Application Note

Designing Smart Rotary Water Meters, Thermal Meters, and Heat Cost Allocators with TI Wireless MCUs

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Abstract

TI's CC1312R, CC1312R7, and CC1314R10 Wireless MCUs integrate a wM-Bus protocol stack with rotation detection metrology and innovative TI-patented segment LCD drive capability with GPIOs. The LCD is enabled upon user request with a Capacitive Touch button and is automatically switched off after a configurable timeout for power savings. Both metrology and LCD functionality are implemented in firmware inside the 16-bit ultra-low power sensor controller engine (SCE) MCU core with 4KB of SRAM. The SCE samples, stores, and processes sensor data independently from the Main M4F or M33 CPU-core.

With extensive security features and cryptographic accelerators, CC1312R, CC1312R7, and CC1314R10 Wireless MCUs offer a complete hardware development platform, making it easy to comply with the EU'S Cyber Resilience Act (CRA) requirements.

The combination of TI-patented MUX resistor network and optimized firmware code enables low-power LCD display functionality, which is mandatory for smart rotary Water Meters and Thermal meters, and Heat Cost Allocators.

The popular Retrofit Add-On wM-Bus-enabled modules for mechanical water meters are another end-equipment type which benefits from the rotary sensing and IrDA link support within these TI Wireless MCUs.

By implementing both LCD control and rotary metrology in ultra-low power in the SCE, TI's single-chip Sub-1GHz Wireless MCU devices enable cost-effective, compact size designs for the fast-growing smart water, thermal meter, and heat cost allocator markets world-wide.

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1 Introduction

The worldwide demand for smart Heat Cost Allocators, Water Meters and Thermal (Heat- and Cold-) meters is growing fast with smart flow meters becoming the predominant type across the world and replacing the legacy mechanical flow meters. Being *smart* means that these meters can communicate over wired or wireless link, either one-way (just reporting the billing relevant data) or bi-directionally, enabling the capability of firmware upgrades in the field.

The 868MHz ISM band is used world-wide because it is license-free and multiple radio protocols exist which transfer meter data to a data collector or a mobile reading unit. Two different network approaches, known as the automated metering infrastructure (AMI) and automated meter reading (AMR) are utilized to establish smart metering infrastructure. The early days of smart metering and sub-metering in the 2000s started with AMR: a mobile reader device in a walk-by or drive-by mode collects wireless telegrams by the meters and then passes those over a dedicated link to the back-end billing system.

The modern approach to remote smart meter reading is AMI: an integrated architecture that connects the smart meters to a permanently installed, continuous fixed Sub-1GHz network, very similar to 4G and 5G cellular networks. This AMI infrastructure consists of multiple data collectors or data gateways and gets installed and maintained by utilities or billing companies.

Both AMI and AMR network architectures are addressed by the OMS protocol stack, which is extremely popular in the EU market, see the OMS Group statement:

OMS is the only open and standardized energy metering system that integrates the consumption values of all energy sectors into one system: Electricity, gas, thermal energy, water – in metering as well as submetering. In addition, OMS is compatible with the international communication standard for building technology KNX. This enables direct integration of building automation, energy management and smart home systems. Communication is based on the proven M-Bus standard.

The OMS wM-Bus v4.2.1 protocol at 868MHz and the C-mode with conducted +14dBm effective radiated power (ERP) is the established standard in many EU countries for Heat Cost Allocators, Water Meters, Thermal meters and Retrofit Add-On modules. New modes, enabling extended range coverage, are defined in OMS wM-Bus v5.0.1 and expected to start deployment soon.

An already popular option for achieving long range (at the expense of higher transmit power and utilizing better RF propagation characteristics) is the 169 MHz ISM band in the EU. This is an established license-free band supported by the EN13757-4 wM-Bus N-mode. The latter is used for smart flow meters readout in Italy and France, with few gateways due to the maximum allowed +27dBm (500mW) ERP power for smart meters, enabling km-wide coverage.

The EUROPEAN SMART METERS DEMAND WM-BUS AT 169 MHz article provides further details on the technical challenges and benefits of using N-mode. Wize technology, a registered trade mark for a low-power, long-range and bi-directional radio communication, is a well-known solution, operating in the 169MHz frequency band in multiple countries.

Sometimes other proprietary protocols are being used in parallel to OMS wM-Bus, either enabling longer communication distance from smart meter to smart gateway or for forwarding data between the smart gateways, which collect data from multiple meters and sub-meters.

Alternatively, cellular technologies, such as NB-IoT, are also entering the smart flow meters market by providing deep penetration and relying on public cellular infrastructure.

1.1 Smart Meter EU Regulations

All smart flow meters also have a pre-defined runtime in the field, often varying between five to ten years and in some markets even longer, after which the meters must be replaced. Any smart meter must provide some form of metrologically controlled display with billing relevant user consumption data. For the EU, this is regulated in the MID 2014/32/EU (Annex I, Essential Requirements) document, stating the display requirements can be met by variety of options. These can be mechanical counters (as in legacy mechanical water meters world-wide), Liquid crystal displays (LCDs) in electronic flow meters, light-emitting diodes (LEDs), or other electronic displays, provided they meet the criteria of the directive for readability, non-ambiguity, and security.

The segment LCD displays are by far the dominant technology in smart flow meters and heat cost allocators. Regulations in the EU do allow us to have the LCD display switched off, but in such case end users must have the possibility to activate it instantly on demand, typically implemented with the help of either a push or capacitive touch button, an optical sensor for lid opening or another user-initiated prompt.

1.2 Rotary Metrology Designs

The metrology function is the key feature, provided by any smart meter device; there are multiple electronic sensing technologies that have been used for decades, with each having advantages and disadvantages.

TI has released the MSP430FR6989 EVM in combination with additional HW, supporting the three most popular sensing methods for the rotary flow meters sensing: inductive (LC-sensing), optical, and magnetic. These reference designs address the high-volume flow metering end equipment, such as hot-water and cold-water meters (popular in Germany), the Retrofit Add-On modules for mechanical meters as well as sub-metering applications, which include both Heat meters and Heat Cost Allocators.

Note that besides rotary flow meters, which still are the dominant technology world-wide, there is also the UltraSonic flow measurement, supported by TI's MSP430FR6043 device family, with ultrasonic flow metering gaining traction in many markets world-wide.

This document focuses on rotary sensing designs with CC1312R, CC1312R7, and CC1314R10 Wireless MCUs, which in many cases allow the development of higher integrated, CRA-compliant designs at the cost of slightly increased power consumption versus MSP430FR6989.

The results presented in this document utilize extensively the ultra-low power SCE module inside the CC1312 and CC1314 device families and prove that integrating rotary metrology, IrDA communications, segment LCD display control with GPIOs, and magnetic tampering in the SCE is feasible.

The market leading ultra-low power consumption numbers, documented in the following sections, are the foundation for developing single-chip metering and sub-metering devices at lower total system cost due to the integrated Sub-1GHz radio and SCE module.

2 Smart Flow Meters and Sub-Metering Devices

The CC1312R SimpleLink™ High-Performance Sub-1 GHz Wireless MCU, designed and manufactured internally at TI, features several unique features: the ultra-low leakage TI CMOS 65nm process and the Ultra-low power Sensor Controller Engine (SCE) with 4KB of SRAM, which can run at either 2MHz or 24MHz. In addition, several dedicated analog peripherals, like programmable current source, analog comparator with internal reference DAC, pulse counter and Time-to-Digital Converter (TDC) are integrated and can be controlled by the SCE module.

State-of-the-art encryption capabilities as AES 128- and 256-bit cryptographic accelerator, TRNG, ECC and RSA public key hardware accelerator, SHA2 accelerator are also included, which makes this platform capable of addressing the upcoming CRA Regulations in EU.

The single-chip CC1312R and CC1314R10 Wireless MCUs, which integrate both a software-defined Sub-1GHz radio system and the programmable 16-bit SCE, are thus able to handle the three most popular rotary metrology methods as well as to control a segment LCD display, using the TI patented LCD control with GPIOs.

2.1 Heat Cost Allocator (Sub-Metering)

Heat Cost Allocators do not directly measure a physical volume of fuel or heat energy in kWh but simply record dimensionless *units* of heat dissipation and for this purpose most HCA devices use the two-sensor principle. Thermal meters, here heat meters, are installed together with HCAs and allow fair billing of the heat energy, per apartment or housing unit. HCA devices have been introduced in Denmark and Germany several decades ago, starting with simple evaporating tubes and moving to fully electronic devices with OMS wM-Bus radio protocol in the mid-2000s.

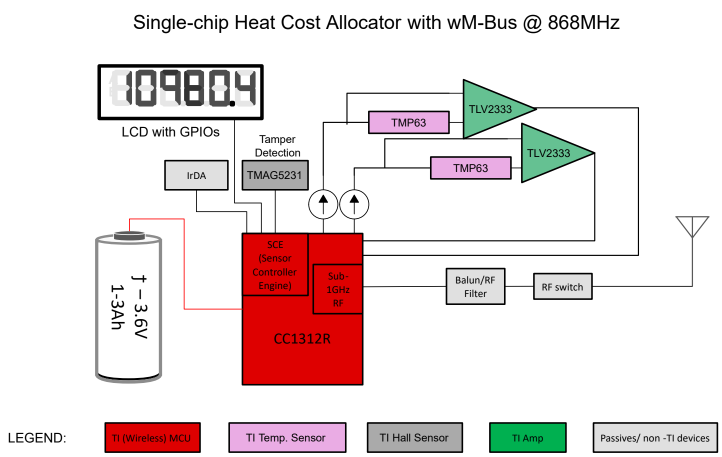

Figure 2-1. Two-Sensor HCA With CC1312R/R7

The EU Energy Efficiency Directive (EED) makes individual sub-metering legally mandatory in all multi-apartment and multi-purpose buildings with collective heating or cooling systems in the EU countries. Note that HCA devices fall under the Remote Readability Mandate: all newly installed HCAs and Thermal meters must be remotely readable. By January 1, 2027, the transition from *legacy* non-electronic and non-smart electronic HCAs must be fully complete, such that a physical entry into the apartments to read the consumption data is no longer required.

Modern digital HCA devices utilize a single Sub-1GHz Wireless CU and two temperature sensors, as shown in Figure 2-1, with radiator sensor measuring the exact surface temperature of the radiator T_{rad}, while the room sensor measures the ambient air temperature T_{air} of the room it is installed in.

2.1.1 HCA Key Functions

The block diagram of a HCA device consists of multiple sub-systems, all controlled by the CRA capable CC1312R Wireless MCU running applications code and the Sub-1GHz wireless protocol (for example, wM-Bus v4.2.1 or v5.0.1):

1. *IrDA half- or full-duplex port in SCE firmware*
2. *Two Temperature sensors (Room and Radiator / Heater)*
3. Sub-1GHz Radio (uni- or bi-directional) with external Balun/RF Filter and Antenna
4. *Segment LCD (optional Button for LCD activation) by SCE firmware*
5. Tamper detection (for example, HCA removal from radiator body)

2.1.1.1 IrDA Communication Port

This key HCA sub-system is used for installation and maintenance and during manufacturing, as a simple way to configure vendor parameters in each HCA device. It is possible to implement a regular polling of the IrDA receive LED to detect a wake-up signal from an external source like an HCA reader unit. Such typical use-case for IrDA is documented in TIDA-01212 "Single Bidirectional Infrared LED Communication Port Reference Design", where a half-duplex IrDA design with ultra-low power and firmware example code in the SCE is provided.

Due to the very minimal HW and FW requirements the IrDA polling functionality from TIDA-01212 can be easily combined with the LCD support from TIDA-00848, both as tasks running within the Sensor Controller Engine. After detecting the polling sequence, see example in Section 2.2.3, the SCE wakes up the main Cortex-MCU which then handles the IrDA protocol data exchange between HCA and the external reader unit.

2.1.1.2 Temperature Measurement (Two-Sensor Method)

Every HCA device is mounted firmly onto the radiator body, and the heater temperature sensor for T_{rad} must have thermal (but not electrical) contact with the body. In contrast, the room temperature sensor for T_{air} is orientated into the opposite direction to the room or away from the radiator body. The HCA device continuously logs the temperature difference over time:

$$DeltaT = T_{rad} - T_{air}$$

If there is an external heat source like an electric heater or direct sunlight shines in, the room sensor senses the air warming up and logs the reduced *DeltaT*.

Two TMP63 Silicon-based thermistors with a positive temperature coefficient (PTC) are combined with a dual TLV2333 Dual, 350kHz, low-noise, RRIO, CMOS operational amplifier for cost-sensitive systems for the dual temperature measurement in HCAs.

Separate circuits for room and radiator sensors have been simulated and proven to provide sufficient temperature resolution when utilizing the full range of the internal ADC12 module. Detailed simulation of the expected performance for each TMP63 circuit is provided within TIDA-00848 Reference design, both sensors are excited by the programmable current source of the SCE module in CC1312R.

For increasing both the measurement accuracy and the resolution, single stage amplification for each sensor is proposed, the main difference being the achievable gain, which depends on two factors: the reference voltage of the ADC12 module and the temperature range supported by each sensor. Using 2.1V as the maximum ADC12 reference voltage, a gain stage of approximately 4 is achieved for the radiator sensor, which covers a large temperature range from 20℃ to 95℃. For the room sensor, with an assumed temperature in 20℃ to 40℃ range, a gain of 12 can be achieved.

2.1.1.3 Segment LCD Support

TIDA-00848 "Single-chip Heat Cost Allocator Reference Design with Segment LCD Control Using GPIO Pins" implements the CapTouch button activation of a Segment LCD display, controlled by GPIOs and TI-patented MUX network.

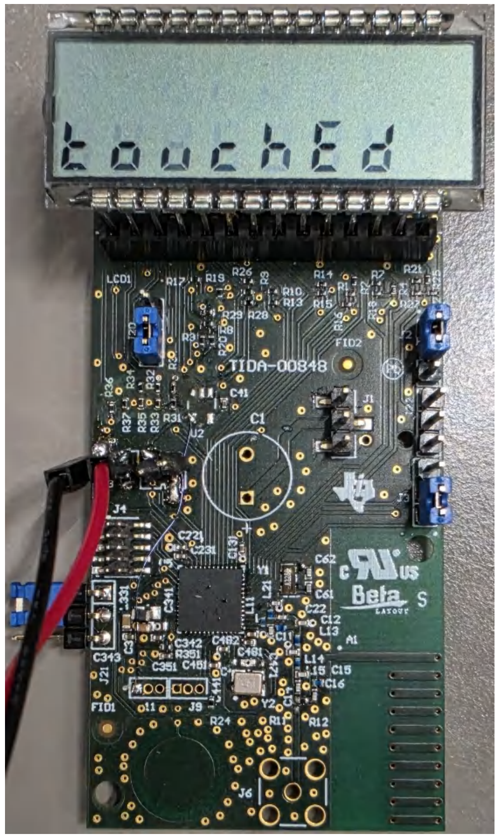

Figure 2-2. TIDA-00848 Single-Chip HCA With CC1312R/R7 and Segment LCD Display

The firmware example in TIDA-00848 has been optimized for ultra-low power consumption, as it uses the LCD resource in Sensor Controller Studio tool, used to develop code for the SCE module. The power consumption is 7.3µA for SCE running LCD timing with segment LCD attached and 11.9µA at 3.3V (28 segments active on BTL002 4-MUX LCD display).

2.2 Retrofit Add-On Module for Mechanical Water Meters

This end equipment is used as a fast and cost-efficient design to make the world's still most popular mechanical water meters *smart* by adding an electronic Retrofit Add-On module. This electronic assembly integrates four key sub-systems: metrology, Sub-1GHz wireless link, tamper detection, and an identical to Section 2.1.1.1 IrDA communication port. As the mechanical dials of the legacy rotary water meter are still visible, there is no need for segment LCD display, nor is any temperature measurement required.

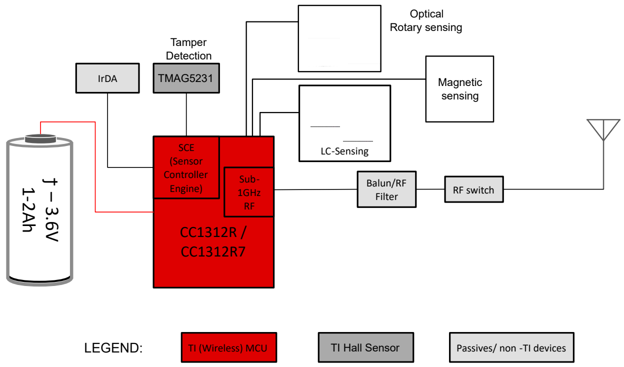

Figure 2-3. wM-Bus Enabled Retrofit Add-On Module for Mechanical Water Meter With CC1312R / R7

2.2.1 Retrofit Add-On Module Key Functions

The block diagram, as shown in Figure 2-3, integrates these sub-systems, all controlled by the CRA capable CC1312R Wireless MCU running applications code and the Sub-1GHz wireless protocol (for example, OMS wM-Bus v4.2.1 or v5.0.1):

1. IrDA half- or full-duplex port
2. Sub-1GHz Radio (uni-directional or bi-directional) with external Balun/RF Filter and Antenna (same as for HCA)
3. Tamper detection (Retrofit AddOn module removal from the mechanical Water Meter or detection of strong magnetic fields near the unit – same/very similar to HCA)
4. Metrology for rotary movement: either optical or inductive or magnetic (flow metrology sub-system)

Note

Capacitive sensing designs for rotary detection also exist, though these are much less widespread, so they are not reviewed in this document.

2.2.2 Rotary Flow Metrology Implementation

A HW prototype with CC1312R in a half-circle form-factor has been developed and tested internally, with focus on ultra-low power consumption. Typically, for best RF performance, four layers PCB design is recommended, which also gives more flexibility for the placement and routing of the components in the small half-circle area.

The most popular sensing methods are optical and inductive, and these are reviewed in the following sections.

2.2.2.1 Optical and Magnetic Rotary Sensing

The firmware code for both the metrology and the IrDA comms is running on the SCE module in 2MHz mode, with both tasks interleaved. The flow measurement has been emulated by the following procedure, running at 12Hz:

1. Emit an excitation pulse with 1µs duration and measure receiving signal against a COMPA threshold value, save result A
2. Emit an excitation pulse with 1µs duration and measure receiving signal against a COMPA threshold value, save result B
3. Update the rotation state of a state machine using the two-measurement results A and B and convert into rotation count for the flow measurement

The 1µs excitation pulses here can be used for both optical and inductive (LC-) sensing, depending on which metrology method is chosen. The state machine implementation in SCE firmware is identical to the design documented in TIDA-010050 "Ultra-low power water flow measurement for AMR reference design" with LC-sensing.

The 12Hz measurement is shown by the power analyzer capture in Figure 2-4 showing 12 spikes in a second where each spike includes the two pulses for each measurement. The two higher spikes are the re-charge pulses for the Sensor Controller Engine (see Markers 1 and 2 with Delta T= 1s).

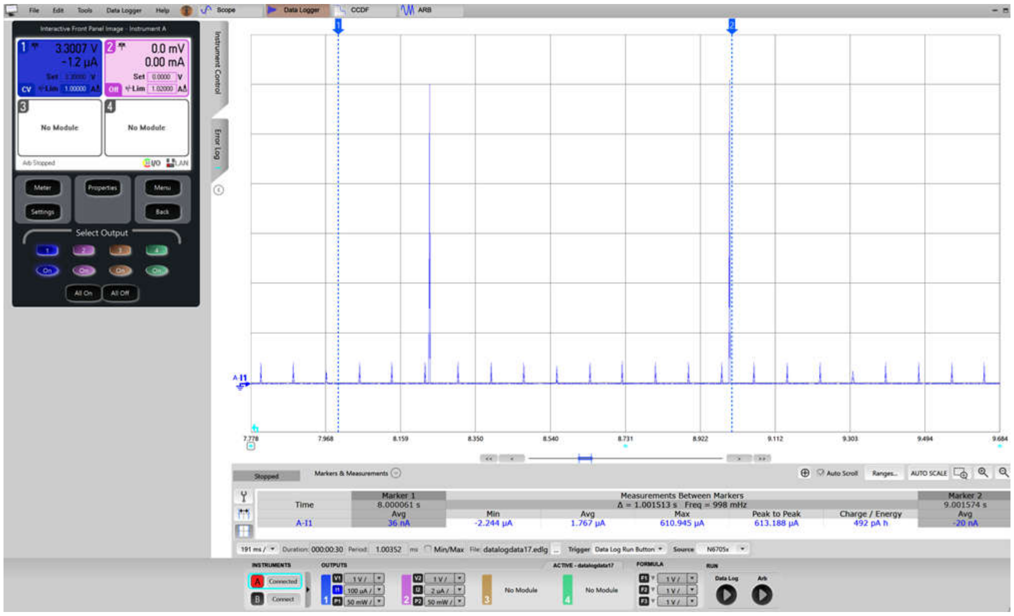

Figure 2-4. Dual Rotary Sensor Excitation at 12Hz with CC1312R

The average power consumption of 1.8µA in Figure 2-4 is a good starting point for estimating the power consumption for the optical or the magnetic sensing approach. There is additional power needed to sense the two (or three if required) optical receivers, which need to detect the reflected light from the half-covered with metal rotary disc being commonly used in many mechanical water meters. For the magnetic sensing using AMR or TMR or GMR sensors, the differential output is fed to the two inputs of the comparator and the result is sampled at the desired sampling frequency, depending on the maximum rotation speed of the magnet used.

2.2.2.2 Inductive Rotary Sensing

Possibly the most popular rotary flow measurement world-wide is the inductive or LC-method, utilizing two or three LC-sensors and documented in TIDA-010050 "Ultra-Low Power Water Flow Measurement for AMR Reference Design". This ultra-low power design for electronic measurement of water flow through a mechanical meter focuses on inductive metrology sub-system for Retrofit Add-On modules or smart rotary water meters. This very compact, single-chip CC1312R Wireless MCU implementation consumes 1.8µA while sampling two LC-sensors at 16Hz with 3.3V power supply, allowing accurate measurement at up to 5.8mm distance between Inductors and the rotating disc.

As the rotating disc inside the mechanical meter is normally behind a glass or plastic cover, and the Retrofit Add-On module is also in a plastic enclosure, the LC sensor inductors is always a few millimeters away from the disc. Supporting larger detection distance, typically in the range of 5mm to 6mm, is a key requirement for any rotary sensing method.

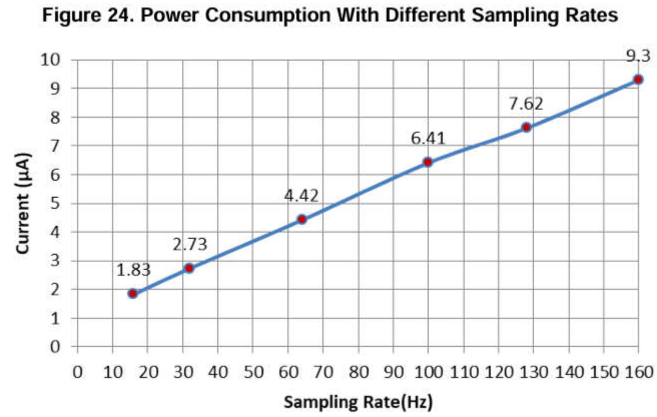

Figure 2-5. Sampling Rate of Two LC-Sensors vs Power

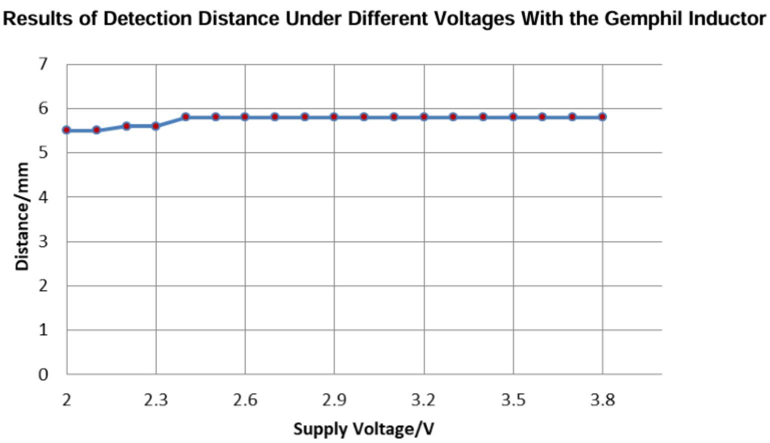

Figure 2-6. Distance L to Half-Plated Disc

To confirm the support for LiMnO2 primary cells, which start with up to 3.2V open circuit voltage and have a typical cut-off voltage at 2V at the end of their lifetime, the data in Table 2-2 has been collected:

Table 2-1. TIDA-010050 Circuit with Two LC-Sensors Power Consumption

Supply Voltage (V)	2	2.1	2.2	2.5	3	3.3	3.5	3.8
Current (µA)	4.5	4.6	4.8	4.3	4.4	4.4	4.5	4.8
Power (µW)	9	9.7	10.5	10.7	13.3	14.6	15.9	18.2

2.2.3 IrDA Wake-Up Detection

For the TI internal hardware prototype with CC1312R for RetrofitAddOn module, example code has been developed and tested and is also available for download (this AN), The routine for the IrDA wake-up sequence is executed after every 12th dual pulse flow measurement, resulting in a sampling rate of 1Hz. An IrDA wake-up sequence, defined here as "0xF0" byte, must be detected: hence, an IR LED is charged and discharged sequentially seven times at a rate of 9600bps and in the presence of IR light, the voltage drops after the discharge timeout if 1 / 9600 = 104us is significantly larger. By checking this voltage drop against a pre-defined COMPA reference threshold, it is possible to reliably detect an IrDA '0' bit, in Figure 2-7 these are the *larger* spikes which go down to slightly below 0V.

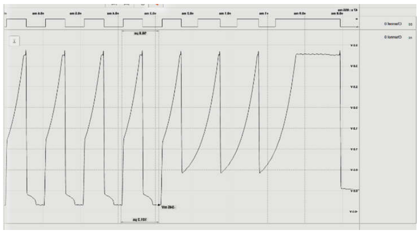

Figure 2-7. IrDA Detection 5cm Apart

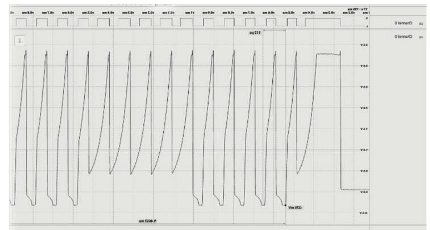

Figure 2-8. IrDA Detection 10cm Apart

If at least one of the '0' bits is detected, the Sensor Controller checks for additional 30 bits at 9600bps to avoid false wakeups, and if at least five '0' bits are then detected, the Main MCU in CC1312 is started to handle the IrDA protocol. In the normal case (no IR light present) the IrDA detection adds an additional approximately 904us of execution every 12th iteration. In the presence of IR light, the duration is about 4ms due to the extra 30 bits checked before waking up.

The power consumption for the combined SCE code for Metrology and IrDA wake-up detection check is shown in Table 2-2:

Table 2-2. Retrofit AddOn Module Power Consumption for 12Hz Dual Sensor Read and IrDA Polling

Power Measurement	Average Current Consumption (uA)
Flow measurement without IrDA	1.4
Flow measurement with IrDA sampled at 1Hz	1.6
Flow measurement with IrDA sampled at 0.5Hz	1.5

2.3 Smart Rotary Water Meter

These are fully electronic devices with integrated Sub1-GHz communication link, a segment LCD display which replaces the mechanical dials, and utilize same metrology function: either optical, magnetic or inductive, as in the Retrofit AddOn modules. Smart water meters also integrate magnetic tamper detection and an IrDA communication link and sometimes support multiple Sub-1GHz wireless protocols, like OMS wM-Bus and proprietary and BLE.

These meters are also referred to as a rotary piston or volumetric smart water meters and measure water consumption using a mechanical rotating element, often a piston or nutating disc that rotates inside the volumetric chamber. An integrated metrology sub-system senses the disc rotation, digitizes the flow measurement and transmits wirelessly the data to a smart gateway or mobile reader unit.

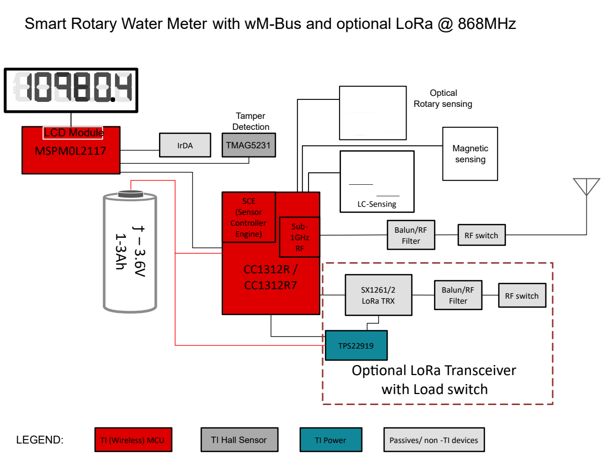

Figure 2-9. Two MCU

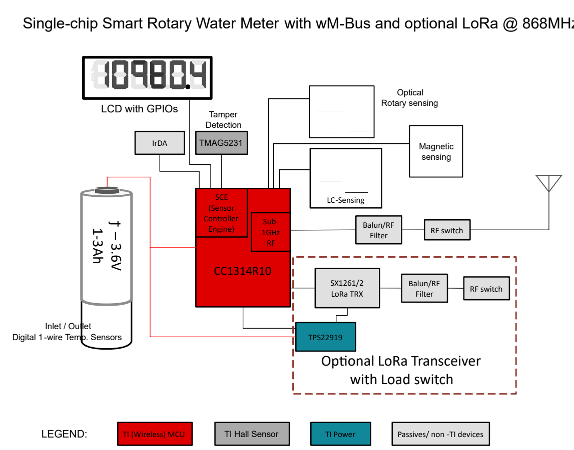

Figure 2-10. Single-Chip Smart Rotary Water Meter With wM-Bus v5.0.1 and optional proprietary WAN

2.3.1 Water Meter Key Functions

The rotary smart water meter block diagram in Figure 2-10 shows multiple sub-systems, all controlled by the CRA capable CC1312R or CC1314R10 Wireless MCU running applications code and the Sub-1GHz wireless protocol (for example, OMS wM-Bus v4.2.1 or v5.0.1):

1. IrDA half- or full-duplex port
2. Sub-1GHz Radio (uni- or bi-directional) with external Balun/RF Filter and Antenna
3. Segment LCD display (with a Button for LCD activation) controlled by SCE firmware
4. Tamper detection (for example, HCA removal from Heater) with TMAG5231

On the left the two MCU approach for LCD always on is presented, here the MSPM0L2117 is used as LCD driver and also can handle the IrDA port and the Tamper detection functionality, offloading the CC1312R device.

If the segment LCD with GPIOs is used, then the second block diagram to the right applies, with CC1314R10 running all LCD control GPIOs in addition to the IrDA port and Magnetic Tampering functions. This design is suited for water meters where the LCD display is typically off and only gets enabled by the user with a Button.

Optionally, an external SPI Flash device (not drawn) can be added on the SPI bus and powered by TPS22919 Load switch to store historical log data or backup firmware image, in the rare case when on chip *1MB Flash* size of CC1314R10 is not sufficient to meet the system requirements.

Another optional device is the transceiver SX1261 or SX1262 by SEMTECH, enabling the proprietary long range Sub-1GHz protocol LoRa WAN, which may be used in some markets. The LoRa WAN software stack runs on CC1314R10 device, which features 296KB of SRAM memory, enabling dual-stack support for wM-Bus and proprietary long range protocols. Both SX126x and the SPI Flash devices are BOM population options and can be simply left out, if not required, providing a flexible system design with a single PCB design which covers multiple configurations across different markets.

The reason for selecting CC1314R10 over CC1312R/R7 for the Water Meter is the higher number of GPIOs required, due to the Segment LCD function. The VQFN64 8mm × 8mm RSK package with 46 GPIOs ensures that there are sufficient GPIOs for the LCD control, as Water Meter displays typically have 80 to 120 segments. TIDA-011020 would use 30 GPIO pins to drive a 96 segment 4 MUX LCD display, for handling the metrology and tampering and the IrDA communication functions the other 16 GPIOs are a must have.

For power saving, the load switch TPS22919 with typical shutdown current ISD of 2nA is added, it enables power to the SX126x and the SPI Flash devices only when these functions are used; otherwise, they are powered off by the load switch. The TPS22919 can be also left populated, when neither proprietary long-range radio nor SPI Flash are required.

2.3.2 Segment LCD with CapTouch Activation

TI's patented MUX LCD control with GPIOs in Figure 2-11 and Figure 2-12 has been implemented in TIDA-011020 as a BoosterPack™ evaluation board for TI LaunchPads™:

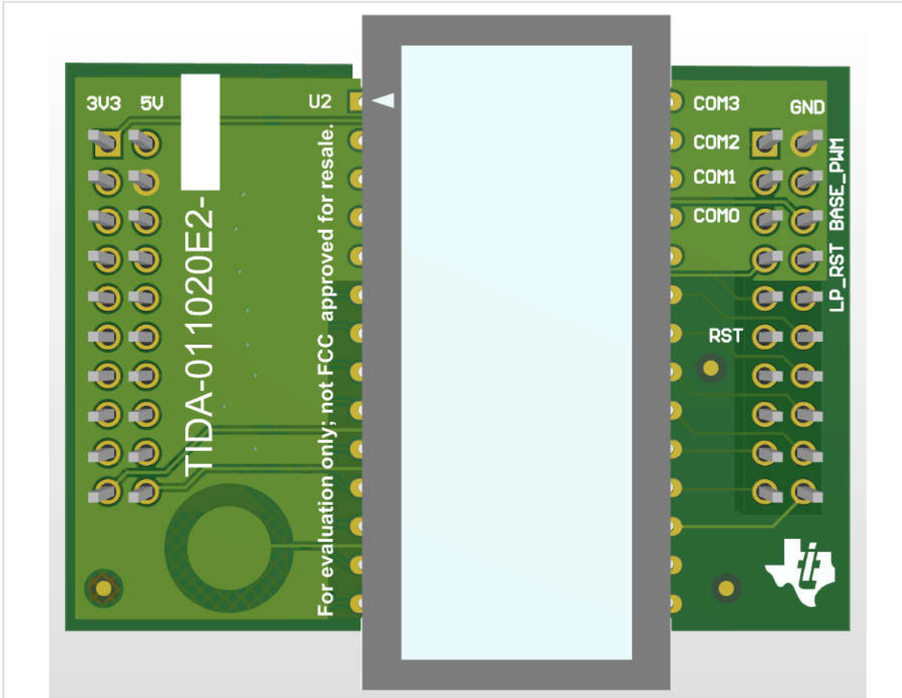

Figure 2-11. TI's Patented MUX LCD as a BoosterPack Design TIDA-011020

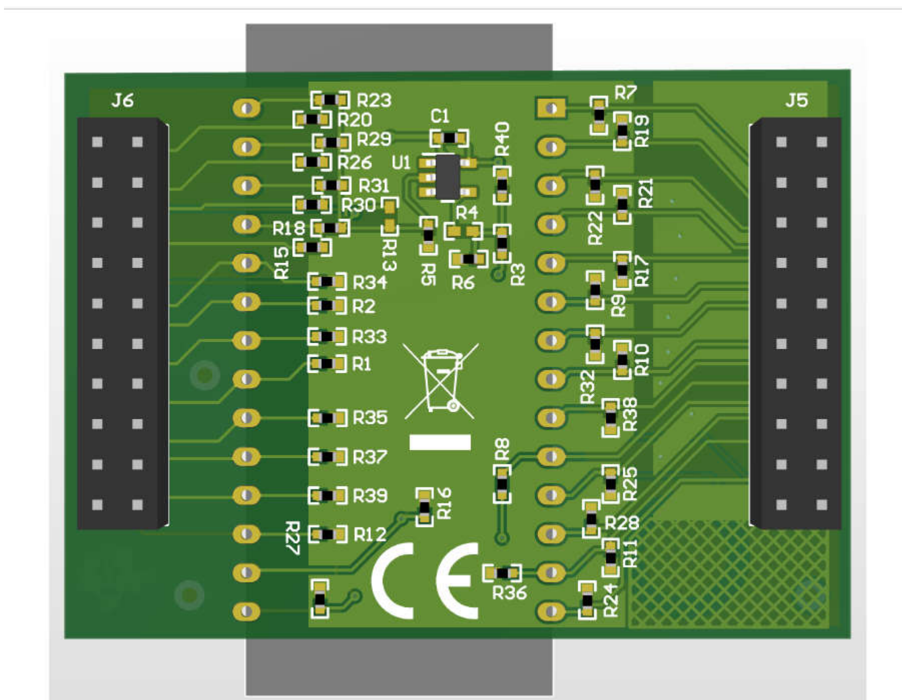

Figure 2-12. TIDA-011020 Bottom Side View

This is the same design as in TIDA-00848 single-chip HCA Reference design and also uses a CapTouch activation of a Segment LCD display, controlled by GPIOs and TI patented MUX network and optimized for ultra-low power consumption. The SCE code for LCD control combined with a CCS example for CC1312R LPAD is provided in the software package for this application note.

Note

This TI patented design for driving segmented LCD displays with Multiplexer Resistor network can only be used free of charge in combination with any wired or wireless MCU products by Texas Instruments Inc., such as MSPM0+, MSPM33, C2000™, CC13xx, CC26xx and CC27xx families and others.

The SCE code is polling the CapTouch area every second (the 1s period is adjustable) and if a touch event is detected, the segment LCD is activated until a pre-defined timeout of 5s (also an adjustable period) expires. Then the LCD is deactivated to save power until the next touch event is detected. Real use case analysis shows that total LCD activity can be 1% or less of the lifetime of the smart meter device and thus save significant power compared to *always on* LCD designs.

For all metering and sub-metering devices, where the LCD activity can be enabled for a short duration upon user request, this TI-patented design is recommended. The full details of the SW and HW implementation with SCE and open-source code example are documented in the TIDA-00848 reference design.

2.3.3 Tamper Detection With TMAG5231

The TMAG5231 is an in-plane Hall-effect switch designed to replace TMR, AMR, and Reed switches used in applications where cost is a priority. When the applied magnetics flux density through the sensor axis of sensitivity exceeds the operate point threshold (BOP), the device outputs a low voltage. The output stays low until the magnetic flux density decreases to less than the release point threshold (BRP), after which the device outputs a high voltage. To minimize power consumption, the TMAG5233 device version is internally duty-cycled down to 5Hz with an average power consumption of only 0.55uA. Due to the fast startup time of 32us and a maximum supply current of 2.6mA, TMAG5233 supply pin can be powered with a medium strength capable GPIO pin on CC1314R10 and additionally duty cycled to reduce the effective sampling rate to 1Hz or below. Thus, two GPIOs are needed to power and read out the TMAG5233 sensor, and this design has been implemented and tested on the internal Retrofit AddOn design, together with the IrDA communication and 12Hz metrology sampling rate. The SCE code example to power on and check the TMAG5233 output signal is provided in the open-source code example.

2.3.4 OMS Compliant wM-Bus Communication Sub-system

If only the widely used OMS wM-Bus protocol in the 868MHz band or the so-called N-mode at 169MHz, popular in Italy and France, is implemented, CC1312R/R7 and CC1314R10 handles it on chip. Only for proprietary long range use cases, the SX1262 transceiver can be used, while the dual protocol stack runs on TI's CC1312R/R7 or CC1314R10 Wireless MCUs.

The dual-band Sub-1GHz and 2.4GHz devices CC1352R/CC1352P and CC1354R10 / CC1354P10 offer an additional capability of running protocols in the 2.4GHz band, for example Matter and BLE. These protocols, due to the short-range coverage, are designed for implementing vendor tools for installation and configuration, using smart phones or tablets.

2.4 Thermal Meters (Heat / Cold)

Smart rotary Thermal meters are fully electronic devices with integrated sub 1GHz communication link, a segment LCD display and rotary metrology function. They also have magnetic tamper detection, use IrDA communication and simply said, thermal meters are the superset of water meters as they add one new key functionality: the precise temperature measurement of two, three or four RTD elements, also called PT100, PT500 or PT1000.

2.4.1 Thermal Meter Key Functions

The rotary smart Thermal Meter block diagram in Figure 2-13 shows multiple sub-systems, all controlled by the CRA capable CC1314R10 Wireless MCU running applications code and the Sub-1GHz wireless protocol (for example, wM-Bus v4.2.1 or v5.0.1):

1. IrDA half- or full-duplex port SCE firmware
2. Sub-1GHz Radio (uni- or bi-directional) with external Balun/RF Filter and Antenna
3. Segment LCD display (with a Button for LCD activation) controlled by SCE firmware
4. Tamper detection (for example, HCA removal from Heater) with TMAG5231
5. *Precise temperature measurement (analog or digital)*

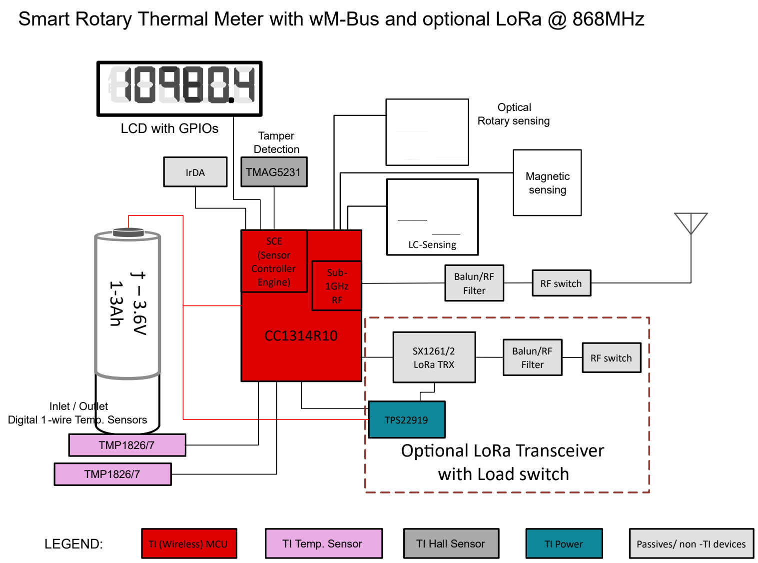

Figure 2-13. Smart Rotary Thermal Meter With CC1314R10 and Digital 1-Wire Temperature Sensors

The temperature designs for thermal meters requires differential temperature measurement (DTM) subsystem of much higher resolution and accuracy compared to HCAs two-sensor measurement.

2.4.2 Analog Signal Chain for DTM

Typically, 24-bit delta-sigma analog converters as the ADS122U04, are utilized, to achieve compliance with EN1434-5:2014 RTD sensor pair temperature measurement sub-systems in thermal meters and heat calculators. This traditional approach for DTM in thermal meters has been documented in *TIDA-01526 High-Precision Temperature Measurement for Heat and Cold Meters*, as it supports standard PT100, PT500 and PT1000 elements.

Such RTD measurement, works well with both the rotary MSP430FR6989 EVM and ultrasonic MSP430FR6043 EVM and meets all requirements as per EN1434, mandatory for thermal meters. The disadvantage of this design is the added complexity of fine-tuned and calibrated analog signal chain with an extra precision ADC device.

2.4.3 Remarkable, Fully Digital Design for DTM

In 2019 TI, together with partner JUMO GmbH & Co. KG, introduced *TIDA-010002: Replacing Platinum RTD Sensors With Digital Temperature Sensors*: a fully digital design approach for Thermal meters precision temperature sub-system.

TMP117, a 0.1°C digital temperature sensor with 48-bit EEPROM is aimed as PT100/PT1000 RTD replacement, as it requires no calibration to meet IEC/EN 60751-2008 Class A accuracy from –55°C to 150°C and only a single-point calibration for achieving Class AA accuracy. This innovative technical design utilizes the integrated precision ADC core and the proprietary calibration techniques in TMP117 and simplifies the design effort by removing many of the complexities of RTDs such as precision references, matched traces, complicated algorithms, and multiple calibration steps in manufacturing.

2.4.3.1 I2C and SMBus-Compatible Digital Sensor for Thermal Meters

TIDA-010002 uses I2C digital interfaces, as they are being supported by virtually all wired and wireless MCUs, available today. The disadvantage of I2C protocol designs, are the four wires for each RTD replacement temperature sensor, one for the inlet and the second for the outlet flow. Typically, residential thermal meters need two 2-wire RTD probes, which are firmly fixed to the device and cannot be replaced. The 4-wire configuration offsets to a large extent the cost savings, achieved by eliminating the complex analog chain design with TMP117 and has driven the need for the next generation solution with two copper wires only.

2.4.3.2 1-Wire Compatible Digital Sensor for Thermal Meters

Building upon the high accuracy TMP117 device, the TMP1826 digital integrated ±0.2°C temperature sensor, compatible with 1-Wire® protocol has been developed. The use of 1-Wire® protocol enables the implementation of two-wire digital temperature sensors as an alternative to the common two-wire RTD100/500/1000 sensors. While the exterior look and feel of analog RTD elements and TMP1826 1-Wire™ temperature sensors are identical, it is important to note that these are not pin-to-pin compatible. The legacy analog result elements require a programmable current source excitation to measure the voltage drop across the PT element inside using a precision ADC, such as ADS1220. The digital sensor needs a simple digital 1-wire protocol to a MCU core, with one data line and one ground line.

With TMP1826 and the pin-to-pin TMP1827 with integrated SHA-256 authenticator, TI enables significant system cost reductions by radically simplifying the manufacturing flow for thermal meters calibration.

Table 2-3. Comparison Between Standard RTDs and 1-Wire Digital Temperature Sensors

	RTD	TMP1826/7 1-Wire
Total Wires	2	2
Recommended Max. Length	10m	300m
Analog signal chain	Yes	No (Inside TMP1826/7)
Programmable Current Source needed	Yes	None
Precision reference resistor	Yes	None
Layout complexity	High, matched traces and Kelvin connection	None (Digital interface)
Calibration points	3	1
Vendor information (per sensor)	Not possible	2kbit EEPROM
NIST traceability	Not possible	Yes (Factory programmed)

2.5 Bluetooth® Low Energy (BLE) in Flow Meters

The dual-band CC2652 and CC2654 Wireless MCUs are adding extra support for 2.4GHz ISM radio band and can handle time-multiplexed communication on both Sub-1GHz and 2.4GHz ISM bands. With dual-band radio sub-system all major protocols are supported: 6LoWPAN, Amazon Sidewalk, Bluetooth Low Energy (BLE), IEEE 802.15.4, MIOTY™, Matter, Proprietary, Proprietary 2.4GHz, Thread, Wi-SUN, OMS Wireless M-Bus v5.0.1, and Zigbee.

The 2.4GHz band can be particularly useful as enabler for BLE installation and configuration tools, which run on a smart phone or tablet device using a mobile application. The BLE protocol is supported by almost 100% of the mobile devices today and represents a major improvement over legacy designs which traditionally rely on IrDA communication protocol, due to its high data rate, bidirectionality and ease-of-use for end users and metering vendors.

2.6 Influence of CRA on Smart Flow Meters and Heat Cost Allocators

The European Cyber Resilience Act (CRA, Regulation EU 2024/2847) is an EU-wide regulation establishing mandatory cybersecurity requirements for all products with digital elements placed on the EU market. It entered into force on December 10, 2024, with full enforcement applying from December 11, 2027. The regulation covers any hardware or software product that processes digital data and is intended, or reasonably expected, to be connected to another device or a network. This definition encompasses all modern smart flow meters and Heat Cost Allocators.

A fundamental principle of the CRA is that it applies to the complete finished product placed on the market. While TI pursues certifications for its devices (like Wireless MCUs) for selling them on the EU market, it is the meter vendor who bears responsibility for verifying that the complete product meets all applicable CRA requirements as a system and affixes the CE marking accordingly. A CRA certified semiconductor product does not automatically confer CRA compliance on the finished meter product.

The CRA classifies products with digital elements into four categories with progressively stringent conformity assessment obligations:

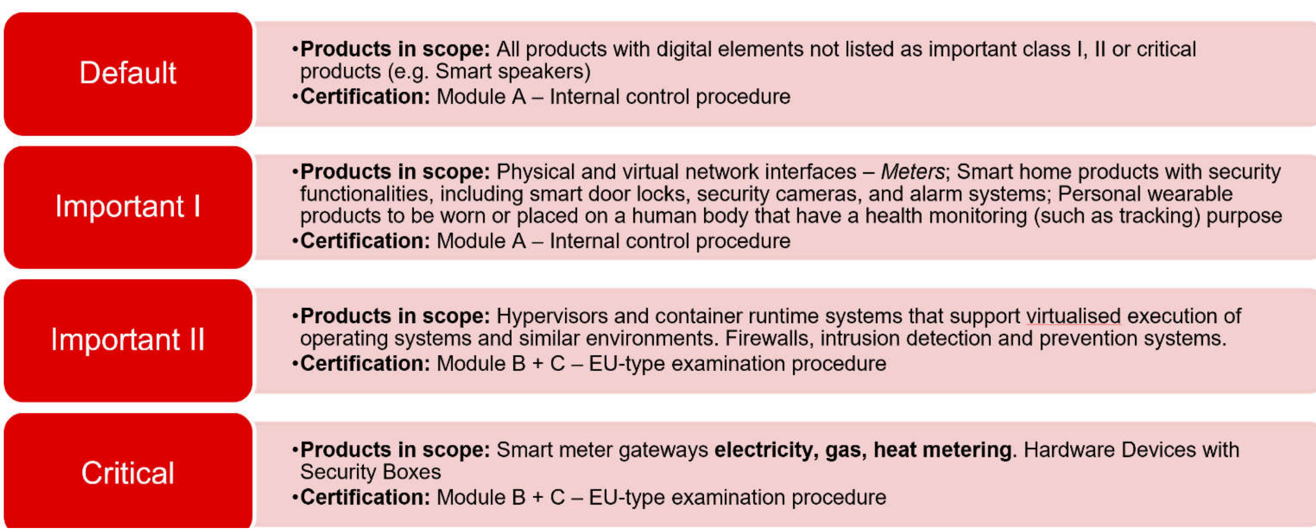

Figure 2-14. Product Categories in CRA

Meters are listed in the Important I category. This includes Smart Water Meters, Thermal Meters, and Retrofit Add-On modules. Heat Cost Allocators are not explicitly listed as products under the CRA but because they collect user data and transmit it to a gateway, exactly as smart flow meters do, they are likely to be classified as Important Class I devices, requiring at minimum a self-declaration of conformity applying relevant harmonized standards.

The key requirements of CRA are outlined as essential cybersecurity requirements in Annex I of the law. These include the development process and lifetime requirements.

1. Development requirements:
   - **Security by design and by default:** Security features must be active in the default product configuration, not optional add-ons. No known exploitable vulnerabilities at the time of market placement.
   - **Technical documentation:** A technical file including a Software Bill of Materials (SBOM), Threat and Risk Assessment (TARA), test reports, and a security update policy maintained for the support period.
   - **Security event logging:** The product must record security-relevant events and take appropriate action.
2. Life cycle requirements:
   - **Vulnerability handling process:** The OEM must provide a portal where discovered vulnerabilities can be reported. These need to be processed and if confirmed disclosed within the defined response timelines (acknowledgment within 24 hours, patches within 30, 60, or 90 days depending on severity, and ENISA notification for significant vulnerabilities).
   - **Post-market surveillance:** The OEM must actively monitor deployed products for new vulnerabilities and issue security updates throughout the declared support period. These security updates can require over the air updates for deployed devices.

2.6.1 Achieving CRA Conformance Through Careful System Design

CRA conformance for HCA and smart flow meters requires security architecture that addresses both the hardware root of trust and the full product lifecycle from design through post-market vulnerability handling. The central design argument available to HCA and Smart Flow Meter manufacturers is that the sealed, tamper-monitored housing defines a physical security perimeter: all components inside the casing operate within a trusted environment, provided the device enforces verified boot process and the wireless link uses authenticated, encrypted communication.

2.6.1.1 Tamper Detection as a Physical Security Argument

Smart flow meters and HCAs are field-deployed devices accessible to end users, hence CRA requires protection against unauthorized physical access. As described in Section 2.3.3, the TMAG5231 Hall-effect sensor implements tamper detection by monitoring for device removal from the heater or for exposure to strong external magnetic fields. When tampering is detected, the CC1312R Wireless MCU can log the event with a timestamp, raise an alarm over the wireless link, and optionally erase sensitive data.

This mechanism satisfies two CRA Annex I requirements at the same time: the mechanism provides protection from unauthorized access, and enables recording and monitoring of security relevant events. The mechanism also underpins the compliance argument for the internal architecture: because any breach of the physical housing boundary triggers a detectable, logged event, the internal components - MCU, firmware, cryptographic keys, and metering data - can be treated as operating within a monitored trust boundary.

2.6.1.2 Secure Key Storage

The above argument for protected housing can be leveraged to argue that any key stored on the device inside the enclosure is secure. Once a breach is detected, one must erase the cryptographic key to prevent unauthorized access to the network. If further application separation is needed to prevent certain parts of the software accessing the cryptographic key, the Trust Zone feature of the CC1314 and CC1354 can be used.

2.6.1.3 Secure Boot

All CC1312 devices relevant to HCA and Smart Flow Meter designs support secure boot. The previous generation CC1310 device uses the Boot Image Manager (BIM), while all newer devices use MCUBoot, which verifies the digital signature of each firmware image before allowing execution. This prevents execution of unauthorized or corrupted firmware images, directly satisfying the CRA requirement for an appropriate level of cybersecurity.

An additional aspect is the security of the whole system while booting. One can argue that the tamper detection securing the product is not active to protect physical access. This can be mitigated through clear security guidelines, making sure that only a trusted person installs and boots the device. Afterwards, the tamper detection can be used to trigger steps in the event of unauthorized physical access to the device.

2.6.1.4 Authenticated wM-Bus Communication

OMS wM-Bus v4.5.1 supports security profiles A or B (encryption modes 5 and 7), which provide an AES-128 authenticated encryption for all wireless data frames, protecting metering data in transit against eavesdropping and manipulation. This directly meets the CRA requirement for confidentiality and integrity of data, commands, and programs transmitted by the product. The cryptographic accelerators of the CC1312 and CC1314 wireless MCUs can be used to efficiently run the encryption.

2.6.1.5 Secure Firmware Update via Over-the-Air Download (OAD)

The CRA mandates that security patches can be deployed to products already in the field. CC1312R7 and CC1314R10 support On-Chip OTA via MCUBoot, where a new firmware image is received over the Sub-1GHz radio link, cryptographically verified, and applied without requiring physical access to the device. This is the primary mechanism for satisfying the CRA vulnerability remediation timeline requirements. CC1312R supports Off-Chip OAD, staging the new image in external SPI Flash before verification and application. In all cases, OTA image transfers must be AES-128-encrypted and ECDSA- or CMAC-authenticated to prevent installation of unauthorized firmware images.

2.6.1.6 Security Event Logging

The CC1312 and CC1314 SDK provides the TI Logger driver, which records security-relevant events with timestamps: tamper alerts, failed authentication attempts, OAD operations, and interface lock state changes. These logs satisfy the CRA requirement to record and monitor security-relevant events and form part of the post-market surveillance evidence required from the OEM.

3 Summary

TI's single-chip CC1312R, CC1312R7, and CC1314R10 Wireless MCUs offer support for OMS wM-Bus protocol stack on-chip and optionally run proprietary long-range protocol stacks for off-chip transceivers. With their extensive security features and cryptographic accelerators, CC1312R, CC1312R7, and CC1314R10 Wireless MCUs offer an optimized hardware development platform for smart rotary Water Meters, Thermal Meters and Heat Cost Allocators, able to address the stringent EU CRA requirements.

Three key features enable cost-efficient system designs for smart rotary Water and Thermal meters, Retrofit Add-On modules and HCAs:

1. CRA ready with latest EU regulations
2. Ultra Low-power consumption over the full temperature range up to +105℃
3. Highly integrated design (LCD) with TI-patented Segment LCD drive capability with GPIOs.

By combining these three highlighted features with ultra-low power rotation detection metrology in the SCE module, TI's SimpleLink Arm Cortex CC1312R/R7 and CC1314R10 Wireless MCUs enable cost-effective, compact size designs for the fast-growing smart flow meters and Heat Cost Allocator markets worldwide.

The presented system design also address single-chip smart Thermal meters and Retrofit Add-On wM-Bus enabled radio modules for mechanical water meters. All these end equipment types have been analyzed and an optimized HW architecture for each type with very small PCB footprint has been presented.

Firmware open source code implementations for LC-sensing, magnetic tamper detection, segment LCD drive capability with GPIOs and IrDA communications have been tested, with the ultra-low power examples for each function provided here.

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