



## TUTORIAL

# The What, Why, When, Where and How of Real-Time Clocks (RTCs)

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## Abstract

Tiny real-time-clock (RTC) circuits provide low-cost, low-power, and effective timekeeping, a simple but critical feature for today's complex electronic systems. The following tutorial provides an overview of these circuits by answering some of the most common questions about this often forgotten but very necessary piece of electronic technology.

## What is a Real-Time Clock?

Electronic devices perform tasks in response to the periodic oscillation of an electrically varying digital voltage signal or clock signal. On the other hand, human time (also known as “real” time) is measured in seconds, minutes, hours, days, months, and years as dictated by the rotational cycles of the earth. For electronic devices (such as a smart watch shown in Figure 1) to perform their tasks when required by a user, they must store a digital representation of real time, which is then kept in sync by the digital clock signal. In an electronic device, real-time information is maintained by its RTC circuitry. This will usually be located within the device microcontroller or may be a separate IC on the system board.



Figure 1. Smart Watch

## Why Use an RTC?

If the main power source for an electronic device fails, then real-time information will be lost and will need to be reset once power has been restored. While many portable IoT devices have the functionality to reset the time using a wireless connection to a remote master, this type

of communication places an extra power drain on the battery (and obviously can only occur if a wireless signal is available). In the absence of a wireless signal, the only (and clearly less desirable) alternative is for the user to manually reset the time, which may not be always straightforward or even possible.

## Where Are RTCs Used?

Real-time clocks are used in many different applications, such as industrial (utility meters, point-of-sale equipment, fire alarms, gaming machines, video security), consumer (digital cameras, portable GPS devices, mobile game devices, DVD recorders, TVs) as well as in portable and home medical equipment.

## How Does an RTC Keep Time?

A 32.768kHz quartz tuning-fork crystal oscillator is the standard timekeeping reference for most electronic applications. The real-time clock maintains the time and date by counting seconds, which requires a 1Hz clock signal derived from the 32.768kHz crystal oscillator. The time and date information are stored in a set of registers, which is accessed through a communication interface, such as I<sup>2</sup>C. The crystal may be external to the RTC or integrated within the same package. For applications requiring higher accuracy, an integrated MEMS (micro-electromechanical system) resonator is used as the timing reference.

## What Are the Key RTC Specs?

Accuracy, current consumption, ruggedness, and size are the key specifications to look for when choosing a real-time clock. Designers must also decide when to use a stand-alone RTC IC instead of using one that may already be integrated into a system microcontroller.

## How Accurate is an RTC?

The timekeeping of a real-time clock will only be as accurate as the timing reference used. Unfortunately, the typical 32.768kHz tuning-fork crystal is not very accurate over a wide temperature range. Due to its parabolic nature over temperature (Figure 2), this accuracy is typically  $\pm 20\text{ppm}$  at room temperature ( $+25^\circ\text{C}$ ). This is the equivalent of gaining or losing 1.7 seconds of time each day, or 10.34 minutes per year. As Figure 2 shows, accuracy decreases at more extreme high and low temperatures. The typical accuracy at these temperatures is much worse than 150ppm, which is the equivalent to losing almost 13.0 seconds of time each day, or over 1.3 hours per year.

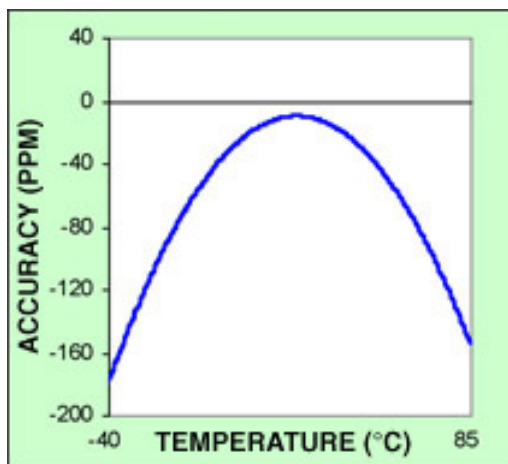


Figure 2. Temperature vs. Accuracy of a Typical 32.768kHz Tuning-Fork Crystal

A more desirable option, which greatly improves timekeeping accuracy, is to use a 32.768kHz temperature-compensated crystal oscillator (TCXO) as the clock source for a stand-alone RTC. These devices are factory calibrated and can provide accuracy as high as  $\pm 3.5\text{ppm}$  over the industrial temperature range ( $-40^\circ\text{C}$  to  $+85^\circ\text{C}$ ). The effect of a TCXO is to flatten the parabolic nature of the crystal curve over temperature (Figure 3). A TCXO includes an integrated sensor to periodically measure device temperature. This measurement is used to access a lookup table, whose output is then used to calculate and apply a variable load-capacitance value for the integrated 32.768kHz crystal to increase accuracy. The lookup table exists on the device and requires no external inputs. An example of an extremely accurate RTC with the TCXO and crystal integrated into the package is the [DS3231S](#).

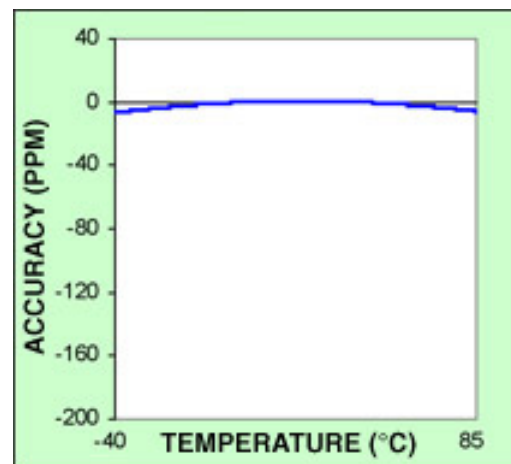


Figure 3. Crystal Curve Flattened by a TCXO



The overall accuracy for MEMS-based RTCs is specified by lifetime accuracy and stability figures of  $< \pm 5\text{ppm}$ . An example of a high-accuracy temperature-compensated RTC with an internal MEMS resonator is the [DS3231M](#).

Typical accuracies for RTCs with different resonator types are shown in Table 1.

**Table 1. Typical RTC Resonator Accuracy**

	XTAL	XTAL (TCXO)	MEMS
Accuracy (ppm)	$\pm 150$	$\pm 3.5$	$\pm 5$

## Why is Ruggedness Important?

Printed circuit boards are repeatedly subjected to high temperatures during assembly (reflow). This process can adversely affect the accuracy of an RTC. Figure 4 shows the effect of a typical reflow operation (pre and post) on the performance of a crystal-based RTC, demonstrating a shift of up to 5ppm.

By contrast, as shown in Figure 5, the DS3231M MEMS-based RTC shows negligible deviation in frequency ( $< 1\text{ppm}$ ) pre- and post-reflow operations.

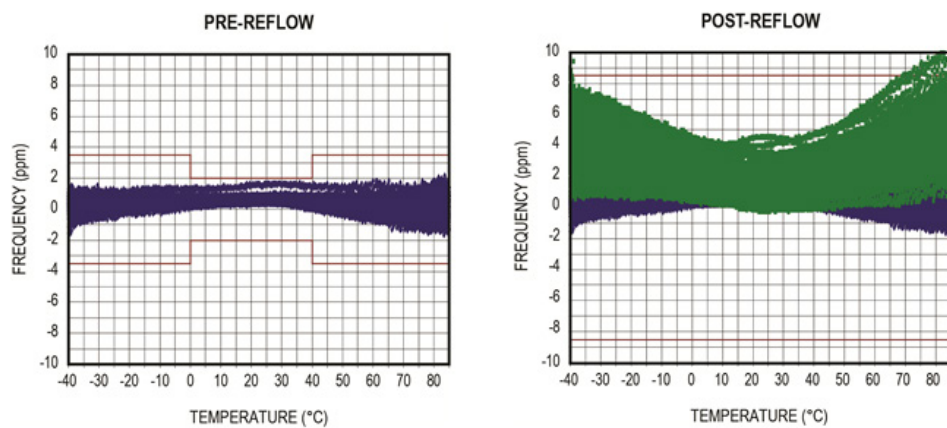


Figure 4. Data for a Crystal-Based RTC Pre and Post Reflow

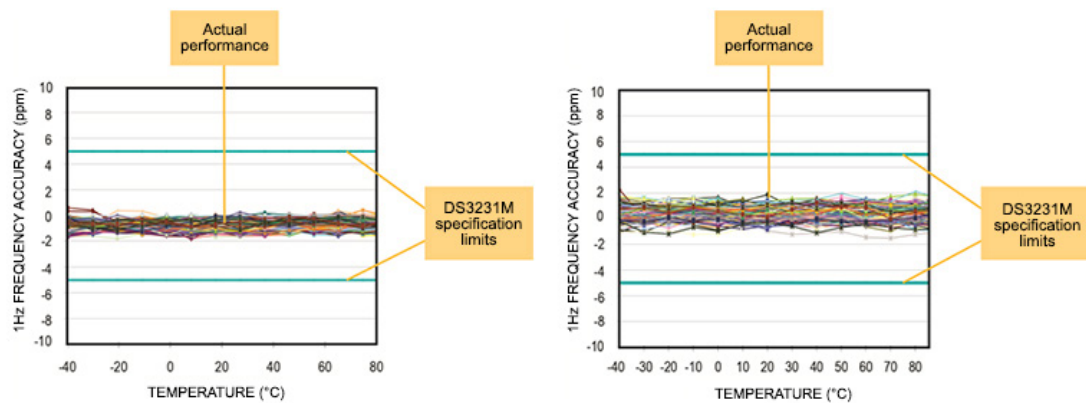


Figure 5. DS3231M Accuracy Pre and Post Reflow

Crystal-based clocks have typical aging characteristics of  $\pm 1\text{ppm}$  per year. By contrast, aging is negligible ( $< 1\text{ppm}$  lifetime) for MEMS resonators. MEMS resonators are also significantly more robust to shock and vibration. MEMS resonators can withstand mechanical shock (up to  $2900g$ ; 5 shocks  $\times$  6 axes, JESD22-B104C Condition H) and vibration (with variable frequency of  $20g$ ;  $20/2000\text{Hz}$ , JESD22-B103B Condition 1). This rugged performance comes with no discernible frequency perturbations greater than  $\pm 1\text{ppm}$ .

## Other Than the Resonator, What Else Can Affect RTC Accuracy?

Other factors that can affect the accuracy of an RTC include incorrect capacitive loading of the crystal and poor board layout. Some RTCs have the capacitors integrated within the IC but this means that the accuracy of the RTC is limited by the IC manufacturer, instead of allowing the designer to choose a capacitor with a desired tolerance.

## How Much Current Does an RTC Consume?

Current consumption is dependent on the type of resonator used. While state-of-the-art RTCs, such as the [MAX31341](#), can consume as little as  $180\text{nA}$ . Table 2 shows the typical current consumption to be expected for each type.

**Table 2. Typical RTC Resonator Accuracy**

	XTAL	XTAL (TXCO)	MEMS
Current (typical)	$250\text{nA}$	$2\mu\text{A}$	$1\mu\text{A}$

## How Are RTCs Powered?

RTCs can be powered in several ways (Figure 6) but typically, an RTC will be powered by the main system power supply during normal operation. However, in the event of a power failure (or the main power level falling below a predefined threshold), the RTC will automatically switch over to a backup power source which will usually be a rechargeable battery or supercapacitor. It will continue to draw on the backup source until the main system power has been restored, at which time, the backup battery will be recharged. Once fully recharged, the battery voltage will be maintained by a trickle charge from the main power supply.

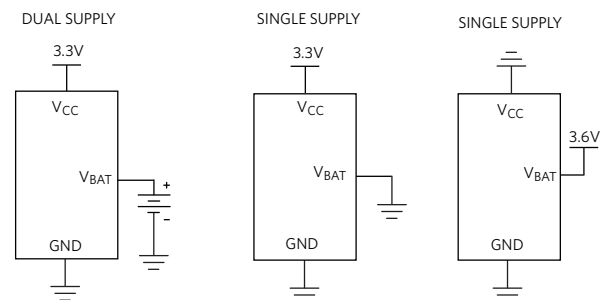


Figure 6. Options for powering an RTC circuit

## How Long Will the Backup Battery Last?

The duration of the battery backup depends on several factors, including the type of battery used (it should have a very low self-discharge rate) and the current consumption of the RTC itself. For example, a BR1225 lithium battery (rated for  $48\text{mAh}$ ) acting as backup to the [DS1307](#) RTC with a timekeeping current of  $500\text{nA}$  (max) would achieve a cell life of  $48\text{mA}/500\text{nA} = 96,000$  hrs or approximately 11 years. For convenience, a battery life calculator is included at the end of this tutorial (see [Manganese Lithium Rechargeable Cell Lifetime Calculator](#)).

## When Should I Use an External RTC IC?

While many microcontrollers contain an integrated RTC, there is a caveat to using it. When an IoT device is in sleep mode, its microcontroller must still maintain real-time information. This means that the micro can never be fully powered down into a deep-sleep mode because some auxiliary circuits must be kept active to allow its RTC to function (even when most of the remainder of its circuitry has been powered down). A microcontroller in sleep mode will typically consume an extra 400nA of current with its RTC enabled, compared to only 200nA (or less) for a stand-alone RTC IC, such as the MAX31341, as shown in Figure 7.

## What Else Can an RTC Do?

Apart from timekeeping, some other features offered by RTCs include independent time-of-day alarms; user-configurable memory for storage of system information; accurate temperature sensing to advise on thermal environmental conditions and the ability to timestamp critical system events.

## How Small is an RTC IC?

To minimize impact on the system board area, ideally the package size should be as small as possible. For example, the MAX31341 is available in a tiny 2mm x 1.5mm, 12-bump WLP.

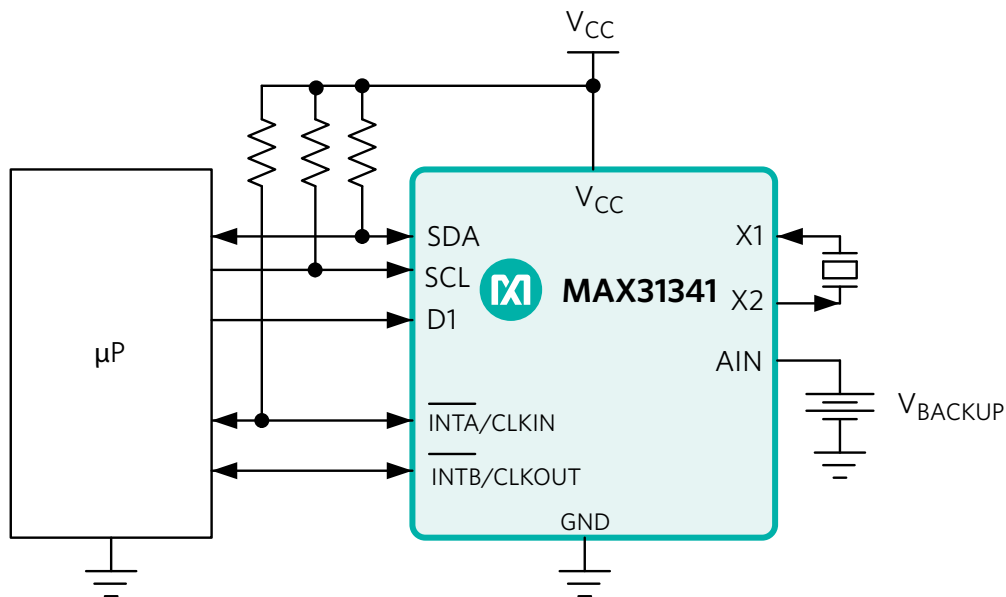


Figure 7. MAX31341 RTC Typical Operating Circuit

## Conclusion

In this tutorial, we have reviewed the function, operation, and limitations of different types of RTC circuits. Low current, size, and accuracy are all important specifications, each of which are dependent on the RTC resonator type. While MEMS RTCs are the most accurate and reliable over their lifetime, the correct choice of RTC for a design is greatly dependent on the end application. We offer the widest and most flexible portfolio of low-power, high-performance and low-footprint RTC ICs, including integrated MEMS RTCs which provide class-leading performance in the most rugged of conditions.

### Learn more:

[MAX31341 Low-Current, Real-Time Clock with I<sup>2</sup>C Interface and Power Management](#)

[DS3231M ±5ppm, I<sup>2</sup>C Real-Time Clock](#)

[DS3231 Extremely Accurate I<sup>2</sup>C-Integrated RTC/TCXO/Crystal](#)

[DS32kHz 32.768kHz Temperature-Compensated Crystal Oscillator](#)

## Application Notes

[Industry Turns to MEMS for Accurate Real-Time Clocks](#)

[MEMS Technology Provides Tangible Benefits for Real-Time Clocks](#)

[Selecting a Backup Source for Real-Time Clocks](#)

[Estimating Super Capacitor Backup Time on Trickle-Charger Real-Time Clocks](#)

## Design Tools

[Super Capacitor Calculator](#)

[Manganese Lithium Rechargeable Cell Lifetime Calculator](#)

## Product Guide

[Accurate MEMS Real-Time Clocks Product Guide](#)

For more information, visit:

[Real-Time Clock \(RTC\) ICs](#)