MICRO CRYSTAL SWITZERLAND

White Paper

Keep Accurate Track of Time and Temperature while Saving Power with RV-3032-C7 Real-Time Clock Module

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Content

1. Introduction

Real-Time Clocks (RTCs) are used in a variety of applications where they play a critical role in keeping an updated track of the current time while providing alarms, timer and interrupt functions. RTCs are most often used when humans need a smart device to interact with them in daily life. Fitness bands all have RTCs because most people want to know when and how long an event occurred with respect to times that they can relate to. An RTC design generally contains as well a long-life battery to allow it to keep track of the time even when there is no main power applied.

RTC ICs combined with an external quartz crystal or fully integrated RTC modules are known solutions to improve today's design of personal electronics, medical devices, or industrial products where power savings and backup timekeeping are at premium. RTCs can also help designers address the challenges of designs where increased performance and added features are built into smaller and smaller form factor.

Increased performance

Use of an RTC allows the designer to power down the microcontroller resulting in significant power savings.
Even if microcontrollers with integrated RTCs can go into a sleep or low-power modes, the clock needs to keep running in order to provide accurate time-keeping and alarm functions. Microcontroller power consumption, even with only the internal RTC function active, is far above the one of external RTC. Ultra-low quiescent current achieved by today's RTC circuits allows an extended battery life limited by battery lifetime rather than by the RTC energy drain.

Reduced form factors

In order to simplify the implementation of time tracking in a system, designers are keen to use fully and highly integrated RTC module components in a small form factor as a replacement of quartz crystal resonators combined with specific load capacitors and driven by active circuits found in microcontrollers or RTC ASICs. It is even possible to save on other external components when using a RTC module with integrated functionalities like smart power management (trickle charger or automatic battery backup switch) and event interrupts.

Why add a temperature sensor?

One of the main datasheet specification of an RTC is its clock-over-time stability, expressed in parts/million (ppm) and linked to gain or loss of seconds per day, minutes per year.

As the timing reference used in RTCs is a 32.768 kHz tuning fork crystal resonator, the time deviation is directly linked to its intrinsic material characteristics. Due to its negative temperature coefficient with a parabolic frequency deviation, a change of up to -200 ppm across the entire industrial operating temperature, ranging from -40°C to +85°C, can result. Designs using RTC chip combined with external crystal resonator without temperature compensation will typically achieve such limited level of stability.

Because a time deviation of ±20 ppm is equivalent to gaining or losing 1.7 seconds of time each day, leading to a potential error of more than 10 minutes per year) at 25°C, some RTC modules are adjusted at ambient temperature during production in order to reduce this variation.

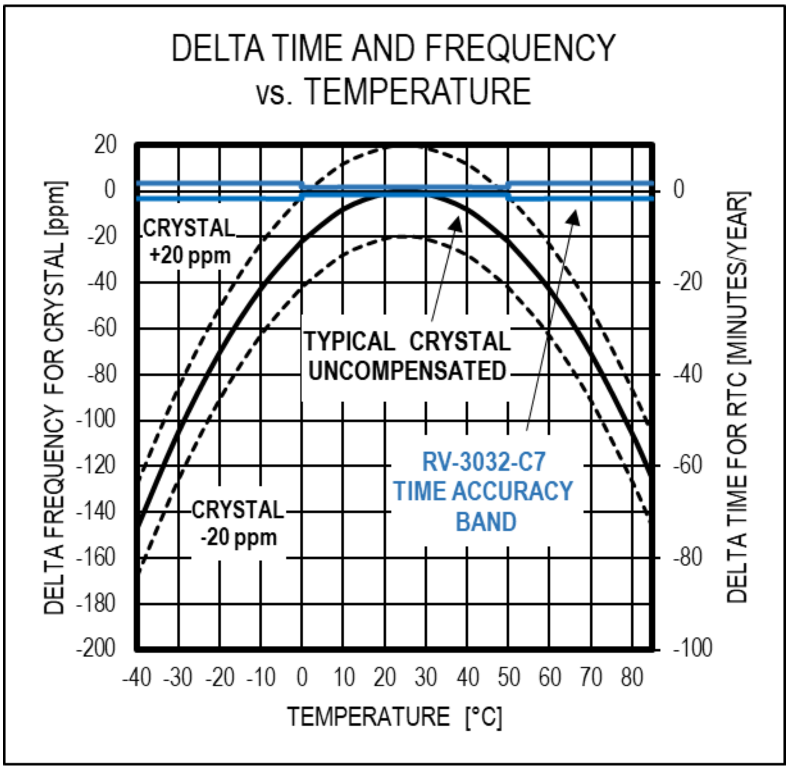


Figure 1: Temperature influence on crystal and RTC

This can be acceptable for applications with limited operating temperature range, but for better performances over extended temperature conditions, a thermal compensation is applied over the full operating temperature range.

Several approaches can be used to correct temperature impact on oscillator frequency. For RTC this is done by using integrated temperature compensated crystal oscillator (TCXO).

In a TCXO, the temperature is measured and usually a correction voltage is applied to the oscillator that provides a frequency change that is the inverse of the temperature curve. Another approach is to use a compensation algorithm to digitally correct the timing output values with no direct impact on the oscillator frequency.

The compensation circuitry, generally in special ASIC, manages that all portions of the crystal temperature curve can be properly linearized through digital processing and use of calibration data stored in memory.

Table 1: TCXO and RTC performance summary

TEMPERATURE RANGE	BASIC CRYSTAL OSCILLATOR	TCXO	RTC with TCXO
25°C	± 20 ppm	± 1 ppm	± 0.09 sec/day
0°C to 50°C	- 40 ppm to +20 ppm	± 1.5 to 3 ppm	± 0.13 to 0.26 sec/day
-40°C to 85°C	- 170 ppm to +20 ppm	± 2.5 to 5 ppm	± 0.22 to 0.43 sec/day

Table 1 shows typical figures that might be expected for standard crystal oscillator, a TCXO and an RTC.

As the crystal curves are relatively similar from one part to the other, the same compensation function model can be used. When using an RTC with embedded quartz, it is possible to benefit from a factory calibration approach and to generate a curve for each individual crystal minimizing temperature related residual error.

The technology used for temperature measurement varies from a thermistor to a band-gap type. Initially, the temperature measurement was only planned for internal use to optimize the RTC temperature compensation. However, the accuracy and the resolution of the temperature measurement data allows meaningful information to be provided relating to the application. RTC's integrated temperature sensors can then be used to replace external component to help keeping devices safe for users while operating at maximum performance. A good example is for monitoring operational conditions (environmental temperature) and providing alerts to prevent component or system damage at the printed circuit board level.

ACCURACY AND RESOLUTION OF TEMPERATURE SENSOR MEASUREMENT DATA ALLOWS TO PROVIDE MEANINGFUL INFORMATION RELATED TO THE APPLICATION

Following the trend for product simplification pushing for functions combination in single device and answering to customer demand for accurate temperature reading availability in RTC module, manufacturers are proposing now TCXO based RTC devices including temperature monitoring function and detection of defined temperature threshold levels.

RV-3032-C7 Real-Time Clock module RTC & Digital Temperature Sensor is such a fully integrated combined solution. Providing accurate and stable timing functions (±2.5 ppm or ±0.22 sec/day over full industrial temperature range) and 12-bit temperature measurement with detection limit interrupts and timestamps, it is supplied in an extra-small form factor package.

This document describes specific details about the features and usage of the temperature sensor embedded in this high performance and ultra-low power device.

2. Theory of operation

The RV-3032-C7 is an extremely accurate and low power I²C RTC module with an embedded 32.768 kHz crystal, a high frequency (HF) oscillator and a temperature sensor integrated into a dedicated ASIC. This module provides standard Clock & Calendar and power management functions with extra features related to its 12-bit Temperature Sensor.

Contrary to TCXOs using an active analogic method on the oscillator to modify the resonator conditions by pulling the frequency to the corrected value, the time accuracy and stability is achieved in RV-3032-C7 RTC module by the built-in Digital Temperature Compensation Crystal Oscillator circuitry (DTCXO).

Figure 2: RV-3032-C7 Real-Time Clock Module

Every second a temperature reading is performed and period duration of the clock at the 16.384 kHz level of the divider chain is modified by adding or subtracting 32.768 kHz level pulses. The pulses are added or subtracted according to the expected frequency deviation computed by the temperature compensation algorithm. 1 Hz clock period is adjusted with a resolution of 0.1 ppm (0.01 second) using both, digital coarse and digital fine temperature compensation steps. This precise and accurate rising edge of 1 Hz clock is then used to increment all subsequent clock and calendar registers.

The crystal clock frequency itself and the frequencies from the HF oscillator present in the device are then not temperature compensated which allows for less circuitry and reduces the associated waste of current consumption.

The digital compensation method (adding and subtracting clock pulses) is affecting the cycle-to-cycle jitter of the other digitally compensated clocks (64, 100, 1024 and 4096 Hz). Those clocks remaining also within ±2.5 ppm accuracy over the entire industrial temperature range but with adjustment inherent phase jumps.

Each RTC device is factory calibrated over the extended industrial temperature range. This provides coverage over the operating temperature range specified, with a safety margin, and to verify consistent behavior of parts. This process is done in dedicated climatic chambers with uniform conditions allowing measurement and recording of values from reference probes and RTCs over a multipoint profile.

> ***“ WITH TEMPERATURE SENSOR AND COMPENSATION ALGORITHM OPERATION, THE TIMEKEEPING CURRENT REMAINS AT THE ULTRA-LOW LEVEL OF MAXIMUM 180 nA.”***

For the temperature calibration, Micro Crystal uses transfer standards, which are subject to a scheduled calibration procedure. The calibration of the reference, used for the calibration of the transfer standards, is traceable through an ISO/IEC 17025 accredited laboratory.

The measurement data is post-processed to extract the calibration parameters for the temperature corresponding function and the frequency compensation. The polynomial coefficients of an individual compensation curve are calculated for a best-fit function minimizing residual error and stored in the EEPROM of the Digital Temperature Compensation Unit (DTCU). To prevent any error, this EEPROM is not accessible to the user.

Temperature reading is performed each second to allow temperature related 1Hz frequency deviation correction. Even with the temperature sensor and compensation algorithm operation, the timekeeping current remains at the ultra-low level of maximum 180 nA.

The device incorporates a battery input and automatic backup switchover feature. This function detects when the power supply is below the supply voltage limit and automatically switches over to the backup source.

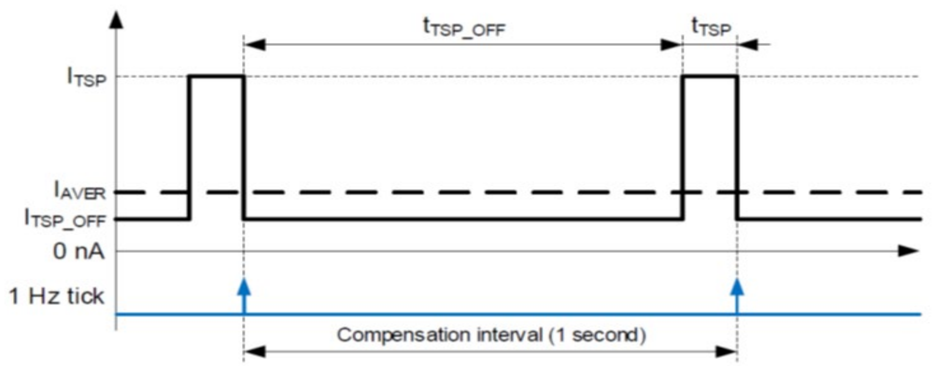
When RTC module is operated with a battery backup (coin cell or similar), it maintains accurate timekeeping when the main power to the device is interrupted. The interrupt and time stamp functions are also working in the backup power state. This ensures reliable detection of temperature falling above or below an alarm window with related interrupt and time stamp recording.

2.1. Temperature Sensor

Most temperature sensor ICs rely on a bandgap-based circuit that is using the temperature coefficient of the differential voltage between two silicon junctions to produce an output that is proportional to absolute temperature. This kind of circuit, often called a PTAT circuit, is not used in RV-3032-C7 where it is replaced with a thermistor-based RC oscillator.

The architecture is similar to the legacy temperature sensors found in previous generations of low-power Micro Crystal's TCXO RTCs. However, through technology improvement, both the minimum operating voltage of the circuit and its power consumption have been significantly reduced compared to previous generations and competing products.

The time needed to perform temperature sensor measurement is of 1.3 ms. During this measurement, the active sampling current reaches 14 µA. Thanks to its intrinsic "one-shot" operation principle the sensor does not require multiple A to D conversions and therefore the current consumption can be reduced drastically with no compromise on accuracy or noise level.



$$I_{AVER} = ((I_{TSP\_OFF} \times t_{TSP\_OFF}) + (I_{TSP} \times t_{TSP})) / 1\ s$$

$$I_{AVER} = ((I_{TSP\_OFF} \times (1\ s - t_{TSP})) + (I_{TSP} \times t_{TSP})) / 1\ s$$

$$I_{AVER} = ((145\ nA \times 998.7\ ms) + (14\ \mu A \times 1.3\ ms)) / 1\ s = \underline{163\ nA}$$

Figure 3: Typical average current I_{AVER}

Even if digital devices do not acquire temperature instantaneously this is not critical. The polling rate (frequency of data retrieval) and conversion rate (how often temperature is measured) are usually low (1 to 4 Hz) to avoid power waste and data redundancy. For RV-3032-C7, $t_{TSP} + t_{TSP\_OFF}$ (sampling period) is 1 second, which is fast enough for sensing temperature changes in most applications.

Access through digital I²C communication of the RV-3032-C7 simplifies greatly system design when compared with other types of temperature sensors solutions like temperature detector (RTD) or thermistors (NTC, PTC). Unlike those analog devices, the digital sensor has integrated analog front-end and analog to digital conversion blocks on to one chip. It does not require any additional linearization or extra calibration and reduces the piece-part count in a manufacturing line. The features like limits crossing detection being also already present in this smart device.

Table 2: RV-3032-C7 Temperature Sensor Specifications

Parameter	Symbol	Typ	Unit	Test Conditions /Comments
TEMPERATURE SENSOR				
Calibrated Temperature range	T_A	-40 to +85	°C	
Calibrated Temperature sensor accuracy		±1	°C	
ADC resolution		12	bits	
Temperature resolution		0.0625	°C	
Temperature ref adjustment resolution		0.0078125	°C	Used to correct TREF 16-bit value (offset adjustment)
Temperature conversion time		1.3	ms	
Temperature refreshing frequency		1	Hz	Temperature registers refreshed every 1 second
Long Term Drift		0.01	°C/year	
Temperature sensor value vs. voltage		0.1	°C/V	V_{DD} = 1.5 V to 5.5 V, T_A = 25°C, $V_{DD\ calibration}$ = 3.0V
POWER REQUIREMENTS				
Supply Voltage	V_{DD}	1.2 to 5.5	V	
Average Supply Current	I_{AVER}	160	nA	Typical value
Supply Current	I_{TSP}	14	µA	Current while T sampling and converting
Average Power Dissipation	P_D	0.48	µW	V_{DD} = 3.0V, timekeeping mode at 25°C

2.1.1. Temperature accuracy

The polynomial compensation function generates an undulated residual error comprised in the ±3°C range (maximum). The following curves are obtained with preconfigured (Factory Calibrated) T_{REF} value. For this diagram, the RTC modules have been powered in V_{DD} Power state (i.e not with a backup voltage) in order that temperature value can be read with I²C.

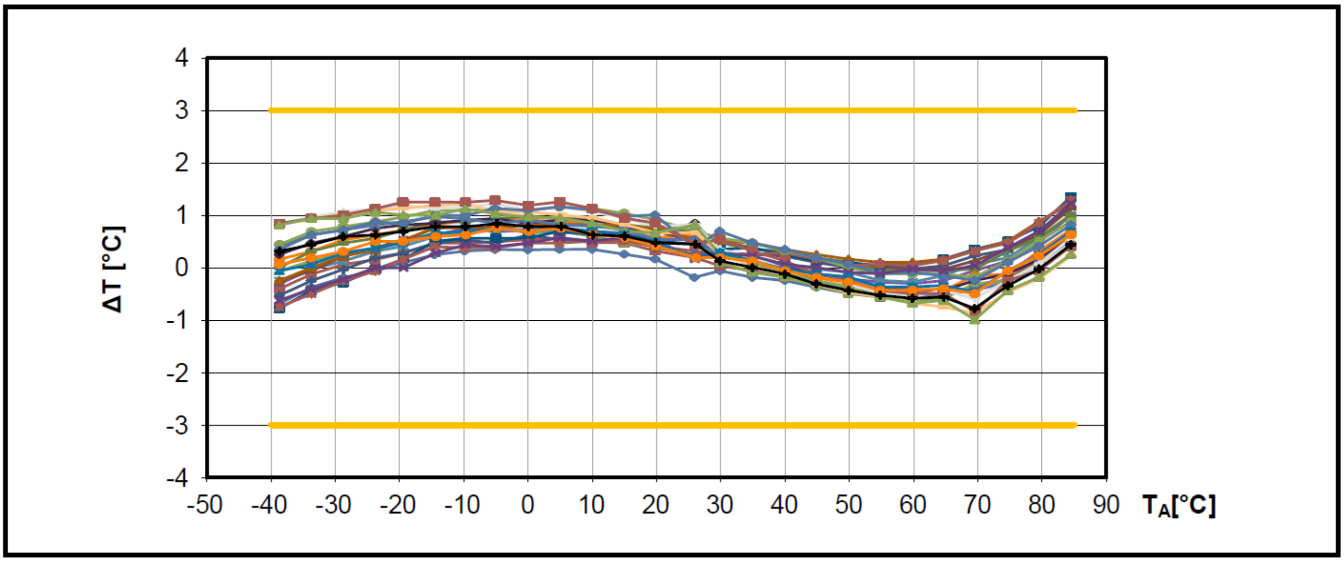


Figure 4: Temperature residual error vs. temperature

Defining the temperature accuracy you need to comply with depends on your specific business sector and on your own requirements. For example, when transporting perishable goods, your recorder must have an accuracy of ±2°C. This means it must be Class 2 or superior.

Transportation of pharmaceutical products and blood requires a Class 1 (±1°C accuracy) recorder temperature when it comes to negative temperature ranges, and a Class 0.5 (±0.5°C accuracy) for positive temperature ranges.

The RV-3032-C7 module is able to cover most applications with its accurate high-resolution temperature sensor. However when the application requirements are too severe to be satisfied, the RV-3032-C7 still offers helpful features. **By setting a programmable temperature window with a safety margin, it enables accurate enough timestamps for temperature alarm events and interrupts while keeping an updated track of the current time as a primary function. It also answers to the redundancy requirements present in stringent temperature monitoring solutions with an alternative technology.**

2.2. Temperature Features

2.2.1. Readable Temperature value in °C

The temperature is measured and refreshed every second. The temperature value (TEMP) is coded on 12 bits and written in Temperature LSBs (fractional part by 1/16 step) and Temperature MSBs registers (integer part).

As those registers have no blocking/shadowing; to get a valid 12-bit temperature value, the TEMP value should be read after the 1 Hz tick, or up to 1 ms before a 1 Hz tick.

All registers are accessible via I^2C bidirectional bus (2-wire Interface).

2.2.2. Temperature window definition

It is possible for the user to set threshold values for the temperature window limits definition. The threshold values, for low and high temperature limits, are coded on one byte with 1°C resolution.

Those limit values are automatically compared to the temperature reading every second. An interrupt event is generated when the integer part of TEMP is lower than low temperature window limit or higher than high temperature window limit. Each time the condition is true, the time stamp registers are updated accordingly.

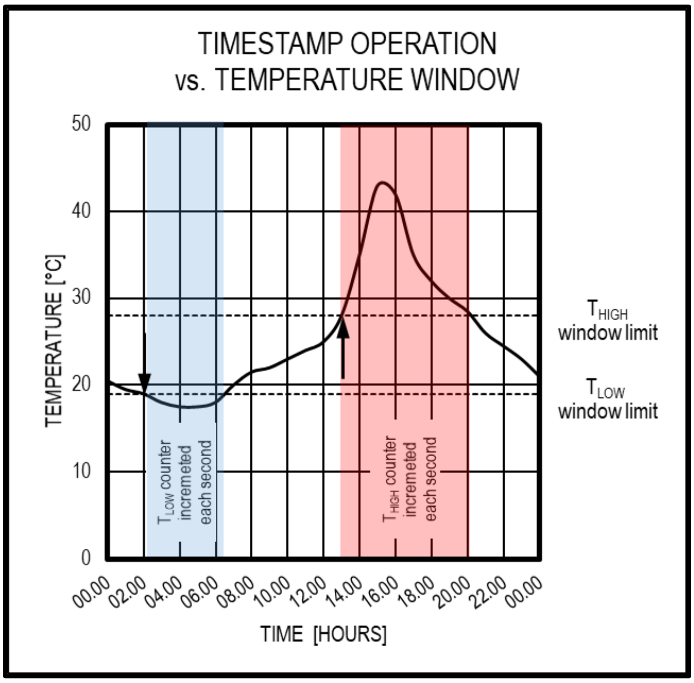


Figure 5: Temperature window

2.2.3. Adjustable Temperature Reference (offset adjustment)

It might be necessary to adjust the temperature reference value (TREF) following the assembly process, as variation in thermal resistance between the one present during calibration process and the one of fully assembled printed circuit board will affect temperature sensor baseline. Reference temperature adjustment can also be necessary to compensate for self-heating or heat generated by operation of nearby components.

TREF is a 16-bit value used to perform one-point offset calibration of the digital thermometer when compared to a reference thermometer in defined conditions. The adjustment of TREF is purely digital and has the effect of shifting the linear curve of the thermometer vertically up or down with no effect on slope.
With a minimum adjustment step (one LSB) of ±1/128 = ±0.0078125°C it is possible to modify the factory setting by access to the two registers located in the EEPROM.
The change in TREF has no effect on the temperature compensation of the RTC as it is not modifying the relation between internal digital thermometer reading and oscillator frequency.

2.2.4. Time Stamp

Time stamp allows to keep in memory the timing details of first or last detection of a limit crossing according to the user's configuration. Not only the full timing values (second, minutes, hours, date, month and year) of detection of a temperature window limit crossings are stored in time stamp registers but also the amount of temperature excursions above or below the limits are updated (Count).

While all monitoring applications require some type of immediate data reporting, many also include recording values for historical purposes. The presence of 32 bytes of User EEPROM in RV-3032-C7 offers option for some historical data storage.

2.2.5. Key application features of RV-3032-C7 RTC with readable 12-bit Temperature Sensor

- Features all RTC's standard with associated timers and interrupts
- I²C 2-lines bus communication
- Smart power management functions (automatic backup switchover, trickle charger)
- Clock and frequency accuracy (± 2.5 ppm or ± 0.22 sec/day) guaranteed over full operating industrial temperature range (-40 to +85°C), in extended range accuracy is of ± 20 ppm (+85 to 105°C)
- 12-bit temperature sensor measurement readable (accuracy ± 1°C typ., resolution 0.0625°C/step)
- Temperature reference correction available with minimum adjustment step (one LSB) of ±1/128 = ±0.0078125°C. Allows for physical system gradient correction
- Temperature measurement refreshing period of 1Hz
- Interrupt when temperature falls above or below a user defined alarm window
- Continuous temperature monitoring and time stamping even in battery backup mode, down to 1.2V
- Ultra-low power consumption temperature sensing (14 µA for 1.3 ms every second), 160 nA in typical average in timekeeping & Temperature mode
- No need for structural change, minimal footprint of 3.2 x 1.5 mm² (temperature sensor is embedded in RTC package), low thickness 0.8 mm
- Compact single device, simplify integration, coding and I²C slave amount (single address for two functions Time & Temperature)

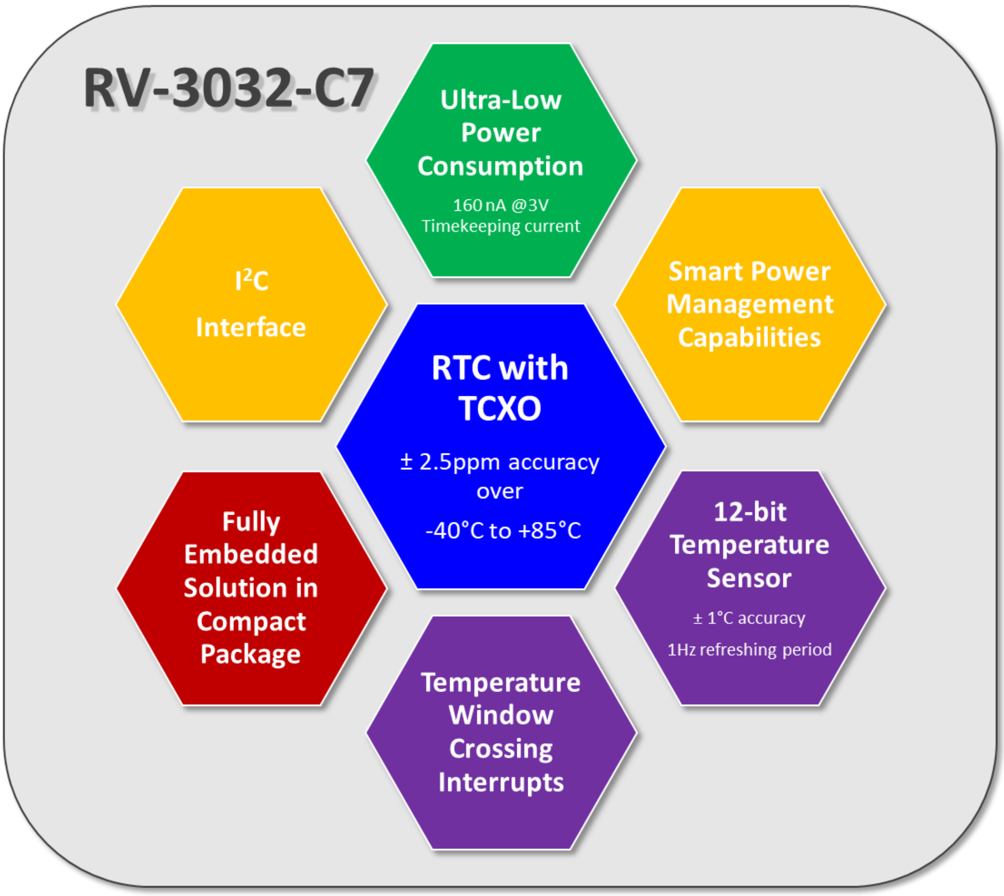


Figure 6: RV-3032-C7's Key Features

2.2.6. Beside the RV-3032-C7 RTC module, what do I need to perform temperature readings?

The sensor and measurement circuit used to digitize the temperature is fully embedded in the RTC package. Except for the supply voltage's decoupling capacitors and communication interface pull-up resistors, there is no need for other external components. Communication (parameters settings & readings) is done through the I^2C interface consisting of two lines: one bi-directional data line (SDA) and one clock line (SCL). Both lines are connected to a positive supply via pull-up resistors of typically 3.3 kOhms for a 400 kHz communication.
The built in I^2C interface is compatible with I^2C modes up to 400 kHz.

V_{DD} minimum: 1.4 V for 100 kHz and 2.0 V for 400 kHz.

A key feature is that temperature monitoring will continue even with the RTC operated with a backup battery and the time stamp linked to any temperature window limits crossing stored accordingly.

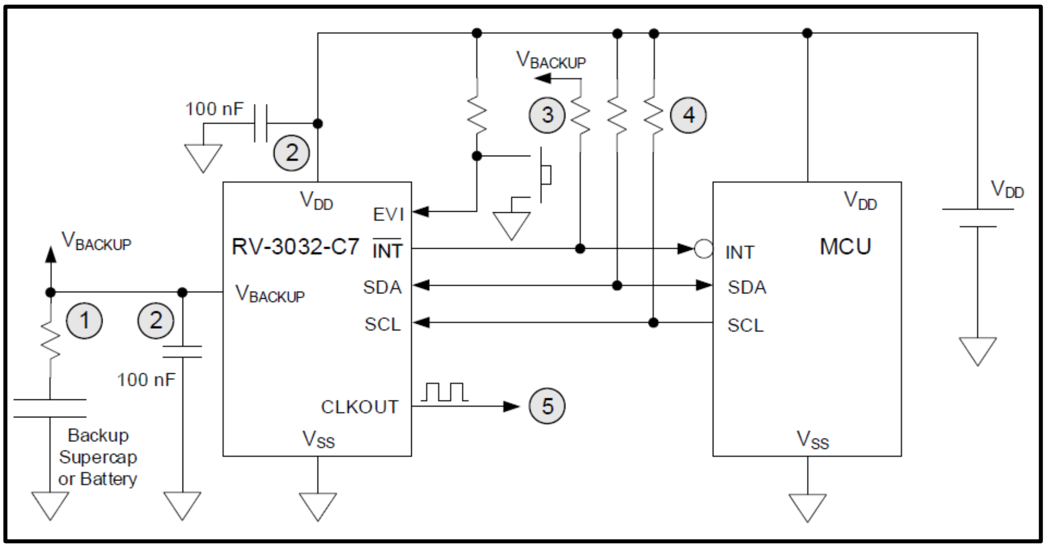


Figure 7: Typical operating circuit

1. When a Lithium Battery is used, it is recommended to insert a protection resistor of 100 – 1000 Ω. to limit battery current and to prevent damage in case of soldering issues causing a short between supply pins.
2. For VDD and VBACKUP, a 100 nF decoupling capacitor is recommended close to the device.
3. If a backup supply is connected to the VBACKUP pin, the $\overline{\text{INT}}$ signal can also be used in VBACKUP mode. To do this, the $\overline{\text{INT}}$ signal pull-up resistor must be connected to VBACKUP.
4. Interface lines SCL, SDA are open drain and require pull-up resistors to VDD.
5. CLKOUT offers the selectable frequencies 32.768 kHz (default value on delivery), 1024 Hz, 64 Hz or 1 Hz, or a HFD frequency (8.192 kHz to 67.109 MHz in 8.192 kHz steps) for application use.

If not used, it is recommended to disable CLKOUT for optimized current consumption. This is particularly important for temperature measurements using the high frequency oscillator (HF). The HF oscillator will generate an offset in temperature readings caused by internal self-heating.

3. Thermal Considerations

3.1. Thermal response time

The time required for a temperature sensor to settle to a specified accuracy is a function of the thermal mass of the sensor and the thermal conductivity between the sensor and the object or the ambient air being sensed.

Thanks to its construction in a leadless DFN ceramic package with multiple pads, the RV-3032-C7 offers the advantages of surface mount temperature sensor. The small and low profile package size allows quick response to temperature changes of the copper pads which the component is soldered onto. The IC RTC die is assembled with gold bumps onto the ceramic which is in direct contact with the PCB (minimal air gap).

The crystal blank is in the immediate vicinity of the temperature sensor integrated in the IC to ensure that both devices are exposed to the same thermal conditions with minimized latency for optimum temperature compensation.

The Kovar (FeNiCo) metal lid, having the same thermal conductivity as the ceramic package (17 $Wm^{-1}K^{-1}$), is efficiently limiting the temperature gradient present between the top and bottom sides of the device.

The drawback of such construction is that it can be difficult to isolate the sensor in order to ensure that the ambient temperature is measured rather than the one of PCB. An efficient solution requires specific PCB layout design; this point is discussed further in this paper.

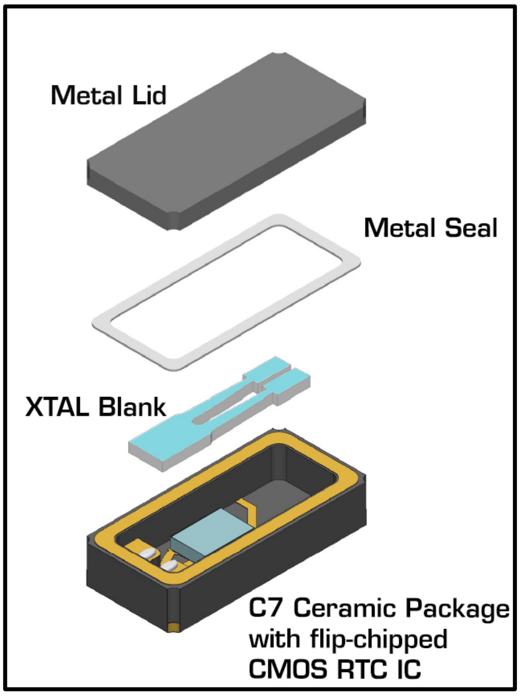


Figure 8: RV-3032-C7 construction

According to the minimal size of the package and to the mass (< 12 mg) of RV-3032-C7, one can consider however that there is no delay in thermal response as long as design rules are applied.

In most applications, the settling time is best determined empirically with the whole assembly (PCB + enclosure) and in the application's conditions (airflow).

3.2. Self-heating effects

As for any other temperature sensor, the critical aspect is to ensure that the measured value is representative of the ambient temperature. With self-heating, the temperature sensor is reporting the effective temperature inside the RTC package, but that temperature is shifted above the ambient due to the power dissipation of internal circuitry.

The self-heating is quantified by the product of the power dissipation and the overall thermal resistance (in °C/W) between the RTC package and the surrounding elements (PCB and air). In order to compute accurately the ambient temperature, it is then needed to subtract the amount of self-heating from the temperature measured by the temperature sensor.

Factors linked to the PC board (material, thickness/size/layer−number of copper plane, size/number of thermal vias, and copper plane pattern) and the enclosure volume and air flow can greatly affect the thermal resistance of the component.

We recommend measuring the overall thermal resistance between the RTC and ambient in the real physical application while operating the global system with the application firmware to determine the amount of self-heating.

The thermal resistance may be measured using the calibrated RTC temperature sensor to measure the temperature at two different power dissipation values of the RTC; the thermal resistance is then the change in temperature divided by the change in power dissipation.
The amount of self-heating can be calculated based on the thermal resistance obtained. In most cases with RV-3032-C7 operation, the self-heating is small enough that it does not materially affect the result. For example, the timekeeping and periodic temperature sensor operations result in a current consumption of about 160 nA, giving a power dissipation of 0.48 μW with a 3.0V power supply.

In an example where a circuit board has a thermal resistance of 50 °C/W, the amount of self-heating is:

(0.48 μW) * (50 °C/W) = 0.000024 °C.

Thanks to RV-3032-C7's ultra-low power consumption, this insignificant amount of self-heating can be ignored in most applications where the RTC is used as timekeeper and the temperature sensor as an alarm trigger while having the microcontroller in deep power saving mode.

EXTREME LOW POWER CONSUMPTION ENSURING ACCURATE TEMPERATURE MEASUREMENT WITH NO SELF-HEATING IMPACT

To benefit from the advantages of the extreme low power consumption of the device and to ensure accurate temperature measurement with no self-heating impact, the RTC module frequency output can be disabled allowing drastic power reduction when clock output is not required.

In the case of an application operating with much higher power dissipation than in previous example (like with activation of the clock output in high frequency mode (MHz) for a significant period), there is a need to better characterize power dissipation and related self-heating.

According to the different operating modes of the application, the thermal time constant of the RTC must be known in order to calculate how long a particular power dissipation level must be maintained to ensure that the RTC temperature has stabilized at its steady-state value. Through this, the application firmware can apply a valid self-heating correction to the reading of the temperature sensor with a lookup table for instance.

This thermal time constant can be determined when measuring the thermal resistance at various power dissipation levels as explained here above. The profile can then be used to determine how long the firmware must wait before taking into account a temperature reading when the power dissipation changes in the final application.

As an example, a self-heating corresponding to +3°C is observed with RV-3032-C7 providing a 50 MHz clock when tested on RV-3032-C7 Development board after 3 minutes of operation. This demonstrates that high frequency operation should be avoided if fast and accurate temperature monitoring is required.

4. Design considerations

4.1. Temperature sensor solution

Temperature sensors are available with different interfaces and performances. As a design study exercise concerning a wearable product, for example, let us compare the various options that can provide RTC functionality with temperature measurement.

Engineers consider usually three main design options for temperature measurement combined with the RTC function. Here below, the calendar function is provided by an external RTC chip connected to a quartz crystal resonator for all three designs under study.

For a meaningful comparison exercise, the same basic temperature sensing performances are expected from all solutions explored. For each of these options, essential variables for consideration are battery current drain, size and ease of integration.

4.1.1. Analog temperature sensor

The first option is to use an analog sensor (NTC for instance) linked to an analog interface block. The output of the analog block is read by an ADC present in host microcontroller. This option requires more discrete components than the other ones. Those components are needed for voltage conversion, amplification and filtering. Therefore, they occupy more surface area on PCBA.

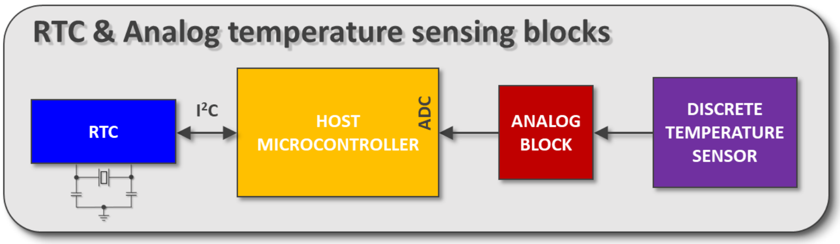


Figure 9: Temperature sensing with analog sensor

The MCU-integrated or external A to D converter requires a minimum of 10-bit resolution to provide comparable resolution over industrial temperature operating range (<0.5°C). The transfer function for thermistors is very nonlinear. It may be sufficiently linear over the narrow temperature range required in many applications but you will still need to calibrate your device at least at two points adding costly process steps. You can compensate for the nonlinearity with a look-up table, but this approach, combined with A/D conversion into temperature value requires resources that may not be available. Advantage of analog sensing is found when high polling rate is required but this will impair greatly power consumption. For analog temperature sensor, the active current is already reaching tens of µA. The average current consumption being increased by other added components required in measurement chain.

4.1.2. Digital temperature sensor

The second design option is to use a digital temperature sensor with I²C or SMBus communication interface. Digital temperature measurement offers a great deal of convenience. These devices are factory calibrated and proposed typically in DFN package with a small footprint.

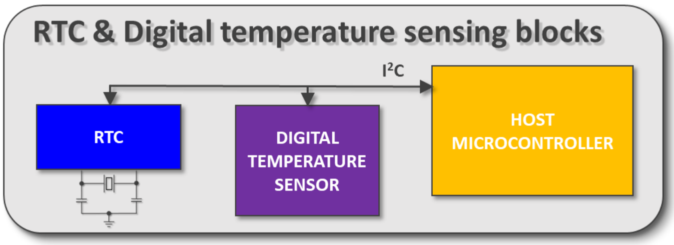


Figure 10: Temperature sensing with digital sensor

The digital solutions save power by measuring temperature quickly, and spending rest of time in an idle low power mode that an analog solution cannot do. The average current consumption with a measurement per second can remain below 2 µA. The measurement needs however to be triggered by the MCU and overall average current consumption is therefore not below tens of µA.

4.1.3. Temperature sensor embedded in MCU

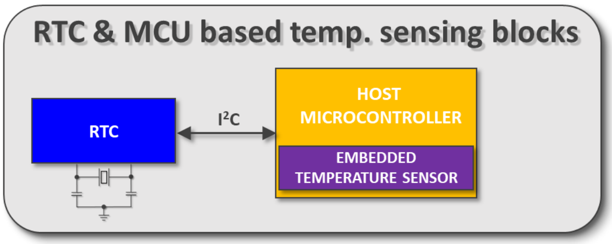


Figure 11: Temperature sensing with MCU

By using the integrated temperature sensor of the microcontroller, the temperature measured is the one of the die and is therefore strongly linked to the MCU activity as accuracy will vary with MCU current consumption.
There is a limited number of cost effective MCU with calibrated temperature sensing and therefore associated calibration process steps will increase production cost.
With such design, the temperature sensor cannot be easily located close to the desired point of measurement.
A variant of this design option would be to select an MCU with built-in RTC functionality. Time accuracy and power consumption are however strongly impaired with such approach. An-ultra-low power microcontroller may be unable to achieve its lowest level of power consumption in using its integrated temperature measurement and RTC functionality. Current consumption of MCU during extended idle periods being a significant limiting factor when not set in deep sleep (low-power) mode.

4.1.4. RTC temperature sensor

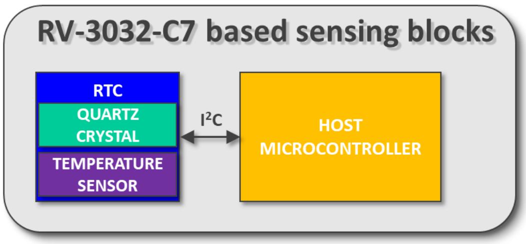
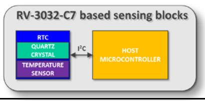
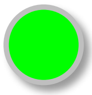
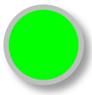
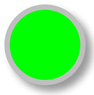
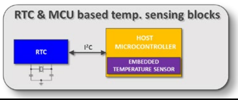
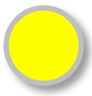
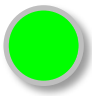
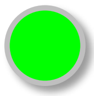
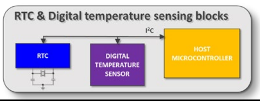
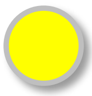
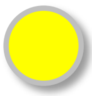
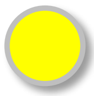
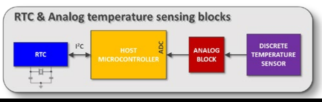
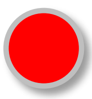
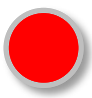
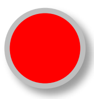


Figure 12: Temperature sensing with RV-3032-C7 RTC module

An ideal solution to answer to this design study is found with the RV-3032-C7 RTC module. The ultra-low intrinsic current consumption, combined with autonomous alert mode when MCU is placed in deep sleep mode, place it in first place in term of lowest battery drain.
By integrating the quartz crystal and the temperature within the ultra-small RTC package, it allows to minimize the footprint. It does not require any oscillator adjustment during OEM design phase, minimizing integration constraints thus lowering development cost and time to market.
The RV-3032-C7 is a calibrated device that simplify manufacturing process where a 1-point temperature verification is sufficient.
This solution is ideal as it help minimize BOM costs and integration in applications that require accurate timekeeping, ultralow power temperature monitoring and temperature window crossing alarm.

Table 3: RV-3032-C7 offers almost zero power consumption in ultra-small package and its RTC&T capabilities promote ease of use

Design variant	Battery current drain	Size	Ease of integration and use
RV-3032-C7 RTC & 12-bit Temp. sensor 			
Temp. sensor in microcontroller 			
Digital Temp. sensor 			
Analog Temperature sensor 			

4.2. Reliability

A fully embedded RTC and Temperature sensing solution is immune to performance degradation caused by a decrease of insulation of discrete components on the PCB. Temperature cycles combined with high humidity are well known, long-term issues of oscillator circuits or analog temperature sensors made with discrete components on a PCBA. These conditions will not impair a fully integrated device thus achieving significantly better stability and reliability characteristics.

The fully integrated RV-3032-C7 reduces time to market and development costs by providing an easier to implement solution that also provides enhanced quality of operation over product lifetime.

4.3. Physical isolation

When designing a PCB with a temperature sensor, the system designer needs to consider if the objective is to measure ambient air temperature or to monitor the temperature of a nearby power hungry device. In order to perform efficient temperature measurement it is then important to manage how thermal conductivity through the PCB would affect the sensor. Today, thermal conduction through a PCB can be modeled accurately and many tools are available. By knowing the material used in the PCB (FR4 epoxy, copper, soldermask polymer) and by varying the design parameters (type and number of vias, copper thickness, copper plane geometry, number of layers), the design can be adapted and optimized for thermal performance.

Although the RV-3032-C7 can be used to monitor a component's temperature by locating the device as close as possible to the heat source, the design examples and applications discussed further are for typical low-power applications. A real added value to the final solution being smart ambient air temperature monitoring while operating in an energy saving mode.

For accurate and meaningful ambient air temperature measurements, physical isolation between the sensor and all continuous or intermittent heat generating components like voltage regulators or MCUs on the same PCB is critical. It is then preferable to isolate the sensor by design.

The RV-3032-C7 RTC does not need to be located close to MCU as it is the case when using a bare quartz device This offers flexibility for the designer to place the RTC device according to temperature measurement constraints only. The ideal thermal design is to locate the device on an isthmus to reduce the heat transfer of FR4 as shown in **Figure 13**. The air can then pass all around the sensor; favoring the thermal exchange and minimizing response time. One can also limit the thermal mass of the PCB supporting the sensor by using a thin or flex PCB and by minimizing the surface area with multiple vias.

In this example, you can see U1 (RV-3032-C7) with C1 and C2 (typ. 100 nF), the two decoupling capacitors used for power supply (V_{DD}) and battery backup (V_{backup}).

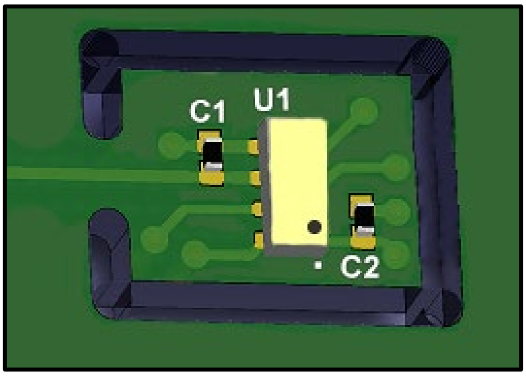


Figure 13: RV-3032-C7 RTC on PCB isolation isthmus

The design of the enclosure is also of importance for temperature monitoring in order to ensure air exchange between sensor and ambient conditions. A permeable membrane covering the hole in the enclosure housing is an option allowing air exchange through the sensor area and offers the best response time when at premium. Typically, PTFE (Teflon) type membrane provides perfect protection against water and dust ingress while allowing air exchange.

When specifying temperature monitoring applications it may help also to consider some factors mentioned in next points.

4.4. Thermal buffer effect

The choice of the temperature sensor type and type of thermal buffer required by reaction/response time characteristics is defined by the application. Even the compressor cycling of a temperature controlled, storage unit can cause false alarms and pose a major inconvenience along with widely-varying temperature data that does not reflect the actual product temperature. If the alarms limits are set too tightly, even a small variation in the cycling can trigger an alarm. Since stabilizing your temperature readings may be critical, you can avoid nuisance alarms and get much more accurate data by using a thermal buffer. Good examples are a nylon block, a bottle filled with ethylene glycol or glass beads. Thermal buffers can be easily applied onto an integrated temperature sensor bonded to the PCB like the RV-3032-C7.
Thermal buffers allowing smooth, rapid temperature fluctuations are not only becoming standard in hospitals, clinics, and pharmacies, but also in laboratories and even cold chain settings. For instance, by using a thermal buffer, you can eliminate the temperature spikes in the monitoring system data caused by opening the refrigerator or freezer door.

4.5. I^{2}C

Most digital sensors feature I^{2}C open-drain driver for bus communication. Pull-up resistors are required to generate logic High when no device is pulling down on the bus. The correct choice of these pull-up resistors will have an impact on the current consumed by the I^{2}C interface. Experience has shown that it is beneficial for power consumption to set bus frequency as high as possible in order to lower time spent communicating even at the cost of higher pull-up current.

4.6. Data storage

32 Bytes of User EEPROM are available in the RV-3032-C7 for general purpose storage. This can help to store specific data in application for parameters and history.

4.7. Software and configuration

The software code used for temperature monitoring is here again deeply related to the application.
Configuration of the RTC's registers will allow the user to set interrupts and temperature limits. The related interrupts will condition alarm management and for instance, smart adaptation of window size for more accurate tracking of temperature variations. Through I^{2}C communication, it will be possible to retrieve the timestamp data concerning the timing details of the first or last detection of limits crossing, according to user configuration, for historical purposes.

TIMING, POWER AND TEMPERATURE-WINDOW CROSSING INTERRUPTS WITHIN THE SAME COMPONENT

4.8. Alarm

Alarming functions, the capability to alert someone, somehow whenever the programmed limits are reached, are usually already present in applications using RTCs. For most temperature monitoring applications, alarming, is a core requirement. The various interrupts features present on the RV-3032-C7 allow the application to send a message or activate a counteraction, if the system ever goes off-line or if there is a power outage. Functions like this are critical when the product being monitored is irreplaceable. The presence of timing, power and temperature-window crossing interrupts within the same component, offers a significant design advantage with reduced piece-part count and minimized number of physical lines required for interrupt readings.

5. Applications

Temperature monitoring could be considered as a secondary function within an RTC. There are, however, a large and growing number of applications that would benefit from a low-power RTC offering temperature measurement and temperature window crossing interrupt to help ensure reliable function or equipment operation.

Typical application areas can be found in Industry 4.0, metering, HVAC, automobiles and utility vehicles, battery management systems, healthcare, laboratory technology, white goods, as well as in machinery construction and industrial engineering.

Two examples of applications are presented here below.

5.1. RV-3032-C7 as Battery Management System (BMS) black box

Today's batteries deliver a lot of current while maintaining a constant voltage, which can lead to a runaway condition that causes the battery to catch fire. Temperature measurements are not just used for safety conditions, they can also be used to determine if it is desirable to charge or discharge a battery. Temperature sensors monitor each cell for energy storage system (ESS) applications or a grouping of cells for smaller and more portable applications. Thermistors powered by an internal ADC voltage reference are commonly used to monitor each circuit's temperature.

> ***"…CAN PROVIDE TEMPERATURE MONITORING REDUNDANCY IN ASIL DESIGNS."***

Knowing the battery pack's behavior prior to a catastrophic event can be facilitated through usage of RV-3032-C7 RTC. With timestamp and memory for storing data coupled with temperature sensing for safety required redundancy (ASIL) in BMS, this RTC offers a solution to low-power continuous monitoring of battery packs where it is never a bad idea to have an extra layer of detection and protection. Temperature survey with the RV-3032-C7 of portable power-supply systems can be effectively implemented in combination with small microcontrollers in battery packs that communicate with host processors.

5.2. RV-3032-C7 in drug delivery devices like smart insulin pen or infusion pump

Through the combined functions of temperature survey and timekeeping, such smart devices can be used in low-power system to monitor usage and temperature events in drug delivery devices. Thanks to its compact form factor, RV-3032-C7 can be placed close to the disposable reservoir and allow indirect fluid temperature monitoring and trigger an alarm in case of temperature overshoot.

With its timers and interrupts capabilities, it can ease management of useful information**.** For example by tracking the delay from first use and the recommended discarding of cartridges and prefilled devices 28 days after opening (example value only) or in the case of prolonged storage above or below the suitable temperature (insulin that has been frozen or exposed to direct heat should ideally not be used for instance). **However, this device cannot be used as critical component in life support devices or systems.**

Smart predictive algorithm can also be used to maintain drug potency by regular temperature monitoring in order to alarm the user for countermeasure before product alteration. Detection of abnormal temperature profile or trend being used to set a visible flashing alarm on the pump for instance.

Similar functions can be used in a large variety of products and applications related to cold, or temperature in general, chain management to help ensuring that appropriate action is taken during transport, usage or storage if a possible excursion outside of the temperatures limits is about to occur. In case of application where RTC timestamps accuracy can affect in severe way the safety function (for example, medical data storage devices), it is strongly recommended to adopt efficient system-level measures based on hardware and software diagnostics.

6. Conclusion

Industry 4.0 and consumer markets are in constant quest for ever smaller, faster, and safer hardware solutions. With RV-3032-C7 Real-Time Clock module, Micro Crystal is leading the way with its most efficient, compact industrial Real-Time Clock Module, yet. Designed with high-quality quartz crystal resonator coupled with a custom ultra-low power RTC ASIC, featuring I²C interface and temperature sensor, the new fully integrated RV-3032-C7 offers a designer vast opportunities for industrial embedded, healthcare, wearable and IoT deployments in the smallest spaces.

Apart from accurate timekeeping and smart power management features, RV-3032-C7 is offering accurate 12-bit temperature monitoring with interrupt capabilities. While keeping the microcontroller in sleep mode to reduce global system power consumption, this fully embedded temperature monitoring function is ideal to advise on thermal environmental conditions and critical system events through temperature window crossing interrupts and timestamps.

RV-3032-C7 RTC MODULE KEEPS TRACK OF TIME AND GENERATES INTERRUPT TEMPERATURE UNDER/OVERSHOOT WHILE LETTING MCU IN POWER SAVING MODE.

Its high temperature accuracy allows protecting systems without sacrificing performance due to extensive temperature guard-banding in case of measurement uncertainty. This integrated time stamping “black box” make it a product of choice for many new designs in order to enhance safe, reliable and better controlled operation with no increase in power consumption, added cost nor impact on system board area.

While RV-3032-C7 is setting new standards in smallest size and footprint, best accuracy (±2.5 ppm equivalent to ±0.22 s/day over -40°C to 85°C operating temperature), ultra-low current consumption (160 nA timekeeping & temperature mode), 12-bit readable temperature sensor (accuracy ± 1°C typ.) and unique power management capabilities, the correct choice of RTC and temperature sensor for a design is dependent on the end application.

Micro Crystal offers a wide portfolio of low-power, high-performance and small footprint RTC modules, do not hesitate to contact us for any question you may have about how our products can fit into your application and challenge our technical teams.

Additional resources:

For more information about RV-3032-C7 and Micro Crystal’s portfolio of Real-Time Clock modules, please visit:
RV-3032-C7 Real-Time Clock Module
www.microcrystal.com

About the author:

Nicolas Moser

Nicolas joined Micro Crystal AG in June 2020 as Technical Marketing Manager. He benefits of a strong expertise built on his roles and experience in Product Development, Technical Support, Product Management and Technical Sales in sensor business for industrial, consumer and automotive applications. Nicolas holds an EE degree with specialization in Test & Measure and is fascinated by quantifying the world around us.
He thinks that any sensor measurement is significantly enhanced when combined with an accurate and reliable time reference.

7. Reference documents

Document	Name	Link
Data sheet	RV-3032-C7	Download
Application Manual	RV-3032-C7_App-Manual	Download

8. Document version

Date	Version #	Changes
December-24-2020	1.0	Initial version
February-13-2023	1.1	Temperature range extended (-40 to +105°C) and time accuracy passing from ±3 to ±2.5 ppm