SimpleLink™ crystal-less wireless MCU based on TI BAW technology—at the heart of IoT evolution

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Introduction

Wireless technologies are the backbone of our rapidly evolving, connected world. As these technologies push the boundaries of speed, range and integration, end-equipment manufacturers are looking for solutions that offer a simplified approach to Internet of Things (IoT) design.

An innovative technology from Texas Instruments—bulk acoustic wave (BAW) resonators—takes integration a step further by offering the world's first crystal-less SimpleLink™ wireless microcontrollers (MCUs). TI BAW technology enables high-performance, timing-accurate resonators, which when integrated into the MCU package eliminate the need for bulky external crystals without compromising power, latency or frequency stability.

This white paper explores the advantages of adopting crystal-less MCUs in IoT-connected products to provide smaller footprints, better cost optimization and more robust designs.

Wireless microcontrollers are the building blocks for the IoT

The Internet of Things describes every aspect of connectivity, from machine learning-based process automation in automotive factory floors to remotely controlling your toaster. It is in fact an apt term, because "IoT-enabled products" in many cases refers to a collection of "things" that could be anywhere on a spectrum between what needs next-level autonomy (think artificial intelligence) to what makes life easier (your toaster). What is undeniable is that the need to connect is pervasive, immutable and quietly revolutionizing the way we construct problem statements and their solutions. The discussion on the power of data and using the intelligence we gain from data to reach a better quality of life would not be possible today without the IoT.

The core technology enabling these connected products are wireless MCUs, which bridge traditional independent sensor nodes (for example, a door bell or a lock) to the internet. TI's SimpleLink family of highly integrated wireless MCUs have broad applicability in connecting sensor nodes because they provide a breadth of wireless connectivity options, ranging from long-range proprietary solutions to standard-driven protocols like *Bluetooth*® low energy, Zigbee®, Thread and Wi-Fi®.

Although these wireless technologies are being increasingly adopted, the expansion of IoT continues to be limited by multiple factors, including extended time to market, increased costs and increased product size (from the added design complexity that wireless technologies bring). Let's tackle some of these factors and how a crystal-less wireless MCU based on TI BAW technology can address them.

Simplifying IoT design without compromising on performance

TI's BAW technology is the core enabler for integrated microelectromechanical (MEMs)-based on-chip resonators that consist of a piezoelectric material sandwiched between two electrodes (see **Figure 1**). This material can convert electrical energy to mechanical-acoustical energy, producing reliable oscillations that result in a high-frequency, stable clock output. The stable clock can then be used as a precision source for radio-frequency (RF) timing, enabling the radio core to operate reliably without compromising on parameters like frequency error and tight temperature tolerance.

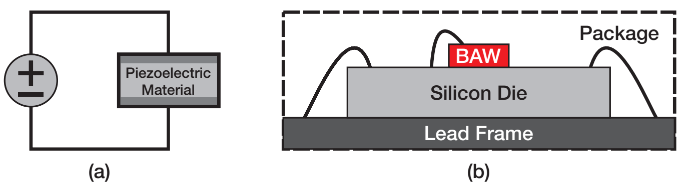

***Figure 1**. Piezoelectric material serving as a resonator (a); BAW technology fabricated on silicon die (b).*

This technology is now integrated in TI's SimpleLink family of wireless MCUs, specifically the CC2652R multi-protocol family supporting *Bluetooth*® low energy, Thread and Zigbee standards, which allows the MCU to operate without any external oscillators. The block diagram of the CC2652RB BAW-enabled wireless MCU shown in **Figure 2** includes an expanded view of the radio core. This MCU also offers:

- A separate application-core central processing unit (CPU) based on ARM® M4F technology.
- An additional autonomous core to enable low-power sensing and actuation ultra-low power sensor controller (ULP-SC).
- Multiple wired communication peripherals.
- 608 kB of integrated nonvolatile memory, including wireless stacks in 256-kB read-only memory and 352 kB of embedded Flash for user programming.

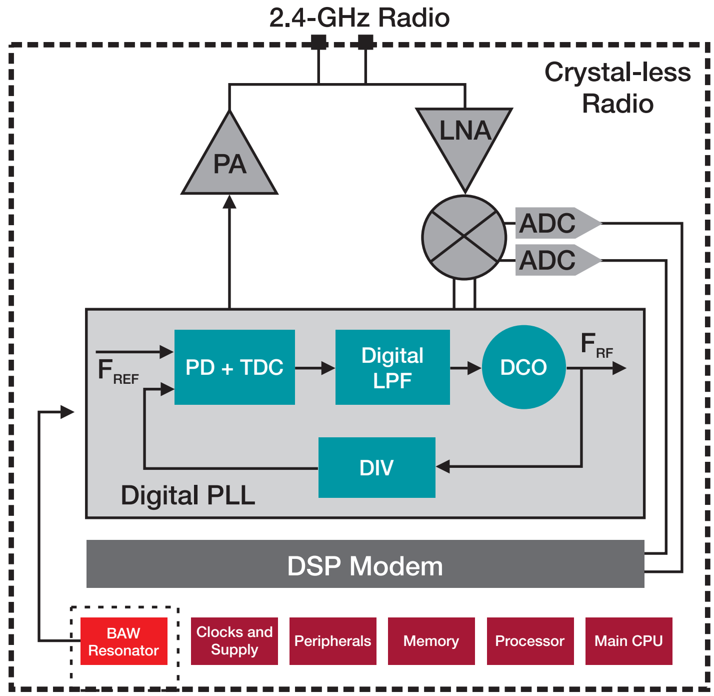

***Figure 2:** CC2652RB SimpleLink crystal-less BAW, expanded to show the radio sub-system and integrated TI BAW resonator.*

As **Figure 1** illustrates, the BAW resonator is fully integrated into the 7-mm-by-7-mm quad flat no-lead (QFN) CC2652RB device package. It services the digital phase-locked loop (PLL) by providing an accurate reference frequency, enabling the PLL to operate at 48 MHz reliably. In order to achieve superior frequency stability over temperature and battery (voltage) conditions, the BAW resonator is actively compensated. This active compensation is carried out in the integrated radio core without impacting the application's MCU bandwidth, and enables the CC2652RB device to provide a tight frequency error of 40 ppm across the full operating voltage (1.8 V–3.6 V) and temperature (–40°C to 85°C) range. In comparison, external 48-MHz crystals exhibit reasonable frequency error (~10 ppm typical) at room temperature but tend to vary by 10s of ppm across the full operating range.

Hence choosing the CC2652RB TI BAW-enabled devices eliminates the complexity of crystal selection (especially when it needs to meet tight ppm requirements), thereby simplifying design decisions.

Additional benefits of crystal-less design include crystal cost savings on average between $0.40–$0.80, not to mention a simpler bill of materials that mitigates crystal-sourcing risks (when external crystals have long lead times).

Figure 3 shows a typical sample plot of frequency error of integrated BAW resonators on the CC2652RB device versus an off-the-shelf external crystal. It can be seen that the frequency accuracy of crystal-less wireless MCU is as good as wireless MCU that uses an external crystal. Note that 40 ppm is the required frequency error specification for protocols such as *Bluetooth*® low energy, Thread and Zigbee® to maintain connection integrity and ensure reliable data transfer.

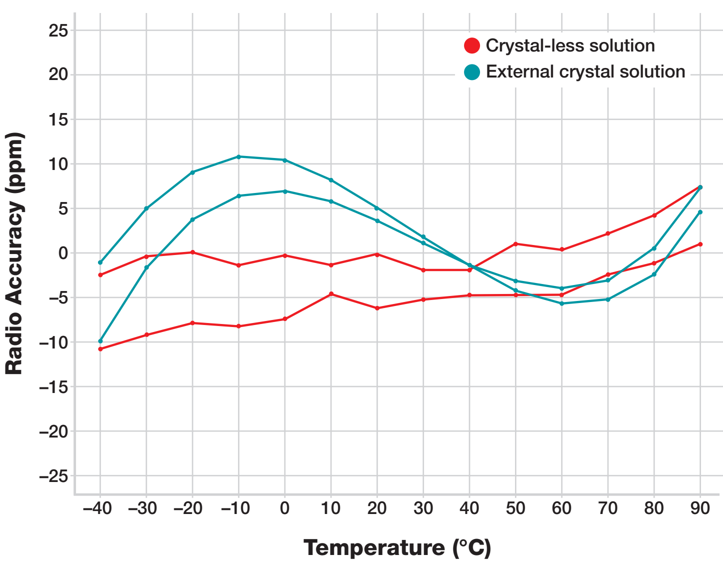

***Figure 3:** CC2652RB crystal-less wireless SimpleLink MCU radio frequency accuracy.*

Another important impact of frequency accuracy can be seen on receiver sensitivity which is defined as the weakest signal a receiver can identify while maintaining an expected PER (packet error rate).

Comparing the receiver sensitivity of the CC2652RB device to an external crystal-based system, you can see in **Figure 4** that the BAW-enabled device is on par and does not compromise receiver sensitivity or show degradation over operating conditions.

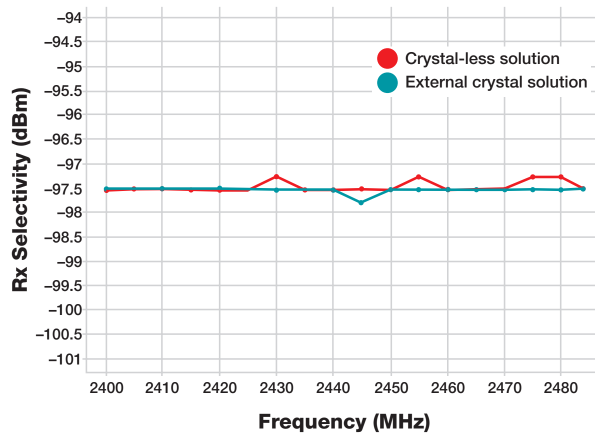

***Figure 4:** Receiver sensitivity on the CC2652RB MCU.*

Now that we've addressed the important aspects of performance such as frequency error over operating conditions and receiver sensitivity, let's look at the power consumption of integrated BAW technology. In doing so, it's best to take into account the use case of standard wireless protocols like *Bluetooth*® low energy. Note that the use of the BAW resonator is seamlessly integrated into the *Bluetooth*® low energy stack, and the software is able to intelligently turn on the resonator as needed (duty cycling) to minimize power consumption. With the integrated BAW resonator, it results in added power consumption typically in the range of 500 μA.

Table 1 on the following page illustrates that for a typical duty-cycled application, the increase in active power consumption when using the TI BAW resonator results in a minimal increase in overall power consumption.

The additional but minimal power impact is outweighed by the benefits of integration and reliability offered by the CC2652RB MCU.

Task	CC2652RB with integrated BAW	CC2652R with external crystal	Standby power increase with BAW enabled
Bluetooth® low energy peripheral, Protocol Data Unit: 328 µs Connection interval = 7.5 ms	771 µA	727 µA	7%
Bluetooth® low energy peripheral, Protocol Data Unit: 328 µs Connection interval = 4 s	2.44 µA	2.36 µA	4.4%

Table 1: *Power consumption comparison for devices with external crystal vs. integrated TI BAW technology.*

Space constrained? TI BAW technology can help.

An emerging trend in connected products is the expansion of wireless technologies in the medical market, providing a significant quality-of-life improvement. Examples of IoT applications that have proven to be game-changers include pacemakers, continuous glucose monitors, infusion pumps and remote patient monitoring systems that provide the ability to extend quality medical care globally in an easy and inexpensive manner. In medical wearables, enabling wireless connectivity must take into account the most significant design consideration: space optimization. In such cases, it is easy to see that every square millimeter of saved space is crucial to the usage of the product.

Figure 5 shows a board layout view of the CC2652R device with an external crystal. The figure highlights the space used by the external crystal and the trace routing it entails. In one example, a standard crystal used on the CC2652R LaunchPad™ development kits (1.7 mm × 2 mm) was replaced by a BAW-integrated CC2652RB device, resulting in an area savings of 12%.

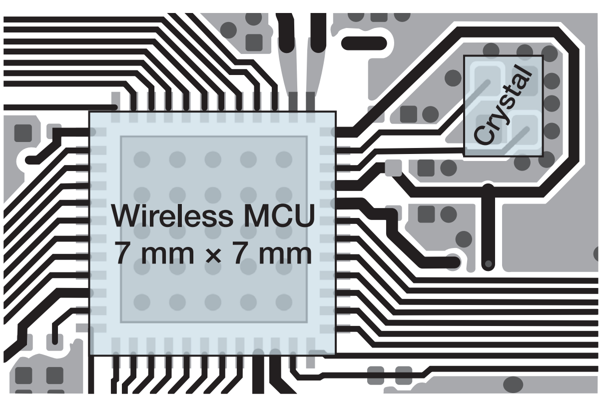

Figure 5: *Board layout showing the space used by an external crystal on the Launchxl-cc26x2r1.*

We've covered various hardware-centric aspects of CC1652RB MCUs with TI BAW technology. But what about ease of use? The operation of the BAW resonator in clocking the RF MCU core is fully transparent to developers because it is seamlessly integrated into the wireless stacks supported by the SimpleLink ecosystem.

Early release versions of the SimpleLink software development kit will support the *Bluetooth*® low energy 5.0 protocol, with planned future support for Thread, Zigbee® and multiprotocol capabilities. For developers currently using SimpleLink products, the effort to port software to the BAW-based CC2652RB device is minimal. See the Getting Started Guide for more information on using CC2652RB MCUs.

Next-level integration with no performance compromise

TI's SimpleLink crystal-less wireless MCUs with integrated TI BAW resonator technology provide compelling benefits to both hardware designers and application developers. It establishes a reliable, robust and space-optimized alternative to external crystals with zero compromise on performance. The unprecedented level of integration enabled by crystal-less MCUs presents an exciting new frontier for IoT products, transforming adoption, implementation and the use of wireless technologies in edge nodes while providing a smarter way to connect.

Resources:

[Product Folder]

[Tool Folder]

[Datasheet]

[Getting Started Guide]

[SDK Folder]

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