MQX-Enabled MK30X256 Single-Phase Electricity Meter Reference Design

Using the MK30X256, MC1322x, and MAG3110
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Chapter 1
Introduction

1.1 Overview

This design reference manual describes the solution for a single-phase electricity meter based on the MK30X256 microcontroller (MCU). The design demonstrates the capabilities of this MCU for electricity metering applications. There are also additional Freescale components used in this design, including the RF (ZigBee®) and magnetometer solution (interface).

The reference design provides a high performance solution for power measurement in single phase two-wire installations. The target market is residential metering. The reference design has the ability to connect to a ZigBee network thanks to the integrated 1322x low power node, hence it can easily become part of the smart grid network. Besides this development, this design uses the MQX real time operating system, to improve the code structure and to serve as a proof of concept for true real-time applications, such as a power meter. Because of the MQX, this power meter is designed for use in advanced markets.

In addition, two measurement methods are explored, implemented, and compared in this reference design (FFT, filter-based method). This reference design manual describes only the hardware solution for the power meter. Software solutions, mainly metering algorithms, are described in associated documents, like application note AN4255, FFT-based Algorithm for Metering Applications.

The power meter reference design is prepared for use in a real customer metering area, as suggested by its implementation of a Human Machine Interface (HMI) and communication interfaces for remote data collecting. Finally, it provides both hardware and software solutions for customer applications.
1.2 General platform features

This chapter describes the main hardware and software features of the MK30X256 Power Meter Reference Design. See also Table D-1.

1.2.1 Hardware design features

- 5 (60) A current range, nominal current is 5 A, peak current is 60 A
- 120/230 V AC, 50/60 Hz operational range
- Active and reactive power (energy) measurement
- Accurate metering function for active and reactive energy: IEC50470-3 class B, 1%
- Meter constants (imp/kWh, imp/kVArh): 500, 1000, 2000, 5000, 10000
- Four-quadrant measurement
- Line frequency measurement (for precision zero-cross detection)
- Cost-effective shunt resistor sensing circuit implementation without an external OpAmp
- Voltage sensing is executed by an inexpensive resistor divider
- Cost-effective bill of materials (BOM) due to low-cost hardware configuration
- Low-power modes effectively implemented, including the use of a built-in real-time clock (RTC)
- 3 V internal battery for proper RTC function
- 4 × 31 segment LCD, including charge pump. Values shown on the LCD: V, A, W, VAr, VA, kWh, kVArh, \(\cos \phi\), Hz, time, date
- Object identification system (OBIS) identifier on the LCD
- Tamper detection via:
  - Two built-in hidden buttons
  - 3-axis MAG3110 digital magnetometer (optional)
- Built-in user push-button
- LED pulse outputs (kWh, kVArh)
• Optically isolated open-collector pulse output
• IEC1107 infrared hardware interface
• Optically isolated RS232 interface (19200 Bd, 8 data bits, no parity)
• JTAG debug interface (non-optically isolated)
• 2.4 GHz RF interface through a 1322x low power node daughter card
• Powered by a 3.3 V SMPS open-frame module (3rd party solution)
• All components—board, sensors, and switch mode power supply (SMPS)—are built into a plastic box with a transparent cover
• EMC proven design (EN61000-4-2, EN61000-4-4, EN6100-4-5, EN6100-4-6, EN6100-4-8, EN6100-4-11)

1.2.2 Software features of the design
• Application C/ASM source code for IAR Embedded WorkBench is available.
• MQX-based design for advanced markets.
• Multiple advanced metering algorithms for precise energy measurements:
  • Fast Fourier Transform
  • Filter based method (optional only)
• ZigBee SE1.0 stack implemented in 1322x low power node for connection to a ZigBee network.
• FreeMASTER visualization script for calibration, watching, and so on.

1.3 MK30X256 microcontroller series
The MK30X256 is a member of the 32-bit Kinetis family of MCUs. This family represents the most scalable portfolio of ARM® Cortex™-M4 MCUs in the industry. Enabled by innovative 90nm Thin Film Storage (TFS) flash memory technology with unique FlexMemory (configurable embedded EEPROM), Kinetis features the latest low-power innovations and high performance, high precision mixed-signal capability with a broad range of connectivity, human-machine interface, and safety & security peripherals. The MK30X256 comes with a full suite of hardware and software tools to make development quick and easy. There is a block diagram of this MCU in Figure 1-1.
The MK30X256 MCU provides the following main features:

- Up to 100 MHz ARM Cortex-M4 core delivering 1.25 DMIPS/MHz with DSP instructions
- Voltage range of 1.74–3.6 V
- 256 KB of program flash memory
- 256 KB of FlexNVM and 4 KB FlexRAM
- 64 KB of SRAM
- 16 independently-selectable DMA channels
- Integrated high-precision 16-bit successive approximations register (SAR) analog-to-digital converters (ADCs) with programmable gain amplifiers (PGAs)
- Two integrated 12-bit digital-to-analog converters (DACs)
- Programmable 1.2 V voltage reference
- High-speed analog comparator with 6-bit DAC
- Timers: FlexTimer, PDB, PIT, LPT, CMT, RTC
- Hardware CRC module to support fast cyclic redundancy check
- Hardware random-number generator
- 128-bit unique identification number per chip
- Human-Machine Interfaces: segment LCD, touch-sensing interface, and GPIO
- Communication interfaces: CAN, SPI, I²C, UART, SDHC, I²S
- –40° C to +105° C operating temperature range

Typical target applications of this MCU are:

- Smart meters
- Thermostats
- Heart rate monitors
- Blood gas analyzers
1.3.1 Peripheral application usage

The power meter concept benefits greatly from plenty of integrated internal peripherals in the MK30X256 MCU.

In this application, the Analog-to-Digital Controller (ADC):

- Employs two channels: one is differential with an internal PGA (x32) for shunt resistor current measurement, the second is single-ended for voltage measurement.
- Includes a linear successive approximation algorithm with a 16-bit resolution.
- Allows high-speed conversion (up to 128 samples per one period).
- Provides a 12-MHz module clock (with 48 MHz bus clock).
- Creates a proper ADC result with 16 hardware-averaged samples.

In this application, the General Purpose Input/Output (GPIO):

- Directly controls some peripherals such as LEDs, open-collector, and so on.
In this application, the Inter-Integrated Circuit (I²C):

- Primarily provides a method for internal communication between the meter (slave) and the 1322x-LPN daughter card (master)—prepared for ZigBee communication.
- Secondarily, allows internal communication with the 3-axis digital magnetometer MAG3110 (optional only)—prepared for tamper detection.
- Drives interrupts with byte-by-byte data transfer.
- Communicates at up to 100 kbit/s with software selectable-slave address.

In this application, the Low-Leakage Wake-up Unit (LLWU):

- Allows button and tamper pins to wake the MCU from low-power mode.

In this application, the Liquid Crystal Display (LCD) controller:

- Allows up to 320 segments (4 × 31 is currently used).
- Displays data.

In this application, the 16-bit FlexTimer Module (FTM):

- Allows a free-running mode with interrupt.
- Generates precision time marks for zero-crossing.

In this application, the Comparator Module (CMP):

- Compares the input voltage signal with a bias voltage (reference).
- Allows interrupts on rising edges.
- Generates capture flags for zero-cross voltage signal detection. Due to this, a variable time window for the PDB is generated.
- Measures line frequency.

In this application, the Programmable Delay Block (PDB):

- Allows hardware triggering of the ADC channels.
- Provides two individually-controlled trigger conditions (one for each ADC channel) depending on the phase shift of the sensors.

In this application, the Real-Time Clock (RTC):

- Provides an ultra-low power independent real-time clock with calendar features (iRTC).

In this application, the Universal Asynchronous Receiver/Transmitter (UART):

- Provides a communication interface with an external PC (for calibration, watching). Communication settings are 19200 Bd, 8 data bits, one stop bit, and no parity.
- Provides communication interface for the IEC1107 infrared communication port (optional).
In this application, the Serial Peripheral Interface (SPI):

- Provides a communication interface with the MRAM (optional).

In this application, the Voltage Reference (VREF):

- Provides a reference voltage for internal analog peripherals such as the ADC and CMP.
- Uses a low-power buffer mode.

### 1.4 1322x Low Power Node (LPN)

The 1322x-LPN is one of the Freescale 1322x development kits designed for connecting to a ZigBee network. The 1322x low power node is designed as a stand-alone development board, including an MC1322x, two LEDs, two push buttons, a GPIO connector, header pins, and a programming and debug port. Note that the ZigBee capabilities of this board are only used in the MK30X256 metering concept; because of this feature, the power meter can easily become part of the smart grid. The Low Power Node board is internally connected to an MK30X256 metering board through an I²C interface. Here are the main features of the 1322x low power node board:

- 2.4 GHz wireless nodes compatible with the IEEE 802.15.4 standard
- Based on the MC13224V Platform in a Package (PiP)
- Hardware acceleration for both the IEEE® 802.15.4 MAC and AES security
- Printed F antenna
- Over-the-air data rate of 250 kbit/s
- Typical range (outdoors, line of sight) is 300 meters
- Onboard expansion capabilities for external application-specific development activities
- Programmable flash memory
- JTAG port for reprogramming and in-circuit hardware debugging
- Buttons and LEDs for demonstration and control
- Connections for battery or external power supply

The core of the 1322x low power node is the Freescale MC1322x 99-pin LGA Platform-in-Package (PiP) solution that can be used for wireless applications ranging from simple proprietary point-to-point connectivity to complete ZigBee mesh networking. The MC1322x is designed to provide a highly-integrated, total solution, with premier processing capabilities and very low power consumption. A full 32-bit ARM7TDMI-S core operates up to 26 MHz. The RF radio interface provides for low cost and high density as shown in Figure 1-2.
As described above, the 1322x low power node is used for connecting an MK30X256 power meter to a ZigBee network. ZigBee, an IEEE 802.15.4 standards-based solution, as defined by ZigBee Alliance, was developed specifically to support sensing, monitoring, and control applications. The ZigBee solution offers significant benefits, such as low power, robust communication, and a self-healing mesh network. The ZigBee solution frequencies are typically in the 868/915 MHz or 2.4 GHz spectrums.

The ZigBee data rate for technology solutions is 250 Kbps. ZigBee technology theoretically supports up to 65,000 nodes. Common applications in sensing, monitoring, and control, which are best supported by a ZigBee technology solution include:

- Personal and medical monitoring
- Security, access control, and safety monitoring
- Process sensing and control
- Heating, ventilation, and air conditioning (HVAC) sensing and control
- Home, building, and industrial automation
- Asset management, status, and tracking
- Fitness monitoring
- Energy management

**NOTE**

For connection of the power meter to a ZigBee network via the 1322x-LPN daughter card, it is necessary to program the 1322x-LPN with the correct firmware. That description is beyond the scope of this design reference manual.
1.5 MAG3110 3-axis digital magnetometer

The MAG3110 is a small, low-power, digital 3-axis magnetometer. It features a standard I²C serial interface output and smart embedded functions. The device can be used in conjunction with a 3-axis accelerometer to produce orientation-independent, accurate compass heading information.

The MK30X256 metering concept is prepared for tamper detection or any illegal opening of the power meter's cover. However, the tamper function using a 3-axis I²C magnetometer is optional.

The MAG3110 provides the main following features:

- 1.95–3.6 V supply voltage (VDD)
- 1.62 V–VDD IO voltage (VDDIO)
- Ultra small 2 × 2 × 0.85 mm DFN 10-pin package
- Full scale range ±1000 μT
- Sensitivity of 0.1 μT
- Noise down to 0.25 μT rms
- Output Data Rates (ODR) up to 80 Hz
- I²C digital output interface (operates up to 400 kHz fast mode)
- 7-bit I²C address = 0x0E
- Sampled low power mode
- RoHS compliant

Typical applications for this magnetometer are:

- Electronic compass
- Dead-reckoning assistance for GPS backup
- Location-based services

There is a simplified magnetometer functional block diagram in Figure 1-3.
Figure 1-3. Simplified magnetometer functional block diagram
Chapter 2
Basic Theory

2.1 Definition of terms

This section defines basic terms of electricity metering theory.

2.1.1 Power

AC power flow has three components: real power (P) measured in watts (W), apparent power (S) measured in volt-amperes (VA), and reactive power (Q) measured in reactive volt-amperes (VAr).

Active power (P), also known as real or working power, is the power that actually powers the equipment. As a rule, true power is a function of a circuit's dissipative elements, usually resistances (R).

\[ P = I^2 \cdot R = \frac{U^2}{R} \quad [W] \]

Reactive power (Q) is a concept used by engineers to describe the loss of power in a system arising from the production of electric and magnetic fields. Although reactive loads such as inductors and capacitors dissipate no power, they drop voltage and draw current, creating the impression that they actually do. This imaginary power or non-working power is called reactive power (Q). If the load is purely inductive or capacitive, then the voltage and current are 90 degrees out of phase (for a capacitor, current leads voltage; for an inductor, current lags voltage) and there is no net power flow. This energy flowing backwards and forwards is known as reactive power. Reactive power is thus produced for system maintenance and not for end-use consumption. By convention, a "lagging," or inductive load, such as a motor, will have positive reactive power. A "leading," or capacitive load, has negative reactive power. Reactive power is a function of a circuit's reactance (X).
Apparent power ($S$) is the vector summation of active and reactive power. It is the product of a circuit's voltage and current, without reference to phase angle. Apparent power is a function of a circuit's total impedance ($Z$).

$$Q = I^2 \cdot X = \frac{U^2}{X} \quad [VAR]$$

These three types of power—true, reactive, and apparent—relate to one another in a trigonometric form. This is called a power triangle (see Figure 2-1). The opposite angle is equal to the circuit's impedance ($Z$) phase angle. Apparent power is often computed from this power triangle using the Pythagorean Theorem as:

$$S = I^2 \cdot Z = \frac{U^2}{Z} \quad [VA]$$

A common utility system is often based on total apparent power ($S_{tot}$) measured also in volt-amperes (VA). Total apparent power is a product of the RMS voltage and RMS current, and is defined as:

$$S = \sqrt{P^2 + Q^2} \quad [VA]$$
This a general proposition:
In a pure sinusoidal system with no higher harmonics, the apparent power (S) equals $S_{tot}$. If there are some higher harmonics in the line, apparent power is not the same as total apparent power, because the simple vector sum in apparent power computing is less accurate. Therefore, $S_{tot}$ is often used because it is more precise in these situations.

2.1.2 Energy

Energy is the accumulated power over a period of one hour.

Active energy means the electrical energy produced, flowing, or supplied by an electric circuit during a time interval, being integral with respect to time of the instantaneous active power and measured in units of watt-hours (Wh). For practical use in power meters, a higher unit called a kilowatt-hour (kWh) is used, which is 1000 watt-hours (Wh).

Apparent energy means the integral with respect to time of the apparent power. Kilovolt-ampere-hour (kVAh) is the unit for total (apparent) energy.

Reactive energy means the integral with respect to time of the reactive power. Kilovolt-ampere-reactive-hour (kVArh) is the unit for reactive (non-working) energy.

2.1.3 Power factor

The power factor of an AC electric power system is defined as the ratio of real power flowing to the load to the apparent power in the circuit, and is a dimensionless number between 0 and 1 (frequently expressed as a percentage, that is $0.5 \text{ pf} = 50\% \text{ pf}$). Real power is the capacity of the circuit for performing work in a particular time. Apparent power is the product of the current and voltage of the circuit. Due to energy stored in the load and returned to the source, or due to a nonlinear load that distorts the wave shape of the current drawn from the source, the apparent power will be greater than the real power.

In an electric power system, a load with a low power factor draws more current than a load with a high power factor for the same amount of useful power transferred. The higher currents increase the energy lost in the distribution system and require larger wires and other equipment. Because of the costs of larger equipment and wasted energy,
electrical utilities usually charge a higher rate to industrial or commercial customers where there is a low power factor. Therefore, a modern electronic smart power meter must also measure the power factor.

Power factor is defined as:

\[ PF = \frac{P}{S} = \cos \varphi \]

\( \varphi \) is the phase angle between voltage and current.

When power factor is equal to 0, the energy flow is entirely reactive. Stored energy in the load returns to the source on each cycle. When the power factor is 1, all the energy supplied by the source is consumed by the load. Power factors are usually stated as leading or lagging to show the sign of the phase angle. It is often desirable to adjust the power factor of a system to near 1.0.

### 2.2 Electricity distribution

Electricity distribution is the final stage in the delivery of electricity to end users. A distribution system's network carries electricity from the transmission system and delivers it to consumers. Part of what determines the design of the electricity meter is the transmission supply design, the most common residential arrangements being:

- 1-phase, 2 wire (1P2W) — Europe and Asia 220 V-240 V, US 2-wire 110 V
- 1-phase, 3 wire (1P3W) — US 3-wire, sometimes called 2-phase
- 3-phase, 4 wire (3P4W)

The 1-phase 2-wire installation is the most common form of electricity distribution in the world. Finally, more than 80% of the population in the world uses a 1-phase 2-wire installation of 230 V/50 Hz (see at Figure 2-2). Much of the US installation is 110 V/60 Hz 1-phase 2-wire. The electricity meter described in this design reference manual is designed for use in 1P2W installations.
2.3 Electricity meters

An electric meter or energy meter is a device that measures the amount of electrical energy consumed by a residence, business, or an electrically powered device. Electric meters are typically calibrated in billing units, the most common of which is the kilowatt hour (kWh). Periodic readings of electric meters establish billing cycles and energy used during a cycle.

A kilowatt hour is equal to the amount of active energy used by a load of one kilowatt over a period of one hour, or 3,600,000 joules. Some electricity companies use the SI megajoule instead. Similarly to active energy in kWh, there is also reactive energy (kVArh) and apparent energy (kVAh). See Section 2.1.2 Energy.

Electricity meters operate by continuously measuring the instantaneous voltage (volts) and current (amperes) and finding the product of these to give instantaneous electrical power (watts) which is then integrated against time to give energy used (joules, kilowatt-hours, and so on.). Meters for smaller services (such as small residential customers) can be connected directly in-line between source and customer. For larger loads of more than about 200 amps, current transformers are used so that the meter does not have to be located in-line with the service conductors.

Standard electricity meters fall into two basic categories, electromechanical and electronic.
2.3.1 Electromechanical meters

The most common type of electricity meter is still the electromechanical induction watt-hour meter. These meters will be progressively substituted by fully electronic meters because of their many additional advantages (see Section 2.3.2 Electronic meters).

The electromechanical induction meter operates by counting the revolutions of an aluminium disc that is made to rotate at a speed proportional to the power. The number of revolutions is proportional to the energy usage. It consumes a small amount of power, typically around 2 watts.

The metallic disc is acted upon by two coils. One coil is connected in such a way that it produces a magnetic flux in proportion to the voltage, and the other produces a magnetic flux in proportion to the current. The field of the voltage coil is delayed by 90 degrees using a lag coil. This produces eddy currents in the disc and the effect is such that a force is exerted on the disc in proportion to the product of the instantaneous current and voltage. A permanent magnet exerts an opposing force proportional to the speed of rotation of the disc. The equilibrium between these two opposing forces results in the disc rotating at a speed proportional to the power being used. The disc drives a register mechanism that integrates the speed of the disc over time by counting revolutions, much like the odometer in a car, to render a measurement of the total energy used over a period of time.

2.3.2 Electronic meters

Electronic meters display the energy used on an LCD or LED display, and can also transmit readings to remote places. In addition to measuring energy used, electronic meters can also record other parameters of the load and supply such as maximum demand, power factor, reactive power used, and so on. They can also support time-of-day billing, for example, recording the amount of energy used during on-peak and off-peak hours.

A typical electronic power meter has a power supply block, a signal conditioning circuit, a metering engine (AFE), a processing and communication engine (that is, a microcontroller), and other add-on modules such as RTC, LCD, communication ports and modules, and so on. For a basic block outline of the electronic power meter, see Figure 2-3.
The signal conditioning circuitry is used for adapting a high-amplitude signal from the line to a lower one accepted by the Analog Front End (AFE) and Analog-to-Digital Converter (ADC).

The metering engine is given the voltage and current inputs, has a voltage reference, samplers, and quantizers followed by an ADC section to yield the digitized equivalents of all the inputs. All of this is sometimes called the Analog Front End (AFE). These inputs are then processed using a DSP or MCU to calculate the various metering parameters such as powers, energies, and so on.

The processing and communication section has the responsibility of calculating the various derived quantities from the digital values generated by the metering engine. This also has the responsibility of communication using various protocols and interfaces with other add-on modules connected as slaves.

RTC and other add-on modules are attached as slaves to the processing and communication section for various input and output functions. On a modern meter, most, if not all, of this is implemented inside the microprocessor, such as the Real Time Clock (RTC), LCD controller, temperature sensor, memory, and analog-to-digital converters.

One of the important features of the modern electronic power meter is automatic meter reading (AMR) technology. AMR is the technology of automatically collecting consumption, diagnostic, and status data from energy metering devices and transferring that data to a central database for billing, troubleshooting, and analyzing. This advance mainly saves utility providers the expense of periodic trips to each physical location to
read a meter. Another advantage is that billing can be based on near real-time consumption rather than on estimates based on previous or predicted consumption. This timely information, coupled with analysis, can help both utility providers and customers to better control the use and production of electric energy. Electronic meters with AMR technology can read and communicate through several mechanisms such as:

- Infrared
- Radio frequency
- Data modem (via a telephone line)
- Power line carrier
- Serial port (RS-485)
- Broadband

AMR meters often have sensors that can report the meter cover opening, magnetic anomalies, extra clock setting, stuck buttons, inverted installation, reversed or switched phases, and so on. These events may be immediately sent to the utility company thanks to AMR technology.

Smart meters go a step further than simple AMR. They offer an additional function, including a real-time or near real-time reading, power outage notification, and power quality monitoring. They allow price setting agencies to introduce different prices for consumption based on the time of day and the season. The feedback they provide to consumers has also been shown to cut overall energy consumption.

In comparison to the traditional mechanical or electromechanical power meter solution, the electronic meters offer the utility market several additional advantages including:

- Improved immunity and reliability
- Higher accuracy
- Higher security
- Support of a wide range of power factor loads
- Easier calibration
- Anti-tampering protection, including traditional or modern solutions
- Automated meter reading (AMR)
- Advanced billing methods (prepay, time-of-use, and so on)

### 2.4 Voltage and current measurement

In electricity meters, the energy is calculated from two measured signals, voltage and current. For line voltage and line current measurement, systems that are generally called sensors are used. Whichever sensor is used, voltage and current measurements result in an AC voltage with a magnitude proportional to the signal being measured.
The voltage sensor results in a sine wave with a fundamental frequency of typically either 50 or 60 Hz depending upon the power distribution used. See Section 2.2 Electricity distribution.

For current measurement, the sensor provides a fundamentally sinusoidal signal (possibly with harmonics), which may lag or lead the voltage signal depending upon the load.

A typical simplified configuration for metering voltage and current in a 1-phase 2-wire installation is shown in Figure 2-4. There are three typical sensors used for sensing current and voltage in power meters. All of these sensors are also used in the electronic power meter described in this manual.

![Figure 2-4. Typical measurement circuit in 1P2W installation](image)

The following sections describe the commonly used methods for sensing the voltage and current used in electronic power meters.

### 2.4.1 Voltage divider

A voltage divider is used for voltage measurement. In a practical implementation, multiple series resistors are used instead of R1 to limit the power dissipation and reduce the heat generated, thus improving accuracy. See Figure 2-4.

The equation for computing output voltage of the voltage divider is defined as:
Where $V_{in}$ is the phase voltage and $V_{out}$ is the voltage measured by the ADC (voltage drop at R2).

The voltage divider can be selected to more closely meet the specification of the ADC.

### 2.4.2 Shunt resistor

A shunt resistor is used to sense the current because it does not distort the signal and it costs less than other current measurement methods. The downside of using a shunt resistor is primarily the power dissipation that can create inaccuracies in the measurement due to resistive changes, and due to temperature and the waste of power. To limit the self-heating effect of the shunt, the resistor is made using a metal with suitable properties. The resistance of the shunt is kept very low to reduce power dissipation.

Typically, shunt resistors are in the range of 100–300 $\mu$Ω, and as such, the voltage developed across them is very small. For example, 100 A drawn through a 200 $\mu$Ω shunt develops only 20 mV (voltage = current $\times$ resistance). Through a 300 $\mu$Ω shunt, this would be 30 mV, which entails 2 W power loss and 3 W, respectively.

The problem with this approach is the very small voltages derived from the shunt resistor and the even smaller resolution of valid measurements. Therefore, a signal derived from the shunt resistor must be amplified to keep the correct measurement precision. Operational amplifiers are frequently used for this purpose in most applications, but the MK30X256 power meter uses an internal PGA for this.

There are several rules for the right selection of a shunt resistor in the application:

- A shunt resistor must have good thermal properties (that is, Manganin® alloy with a low temperature coefficient of resistance).
- The shunt size must be selected to maximize the dynamic range of the ADC input.
- The shunt resistor must be selected to minimize power dissipation.

#### NOTE

Power dissipated by the shunt resistor, plus the power supply used by the meter, must be below the specification for the meter (IEC1036 specifies a 2 W/10VA total power loss).
2.4.3 Current transformer

Current transformers (CT) are used extensively for measuring current and monitoring the power grid. Like any other transformer, a current transformer has a primary winding, a magnetic core, and a secondary winding. The alternating current flowing in the primary produces a magnetic field in the core, which then induces a current in the secondary winding circuit, as in Figure 2-5. The CT is typically described by its current ratio (N) from primary to secondary. Relative to current output of the CT, it is necessary to use an external current to a voltage converter, such as a burden resistor \( R_b \) (see Figure 2-4), in systems where the voltage input of the ADC is used in the majority of applications. The primary objective of the current transformer design is to ensure that the primary and secondary circuits are efficiently coupled, so that the secondary current bears an accurate relationship to the primary current.

The benefits of using a CT are that the output voltage can easily be matched to the capability of the ADC input by selecting the appropriate winding or appropriate burden resistor (\( R_b \)), and because of this, an external OpAmp is not necessary. Another important benefit of using a CT is that this sensor isolates the measuring engine from the line; therefore, the CTs may be easily used in polyphase meters.

A typical feature of a CT is the time shift between the primary and secondary currents in the windings. For using this in the power meters, it is good to know that the power meters must wait a specific time after the voltage measurement before reading the current from the CT. The delay required is specific to each CT, and is established during calibration of the meter and programmed into the meter, as a part of the calibration constants.

CT coils have the negative effect of distorting the current measurement. Considering the magnetic core of the CT, it is necessary to respect a maximum recommended current in the primary winding (rating factor) because of saturation of its core. A good accuracy in the case of CT current measurement is directly related to other factors, including external electromagnetic fields and a change of temperature.

![Figure 2-5. Current transformer principle](image-url)
2.4.4 Rogowski coil

A Rogowski coil is an electrical device for measuring alternating current (AC) or high-speed current pulses. It consists of a helical coil of wire with the lead from one end returning through the centre of the coil to the other end, so that both terminals are at the same end of the coil, as in Figure 2-6. The whole assembly is then wrapped around the straight conductor whose current is to be measured. Because the voltage that is induced in the coil is proportional to the rate of change (derivative) of current in the straight conductor, the output of the Rogowski coil is usually connected to an electrical, or electronic, integrator circuit to provide an output signal that is proportional to the current.

One advantage of a Rogowski coil over other types of current transformers is that it can be made open-ended and flexible, allowing it to be wrapped around a live conductor without disturbing it. Because a Rogowski coil has an air core rather than an iron core, it has a low inductance and can respond to fast-changing currents. Also, because it has no iron core to saturate, it is highly linear even when subjected to large currents, such as those used in electric power transmission, welding, or pulsed power applications. A correctly formed Rogowski coil with equally spaced windings is largely immune to electromagnetic interference.

The benefits of using a Rogowski coil are similar to using a CT; namely, the output voltage can more easily be matched to the capability of the ADC input by selecting an appropriate winding, load resistor, and filter. Another advantage of a Rogowski coil is that it costs less than a traditional CT, although it requires an integrator and additional phase compensation.
3.1 Application description

A standard system block diagram of the MK30X256 power meter concept is shown in Figure 3-1. The full-metering system solution—that is, all the components within the outer black-dashed rectangle—incorporates the following parts:

- Metering board (inside the diagram's inner black-dashed rectangle). The main metering engine, this is the concentrated majority of metering components.
- Switch Mode Power Supply boardv(SMPS). This board is used for supplying the metering engine and the 1322x-LPN daughter card.
- External current sensor (shunt resistor). Located directly at the line power connector inside the metering case.
- 1322x-LPN. Daughter card for ZigBee communication.
- Power meter case with an integrated line power connector and an RS232 communication connector.

Some common parts of the power meter in the block diagram have the same color for better function identification. The voltage signal conditioning and current sensor, for instance, are colored red. See Figure 3-1. There is one current sensor in the power meter (shunt resistor), that is located near the line power connector inside the terminal compartment of the power meter case, outside the metering board. There is a voltage measurement signal conditioning part (voltage divider) that is located directly on the metering board.
3.1.1 Metering board

The metering engine (board) is the main part of the power meter. It is comprised of components such as the MCU with the AFE, signal conditioning part, LCD, button, LEDs, optical interface for the IEC1107 and RS232, voltage signal conditioning, tamper button, 3 V battery, magnetometer, and some communication connectors. The metering board is designed on a two-sided printed circuit board. Most of the components are soldered on its top side (see Figure 3-2), while some components are soldered on the bottom side of the printed circuit board (see Figure 3-3).
Chapter 3 System Concept

Figure 3-2. Metering board, top view

Figure 3-3. Metering board, bottom view

MQX-Enabled MK30X256 Single-Phase Electricity Meter Reference Design, Rev. 0

Freescale Semiconductor, Inc.
The core of the metering engine placed on the top side of the board is the MK30X256, a 32-bit ARM Cortex-M4 MCU. (For a description, see Section 1.3 MK30X256 microcontroller series.) All of the MCU peripherals used in the application, except for the JTAG interface, are pictured in the block diagram in Figure 3-1.

A simplified function of the MCU in the application is as follows:

The ADC, which is a part of the MCU, reads data from voltage and current sensors. The MCU computes other values such as powers, energies, power factor, and line frequency consecutively. Moreover, the MCU communicates with the user through the built-in HMI (LCD and button) or several communication interfaces (RS232, ZigBee, IEC1107, LEDs, OC). A description of the metering algorithm is beyond the scope of this design reference manual, but is described in application note AN4255, *FFT-based Algorithm for Metering Applications*.

The HMI of this power meter is comprised of the following parts: an LCD, a push-button, and one (red) LED. The LCD displays plenty of computed values, such as the RMS value of line voltage and current, powers, energies, power factor, line frequency, and also the actual time and date. The push-button allows you to select one of these values to be shown on the LCD.

**NOTE**

There is only one main value shown on the LCD at a time.

The next important part of the metering engine board is signal conditioning. This part is used for adapting the signal level from sensors to the AFE (part of the MCU including the ADC and PGA). There are two different types of signal conditioning with regards to sensors used: the part for voltage measurement is made of a simple voltage divider. The part for current measurement via a shunt resistor is made from a simple resistor bridge, which is used for shifting the signal on the shunt above 0 V. Thanks to the internal PGA, no external operational amplifier is needed.

There are several communication interfaces on the metering board. The interface for RS232 is optically isolated by optocouplers, and the interface for the IEC1107 is optically isolated by infrared components. The open-collector is an optically-isolated output of the power meter; this may be used for switching some small loads. One of the most interesting types of communication in this power meter is RF or ZigBee. Communication through RF/ZigBee is accomplished by the external 1322x-LPN daughter card (outside the metering engine), which communicates with the metering board through the I²C interface. Finally, two red LEDs are used for optical communication with the utility service provider. This is the energy output interface; the first LED here is for active energy counting and the second LED is for reactive energy counting.
The essential parts of the metering board are components for the proper functioning of the MCU's real-time clock (RTC), including the 3 V battery (for saving date and time) and crystal. Two hidden tamper buttons recognize any illegal opening of the cover or terminal compartment section of the meter, one soldered directly on the metering board, and the second outside of the board in the terminal compartment section.

The power meter also offers another method of tamper detection through the use of a 3-axis I²C magnetometer (the MAG3110 silicon may be used for this). The MK30X256 power meter does not currently use this type of tamper detection; however, the interface for it is now prepared. An illegal cover opening can cause a 3-axis motion that is detected by the magnetometer and interpreted as an illegal opening by an algorithm sophisticated enough to distinguish it from the ordinary motions of the meter. But this type of operation is optional, since the tamper push-buttons are used for tamper detection.

### 3.1.2 Switch Mode Power Supply board connection

The SMPS board is used for supplying the metering board engine. The SMPS used in this application is a 3rd party open-frame solution for the power supply that produces one galvanic-isolated level of output voltage. This open-frame SMPS module has a wide range of input AC voltages (85–264 V, RMS) with a wide range of line frequencies (47–63 Hz) as well. Thanks to these input parameters of the SMPS, the whole power meter can work with line voltages and frequencies in these ranges. The output voltage is fixed to a 3.7 V DC level with a 1.16 A nominal output current and a power rating of 4.3 W. Figure 3-4 provides an overview of the board. There are two power connectors on this board: on the left side there is an input socket for connection to the mains (L_inp, N_inp), and on the right side there is an output socket for supplying the board. The SMPS is housed in the left part of the power meter case (under the metering board) and connected to the line and metering board by two thin cables.

![Figure 3-4. SMPS Board View](image)
NOTE
Default output voltage level for this type of SMPS is 3.3 V. Other output voltage levels are adjusted by small trimmer on the SMPS board (in the 3.0–3.6 V range, approximately) or by adding an SMD resistor in parallel to the output voltage divider on the SMPS board (27 kΩ for +3.7 V).

3.1.3 External current sensor connection

The MK30X256 power meter uses a shunt resistor as the external current sensor for phase current measurement.

The shunt resistor is specifically a Manganin resistor of an accurately known resistance, in this case 300 μΩ. This shunt resistor is intended for current measurement of up to 60 A RMS. The voltage drop across the shunt resistor is proportional to the phase current flowing through it; because its resistance is known, a small voltage drop is amplified by the internal PGA of the MCU, and then measured by the internal ADC of the MCU. For a photo of the shunt resistor, see Figure 3-5. The terminal connection of this shunt resistor is divided into two parts—power connection and sense connection—and because of this, a 4-wire current measurement may be done. The power connection is intended for a connection between the phase input (L_inp) and phase output (L_out) connectors. The sense connection of this shunt resistor is intended only for measuring its voltage drop.

![Figure 3-5. Shunt resistor description](image)
NOTE
There is also a separated ground terminal (GND) in the sense connection area for the metering board ground connection. This ground terminal is located on the same side as the power phase input (L_inp).

3.1.4 1322x-LPN connection

The 1322x-LPN is intended for use as a ZigBee node for the power meter. It works as an intermedier between the power meter and a ZigBee coordinator, which is based at the utility provider area, for example. The ZigBee coordinator scans data from various equipment (power meter, home thermostat, sensor, dimmer switch, and so on) in the ZigBee network and sends it to the central (PC) station. The 1322x Low Power Node is screwed onto the bottom part of the power meter case, near the SMPS, and connected as a daughter card to the metering engine through a thin flat cable. The board overview is in Figure 3-6. There are two pairs of wires for connection to the metering board: the first pair is for supplying the node (3.3 V, GND), and the second pair is for the I²C communication lines (SCL, SDA).

![1322x-LPN board view](image)

Figure 3-6. 1322x-LPN board view
3.1.5 Power meter case

All the components mentioned (boards, sensor, and so on) are housed in a power meter case. This is made as a base with transparent main and terminal compartment covers. It is intended primarily for mounting in a vertical position (on a wall, for example) by three screws. Because of the transparent cover, the metering board with the main components, including the LCD primarily, are easily visible.

Figure 3-7. Power meter case, inside view

Figure 3-7 shows a photo of the metering case without either of the transparent covers. You can see the boards and the current sensor placements. There are also four power terminals in the terminal compartment section; the first is for phase input, the second is for phase output, and the remaining two terminals are for neutral connections. The main metering board is mounted onto four plastic columns (spacers) on the front side of the power meter case. On the left side of the case, there is the SMPS, and on the bottom side of the case there is the 1322x-LPN daughter card. The shunt sensor is soldered directly between the two left power terminals, namely the phase input (L_inp) and the phase output (L_out). On the right side of this case, there is an RS232 connector, which is connected to the main board by a thin 9-pin flat cable.
3.2 Application usage

3.2.1 Power meter hardware configuration

The MK30X256 power meter is pictured in Figure 3-8. This power meter is primarily intended to demonstrate the MCU in a single-phase, two-wire installation. For a better practical demonstration of the power meter, it is placed on a perspex base with an outlet (for load connection) and a cable with a plug (for connection to the power line). The whole configuration, shown in Figure 3-9, is also called the power meter demo.

![Figure 3-8. Power meter view](image_url)
Figure 3-9. Power meter demo view

Although the current range of this power meter is internally set for a measurement of up to 60 A, for practical use this range is reduced to approximately 16 A, adequate for demonstration purposes. This is due to a maximum current rating of the outlet and the plug used. For those who want to use the entire metering range of up to 60 A, both the plug and outlet must be replaced by more powerful ones.

For remote data communication, either the RS232 port or the in-built ZigBee node may be used.

**NOTE**

An open-collector communication interface is not directly accessible. You must first open the cover of the case to access its connections.
Chapter 4
Hardware Design of the Metering Board

4.1 Introduction to hardware implementation

This chapter describes the design of the application hardware, that is, the design of the metering board (engine). The main hardware is divided into two main parts, digital hardware (HW) and analog hardware. Analog hardware is also called signal conditioning in this manual. Digital hardware is configurable depending on the customer request, from a low-cost solution to a high-performance (full) configuration. The stand-alone section of the metering board is the power supply section, and this is a mandatory part of each configuration of the power meter.

With regards to various digital hardware configurations, there are also various power meter configurations. These power meter configurations are differentiated:

- Full power meter configuration. For a schematic view, see Figure A-1. For layout views, see Figure B-1 and Figure B-2. For the BOM, see Table C-1.
- Low-cost power meter configuration with only the necessary components. For a schematic view, see Figure A-2. For layout views, see Figure B-3 and Figure B-4. For the BOM, see Table C-2.

4.2 Power supply section

The power supply section is used mainly for adapting the voltage level from the external SMPS (3.7 V) to the internal board, and also includes the overvoltage protection (see Figure 4-1). The 3 V battery is also a part of the power supply section; it is used for supplying the MCU in case of a power outage. Connector J4 placed on the bottom side of the printed-circuit board is the input power supply connector of the board. This connector must be joined to the external SMPS; that is, pin 2 of connector J4 to 3.7 V on the SMPS and pin 1 of the connector J4 to the GND of the SMPS.
As you can see, there is a simple overvoltage protection including the Zener diodes D12 and D13. These diodes protect against a reversal of polarity.

The power supply section of the metering board produces four power supply levels for individual blocks of the metering board:

- VDDMCU—digital voltage 3.3 V for the MCU only
- VDDAMCU—analog voltage 3.3 V for the MCU only (for AFE)
- VDD—digital voltage 3.7 V for all peripherals
- VDDA—analog voltage 3.7 V for the DC bias circuit only

Some circuits in the design require two separated power supply levels, a digital and an analog power supply. The analog power supply level of the MCU is separated from its digital power supply by the chip inductor L2 with cooperation of filters C45–C47. The analog power supply level of the DC bias circuit is separated from the digital part of the power supply by the chip inductor L1 with cooperation of filters C37–C39. Power supply levels for the peripherals and for the MCU are separated by diode D11. Because of this, the peripherals are not powered in the case of a power outage (in this case, only the MCU is powered, via the 3 V battery). The voltage drop on this diode is approximately 0.4 V; therefore, analog and digital voltage levels for peripherals are far above this voltage level in comparison to voltage levels at the MCU.

There are two separated grounds in the design, a digital ground (GND) and an analog ground (GNDA). Both of these grounds are joined together through the chip inductor marked L3 in the schematic.

![Figure 4-1. Power supply part of the metering board](image)
The presence of an external power supply level (from the SMPS) is shown through a simple voltage divider (R30, R31) in the power supply section. Logic 0 on the VCC_PRESENT pin means there is a power outage. In this case, the metering board is supplied from the internal 3 V battery, and the software causes a power down for most of the MCU peripherals.

NOTE
The peripheral supply voltage level on the metering board is the same as that of the external SMPS. The MCU supply voltage level is consequently lower around the voltage drop on diode D11.

4.3 Digital hardware

4.3.1 MCU core

The MCU is the core of the metering board. It is marked as U1 in the schematic. The MCU core, with all key components, is displayed in both Figure A-1 and Figure A-2. For the MCU to function correctly, several components are necessary:

- Filters C2–C8, C10–C12, C19
- RC filter for resetting the MCU, including R20 and C16
- Crystal Y1 with filters C20 and C21

Another part of the the MCU core, which we may simply assign to it, is the Human Machine Interface (HMI). This includes components such as the display DS1 and the user push-button SW1, with the simple filter C23. There is one tamper button, SW2, on the board, and connector J5 for connecting the second tamper which is placed in the terminal compartment section. Pull-up resistors for the button and tampers are software selectable by the MCU; therefore, no external pull-ups on the board are needed. The charge pump for the LCD is a part of the MCU. Therefore, the LCD requires minimal external components—in fact, only capacitors C28, C31, C32, and C33.

Connector J1 is the JTAG interface for MCU programming. Be careful about programming the MCU through this interface in a configuration where the power meter demo is fed from the line. This interface is not isolated from the line, and an electric shock can arise. To prevent this, use an external optically isolated JTAG interface.
4.3.2  RS232 interface

This interface is used primarily for a basic set-up of software for the meter, including calibration, checking sensor outputs, and visualization. Communication is optically isolated through optocouplers ISO1 and ISO2. Because two additional signals are used on the serial data line, RTS and DTR, the secondary side of ISO1 and the primary side of ISO2 are powered from the RS232 data line (from the PC side). These signals are normally used for transmission control, but this function is not used in the application. As there is a fixed voltage level on the control lines, it may be used to supply the optocouplers, in cooperation with other components. These components include D6, D7, D9, C15, R19, and R13. The part of the schematic including the RS232 communication interface can be seen in Figure 4-2.

![RS232 communication interface of the metering board](image)

4.3.3  Infrared interface (IEC1107)

This interface uses infrared components, the high efficiency IR emitting diode D10, and the NPN phototransistor Q1. Both of these are through-hole assembled. Apart from these, some necessary passive components are used, such as R27, R28, R29, and C36. The part of the schematic including the IEC1107 communication interface can be seen in Figure 4-3.
4.3.4 Open collector interface

The open collector interface portion of the schematic can be seen in Figure 4-4. This is a galvanic-isolated interface thanks to optocoupler ISO3. It may be used for switching some small loads with a maximum collector-to-emitter voltage of $V_{CEO}$ of up to 70 V, and a maximum collector current of up to 50 mA. Output from this interface is accessible on connector J6.

4.3.5 LED interface

The two high-efficiency LEDs in this part are used for energy counting: D2 for active energy counting and D1 for reactive energy counting. They are used primarily for calibration of the meter; the number of flashes of the LEDs is proportional to total accumulated energy, that is, the sum of import and export energy. Both of these LEDs are through-hole assembled for a better placement near the cover. The final LED used in this part of the schematic is the user LED D3, which may be used for detecting some program states, for example. Each of these LEDs is lit by logic 0 from the MCU. The part of the schematic including the LED interface can be seen in Figure 4-5.
4.3.6 SPI interface

The SPI interface is optional. It is not used at this time, but it has been prepared for future usage. It is connected to the MCU by the 6-pin header J9. Apart from the supply voltage, all the SPI data lines are connected (SOUT, SIN, CLK and CS). The part of the schematic including the SPI communication interface can be seen in Figure 4-6.

![Figure 4-6. SPI interface part of the metering board](image)

4.3.7 Magnetometer interface

The magnetometer function in this power meter is described in detail in Section 3.1.1 Metering board. The section of the schematic including the magnetometer interface can be seen in Figure 4-7. In this schematic, the magnetometer is marked as U3. The magnetometer may be used in this power meter for tamper detection (optional) instead of the standard button. The magnetometer communicates with the MCU through I²C data lines; therefore, external pull-ups R25 and R26 on the SDA and SCL lines are required. The magnetometer uses the same I²C data lines as the 1322x-LPN daughter card; therefore, the software selectable addresses of both of these peripherals are required (done by the MCU).

**NOTE**

Because of very the small supply current of this chip, it may be powered directly through the GPIO pin of the MCU (see VDDMAG net in the schematic).
4.3.8 \textit{I}^2\textit{C} interface

The \textit{I}^2\textit{C} interface is used for joining the 1322x-LPN daughter card and the MCU. This daughter card is used primarily for RF/ZigBee communication. The 1322x-LPN board is connected by a thin flat cable directly to the 6-pin header J7 of the metering board. Pull-ups for \textit{I}^2\textit{C} data lines are required (R25, R26). It is better to use hardware pull-ups than software configurable pull-ups inside the MCU. A schematic of the connection between the metering engine and the daughter card can be seen in Figure 4-8.
4.3.9 MRAM interface

The MR25H10 (U2 in the schematic) is a 1-Mbit magnetoresistive random access memory (MRAM) device organized as 131072 words of 8 bits. The MR25H10 offers serial EEPROM and serial flash memory compatible read/write timing with no write delays and unlimited read/write endurance. It allows the use of more data memory in the application than the standard MCU can offer. Using this memory in the design is optional, because the capacity of the internal SRAM of the MCU is enough for most applications. The section of the schematic including the MRAM interface can be seen in Figure 4-9. The MRAM communicates with the MCU through a standard SPI interface.

NOTE
Because of the very small active read/write current of this chip, it may be powered directly through the GPIO pin of the MCU (see VDDMRAM net in the schematic).

Figure 4-9. MRAM interface part of the metering board

4.4 Signal conditioning

4.4.1 Voltage measurement

There is a simple voltage divider used for the line voltage measurement in Figure 4-10. This is a basic and key part of each configuration of the power meter. In the basic block diagram (see Figure 3-1), there is a voltage divider, based on two simple resistors. In a practical implementation it is better to design this divider from several resistors connected serially due to the power-loss spread. One half of this total resistor consists of R5, R7, R9, and R11, the second half consists of resistor R6. The basic voltage divider described produces a sine voltage signal around ground. This is not acceptable for the ADC, because all voltage signals connected to it must be above ground (single-ended configuration). Therefore, a further voltage divider that raises the signals is added to the connection. This second divider is made from R4 and R6 (a part of the line divider). The
ratio of this second divider allows a voltage on the ADC input from 0—1.2 V (Vref). The sine voltage signal from the line is then shifted to Vref ÷ 2; that is, approximately 0.6 V. See Figure 4-10.

Finally, there is a simple RC low-pass filter (R10 + C9) at the end of the voltage divider. The cut-off frequency for that is set to 3.4 MHz according to this relation:

\[ f_{3dB} = \frac{1}{2 \pi \cdot R10 \cdot C9} \approx 3.4MHz \]

NOTE
Some components in the voltage measurement part of the schematic are depicted for a 3.7 V DC bias supply net. For a 1.2 V DC bias supply voltage level, see the resistors selection in Figure 4-11.

4.4.2 DC bias connection

The DC bias voltage (V_BIAS net in the schematic) is used for supplying some circuits in the analog signal conditioning parts. These parts are: a voltage divider in the voltage measurement section, a resistor bridge in the current measurement section, and a zero-cross detection circuit. The correct DC bias voltage is selected by the SJ1 jumper on the board, which assigns one of the following power nets to V_BIAS:

- 3.7 V (VDDA) analog peripheral supply voltage net (default configuration used in the schematic)
- 1.2 V (VREF_OUT) reference output of the MCU
Because of the different voltage levels of individual configurations, some resistors in relevant blocks must be reconfigured, particularly R4, R6, R11, R22, R24. The part of the schematic including the jumper for the DC bias selection and the right resistor selection table is in Figure 4-11.

**NOTE**

The 1.2 V reference output of the MCU is powerful enough to supply all analog peripherals of the MK30X256 power meter which are tied on the V_BIAS net.

<table>
<thead>
<tr>
<th></th>
<th>SJ1</th>
</tr>
</thead>
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<tr>
<td>1</td>
<td>VDDA</td>
</tr>
<tr>
<td>2</td>
<td>V_BIAS</td>
</tr>
<tr>
<td>3</td>
<td>VREF_OUT</td>
</tr>
</tbody>
</table>

![Figure 4-11. DC bias circuit and resistors selection](image)

**4.4.3 Shunt resistor current measurement**

Because there is a very small voltage drop at the shunt resistor, the drop must be amplified before it is processed in the ADC. This operation is carried out by an external operational amplifier mostly, though in the MK30X256 power meter it is possible to use the internal PGA. The upshot of this solution is obvious: the designed power meter might be cheaper in comparison to a traditional one that uses an external OpAmp. Since the voltage drop at the shunt is around ground, and the internal PGA accepts voltages above ground, the voltage drop on the shunt must be shifted above ground. A simple resistor bridge is used for this. The bridge is made from resistors R14, R15, R17, and R18. The original zero voltage level is then shifted to 75 or 25 mV, respectively, depending on the correct DC bias voltage (for selection, see Section 4.4.2 DC bias connection). Differential output of this resistor bridge (L_DP, L_DN) is joined directly to an analog pin (PGA0) of the MCU. Finally, two protection diodes D5 and D8 are used. These diodes, in conjunction with half of the resistor bridge (R14, R18), protect inputs of the MCU against spikes from the line. The schematic of the shunt resistor current measurement block is in Figure 4-12.

**NOTE**

Filter capacitor C14 should be placed as close as possible to the chip inputs (see the layout in the Appendix section). This requirement is also valid for filter C9 in the voltage section.
4.4.4 Zero-cross detection circuit

The MK30X256 power meter can measure the line frequency. In order to do so, the zero-crossing of the input line voltage must be measured. The main principle for doing this is to compare output voltage from the voltage conditioning part (see Section 4.4.1 Voltage measurement) with a known voltage level (the DC bias voltage in this case). This is done by the analog comparator (CMP) of the MCU. The first input of this comparator is connected to the DC bias voltage through a voltage divider that divides the DC bias voltage to 0.6 V, and the second input of the comparator is joined to the line through a voltage divider (V_OUT net in the schematic). The part of the schematic including the zero-cross detection circuit can be seen in Figure 4-13. For proper operation of the analog comparator, there should be also two filters, C17 and C18.

NOTE

Some components in the schematic of the zero-cross detection circuit are depicted for a 3.7 V DC bias supply net. For a 1.2 V DC bias supply voltage level, see the resistors selection in Figure 4-11.
Chapter 5
Application Set-Up

5.1 Setting-Up the Demo Hardware

The following section is focused on setting up the metering demo hardware.

![Power meter line connection](image)

**Figure 5-1. Power meter line connection**

- Connect the power meter directly to the line (see Figure 5-1).
- Connect an external load to the power meter (see Figure 5-1).
- For a better practical demonstration of the power meter, the metering case may alternatively be placed on an acrylic base with an outlet (for a load connection) and a cable with a plug (for connection to the power line). The whole configuration is also called the power meter demo (see Figure 3-9).
After connecting the power meter to the line, the display turns on and shows the last value that was there before turning it off. Apart from the main value, the display shows the other symbols (see Figure 5-2), such as OBIS codes, tamper identifiers, actual tariff, and unit (regarding the main value). You can also select other values to be shown on the display by pressing the push-button. The following is a list of these values:

<table>
<thead>
<tr>
<th>Value</th>
<th>Units</th>
<th>Format</th>
<th>OBIS code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line voltage</td>
<td>V_{RMS}</td>
<td>0.01V</td>
<td>32.7.0</td>
</tr>
<tr>
<td>Line current</td>
<td>A_{RMS}</td>
<td>0.001A</td>
<td>31.7.0</td>
</tr>
<tr>
<td>Signed active power</td>
<td>W</td>
<td>0.1W (+ forward, - reverse)</td>
<td>1.7.0</td>
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<tr>
<td>Signed reactive power</td>
<td>VAr</td>
<td>0.1VAr (+ lag, - lead)</td>
<td>3.7.0</td>
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<tr>
<td>Apparent power</td>
<td>VA</td>
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<td>9.7.0</td>
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<tr>
<td>Power factor</td>
<td>—</td>
<td>0.0001</td>
<td>13.7.0</td>
</tr>
<tr>
<td>Active energy—import</td>
<td>kWh (Wh)</td>
<td>0.0001kWh, 0.01Wh, 0.001Wh</td>
<td>1.8.0</td>
</tr>
<tr>
<td>Active energy—export</td>
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<td>0.0001kWh, 0.01Wh, 0.001Wh</td>
<td>2.8.0</td>
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<tr>
<td>Reactive energy—import</td>
<td>kVArh (VArh)</td>
<td>0.0001kVArh, 0.01VArh, 0.001VArh</td>
<td>3.8.0</td>
</tr>
<tr>
<td>Reactive energy—export</td>
<td>kVArh (VArh)</td>
<td>0.0001kVArh, 0.01VArh, 0.001VArh</td>
<td>4.8.0</td>
</tr>
<tr>
<td>Frequency</td>
<td>Hz</td>
<td>0.001Hz</td>
<td>14.7.0</td>
</tr>
<tr>
<td>Time</td>
<td>hour, min, sec</td>
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<tr>
<td>Date</td>
<td>year, month, day</td>
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<tr>
<td>SW version</td>
<td>—</td>
<td>x.x.x</td>
<td>0.2.0</td>
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</tbody>
</table>

All of the energies (four counters) are saved into the non-volatile memory. These energies remain in memory after resetting the power meter. To clear the energy counters, you must use the FreeMASTER application (see Section 5.2.1 FreeMASTER data visualization) and apply a Clear Energies command.

There are two tampers hidden under the cover. When you remove the cover, tamper symbol(s) is/are shown on the LCD. These symbols remain on the LCD even after a reset, because this information is saved in the non-volatile memory. To clear the tamper status you must use the FreeMASTER application (see Section 5.2.1 FreeMASTER data visualization) and apply a Clear Tampers command.

When you push the user button during power-on, the LCD shows the actual version of the internal software.

Both energy LEDs flash simultaneously with the internal energy counters. This means that flashes of each energy LED are proportional to the sum of import and export energy (active or reactive).

A 3-V battery is used for the proper RTC function.

RS232 plug is used for FreeMASTER data visualization and calibration.
5.2 Setting up the software demo

The following section focuses on setting up the metering demo software.

5.2.1 FreeMASTER data visualization

For FreeMASTER data visualization, the RS232 cable between the power meter and the PC must first be connected. The FreeMASTER visualization script is the software for remote visualization and remotely setting up the power meter via an RS232 cable. This software runs on the PC that connects to the power meter via an RS232 cable. The FreeMaster visualization script is the application that runs under the FreeMASTER software. FreeMASTER software is one of the off-chip drivers that supports communication between a target microcontroller and a PC. This tool allows the programmer to remotely control an application with a user-friendly graphical environment running on a PC. It also provides the ability to view some real-time application variables in both textual and graphical form. FreeMASTER software runs under Windows 98, 2000, or XP. It is a versatile tool to be used for multipurpose algorithms and applications, providing a lot of excellent features, including:

- Real-time debugging
- Diagnostic and visualisation tools
- Demonstration tool
- Educational tool

Before running a visualization script, FreeMASTER software must be installed on your PC. After that, a FreeMASTER visualization script may be started after double-clicking on the MK30X.pmp file in the Visualisation directory. Following this, a visualization script will appear on your PC. For more information, see Figure 5-3.
You should set the proper serial communication port and speed in the Project/Option menu (see Figure 5-4) now. After doing so, you must set the proper Project.out project file in the menu Project/Option/MAPfiles (see Figure 5-5). This file is accessible in subdirectory FLASH_256KB_PFLASH_256KB_DFLASH. If all previous settings are correctly done, the FreeMASTER visualization script for the power meter is now prepared for running. To do this, you must click on the Start/Stop Communication button. At this time, you can see the voltage and current diagrams in the time domain and in the frequency domain (in an FFT window) too. You may also see other variables in a textual format, such as frequency, $V_{RMS}$, $I_{RMS}$, energies, and so on.

Alternatively, you may set some values, such as an impulse number, clock and date, and so on. After setting the appropriate value in the column cell, use the right command for transferring this value to the meter's RAM. Only the following commands are allowable: clock setting, impulse number setting, clear energies, clear tampers. After application of these commands, it is also suitable to use the flash save command to save these values into a non-volatile memory of the MK30X256. You are not allowed to change "red" values in the Calibration section of the FreeMASTER visualization script, because of the loss of calibration constants. These values include: voltage and current gain, voltage phase delay, and power offset.
NOTE
All system (FreeMASTER) values are saved automatically during meter power-down. Therefore, the flash save command doesn't have to be used.

Figure 5-4. FreeMASTER communication port setting

Figure 5-5. FreeMASTER project file setting
5.2.2 ZigBee communication

ZigBee communication is optional and is not implemented in every power meter demo. There is a 2.4 GHz 1322x-LPN daughter card inside the power meter. The ZigBee module and the power meter are connected through the I\(^2\)C. For joining the power meter to the ZigBee network, you will need the 1322x-SRB module, which is like a ZigBee coordinator (see Figure 5-6). The power meter can now easily become part of a smart grid.

![Figure 5-6. 1322x-SRB as a ZigBee coordinator](image)

The following is a standard communication procedure for joining the power meter to a smart grid:

- Install the latest version of the BeeKit from the Freescale web page. There is also a ZeD monitor as a separate part of the BeeKit. Use the ZeD monitor for demonstrating ZigBee communication between the power meter and the PC.
- Switch the power meter on and connect a load to it.
- Connect the ZigBee coordinator (1322x-SRB) to the PC with a USB cable and switch the coordinator on. The coordinator must be powered. To do this, plug the AC adaptor to the coordinator (you may also use the internal battery inside the coordinator module), or use a USB power line from the PC side (this is the best choice). You will have to install the software driver for this equipment after the first connection of the 1322x-SRB to the PC. The driver is on the CD in the Drivers \LuminaryFTDI directory, or alternatively on the Future Technology Devices International (FTDI) web page.
- Push the SW1 button on the coordinator—it looks up all ZigBee equipment connected to the ZigBee network at this time. Two red LEDs on the coordinator are then lit (see Figure 5-6).
- Start the ZeD monitor and then click on the OK button. Before running the ZeD GUI, the ZigBee coordinator must be connected to the PC through a USB cable.
• At this moment, there are icons for all of the devices connected to the ZigBee network—the power meter plus the coordinator, in this case (see Figure 5-7). If there is no icon for the power meter, you must reset the power meter by disconnecting from the line and reset the ZeD GUI using the F5 key. You may also repeat the installation from point 2 in this case.

• In the ZeD GUI menu, you may open a new window for showing the ZigBee data transfer. This is in Tools/Start SE Utility Control Panel menu. You must address the meter by clicking the Add New Household ESP Connection, and then click on the Connect icon (see Figure 5-8).

• To show data (only import active energy at this time), click on the Metering icon—a kWh data table is now refreshed every 5 seconds. The Meter Report column displays active energy from the power meter (see Figure 5-9). These numbers are in HEX format with a widely variable resolution that may be changed by the FreeMASTER GUI (ZigBee kWh divider dialogue box). Therefore, the kWh-number on the LCD of the power meter may have a different resolution in comparison to the number in the ZeD GUI metering data report.

**NOTE**

Impulse number setting command in the FreeMASTER GUI (see FreeMASTER data visualization) should be used after modification of ZigBee kWh divider number.

Figure 5-7. ZeD GUI
Figure 5-8. Add New Household ESP Connection dialog box

Figure 5-9. Metering report in ZeD GUI
Appendix A
Schematics
A.1 Schematic for full configuration of the metering board

Figure A-1. Schematic for full configuration of the metering board
A.2 Schematic for low-cost configuration of the metering board

Figure A-2. Schematic for low-cost configuration of the metering board
Appendix B
Layouts
B.1 Layouts for full configuration of the metering board

Figure B-1. Top side of the board for full configuration
Figure B-2. Bottom side of the board for full configuration
B.2 Layouts for low-cost configuration of the metering board

Figure B-3. Top side of the board for low-cost configuration
Figure B-4. Bottom side of the board for low-cost configuration
Appendix C
BOM

C.1 Bill of materials for full configuration of the metering board

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<th>Part Number</th>
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<td>EPCOS</td>
<td>B72220S0271K101</td>
</tr>
<tr>
<td>SJ1</td>
<td>1</td>
<td>JUMPER 3 PAD 40MIL SQUARE SMT</td>
<td>N/A</td>
<td>NO PART TO ORDER</td>
</tr>
<tr>
<td>SJ2</td>
<td>1</td>
<td>JUMPER 2 PAD 40 MIL SQUARE SMT</td>
<td>N/A</td>
<td>NO PART TO ORDER</td>
</tr>
<tr>
<td>SW1</td>
<td>1</td>
<td>SW SPST MOM NO PB 20MA 15V TH</td>
<td>PANASONIC</td>
<td>EVQPAC05R</td>
</tr>
<tr>
<td>SW2</td>
<td>1</td>
<td>SW SPDT SNAP ACTION 0.1A 30V TH</td>
<td>OMRON</td>
<td>D2F-01L</td>
</tr>
<tr>
<td>TP1 TP2 TP3 TP4 TP5 TP6 TP7 TP8 TP9 TP10 TP11 TP12 TP13 TP14 TP15 TP16 TP17 TP18 TP19</td>
<td>19</td>
<td>TEST POINT TH PAD 60 DRILL 35 DIAM, NO PART TO ORDER</td>
<td>N/A</td>
<td>NO PART TO ORDER</td>
</tr>
<tr>
<td>U1</td>
<td>1</td>
<td>IC MCU P2 MARCONI 32BIT 96K FLASH 16K RAM 2.7-5.5V LQFP144</td>
<td>FREESCALE SEMICONDUCTOR</td>
<td>PK40X256VLQ100</td>
</tr>
<tr>
<td>U2</td>
<td>1</td>
<td>IC MEM MRAM 1Mb SPI 2.7-3.6V DFN8</td>
<td>EVERSPIN TECHNOLOGIES, INC</td>
<td>MR25H10CDC</td>
</tr>
<tr>
<td>U3</td>
<td>1</td>
<td>IC 3-AXIS DIGITAL MAGNETOMETER 1.95-3.6V DFN10</td>
<td>FREESCALE SEMICONDUCTOR</td>
<td>MAG3110</td>
</tr>
<tr>
<td>Y1</td>
<td>1</td>
<td>XTAL 32.768KHZ PAR 20PPM -- SMT</td>
<td>Citizen</td>
<td>CMR200T32.768KDF-ZF-UT</td>
</tr>
</tbody>
</table>
### C.2 Bill of materials for low-cost configuration of the metering board

#### Table C-2. BOM report for low-cost configuration

<table>
<thead>
<tr>
<th>Part Reference</th>
<th>Quantity</th>
<th>Description</th>
<th>Manufacturer</th>
<th>Part Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>BT1</td>
<td>1</td>
<td>Battery holder CR2032 3V ROHS COMPLIANT</td>
<td>Renata Batteries</td>
<td>SMTU2032-LF</td>
</tr>
<tr>
<td>C1 C2 C3 C4 C5 C6 C7 C8 C10 C11 C12 C16 C18 C19 C23 C28 C31 C32 C33 C34 C35 C37 C41 C43 C45</td>
<td>25</td>
<td>CAP CER 0.1UF 25V 10% X7R 0805</td>
<td>SMEC</td>
<td>MCC104K2NRTF</td>
</tr>
<tr>
<td>C9</td>
<td>1</td>
<td>CAP CER 1000PF 50V 10% X7R 0805</td>
<td>AVX</td>
<td>08055C102KAT2A</td>
</tr>
<tr>
<td>C14</td>
<td>1</td>
<td>CAP CER 220PF 100V 5% C0G 0805</td>
<td>AVX</td>
<td>08051A221JAT2A</td>
</tr>
<tr>
<td>C15</td>
<td>1</td>
<td>CAP TANT 2.2UF 16V 10% -- 3216-18</td>
<td>KEMET</td>
<td>T491A225K016AT</td>
</tr>
<tr>
<td>C17 C39 C42 C46</td>
<td>4</td>
<td>CAP CER 100PF 50V 10% C0G 0805</td>
<td>AVX</td>
<td>08055A101KAT2A</td>
</tr>
<tr>
<td>C20 C21</td>
<td>2</td>
<td>CAP CER 18PF 50V 5% C0G 0805</td>
<td>AVX</td>
<td>08055A180JAT2A</td>
</tr>
<tr>
<td>C38 C44</td>
<td>2</td>
<td>CAP CER 10UF 16V 10% X5R 0805</td>
<td>AVX</td>
<td>0805YD106KAT2A</td>
</tr>
<tr>
<td>C40 C47</td>
<td>2</td>
<td>CAP ALEL 47UF 6.3V 20% -- CASE C SMT</td>
<td>PANASONIC</td>
<td>EEE0JA470SR</td>
</tr>
<tr>
<td>D1 D2</td>
<td>2</td>
<td>LED RED SGL 30mA TH</td>
<td>Kingbright</td>
<td>WP7104LSRD</td>
</tr>
<tr>
<td>D4 D5 D8</td>
<td>3</td>
<td>DIODE DUAL SW 215MA 70V SOT23</td>
<td>ON SEMICONDUCTOR</td>
<td>BAV99LT1G</td>
</tr>
<tr>
<td>D6 D7 D9</td>
<td>3</td>
<td>DIODE SW 100V SOD-123</td>
<td>ON SEMICONDUCTOR</td>
<td>MMSTD4148T1G</td>
</tr>
<tr>
<td>D11</td>
<td>1</td>
<td>DIODE SCH DUAL CC 200MA 30V SOT23</td>
<td>ON SEMICONDUCTOR</td>
<td>BAT54CLT1G</td>
</tr>
<tr>
<td>D12 D13</td>
<td>2</td>
<td>DIODE ZNR 5.1V 0.5W SOD123</td>
<td>ON SEMICONDUCTOR</td>
<td>MMSSZ5231BT1G</td>
</tr>
<tr>
<td>ISO1 ISO2</td>
<td>2</td>
<td>IC OPTOCOUPLER 100MA 70V SMD</td>
<td>VISHAY INTERTECHNOLOGY</td>
<td>SFH6106-4</td>
</tr>
<tr>
<td>J1</td>
<td>1</td>
<td>HDR 19P SMT 50MIL SP 251H AU</td>
<td>SAMTEC</td>
<td>ASP-159234-03</td>
</tr>
<tr>
<td>J2 J3 J4 J5</td>
<td>4</td>
<td>CON 1X2 TB TH 5MM SP 394H --</td>
<td>N/A</td>
<td>DON'T POPULATE</td>
</tr>
<tr>
<td>J8</td>
<td>1</td>
<td>CON 2X5 PLUG SHRD TH 100MIL CTR 358H AU 118L</td>
<td>ADAM TECHNOLOGIES</td>
<td>BRH-10-VUA</td>
</tr>
</tbody>
</table>

*Table continues on the next page...*
Table C-2. BOM report for low-cost configuration (continued)

<table>
<thead>
<tr>
<th>Part Reference</th>
<th>Quantity</th>
<th>Description</th>
<th>Manufacturer</th>
<th>Part Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1 L2 L3</td>
<td>3</td>
<td>IND CHIP 1UH@10MHZ 220MA 25%</td>
<td>TDK</td>
<td>MLZ2012A1R0PT</td>
</tr>
<tr>
<td>DS1</td>
<td>1</td>
<td>LCD DISPLAY 3.3V TH</td>
<td>MAK-SAY</td>
<td>150020254</td>
</tr>
<tr>
<td>R1 R2 R3</td>
<td>3</td>
<td>RES MF 10K 1/8W 5% 0805</td>
<td>VENKEL COMPANY</td>
<td>CR0805-8W-103JT</td>
</tr>
<tr>
<td>R2 R3 R12</td>
<td>3</td>
<td>RES MF 390 OHM 1/8W 5% 0805</td>
<td>BOURNS</td>
<td>CR0805-JW-391ELF</td>
</tr>
<tr>
<td>R4 R15 R17 R22</td>
<td>4</td>
<td>RES MF 4.7K 1/4W 1% MELF0204</td>
<td>WELWYN COMPONENTS LIMITED</td>
<td>WRM0204C-4K7FI</td>
</tr>
<tr>
<td>R5 R7</td>
<td>2</td>
<td>RES MF 220K 1/4W 1% 50ppm MELF0204</td>
<td>WELWYN COMPONENTS LIMITED</td>
<td>WRM0204C-220KFI</td>
</tr>
<tr>
<td>R6 R24</td>
<td>2</td>
<td>RES MF 1K 1/4W 1% MELF0204</td>
<td>WELWYN COMPONENTS LIMITED</td>
<td>WRM0204C-1K0FI</td>
</tr>
<tr>
<td>R9 R11</td>
<td>2</td>
<td>RES MF 100K 1/4W 1% MELF0204</td>
<td>WELWYN COMPONENTS LIMITED</td>
<td>WRM0204C-100KFI</td>
</tr>
<tr>
<td>R10</td>
<td>1</td>
<td>RES MF 47 OHM 1/8W 5% 0805</td>
<td>Rohm</td>
<td>MCR10EZPJ470</td>
</tr>
<tr>
<td>R13 R20</td>
<td>2</td>
<td>RES MF 4.70K 1/8W 1% 0805</td>
<td>BOURNS</td>
<td>CR0805-FX-4701ELF</td>
</tr>
<tr>
<td>R14 R18</td>
<td>2</td>
<td>RES MF 100 OHM 1/4W 1% 50PPM MELF0204</td>
<td>WELWYN COMPONENTS LIMITED</td>
<td>WRM0204C-100RFI</td>
</tr>
<tr>
<td>R16</td>
<td>1</td>
<td>RES MF 1.00K 1/8W 1% 0805</td>
<td>KOA SPEER</td>
<td>RK73H2ATTD1001F</td>
</tr>
<tr>
<td>R19</td>
<td>1</td>
<td>RES MF 470.0 1/8W 5% 0805</td>
<td>BOURNS</td>
<td>CR0805-JW-471ELF</td>
</tr>
<tr>
<td>R31 R32</td>
<td>2</td>
<td>RES MF 47K 1/8W 5% 0805</td>
<td>SMEC</td>
<td>RC73L2D473JTF</td>
</tr>
<tr>
<td>RS1</td>
<td>1</td>
<td>RES VARISTOR 275V RMS 10% 4.5kA 151J TH</td>
<td>EPCOS</td>
<td>B72220S0271K101</td>
</tr>
<tr>
<td>SJ1</td>
<td>1</td>
<td>JUMPER 3 PAD 40MIL SQUARE SMT</td>
<td>N/A</td>
<td>NO PART TO ORDER</td>
</tr>
<tr>
<td>SJ2</td>
<td>1</td>
<td>JUMPER 2 PAD 40 MIL SQUARE SMT</td>
<td>N/A</td>
<td>NO PART TO ORDER</td>
</tr>
<tr>
<td>SW1</td>
<td>1</td>
<td>SW SPST MOM NO PB 20MA 15V TH</td>
<td>PANASONIC</td>
<td>EVQPAC05R</td>
</tr>
<tr>
<td>SW2</td>
<td>1</td>
<td>SW SPDT SNAP ACTION 0.1A 30V TH</td>
<td>OMRON</td>
<td>D2F-01L</td>
</tr>
<tr>
<td>TP1 TP2 TP3 TP4 TP5 TP6 TP7 TP8 TP9 TP10 TP11 TP12 TP13 TP14 TP15 TP16 TP17 TP18 TP19</td>
<td>19</td>
<td>TEST POINT TH PAD 60 DRILL 35 DIAM, NO PART TO ORDER</td>
<td>N/A</td>
<td>NO PART TO ORDER</td>
</tr>
</tbody>
</table>

Table continues on the next page...
### Table C-2. BOM report for low-cost configuration (continued)

<table>
<thead>
<tr>
<th>Part Reference</th>
<th>Quantity</th>
<th>Description</th>
<th>Manufacturer</th>
<th>Part Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>U1</td>
<td>1</td>
<td>IC MCU P2 MARCONI 32BIT 96K FLASH 16K RAM 2.7-5.5V LQFP144</td>
<td>FREESCALE SEMICONDUCTOR</td>
<td>PK40X256VLQ100</td>
</tr>
<tr>
<td>Y1</td>
<td>1</td>
<td>XTAL 32.768KHZ PAR 20PPM -- SMT</td>
<td>Citizen</td>
<td>CMR200T32.768KDZF-UT</td>
</tr>
</tbody>
</table>

### C.3 Bill of materials: other components

#### Table C-3. BOM report: other components (not included in schematics)

<table>
<thead>
<tr>
<th>QUANTITY</th>
<th>DESCRIPTION</th>
<th>MANUFACTURER</th>
<th>PART NUMBER</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Shunt-resistor 300 μΩ</td>
<td>MAK-SAY</td>
<td>-</td>
</tr>
<tr>
<td>1</td>
<td>Enclosure</td>
<td>MAK-SAY</td>
<td>M310</td>
</tr>
<tr>
<td>1</td>
<td>Open-frame AC/DC power supply</td>
<td>XP Power</td>
<td>ECL05US03-T</td>
</tr>
<tr>
<td>1</td>
<td>Receptacle Cannon 9-pin</td>
<td>Tyco Electronics</td>
<td>1658609-4</td>
</tr>
<tr>
<td>1</td>
<td>Receptacle 10-pin, ribbon crimp</td>
<td>Tyco Electronics</td>
<td>1658622-1</td>
</tr>
<tr>
<td>1</td>
<td>3V battery</td>
<td>GP</td>
<td>CR2032</td>
</tr>
<tr>
<td>10 cm</td>
<td>Flat cable</td>
<td>any acceptable</td>
<td>-</td>
</tr>
<tr>
<td>1.5 m</td>
<td>Extension Cord 250V/16A</td>
<td>any acceptable</td>
<td>-</td>
</tr>
<tr>
<td>1</td>
<td>Outlet 250V/16A</td>
<td>any acceptable</td>
<td>-</td>
</tr>
</tbody>
</table>
# Appendix D
## Technical Specification

## D.1 MK30X256 power meter specifications

Table D-1. MK30X256 power meter specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
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</thead>
<tbody>
<tr>
<td>Type of meter</td>
<td>Single phase residential</td>
</tr>
<tr>
<td>Type of measurement</td>
<td>4-quadrant</td>
</tr>
<tr>
<td>Metering algorithm</td>
<td>Fast Fourier Transform (FFT)</td>
</tr>
<tr>
<td>Accuracy (active &amp; reactive energy)</td>
<td>IEC50470-3 Class B, 1%</td>
</tr>
<tr>
<td>Voltage range</td>
<td>85 ... 264 V_{RMS}</td>
</tr>
<tr>
<td>Current range</td>
<td>0.02 ... 60 A_{RMS} or 5(60) A_{RMS}</td>
</tr>
<tr>
<td>Frequency range</td>
<td>47 ... 63 Hz</td>
</tr>
<tr>
<td>Meter constant (imp/kWh,imp/kVArh)</td>
<td>500, 1000, 2000, 5000, 10000</td>
</tr>
<tr>
<td>Functionality</td>
<td>V, A, kW, kVAR, kVA, kWh (import/export), kVArh (lead/lag), cos $\varphi$, Hz, time, date</td>
</tr>
<tr>
<td>Current sensor</td>
<td>Shunt-resistor 300 $\mu$Ω</td>
</tr>
<tr>
<td>Energy output interface</td>
<td>Two high-efficiency red LEDs (active, reactive)</td>
</tr>
<tr>
<td>Open-collector output (optional only)</td>
<td>Optically-isolated, $I_C=50mA$, $V_{CEO}=70V$</td>
</tr>
<tr>
<td>User interface (HMI)</td>
<td>LCD, push button, user LED</td>
</tr>
<tr>
<td>Tamper detection</td>
<td>Two buttons, magnetometer (optional only)</td>
</tr>
<tr>
<td>Infrared interface (optional only)</td>
<td>For metering data reading (IEC1107)</td>
</tr>
<tr>
<td>Serial communication interface (RS232)</td>
<td>Optically-isolated, 19200Bd, 8 data bits, 1 stop bit, no parity</td>
</tr>
<tr>
<td>ZigBee interface (optional only)</td>
<td>RF 2.4 GHz 1322x-LPN internal daughter card (SE1.0 stack implemented)</td>
</tr>
<tr>
<td>Internal battery</td>
<td>3V, type CR2032</td>
</tr>
<tr>
<td>Total power consumption</td>
<td>&lt; 1.4 W</td>
</tr>
<tr>
<td>Mechanical dimensions (w x l x h)</td>
<td>110 x 190 x 55</td>
</tr>
<tr>
<td>Weight (bare meter)</td>
<td>370 g</td>
</tr>
</tbody>
</table>
Appendix E
References

E.1 References
2. 3-Axis, Digital Magnetometer Data Sheet (MAG3110), available at freescale.com
4. 1322x Sensor Node Reference Manual (1322xSNRM), available at freescale.com
6. Power Factor—The Basics, available at powerstudies.com
7. ZigBee Environment Demonstration (ZEDESDUG), available at freescale.com
8. FFT-based Algorithm for Metering Applications (AN4255), available at freescale.com
Appendix F

F.1 Glossary

Alternating Current—AC
Advanced Encryption Standard—AES
Analog-to-Digital Converter—ADC
Analog Front-End—AFE
Automatic Meter Reading—AMR
Bill of Materials—BOM
Carrier Modulator Transmitter—CMT
Common-Mode Rejection Ratio—CMRR
Cyclic Redundancy Check—CRC
Current Transformer—CT
Direct Current—DC
Digital-to-Analog Converter—DAC
Dual Flat No leads—DFN
Dhrystone Million Instructions Per Second—DMIPS
Digital Signal Processing—DSP
Fast Fourier Transform—FFT
Flex Timer Module—FTM
General Purpose Input/Output—GPIO
Global Positioning System—GPS
Graphical User Interface—GUI
Glossary

Human Machine Interface—HMI
Institute of Electrical and Electronics Engineers—IEEE
Integrated Circuit—IC
Integrated Interchip Sound—I^2S
Inter-Integrated Circuit—I^2C
Keyboard Interrupt—KBI
Land Grid Array—LGA
Low Leakage Wake-up Unit—LLWU
Low-Power Timer—LPT
Light Emitting Diode—LED
Liquid Crystal Display—LCD
Media Access Control—MAC
Magnetoresistive Random Access Memory—MRAM
Microcontroller Unit—MCU
Object Identification System—OBIS
Operational Amplifier—OpAmp
Open Collector—OC
Periodic Interrupt Timer—PIT
Printed-Circuit Board—PCB
Programmable Delay Block—PDB
Programmable Gain Amplifier—PGA
Random Access Memory—RAM
Root Mean Square—RMS
Real Time Clock—RTC
Successive Approximations Register—SAR
Secured Digital Host Controller—SDHC
Serial Communication Interface—SCI
Surface Mounted Device—SMD
Switch Mode Power Supply—SMPS
Serial Peripheral Interface—SPI
Static Random Access Memory—SRAM
Universal Asynchronous Receiver/Transmitter—UART
Voltage Reference—VREF
Zero-Cross Detection—ZCD
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