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Chapter 1
Introduction

1.1 Overview

This document describes the design of a single-phase energy meter reference design, based on Freescale KM family microcontroller specifically targeted for single-phase metering applications. This design is targeted for basic and smart meters. This design is a reference for designing energy meter or electricity meter, which measures and displays active energy (kWh), reactive energy (kVArh), apparent energy (kVAh), voltage, current, frequency, power factor, active power (kW), reactive power (kVAr), apparent power (kVA), and maximum demand in kW. The LCD panel displays current date and time.

1.2 Application features

The features of KM family reference design are as follows:

- Mode:
  - Single-phase (1Ф-2W)
- Measurement and LCD display of:
  - RMS
    - Voltage
    - Phase current
    - Neutral current
  - Total
    - Active power
    - Reactive power
    - Apparent power
- Frequency
- Tamper count
- Power factor
- Energy
• Active
• Reactive
• Apparent
  • Date
  • Time
  • Maximum demand
• Operating frequency range 45–65 Hz
• Tamper information
• Optical port interface (IEC62056–21)
• Serial port for calibration and diagnostics
• Navigation using key
• Selectable display list in auto scroll and push button modes
• Expansion port for AMR via SCI

The following items are provided to the user to develop energy meter:
• Reference energy meter.
• Software – design document, and source code.
• Hardware documentation – detailed design document (excel format), BOM, Schematics, wiring diagram, and EMI/EMC test reports of reference energy meter.

1.3 KM devices advantages

The advantages of using KM devices are as follows:

• Core frequency can go up to 50 MHz, thus capable of enough horsepower for computation intensive applications.
• 24-Bit Sigma-Delta Analog Front End (AFE) with four independent channels; two with independent PGA.
• Built-in stable voltage reference.
• Selectable voltage reference - Internal or External.
• External gain switching is not required.
• Signal conditioning is not required.
• Phase error compensation using delay registers in AFE.
• PLL for stable clock generation for AFE and other peripherals.
• Watchdog runs on independent RC oscillator which is separate from core clock.
• Capable of running from a single clock source (external 32 kHz crystal).
• Ultra low-power independent RTC with calendar features and three tamper pins.
• RTC runs in independent power domain (always on battery); thus no switch and hence no possibility of any glitch.
• AMR SCI or SPI can communicate with 5 V AMR interfaces.
• Peripheral crossbar that can help in connecting a peripheral to any peripheral including inputs and outputs; helps in layout and other functionalities.
• 4-Channel DMA for data transfers without core intervention.
• Integrated 16-bit SAR Analog-to-Digital Converter.
• Single cycle 32x32 Multiply.
• Built-in LCD controller.

The following figure shows the reference design of a single phase meter:

![Figure 1-1. KM device based on 1-Ph reference design](image_url)
Chapter 2
Metering Theory and Configurations

2.1 Energy meter

Current is sensed using current transformer or shunt resistor or hall sensors. Voltage is sensed using potential divider circuit or voltage transformer. Sensed voltage and current signals are multiplied and integrated over period of time to obtain energy and it is stored in a register.

The following figure shows the concept of block diagram of Energy Meter:

![Block diagram of basic energy meter]

**Figure 2-1. Block diagram of basic energy meter**

- An Electricity Meter or Energy Meter is a device that measures the amount of electrical energy supplied to a residence, business, or machine.
- The unit for measurement of active electrical energy is kilowatt hour (kWh), which is equal to the amount of energy used by load of one kilowatt over a period of one hour.
- Demand is normally measured in watts or VA, but averaged over a period, most often a quarter or half hour.
- Reactive power is measured in "Volt-amperes reactive", (VArh) in kilovar-hours. A lagging or inductive load have negative reactive power, such as an induction motor. A leading or capacitive load have positive reactive power.
- Volt-amperes measures all power passed through a distribution network, including reactive and actual. This is equal to the product of root-mean-square volts and amperes.
- Distortion of the electric current by loads is measured in several ways:
• Power factor—It is the ratio of resistive (or real power) to volt-amperes (apparent power). A capacitive load has a leading power factor, and an inductive load has a lagging power factor. A purely resistive load exhibits a power factor of 1.
• Current harmonics—This is a measure of distortion of the current waveform. Odd harmonics are not permissible to exceed specific limits because it may interfere with the operation of other equipment.

2.2 Common terms used in metering

**Burden:** The load, usually expressed in volt-amperes at a specified power factor, placed on instrument transformer secondary by the associated meter coils, leads, and other connected devices.

**Capacitive reactance:** Impedance due to capacitance. This is expressed in ohms. The capacitive reactance varies indirectly with frequency.

**Circuit, three-wire:** It is a metallic circuit formed by three conductors insulated from each other.

**Circuit, two-wire:** It is a metallic circuit formed by two adjacent conductors insulated from each other. When serving domestic loads one of these wires is usually grounded.

**Constant, watt-hour:** The number of watt-hours represented by one increment (pulse period) of serial data. Example: Kh or Kt = 1.25 watt-hours/pulse.

**Current transformer:** Current transformer (CT) is used for measurement of electric currents.

**Current transformer phase angle:** The angle between the current leaving the identified secondary terminal and the current entering the identified primary terminal. This angle is considered positive when the secondary current leads the primary current. Or The angle between the primary current vector and the secondary current vector reversed; it is conveniently considered as positive when the reversed secondary current vector leads the primary current vector.

**Cycle:** One complete set of positive and negative values of an alternating current or voltage. These values repeat themselves at regular intervals.

**Demand:** The average value of power or related quantity over a specified interval of time. Demand is expressed in kilowatts, kilovolt amperes, kiloVARs, or other suitable units. Its interval could be like 1, 5, 10, 15, 30, or 60 minutes.
**Demand, maximum:** The highest demand measured over a selected period of time such as 30 minutes. It is also termed as Peak Demand.

**Effective value (root-mean-square value):** The effective value of a periodic quantity is the square root of the average of the squares of the instantaneous value of the quantity taken throughout one period. This value is also called the root-mean-square value and is the value normally reported by alternating current instruments.

**Electrical degree:** The 360th part of one complete alternating current cycle.

**Electricity meter:** A device that measures and records the summation of an electrical quantity over a period of time.

**Frequency:** Frequency is the number of occurrences of a repeating event per unit time. Period is the duration of one cycle in a repeating event, so the period is reciprocal of frequency. The unit of frequency is hertz (Hz). One hertz is equal to one cycle per second.

**Lagging current:** An alternating current which, in each half-cycle, reaches its maximum value a fraction of a cycle later than the maximum value of the voltage which produces it.

**Leading current:** An alternating current which, in each half-cycle, reaches its maximum values a fraction of a cycle sooner than the maximum value of the voltage which produces it.

**Meter constant:** The number of times the “Calib LED” blinks to record 1 kWh or 1 unit of energy. For example, if the meter constant is 3200, it means that 3200 impulses of the calib LED will result in the unit register incrementing by 1.

**Optical port:** A communication interface on metering products, which allows the transfer of information while providing electrical isolation and metering security. The communication medium typically used is infrared light transmitted and received through the meter cover.

**Phantom load:** A device which supplies various load current for meter testing, used in portable form for field testing. The power source is usually the service voltage which is transformed to a low value. The load currents are obtained by suitable resistors switched in series with the isolated low secondary voltage and output terminals. The same principle is used in most meter test boards.

**Phase angle:** The phase angle or phase difference between a sinusoidal voltage and a sinusoidal current is defined as the number of electrical degrees between the beginning of the cycle of voltage and the beginning of the cycle of current.
Active power: The time average of the instantaneous power over one period of the wave. For sinusoidal quantities in a two-wire circuit, it is the product of voltage, current, and cosine of the phase angle between them. For non-sinusoidal quantities, it is the sum of all the harmonic components, each determined as above. In a poly-phase circuit it is the sum of the active powers of the individual phases.

Apparent power: The product of the root-mean-square current and root-mean-square voltage for any waveform. For sinusoidal quantities, apparent power is the square root of the sum of the squares of active and reactive powers.

Reactive power: For sinusoidal quantities in a two-wire circuit, reactive power is the product of voltage, current, and sine of the phase angle between them with the current taken as reference.

With non-sinusoidal quantities, it is the sum of all the harmonic components, each determined as above. In a poly-phase circuit, it is the sum of the reactive powers of the individual phases.

Power factor: The ratio of the active power to the apparent power.

Reference meter: A meter used to measure the unit of electric energy. It is usually designed and operated to obtain the highest accuracy and stability in a controlled laboratory environment.

Watt: The practical unit of active power which is defined as the rate at which energy is delivered to a circuit. It is the power expended when a current of one ampere flows through a resistance of one ohm.

Watt-hour: The practical unit of electric energy which is expended in 1 hour when the average power during the hour is 1 watt.

2.3 Metering calculations

The formulas used for calculating various electrical parameters in Freescale reference energy meter are explained in subsequent subsections. These formulae are for reference only and the results obtained from these formulae may be averaged over the period of time to obtain stabilized readings.

\[ V_{AN} = \sqrt{\frac{V_{A1}^2 + V_{A2}^2 + \ldots + V_{An}^2}{n}} \]

Equation 1. Line to neutral voltages
Equation 2. Phase and average current

Where,
- \( n \) = number of samples per cycles
- \( V_{AN} \) = Line to neutral RMS voltages for A phase. \( V_{An} \) is the instantaneous nth sample (1 to 60) of A Phase Voltage.

\[
I_A = \sqrt{\frac{I_{A1}^2 + I_{A2}^2 + \cdots + I_{An}^2}{n}}
\]

\[
I_N = \sqrt{\frac{I_{N1}^2 + I_{N2}^2 + \cdots + I_{Nn}^2}{n}}
\]

Equation 3. Active and net active power

Where,
- \( n \) = number of samples per cycles
- \( I_A \) = Line Currents for A Phase.
- \( I_N \) = Neutral current. \( I_{An} \) is the instantaneous sample (1 to 60) of A Phase Current

\[
W_A = \frac{(V_{A1} * I_{A1}) + (V_{A2} * I_{A2}) + \cdots + (V_{An} * I_{An})}{n}
\]

Equation 4. Reactive and net reactive power

\[
V_{Ar_A} = \frac{(V_{A1} * I_{Ar(A+1)}) + \cdots + (V_{An} * I_{Ar(n+1)})}{n}
\]

Equation 5. Apparent and net apparent power

\[
V_{A_A} = \sqrt{(W_A)^2 + (V_{Ar_A})^2}
\]

Equation 6. Power factor

\[
PA_A = \frac{W_A}{V_{A_A}}
\]

Equation 7. Frequency

\[
FREQ_A = \frac{1}{t_A}
\]

Equation 8. Energy calculation

\[
Wh = W_A \times \text{Accumulationtime\_hours}
\]

\[
V_{A_{rh}} = \text{Accumulationtime\_hours}
\]

\[
V_{Ah} = V_{A_A} \times \text{Accumulationtime\_hours}
\]
NOTE

All the calculations discussed in this section are in terms of ADC counts. The calculated results will be further computed using calibration constants.

RMS apparent power is computed from product of $V_{\text{rms}}$ and $I_{\text{rms}}$. Angle compensation of total power is calculated as follows:

Power Factor = Total Active Power / RMS Apparent Power

Angle = $\acos$ (Power Factor)

An error in angle measurement is derived by measuring powers as shown in the below table:

<table>
<thead>
<tr>
<th>Current</th>
<th>Actual Power</th>
<th>Measured Power at 60</th>
<th>Error in Angle</th>
<th>Measured Power at 300</th>
<th>Error in Angle</th>
</tr>
</thead>
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<tr>
<td>40</td>
<td>4800</td>
<td>4750</td>
<td>-0.343986459</td>
<td>4865</td>
<td>0.448974936</td>
</tr>
<tr>
<td>25</td>
<td>3000</td>
<td>2962</td>
<td>-0.418132799</td>
<td>3039.5</td>
<td>0.436514072</td>
</tr>
<tr>
<td>10</td>
<td>1200</td>
<td>1187.5</td>
<td>-0.343986459</td>
<td>1212</td>
<td>0.331352363</td>
</tr>
<tr>
<td>5</td>
<td>600</td>
<td>595</td>
<td>-0.275283697</td>
<td>605.3</td>
<td>0.292637051</td>
</tr>
<tr>
<td>1</td>
<td>120</td>
<td>119.2</td>
<td>-0.220287608</td>
<td>120.77</td>
<td>0.212489601</td>
</tr>
<tr>
<td>0.25</td>
<td>30</td>
<td>29.8</td>
<td>-0.220287608</td>
<td>30.15</td>
<td>0.165536962</td>
</tr>
</tbody>
</table>

It is difficult to identifying whether the voltage is leading or lagging. This is identified by checking the sign of current sample immediately after voltage's zero crossover. The sign of current at that instance tells lag/lead. Then, the derived current angle derived above is rotated by “Error in Angle” amount to bring it to normal.

2.3.1 Wiring system

The following figure shows the one-phase two-wire wiring system:

![One-phase two-wire wiring system wiring system](Image)
The following figure shows the Lag and Lead concept of an energy meter.

**Figure 2-3. Phasor diagram of an energy meter**

Where,
- $\Phi = \text{(phase angle between voltage and current)} = \Phi_V - \Phi_I$
- $\Phi_V = \text{phase angle of voltage signal}$
- $\Phi_I = \text{phase angle of current signal}$

From the Trigonometric functions, Cosine (cos) components are positive in first and fourth quadrant and negative in second and third quadrant. Similarly, Sine (sin) components are positive in first and second quadrant and negative in third and fourth quadrant. Power (kW) and Power factor (PF) are cosine components and Reactive Power (kVAr) is sine component.

Current lags by an angle $\Phi$ with respect to Voltage is called lagging power factor and the sign of the angle within voltage and current will be positive. Typical example for this load is Inductive load, that is, Induction motor.

Current leads by an angle $\Phi$ with respect to Voltage is called leading power factor and the sign of the angle within voltage and current will be negative. Typical example for this load is capacitive load, that is, Synchronous motor.

A quantity which includes magnitude, direction, and time relationship is known as Phasor. The Phasors are used to represent sinusoidal voltages and currents by plotting on rectangular coordinates.
Chapter 3
Hardware Design

3.1 Block diagram

The following block diagram gives the overview of single-phase reference energy meter based on KM family devices.

Figure 3-1. Hardware block diagram

3.2 Power supply

The reference design runs on one of the following three power sources:

1. Main power supply
2. Auxiliary battery
3. Neutral missing CT

3.2.1 Main power supply

This is a capacitive power supply rating 4 VA. This power supply can provide up to 11.5 ma current at 240 V.

All the blocks and corresponding schematic of Main Power Supply block diagram are explained as follows:

Input AC is fed through two pin terminal and varacter U5 protects against surge. The resistor R30 limits the current in the power supply section which is followed by a high-pass filter formed by the C25 capacitor.

The AC capacitor C21 offers impedance to the current and decides the maximum value of average DC current (\(I_{in}\)) that can be fed to the MCU.

\[
I_{in} = \frac{(V_{peak} \times 2\pi f \times C)}{\pi}
\]

\[\text{Equation 9. Maximum value of average DC current}\]

Where,
- \(I_{in}\) is the average value of DC current
• \(F\) is the frequency of input supply voltage
• \(2\pi FC\) is the impedance offered (in the schematic \(C\) is \(C21\))

The further diodes and transistor network act as one way rectifier and zener diode (D13) acts as voltage regulator. C26 capacitor is the bulk storage capacitor and is charged up to 5.6 V. So the voltage rating should be more than 10 V. This capacitor reduces ripples from the output supply. As one tries to withdraw more and more current, the ripples will increase. The high value of C21 capacitor would reduce the ripples from the supply up to a certain limit; this will increase the rating of power supply. The LDO U4 has an enable input and provides stable 3.3V output.

### 3.2.2 Auxiliary battery

Auxiliary battery provides power to meter in case of mains power missing. This activates the meter whenever Push Button (PB) is pressed and keeps meter powered till the all LCD parameters are displayed once and PB is not pressed further.

![Figure 3-4. Circuit diagram of battery supply](image)
PON signal is generated from the power supply section, so this auxiliary battery will power up meter only in case main power is absent. Latch signal driven from MCU keeps meter ON till its battery operated operation is not completed after the PB is pressed.

### 3.2.3 Neutral missing CT

Neutral missing CT provides the power in case of single-wire metering for tamper detection. If any of the two wires (Phase or Neutral) is removed from the meter terminal and current is passing through the single connecting wire then meter will get power up using this CT.

![Neutral Missing CT Circuit Diagram](image)

**Figure 3-5. Circuit diagram of neutral missing power CT**

### 3.3 Display interface
3.3.1 Liquid Crystal Display (LCD) interface

The following figure represents the typical example of LCD displays used in single-phase metering:

![LCD Display Image](image)

**Figure 3-6. LCD display**

- **Display type:** STN/Yellow-Green
- **Viewing direction:** 6 o’clock
- **Polarizer type:** Transflective, positive.

The LCD can display import, export, lead, lag, kW, kVAR, kWh, kVARh, number of tampers, maximum demand, date, time, frequency (Hz) and many more.

LCD has 80 segments and ¼ duty cycle (4 backplanes).

LCD interfaces to the 'built-in LCD driver' of the controller and driver is operating in ¼ duty cycle and 1/3 bias (voltage levels) mode.

3.3.2 LCD backlight

The LCD built without an internal back light source which necessitates the use of external sources of light to make the screen and information visible.

The following figure shows the circuit diagram of LCD backlight:

![Circuit Diagram Image](image)

**Figure 3-7. Circuit diagram of LCD backlight**
Backlight illuminates the LCD from back of the display panel which increases readability in low light conditions.

3.4 LED interface

This is the calibration LED. Active energy accuracy of the meter is verified by pulse method. kWh LED pulses are used to measure the accuracy of active energy. As the active energy starts accumulating kWh LED will blink at the rate of 3200 impulses/kWh.

The following circuit shows how Calib LED is driven from MCU:

![Circuit diagram calib LED](image)

**Figure 3-8. Circuit diagram calib LED**

3.5 Keyboard (User) interface

There is one push button on the meter, which is used to scroll the display through display list. It powers ON the meter if the main power is OFF.

3.6 Analog signal conditioning

A signal conditioning block is used to bring voltage and load currents to the required voltage levels.
3.6.1 Current signal conditioning circuit

A shunt resistor is present on the phase element and a Current Transformer (CT) on the neutral element. Shunt value is 500 μΩ, which just about saturates at approximately 44 A if a gain of 8 is used on the PGA. A burden resistor of 10 Ω on the CT secondary saturates at 44 A. Signal conditioning like level shifting or external gain is not required for the signals.

3.6.2 Voltage signal conditioning circuit

A resistor divider network is used to step down the voltage to measurable level. No other signal conditioning is required.
3.7 Cover open tamper detection

SW2 switch contact position will be open when the enclosure top cover is closed. This would be considered as no tamper condition and BT1 will not be loaded by R31. When enclosure top cover is opened, SW2 contacts position will be closed. This is Tamper condition and BT1 will be loaded by R31.

The battery voltage will drop across the resistor R31 and the voltage will appear at the tamper pin. The tamper will be detected by RTC inside meter.

The cover open tamper can be detected even under power OFF condition of the meter. There is provision of power on the meter when SW2 switch is closed. This will connect the BT2 power back-up battery to system supply. The following figure displays the circuit diagram of cover open tamper:

![Circuit diagram of cover open tamper](image)

Figure 3-10. Circuit diagram of cover open tamper

3.8 Optical communication port

The Meter has one optical communication port as per IEC62056-21. The following figure displays the hardware circuit associated with optical port communication:

The following figure displays the position of receiver and transmitter of optical port on the meter:

Figure 3-12. Position of receiver and transmitter of optical port on meter
In Figure 3-12 the optical head (optical to RS232 converter) is placed over the optical port interface of the meter and RS232 is connected to PC for communication. The pitch provided on the tariff device is 6.5 mm. The infrared receiver in the tariff device is aligned directly opposite the infrared transmitter in the reading head and infrared receiver in the reading head is directly opposite the infrared transmitter in the tariff device.

### 3.9 Serial Wire Debug (SWD) module

J-link is a 20-pin header, so an adapter cable is used to connect the 20-pin J-link connector with 6-pin headers on board. Its communication interface is used for programming the controller. Reduced 6-pin nonisolated header is available on the meter. So, user must use the isolated power source to power meter, when jlink is connected on meter.

The following figure shows a IAR J-link debugger which is used to program and debug the MCU:
3.10 Microcontroller requirements

Following are the requirements for MCU:
3.10.1 Crystal requirements

External 32.768 kHz crystal is used for RTC and same clock is multiplied by FLL/PLL which is internal to the controller to provide clock to core, bus and peripherals.

3.10.2 LCD requirements

LCD driver of the controller requires three ceramic capacitors whose typical value is 0.1 µF for LCD bias voltages and 0.1 µF for LCD charge pump.

3.11 Assembled printed circuit board

Figure 3-16 shows the top view of the assembled board:
Figure 3-16. Board top view

Figure 3-17 shows the bottom view of the assembled board:
Assembled printed circuit board

Figure 3-17. Board bottom view
Chapter 4
Software Design

4.1 Introduction

This section describes the software design of Single-Phase Energy Meter application. Software design mainly consists of measurement, database, user interface, and communication modules. The objective of this chapter is to understand the software design. The software architecture is custom kernel running on KM device controller. The controller uses the external RTC clock source and PLL to generate the system clock of 12.28 MHz.

The software has following main modules:

- Measurement Module
- Database Management Module
- User Interface Module
- Communication Module

4.2 Hardware resource allocation

The following table lists the MCU resources used in metering application.

<table>
<thead>
<tr>
<th>Peripherals</th>
<th>Usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>TMR1</td>
<td>General purpose timeout timer</td>
</tr>
<tr>
<td>TMR2</td>
<td>Zero crossing timing to compute frequency</td>
</tr>
<tr>
<td>AFE0</td>
<td>Phase Current</td>
</tr>
<tr>
<td>AFE1</td>
<td>Neutral Current</td>
</tr>
<tr>
<td>AFE2</td>
<td>Voltage</td>
</tr>
<tr>
<td>I2C1</td>
<td>EEPROM</td>
</tr>
<tr>
<td>SCI1</td>
<td>Optical communication</td>
</tr>
</tbody>
</table>

Table continues on the next page...
Table 4-1. Hardware resource allocation (continued)

<table>
<thead>
<tr>
<th>Peripherals</th>
<th>Usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>XBAR</td>
<td>Connect CMP1 to TMR2</td>
</tr>
<tr>
<td>CMP1</td>
<td>Zero cross detection to detect voltage and compute frequency</td>
</tr>
<tr>
<td>LCD</td>
<td>Display</td>
</tr>
<tr>
<td>VREF</td>
<td>Voltage reference for AFE</td>
</tr>
<tr>
<td>RTC</td>
<td>Real time management and cover open tamper</td>
</tr>
<tr>
<td>NVIC</td>
<td>Interrupt controller for various interrupts</td>
</tr>
<tr>
<td>PLL</td>
<td>Bus and AFE clock source</td>
</tr>
</tbody>
</table>

4.3 Interrupt priority

The following table shows interrupts priorities of various modules that are set in the software. The lowest number denotes the highest priority.

Table 4-2. Interrupt priorities

<table>
<thead>
<tr>
<th>Interrupts</th>
<th>Priority level</th>
</tr>
</thead>
<tbody>
<tr>
<td>TMR1</td>
<td>2</td>
</tr>
<tr>
<td>TMR2</td>
<td>2</td>
</tr>
<tr>
<td>AFE0</td>
<td>3</td>
</tr>
<tr>
<td>AFE1</td>
<td>3</td>
</tr>
<tr>
<td>AFE2</td>
<td>3</td>
</tr>
<tr>
<td>I2C1</td>
<td>0</td>
</tr>
<tr>
<td>SCI1</td>
<td>2</td>
</tr>
<tr>
<td>RTC</td>
<td>3</td>
</tr>
<tr>
<td>DMA</td>
<td>2</td>
</tr>
<tr>
<td>Push button</td>
<td>3</td>
</tr>
</tbody>
</table>

4.4 Measurement

Metering application software operates MCUs in different configuration depending on the input conditions. The following sections describe the requirement of the different modes, what are the different modes, and how they have been implemented.
4.4.1 Modes

The modes are required because the meter should power up at 90 V upwards and should be fully functional at 120 V upwards. This lays a lot of restrictions on the power supply. The capability of the power supply is as under.

Table 4-3. Metrology engine has various modes

<table>
<thead>
<tr>
<th>Mode</th>
<th>Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Run</td>
<td>V &gt;= 115</td>
</tr>
<tr>
<td>Brownout</td>
<td>V &lt; 115</td>
</tr>
<tr>
<td>Single Wire</td>
<td>V = 0, I ≠ 0</td>
</tr>
<tr>
<td>Battery</td>
<td>V = 0, I = 0</td>
</tr>
</tbody>
</table>

In run mode, the meter consumes about 9.6 mA of current. Hence a new mode – Brownout was created in which the meter runs off 2 MHz IRC. All the parameters are measured but the accuracy is not as good as it is in Run mode, thus allowing meter to function in limited capacity. This process is seamless to the user.

In single wire mode, the meter runs off power up CT (or battery) and hence the capacity of the supply is much limited. The meter is made to run off 2 MHz IRC so that the consumption is brought down to minimum.

In battery mode, the meter is powered up to allow the reading and display. In this mode, the meter is powered up for a very short duration and no measurements are made. This mode allows only three display cycle per day.

<table>
<thead>
<tr>
<th>Voltage (V)</th>
<th>Capacity (mA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>240</td>
<td>17.8</td>
</tr>
<tr>
<td>180</td>
<td>15</td>
</tr>
<tr>
<td>150</td>
<td>13</td>
</tr>
<tr>
<td>120</td>
<td>10.5</td>
</tr>
<tr>
<td>90</td>
<td>9</td>
</tr>
</tbody>
</table>

4.4.2 Meter startup sequence

While booting, depending upon the supply condition and the mode of wake-up (from RESET), the meter takes some time to settle down into the mode. The software first checks if the output from regulator is low. If it is, then an external key press in absence of mains has woken up the meter and it should allow the user to read via communications and/or scroll through the display list.
If the regulator output is high, then initialize analog comparator to check for zero crossing (presence of mains voltage). If voltage is present, comparator interrupt would be visible in a very short duration – of the order of ~20 ms. Otherwise it times out to switch to battery mode. If zero crossing is detected, the brownout mode is selected. Measurement is done in brownout mode and if voltage is above 120 V, then mode is switched to Run mode.

![Flow diagram](image)

**Figure 4-1. Metering on boot**

When the meter is running, changes in supply conditions may require it to switch to another mode. Mode switches are done as per the following flow diagram.
4.4.3 Metering modes

1. **RUN**

   **Clocking scheme:** Controller is in PEE mode (PLL Engaged External). AFE runs off PLL at 768 kHz. Running AFE at less than 1 MHz is required for low-power operation and saves about 1 mA per channel while compromising very little on signal measurement accuracy.
2. Brownout

**Clocking scheme:** Controller is in BLPI mode (FLL Bypassed Low Power Internal). AFE runs off IRC.
3. Single Wire

**Clocking scheme:** Controller is in BLPI mode (FLL Bypassed Low Power Internal). AFE runs off IRC.

<table>
<thead>
<tr>
<th>Type</th>
<th>Used</th>
<th>Available</th>
</tr>
</thead>
<tbody>
<tr>
<td>AFE</td>
<td>AFE0, AFE1, AFE2</td>
<td>AFE3</td>
</tr>
<tr>
<td>TMR</td>
<td>TMR1, TMR2</td>
<td>TMR0, TMR3</td>
</tr>
<tr>
<td>LPTMR</td>
<td>–</td>
<td>LPTMR</td>
</tr>
<tr>
<td>UART</td>
<td>UART3</td>
<td>UART0, UART1, UART2</td>
</tr>
<tr>
<td>(\text{i}^2\text{C})</td>
<td>(\text{i}^2\text{C}1)</td>
<td>(\text{i}^2\text{C}0)</td>
</tr>
<tr>
<td>CMP</td>
<td>CMP1</td>
<td>CMP0</td>
</tr>
<tr>
<td>RTC</td>
<td>RTC, TAMPER0</td>
<td>TAMPER1, TAMPER2</td>
</tr>
<tr>
<td>LCD</td>
<td>4x20</td>
<td>4x20</td>
</tr>
<tr>
<td>PLL</td>
<td>–</td>
<td>PLL</td>
</tr>
</tbody>
</table>

![Figure 4-4. Brownout mode](image-url)

FBI mode

Core Current = 1.2 mA (Duty cycle = 100%)

PGA Disabled

AFE Divider = 16

AFE3Divider = 512

AFE3OSR = 1

AFE Divider = 16

AFE Divider = 1

AFE Divider = 1

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4. Battery

**Clocking scheme:** Controller is in BLPI mode (FLL Bypassed Low Power Internal). Metrology is disabled.
### 4.4.4 Measurement parameters

#### Table 4-5. Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Run</th>
<th>Brownout</th>
<th>SingleWire</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{\text{rms}}$</td>
<td>Yes</td>
<td>Yes</td>
<td>—</td>
<td>Assumed in Single Wire</td>
</tr>
<tr>
<td>$I_{\text{prms}}$</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>—</td>
</tr>
<tr>
<td>$I_{\text{rms}}$</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>—</td>
</tr>
<tr>
<td>Active power</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>—</td>
</tr>
<tr>
<td>Reactive power</td>
<td>Yes</td>
<td>Yes</td>
<td>—</td>
<td>Calibration only and compile time option</td>
</tr>
</tbody>
</table>

*Table continues on the next page...*
Table 4-5. Parameters (continued)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Run</th>
<th>Brownout</th>
<th>SingleWire</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apparent power</td>
<td>Yes</td>
<td>Yes</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Power factor</td>
<td>Yes</td>
<td>Yes</td>
<td>—</td>
<td>Assumed in Single Wire</td>
</tr>
<tr>
<td>Active energy</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>—</td>
</tr>
<tr>
<td>Reactive energy</td>
<td>Yes</td>
<td>Yes</td>
<td>—</td>
<td>Calibration only and compile time option</td>
</tr>
<tr>
<td>Apparent energy</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>—</td>
</tr>
</tbody>
</table>

4.4.5 Initialization

The metering engine requires the following peripherals:
- PLL
- AFE
- Vref
- TMR2
- XBAR
- CMP1

Depending on the mode metering engine is working on, these peripherals are selectively initialized. CMP1 is always initialized to either detect presence of voltage (for battery and single wire modes) or for frequency (brownout and run modes).

<table>
<thead>
<tr>
<th>Mode</th>
<th>Peripheral initialized</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brownout</td>
<td>AFE2, AFE1, AFE0, Vref</td>
</tr>
<tr>
<td>Run</td>
<td>AFE2, AFE1, AFE0, Vref</td>
</tr>
<tr>
<td>Battery</td>
<td>—</td>
</tr>
<tr>
<td>Single Wire</td>
<td>AFE0/1, Vref</td>
</tr>
</tbody>
</table>

NOTE

In Single wire mode, the current channels are enabled one at a time to check current on the two channels and use the one that’s higher of the two.

In Battery mode (which is essentially used for display in mains off mode), CMP1 is enabled to see if mains supply is restored.

Transition from any mode to another mode is done via brownout.

RMS is the typical mode of computation.
4.4.6 Sampling

Samples of the enabled AFE channels are accumulated in data structures for fixed
duration, that is, 1 second. At that instance, the sampler triggers metering. Metering is
triggered either by sampling count (if PLL is active) or when a second has elapsed (when
source is RTC). Offsets are removed from samples before banks are updated. Sums
which are updated during sampling are:

- Voltage rms
- Phase current rms
- Neutral current rms
- Active Phase power
- Active Neutral power
- Reactive Phase power
- Reactive Neutral power

4.4.7 Metering process

Every one second the metering processing engine is triggered. This engine computes the
gathered raw samples into metering parameters. The steps involved are (slightly vary for
different modes):

1. Scale the gathered sums in 64 bits into floating point.
2. Calibration constants are applied. RMS parameters are computed in this step itself as
   they don’t need any further calculations.
3. Active, Reactive and Apparent powers are computed for phase and neutral elements.
   Total powers are also computed.
4. Power factor is derived.
5. Phase correction is applied (see method below).
6. Powers computed are converted into energies. Energy is recorded only in import
   mode (always forwarded).
7. Energy registers are updated.
8. Energy accumulated in this metering period is updated for driving calibration LED.
9. Auto-Calibration is invoked, if enabled.
Complete RMS voltage and currents by:
- Divide sum by number of samples
- Square root
- Multiply by calibration constant

End

Figure 4-7. Metering process
Apply Phase Correction

Get sin of power factor from sign of I at zero cross over of V

Power factor \( \varphi = \cos^{-1} \left( \frac{\text{Active Power}}{\text{Apparent Power}} \right) \)

If leading PF, Apply Phase Correction
\( \varphi = \varphi \times -1 \)

Phase Correction
\( \varphi_c = \varphi + \varphi' \) (From calib)

New active power = App power \( \times \cos \varphi_c \)
Reactive Power = App Power \( \times \sin \varphi_c \)

End

Figure 4-8. Phase error correction
Figure 4-9. Lagging

Figure 4-10. Leading
4.5 User interface

4.5.1 Introduction

The User Interface Module comprises of LCD, keypad, and LEDs and their respective drivers. Custom LCD specific for metering application to displaying various Electrical parameters. Meter has Push button key for manually control the display of parameters. Meter has LED for energies pulse generation. Backlight control of LCD through I/O pin controller.

![LCD block diagram](image)

Figure 4-11. LCD block diagram

4.5.2 LCD panel

This reference design has a configurable list of parameter to be displayed on the LCD. User will select the list of parameter and the sequence of parameter to be displayed on LCD by controlling the Mask set defines. There are two mode for the display Auto Scroll Mode and Manual Scroll Mode. Currently following parameters has been implemented.

- LCD Self Test
- Phase current
- Neutral current
- Voltage
- Frequency
- Active power
Communication

- Apparent Power
- Active Energy (Complete Value)
- Maximum Demand (kW)
- Maximum demand Time
- Maximum demand Date
- Power Factor
- Real Time
- Real Date
- Tamper status of meter cover open
- Latest Cover Open Tamper event date
- Latest Cover Open Tamper event time
- Active Energy (Integer value only)
- Status of Magnetic Tamper
- Latest Magnetic Tamper event date
- Latest Magnetic Tamper event time
- Cumulative active energy for each calendar month for previous six month with display of Month
- Maximum demand (kW MD) in a calendar month for previous six months with date and time

**NOTE**

Any parameter in the above list can be configured to display in the two modes, that is, Auto Scroll Mode and Manual Scroll Mode.

4.6 Communication

Meter facilitates optical port for serial communication, using IEC62056-21 Mode C protocol, with external world for data exchange. On personal computer, hyper terminal or any standard windows utility, like InTerm Version 1.1 from RF innovations, is used for communication purpose. Transmission and reception takes place by interrupt method.
4.6.1 Implementation

- IEC 62056-21 Mode C protocol is used for data exchange.
- An optical head is used for over the optical port interface on the meter and RS232 port connected to PC for communication.
- Transmission and reception is on interrupt based. Reception is disabled until the received packet is processed.
- Data verification implemented in programming mode to ensure correct entry of data.
- Character Transmission
  - Asynchronous serial bit (Start-Stop) transmission
  - Half duplex communication
  - Baud rate – 2400, Standard Baud rate – 300, 600, 1200, 2400, 4800, 9600,19200
  - Character format: 1 start bit, 7 data bits, 1 parity bit, 1 stop bit
  - Character security: Even Parity
- COM port settings
  - Baud Rate : 2400 bps
  - Data Bits : 8
  - Parity : None
  - Stop Bit(s) : 1
  - Flow control : None
- Optical port interface supports following modes
  - Data Collection Mode: Data collection consists of header information (MFG identity, unit serial number and name, version, revision etc.), electrical parameters etc.
• Programming Mode: This mode is used to configure the following meter parameters and settings.
  • Read date, time and configuration parameters.
  • Program date and time.
  • Program serial name and number.
  • Program nominal voltage, current and frequency.
  • Program MD integration period.
  • Program auto scroll period.
  • Program LP interval time.
  • Program persistence time.
  • Program optical baud rate.
  • Program pulse constant.
  • Clear MD parameters, tamper headers and load profile headers.
• Calibration Mode: Calibration of the meter is done in this mode which includes manual and auto calibration. Please refer section 4.7 or user guide for details of calibration.

NOTE
Select odd parity in the com settings to configure for even parity and vice versa. This is a known bug in the In-Term Utility.

4.7 Calibration
Calibration of the meter is done in order to compensate for variations introduced by hardware. Calibration of the meter can be done in auto calibration method only. In Auto Calibration user feeds a known voltage and current and the software calculates the coefficients and stores them in NV memory if calibration is successful.

4.7.1 Auto calibration process
Auto Calibration Module calibrates the meter for various parameters to compensate errors due to tolerance of external components. Calibration of the meter is a single point process. The load points are as follows:
  • 240 V
  • 10 A
  • UPF
NOTE
The load point can be changed as the calibration engine can take any load point.

Once the load point is set, calibration is started. Accumulation happens normally for 10 cycles referred as n following in steps. The following flowchart explains the calibration process:

![Flow diagram of calibration](image)

**Figure 4-13. Flow diagram of calibration**

Ratio error is elaborated in the following flow diagram:
Measured value = Average Accumulated RMS value

New calib co-efficient = \( \frac{\text{Applied value}}{\text{Measured value}} \) \times \text{Old calib co-efficient}

**Figure 4-14. Flow diagram of ratio error**

Phase error is elaborated in the following flow diagram:

\[
\text{Ph Angle} = \tan^{-1}\left(\frac{\text{Reactive Power}}{\text{Active Power}}\right)
\]

Accumulate Phase Angle for 5 metering cycles

Average Phase Angle = \( \frac{\pi}{5} \)

Phase Error = Phase Angle - Applied Angle

**Figure 4-15. Flow diagram of phase error**

### 4.8 Tamper detection

Following Tampers are detectable by the meter:

1. Box Open
2. Magnetic
3. Phase Reversal
4. Partial Earth
5. Neutral Missing
4.8.1 Box Open tamper

Box open tamper switch is mounted on the meter. Each time box cover is open, a tamper is registered in the RTC. This tamper is active even if the main power is OFF. Time stamp of this tamper is also recorded in the RTC. Metering software takes care of the tamper occurrence and release time.

4.8.2 Magnetic tamper

Magnetic tamper is a high magnetic field presence condition near the meter. This tamper condition results in inappropriate functioning of current transformer. A magnetic switch is used in the hardware to detect magnetic tamper condition. Output signal of this switch toggles whenever magnetic field is applied and this signal is tied with one I/O of microcontroller in GPIO mode, this toggle is detected as a tamper. Magnetic tamper is not tested on the reference design.

4.8.3 Phase reversal tamper

Phase reversal tamper is a condition in which meter starts registering energy consumption in negative direction when phase and neutral are reversed. This causes energy units to decrement. So this condition is detected as a tamper in software and energy is always treats as positive. Occurrence and Release time stamp of this tamper is stored in EEPROM.

4.8.4 Partial Earth tamper

Partial earth tamper is a condition in which phase and neutral current are not equal. A partial amount of current is returned back to local earth. Amount of current returning back in neutral line is not equal to the phase line, rather it is lesser. This tamper condition is detected in software. Occurrence and release date and time of this tamper is stored in EEPROM.

4.8.5 Neutral Missing tamper

Neutral missing tamper is a condition in which user disconnects the neutral from the meter. This will causes meter to power OFF and user can draw current from the phase line, which will not be registered in the meter. This condition is taken care by powering the meter by an auxiliary power source know as Neutral Missing power CT. So whenever
neutral missing condition occurs, neutral missing power CT will power on the meter and the current following through phase line will be detected and this condition will also be registered in EEPROM.

4.9 Database

4.9.1 Introduction
Reference Energy Meter design has external serial NV memory interfaced to KM devices over I²C port. NV memory storage structures are as follows:
- Active, Reactive, and Apparent Energies
- Maximum Demand (MD)
- Calibration Coefficients
- Configuration Parameters
- Previous Month MD and Cumulative Energy.
- Tamper Headers and Tamper Data
- Load Profile Header and Load Profile Data.

The details of each structure can be found in the following excel file.

4.9.2 Assumptions, constraints, and limitations
Meter will be configured with default values if nonvolatile memory gets corrupted.
4.9.2.1 **DB Application Block**
- DB Application block will handle the Read/Write operations to NV memory, depending upon other module request.
- Write/Read operations are done one structure at a time.
- Any module can initiate read/write operation after get the database lock.
- DB Applications block handle Init operation, write, read, post wait, bank update and retry states for any read/write operation initiated by other modules.

**NV Driver**
• NV driver will receive a read/write request from the DB Application block.
• Based on type of NV memory, write operation will be executed.
• EEPROM paging concept (maximum of 128 bytes write at a time) will be executed.
• NV driver will call I²C drivers for read/write operation.

I²C Driver
• I²C driver will write and read the data to and from NV memory

4.9.3 Implementation
• The module which needs to access NV memory should first obtain LOCK. Only one module can access NV memory at a time. In case the lock is unavailable the requesting module can either wait until lock is released or can terminate the request by itself.
• Transmission and reception over I²C are interrupt based.
• I²C baud rate configured for EEPROM is 100 kHz.
• NV Read/Write Success – Database application block returns DB_SUCCESS and releases the lock
• NV Read/Write Failure – The application retries the read/write operation for 3 times in case of failure. If read/write is unsuccessful for retry number of counts then database application block returns DB_FAILURE and releases the lock.
• Active Energy and status of various Tampers will be saved in RTC nonvolatile memory at a fixed interval of 1 min
• At the time of power up latest energy from RTC Ram is copied into EEPROM on active bank of energy structure.
• At power ON application validates the signature of current bank. If either of the bank signatures is valid, application reads Energies, Maximum Demand Parameters, load profile, Configuration Parameters, Calibration Parameters, Previous Month MD and Energy headers and tamper headers from NV memory. If both the bank signatures are invalid then defaults are written to NV memory.
• CRC check for each structure for data integrity.

4.9.4 Memory map
EEPROM Size = 64 Kbytes

<table>
<thead>
<tr>
<th>Structure</th>
<th>Bytes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bank Status and Signature for each bank</td>
<td>10</td>
</tr>
</tbody>
</table>

Table 4-7. NV memory details

Table continues on the next page...
### Table 4-7. NV memory details (continued)

<table>
<thead>
<tr>
<th>Description</th>
<th>Bytes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of bytes required by Energy Registers</td>
<td>64</td>
</tr>
<tr>
<td>Number of bytes required by Maximum demand</td>
<td>32</td>
</tr>
<tr>
<td>Number of bytes required by Calibration coefficients</td>
<td>64</td>
</tr>
<tr>
<td>Number of bytes required by Configuration parameters</td>
<td>96</td>
</tr>
<tr>
<td>Number of Bytes Required MD and Energy Cumulative Header</td>
<td>10</td>
</tr>
<tr>
<td>Number of Bytes Required MD and Energy Cumulative Data Part</td>
<td>192</td>
</tr>
<tr>
<td>Number of Bytes Required Reverse Tamper Header</td>
<td>12</td>
</tr>
<tr>
<td>Number of Bytes Required Reverse Tamper Data</td>
<td>1100</td>
</tr>
<tr>
<td>Number of Bytes Required Earth Tamper Header</td>
<td>12</td>
</tr>
<tr>
<td>Number of Bytes Required Earth Tamper Data</td>
<td>1100</td>
</tr>
<tr>
<td>Number of Bytes Required Magnetic Tamper Header</td>
<td>12</td>
</tr>
<tr>
<td>Number of Bytes Required magnetic Tamper Data</td>
<td>1100</td>
</tr>
<tr>
<td>Number of Bytes Required Cover Tamper Header</td>
<td>12</td>
</tr>
<tr>
<td>Number of Bytes Required Cover Tamper Data</td>
<td>1100</td>
</tr>
<tr>
<td>Number of Bytes Required Neutral Missing Tamper Header</td>
<td>12</td>
</tr>
<tr>
<td>Number of Bytes Required Neutral Missing Tamper Data</td>
<td>1100</td>
</tr>
<tr>
<td>Number of bytes required by Load profile</td>
<td>25938</td>
</tr>
<tr>
<td>Total number in Bytes</td>
<td>37512</td>
</tr>
<tr>
<td>Total number in Kbytes</td>
<td>36.633</td>
</tr>
</tbody>
</table>

### 4.9.5 State Machines / Control Charts

Following figure describes the state diagram of Database Communication on EEPROM.
Figure 4-17. State diagram of database communication on EEPROM

<table>
<thead>
<tr>
<th>Events</th>
<th>Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Locked and Write</td>
<td>Event indicates any one of Metering, Init Database, Communication or User interface has locked the database module for writing data to nonvolatile memory.</td>
</tr>
<tr>
<td>Locked and Read</td>
<td>Event indicates any one of Metering, Init Database, Communication or User interface has locked the database module for reading data to nonvolatile memory.</td>
</tr>
<tr>
<td>Write Initiated</td>
<td>Event indicates to initiate writing corresponding data structure to nonvolatile memory.</td>
</tr>
<tr>
<td>Read Initiated</td>
<td>Event indicates to initiate reading of corresponding data structure from nonvolatile memory.</td>
</tr>
<tr>
<td>Error</td>
<td>Event indicates error happened during write/read operation and need to retry.</td>
</tr>
<tr>
<td>Retry</td>
<td>Event indicates the retry of the write/read operation has been started.</td>
</tr>
<tr>
<td>Write Failed</td>
<td>Event indicates write operation has been failed even after maximum number of retries.</td>
</tr>
<tr>
<td>Read Failed</td>
<td>Event indicates read operation has been failed even after maximum number of retries.</td>
</tr>
</tbody>
</table>

*Table continues on the next page...*
<table>
<thead>
<tr>
<th>Events</th>
<th>Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Write Successful</td>
<td>Write operation of banked structure is successfully over and bank status has to be updated</td>
</tr>
<tr>
<td>Read Successful</td>
<td>Read operation is successfully over release of database module has to be done</td>
</tr>
<tr>
<td>Write Successful for non-banked structure</td>
<td>Write operation of non banked structure is successfully over and release of database module has to be done</td>
</tr>
<tr>
<td>Bank Updated</td>
<td>Bank status structure is updated for corresponding banked structure and written into nonvolatile memory.</td>
</tr>
<tr>
<td>Request ACK and UnLock</td>
<td>Indicates respective module that write/read operation done and request to release database module</td>
</tr>
</tbody>
</table>

### 4.9.6 Maximum demand

**Maximum Demand Register**
- Meter will record the Maximum Demand (kW MD) with time stamp in non-volatile memory.
- Maximum demand will be calculated from accumulated imported/exported Active energy for MD interval.
- Maximum Demand and Cumulative Energy for previous six months will be stored in EEPROM
- Configurable MD integration time – 30 and 60 minutes

**Maximum Demand Calculation – Fixed Window Method**
- At the end of each fixed integration period, average power for that period is calculated. If this value is greater than the already existing MD value then this is stored as new MD.
- MD value is cleared in NV memory whenever there is change in date, time or MD integration period.

**MD Reset**
- MD reset by serial communication (optical port). All the MD parameters will be cleared in NV memory.
- MD can be read through serial communication (optical port) with the help of AMR protocol utility.

**MD parameters stored in NV memory**

Following parameters are stored in non-volatile memory:
- Maximum Demand (kW)
- MD Date and Time
4.9.7 Load profile

- Meter shall maintain Load profile data in non-volatile memory as per load profile interval time in circular buffer.
- Load profile parameters for each record
  - Exported kWh for interval period
- Load profile will only be saved for the last 45 days on FIFO basis.
- Load profile records cleared through serial communication (optical port) with the help of In Term utility.
- Load profile records can be read through serial communication (optical port) with the help of AMR protocol utility.
- Load profile of the day on which the Meter was powered off will not be recorded.

For example, let’s assume Load Profile Interval-60 min Meter was powered on for duration in which load profile event storage is triggered on 22nd Nov 2012 and 24th Nov 2012 but it was powered off for whole day on 23rd Nov 2012. Then load profile will not be stored for 23rd November 2012.

**NOTE**

Note: EEPROM Size = 64 Kbytes

Load profile in EEPROM will be stored like shown in the following table:

Table 4-9. Load profile of EEPROM

<table>
<thead>
<tr>
<th>Day 1 (Date)</th>
<th>Day 2 (Date)</th>
<th>Day ...</th>
<th>Day ...</th>
<th>Day 45 (Date)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LP 00:00 to 01:00</td>
<td>LP 00:00 to 01:00</td>
<td>—</td>
<td>—</td>
<td>LP 00:00 to 01:00</td>
</tr>
<tr>
<td>LP 01:00 to 02:00</td>
<td>LP 01:00 to 02:00</td>
<td>—</td>
<td>—</td>
<td>LP 01:00 to 02:00</td>
</tr>
<tr>
<td>LP 02:00 to 03:00</td>
<td>LP 02:00 to 03:00</td>
<td>—</td>
<td>—</td>
<td>LP 02:00 to 03:00</td>
</tr>
<tr>
<td>LP 03:00 to 04:00</td>
<td>LP 03:00 to 04:00</td>
<td>—</td>
<td>—</td>
<td>LP 03:00 to 04:00</td>
</tr>
<tr>
<td>LP 04:00 to 05:00</td>
<td>LP 04:00 to 05:00</td>
<td>—</td>
<td>—</td>
<td>LP 04:00 to 05:00</td>
</tr>
<tr>
<td>LP 05:00 to 06:00</td>
<td>LP 05:00 to 06:00</td>
<td>—</td>
<td>—</td>
<td>LP 05:00 to 06:00</td>
</tr>
<tr>
<td>LP 06:00 to 07:00</td>
<td>LP 06:00 to 07:00</td>
<td>—</td>
<td>—</td>
<td>LP 06:00 to 07:00</td>
</tr>
<tr>
<td>LP 07:00 to 08:00</td>
<td>LP 07:00 to 08:00</td>
<td>—</td>
<td>—</td>
<td>LP 07:00 to 08:00</td>
</tr>
<tr>
<td>LP 08:00 to 09:00</td>
<td>LP 08:00 to 09:00</td>
<td>—</td>
<td>—</td>
<td>LP 08:00 to 09:00</td>
</tr>
<tr>
<td>LP 09:00 to 10:00</td>
<td>LP 09:00 to 10:00</td>
<td>—</td>
<td>—</td>
<td>LP 09:00 to 10:00</td>
</tr>
<tr>
<td>LP 10:00 to 11:00</td>
<td>LP 10:00 to 11:00</td>
<td>—</td>
<td>—</td>
<td>LP 10:00 to 11:00</td>
</tr>
<tr>
<td>LP 11:00 to 12:00</td>
<td>LP 11:00 to 12:00</td>
<td>—</td>
<td>—</td>
<td>LP 11:00 to 12:00</td>
</tr>
<tr>
<td>LP 12:00 to 13:00</td>
<td>LP 12:00 to 13:00</td>
<td>—</td>
<td>—</td>
<td>LP 12:00 to 13:00</td>
</tr>
<tr>
<td>LP 13:00 to 14:00</td>
<td>LP 13:00 to 14:00</td>
<td>—</td>
<td>—</td>
<td>LP 13:00 to 14:00</td>
</tr>
<tr>
<td>LP 14:00 to 15:00</td>
<td>LP 14:00 to 15:00</td>
<td>—</td>
<td>—</td>
<td>LP 14:00 to 15:00</td>
</tr>
<tr>
<td>LP 15:00 to 16:00</td>
<td>LP 15:00 to 16:00</td>
<td>—</td>
<td>—</td>
<td>LP 15:00 to 16:00</td>
</tr>
<tr>
<td>LP 16:00 to 17:00</td>
<td>LP 16:00 to 17:00</td>
<td>—</td>
<td>—</td>
<td>LP 16:00 to 17:00</td>
</tr>
<tr>
<td>LP 17:00 to 18:00</td>
<td>LP 17:00 to 18:00</td>
<td>—</td>
<td>—</td>
<td>LP 17:00 to 18:00</td>
</tr>
<tr>
<td>LP 18:00 to 19:00</td>
<td>LP 18:00 to 19:00</td>
<td>—</td>
<td>—</td>
<td>LP 18:00 to 19:00</td>
</tr>
</tbody>
</table>

*Table continues on the next page...*
Table 4-9. Load profile of EEPROM (continued)

<table>
<thead>
<tr>
<th>Day 1 (Date)</th>
<th>Day 2 (Date)</th>
<th>Day ...</th>
<th>Day ...</th>
<th>Day 45 (Date)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LP 19:00 to 20:00</td>
<td>LP 19:00 to 20:00</td>
<td>—</td>
<td>—</td>
<td>LP 19:00 to 20:00</td>
</tr>
<tr>
<td>LP 20:00 to 21:00</td>
<td>LP 20:00 to 21:00</td>
<td>—</td>
<td>—</td>
<td>LP 20:00 to 21:00</td>
</tr>
<tr>
<td>LP 21:00 to 22:00</td>
<td>LP 21:00 to 22:00</td>
<td>—</td>
<td>—</td>
<td>LP 21:00 to 22:00</td>
</tr>
<tr>
<td>LP 22:00 to 23:00</td>
<td>LP 22:00 to 23:00</td>
<td>—</td>
<td>—</td>
<td>LP 22:00 to 23:00</td>
</tr>
<tr>
<td>LP 23:00 to 00:00</td>
<td>LP 23:00 to 00:00</td>
<td>—</td>
<td>—</td>
<td>LP 23:00 to 00:00</td>
</tr>
</tbody>
</table>

Number of Load profile entries for 45 days depending on the load profile interval is given in the following table:

<table>
<thead>
<tr>
<th>Load Profile Interval</th>
<th>Number of Entries in a day</th>
<th>Total Entries for 45 days</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 min</td>
<td>96</td>
<td>4320</td>
</tr>
<tr>
<td>30 min</td>
<td>48</td>
<td>2160</td>
</tr>
<tr>
<td>60 min</td>
<td>24</td>
<td>1080</td>
</tr>
</tbody>
</table>
Chapter 5
Revision history

5.1 Revision history

<table>
<thead>
<tr>
<th>Revision number</th>
<th>Date</th>
<th>Substantial changes</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>06/2015</td>
<td>Initial release</td>
</tr>
</tbody>
</table>
Appendix A
Schematic

Figure A-1. Schematic
Appendix B
Bill of materials

Table B-1. Bill of materials

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
<th>AgilePN</th>
<th>ASSY OTP</th>
<th>Referenc e</th>
<th>Value</th>
<th>Description</th>
<th>ASSY_OTE</th>
<th>Mfg Name</th>
<th>Mfg Part Number</th>
<th>PCB Footprint</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>801-76144</td>
<td>—</td>
<td>BT1,BT2</td>
<td>CR-2032</td>
<td>BATTERY LITHIUM COIN CELL 3V TH</td>
<td>—</td>
<td>PANASONIC</td>
<td>CR-2032/VCN</td>
<td>bat_2032_th</td>
</tr>
<tr>
<td>2</td>
<td>7</td>
<td>210-79145</td>
<td>DNP</td>
<td>SH1,P_CT 1,CT1,SH 2,P_CT2,CT2,GND</td>
<td>TP</td>
<td>TEST POINT PIN 0.062X0.086 TH, NO PART TO ORDER</td>
<td>—</td>
<td>N/A</td>
<td>N/A</td>
<td>tp_062_086mil_th</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>150-76752</td>
<td>—</td>
<td>C1,C19</td>
<td>0.01 µF</td>
<td>CAP CER 0.01 µF 250V 10% X7R 0805</td>
<td>—</td>
<td>KEMET</td>
<td>C0805C103KARACTU</td>
<td>CC0805_OV</td>
</tr>
<tr>
<td>4</td>
<td>17</td>
<td>150-75599</td>
<td>—</td>
<td>C2,C3,C4,C5,C6,C7,C8,C10,C12,C18,C20,C27,C29,C31,C33,C34,C37</td>
<td>0.1 µF</td>
<td>CAP CER 0.1 µF 25V 10% X7R 0805</td>
<td>—</td>
<td>PANASONIC-ECG</td>
<td>ECJ-2VB1E104K</td>
<td>CC0805_OV</td>
</tr>
<tr>
<td>5</td>
<td>6</td>
<td>150-75594</td>
<td>—</td>
<td>C9,C13,C15,C16,C30,C36</td>
<td>1.0 µF</td>
<td>CAP CER 1.0 µF 10V 10% X7R 0805</td>
<td>—</td>
<td>SMEC</td>
<td>MCCB105K2NRTF</td>
<td>CC0805_OV</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>150-30192</td>
<td>—</td>
<td>C17</td>
<td>470 µF</td>
<td>CAP ALEL 470 µF 35V 20% -- RADIAL</td>
<td>—</td>
<td>Nichicon</td>
<td>UPW1V471MPD</td>
<td>c413_rad_poli</td>
</tr>
<tr>
<td>7</td>
<td>1</td>
<td>150-78638</td>
<td>—</td>
<td>C21</td>
<td>0.22 µF</td>
<td>CAP METPLY 0.22 µF 250VAC 10% -- RADIAL</td>
<td>—</td>
<td>PANASONIC</td>
<td>ECQU2A224KLA</td>
<td>cr709_335</td>
</tr>
</tbody>
</table>

Table continues on the next page...
<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
<th>AgilePN</th>
<th>ASSY_O PT</th>
<th>Referenc e</th>
<th>Value</th>
<th>Description</th>
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Appendix C
Connection diagram

Please refer following picture of the enclosure

Figure C-1. Connection diagram
Figure C-2. Connection diagram
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