	RC1206FR-071K2L	YAGEO	1K2
80	1	R75	Thick Film Resistor	RC0805FR-0722RL	YAGEO	22R
81	2	R77,R80	Thick Film Resistor	RC0402FR-0710KL / DNP	YAGEO	10K
82	1	R82	Thick Film Resistor	RC0603FR-07220RL	YAGEO	220R
83	1	R84	Thick Film Resistor	RC0603FR-070RL	YAGEO	0R
84	1	R86	Thick Film Resistor	RC0805FR-073K3L	YAGEO	3K3
85	1	R88	Thick Film Resistor	RC0603FR-07470KL / DNP	YAGEO	470K
86	1	R91	Thick Film Resistor	PNP300JR-73-100R / DNP	YAGEO	100
87	2	SW1,SW2	6 Pin Push to OFF SW SPST MOM NO PB 12V 50MA SMT	PS-221605-F NS	C&K COMPONENTS6 pin	Switch
88	2	SW3,SW4	Tact Switch DPDT PB 2A 500V TH	PTS645SL952LFS	C&K COMPONENTSTACT	Switch
89	1	T1	Flyback Transformer	M34SM100-TP1V0	Prismatic	EE20
90	1	U1	MCU 32-bit ARM Cortex M0+ RISC 256KB Flash 2.5V/3.3V 100-Pin LQFP Tray	MKM34Z256VLL7	NXP Semiconductors	MKM34Z256
91	2	U2,U6	OPTO COUPLER DIP4	FOD817A / VO617A-9 / DNP	ON Semi / VISHAY	FOD817A
92	1	U12	OPTO COUPLER DIP4	FOD817A / VO617A-9	ON Semi / VISHAY	FOD817A
93	1	U3	Rotary Position Sensor 3.5V Digital Output 6-Pin TSOP	TLV493DA1B6HTSA2 / DNP	Infineon	TLV493DA
94	1	U4	Hall Effect Sensor Omnipolar 3.3V/5V 3-Pin SC-59 T/R	AH180-WL-7 / DNP	DIODE INC	AH180
95	1	U5	Hall Effect Sensor Omnipolar 3.3V/5V 3-Pin SC-59 T/R	AH180-WL-7	DIODE INC	AH180
96	1	U7	EEPROM Serial-I2C 2M-bit 256K x 8 2.5V/3.3V/5V 8-Pin SO N T/R	M24M02-DRMN6TP	ST Micro	M24M02
97	1	U8	NOR Flash Serial (SPI, Dual SPI, Quad SPI) 2.5V/3.3V 4M-bit 512K x 8 8ns 8-Pin SOIC N	IS25LQ040B-JNLE / DNP	ISSI	IS25LQ040B
98	1	U9	LDO Regulator Pos 3.6V 0.3A Automotive 5-Pin SOT-23 T/R	ST732M36R	ST Micro	ST732M36R
99	1	U10	Processor Supervisor 2.64V 1 Active Low/Push-Pull	TLV809L30DBVR / DNP	TI	TLV809
100	1	U11	AC to DC Switching Converter Flyback 60kHz T/R 16-Pin	VIPER267KDTR	ST Micro	VIPER267KDTR
101	1	U13	V-Ref Adjustable 2.495V to 36V 100mA 3-Pin SOT-23 T/R	TL431AIL3T / TL431AIDBZR	ST Micro / TI	TL431
102	1	XT2	Tuning fork crystal resonator/kHz band	AB26T-32.768KHZ	Abracon Corporation	32.678kHz

Figure 29. BOM report of meter PCB

14 Appendix D: Bill of materials of the GPRS board

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 50	CC0603KRX7R9BB104	YAGEO	0.1uf
5	1	C3	Multilayer Ceramic Capacitors MLCC - SMD/SMT 1.0nF 50	CC0603KRX7R9BB102	YAGEO	1nf
6	2	C10,C14	Multilayer Ceramic Capacitors MLCC - SMD/SMT 0.1uF 50	CC0402KRX7R9BB104	YAGEO	0.1uf
7	3	C11,C12,C13	Multilayer Ceramic Capacitors MLCC - SMD/SMT 33pF 50	CC0402JRNPO8BN330	YAGEO	33pf
8	3	C4,C21,C22	Multilayer Ceramic Capacitors MLCC - SMD/SMT 33pF 5	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		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 Ba	STPS3H100U	STMicroelectronics	STPS3H100U
17	2	D5,D6	Schottky Diodes & Rectifiers SCHOTTKY RECT 30V 3APME	G3030EP,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 Waterc	150080RS75000 / QTLP630C-2TR	Wurth Elektronik / EVERLIGHT	LED
21	4	L1,L2,L3,L4	Fixed Inductors WE-KI 0402 27nH 400mA DCR=298mOhm	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	47553-2001	Molex	SIM Holder
36	1	SIM2	Memory Card Connectors ASSY FOR PUSH PUSH 6 PIN SIM	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	1909763-1	TE Connectivity	RF Connector
39	1	U1	LDO Voltage Regulators 300mA, 28V low-dropout voltage	ST732M28R	STMicroelectronics	ST732M28R
40	1	U2	Switching Voltage Regulators 1A High EFF DC DC 1.5MHz	STBB1-APUR	STMicroelectronics	STBB1-APUR

Figure 30. BOM report of GPRS module

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