AN14298

32 kHz Crystal-less mode on KW45

Rev. 1.0 — 7 November 2025 Application note

Document information

Information	Content
Keywords	AN14298, KW45, crystal-less mode
Abstract	This application note provides information on the 32 kHz crystal-less mode on the KW45 device.

1 Introduction

This application note provides information on the 32 kHz crystal-less mode on the KW45 device. This mode allows you to reduce the cost of the system, without compromising the 32 kHz clock accuracy. The FRO32K is used as the 32 kHz clock source and is calibrated against the 32 MHz RF oscillator through the Signal Frequency Analyzer (SFA) module of KW45. The monitoring and calibration processes are handled by the Smart Frequency Calibration (SFC) software module. It allows calibrating the FRO32K clock source to the desired frequency to keep the timebase of the Radio within the allowed tolerance as specified by the connectivity standards. Even in the XTAL32K solution, the SFC module can be used during the initialization phase until the XTAL32K becomes stable. The system first runs on the FRO32K as the clock source, then switches to the XTAL32K when it is ready with enough accuracy. This setup allows the system to save significant boot time as the FRO32K startup (including calibration) is faster compared to the XTAL32K crystal.

The following sections cover the 32 kHz crystal-less mode in detail.

2 Software enablement

This section covers the functional description and details on how to enable the crystal-less mode in software.

For detail about the software implementation of the SFC, refer to the readme file located in the `SDK_folder\middleware\wireless\framework\SFC` folder.

2.1 Functional description

The 32 kHz crystal provides a stable clock for the Real-Time Clock (RTC) in a system. However, it is possible to remove the external crystal and use an internal 32 kHz Free-Running Oscillator (FRO32K) instead. The SFC software module is used in this scenario. The module handles:

- Measurement of the FRO32K clock frequency against the 32 MHz crystal. It schedules the start of the measurement appropriately and gets the result when completed.
- Filtering and estimation of the 32 kHz frequency value and error by averaging from the last measurements.
- Calibration of the FRO32K to update the trimming value to reduce the frequency error on the clock.

The target accuracy of the 32 kHz clock generated from the FRO32K can be configured in the software with the definition of `BOARD_FRO32K_PPM_TARGET`. The SFC module switches automatically between two modes of operation to keep the clock frequency accuracy within 200 ppm by default.

Note: *200 ppm is the recommended value for the target accuracy.*

The 32 kHz FRO frequency measurement and recalibration are done during Narrow Band Unit (NBU) low-power entry and exit when the low-power feature is enabled. Also, the 32 kHz FRO frequency measurement and recalibration are done periodically during the NBU IDLE state when it is disabled.

2.1.1 Convergence mode

This mode is entered when the clock accuracy value is greater than the target value (200 ppm by default). Typically, it occurs:

- During power-on reset or other reset when the NBU is switched OFF
- When temperature varies and FRO32K frequency deviates outside the 200 ppm threshold target

During the convergence mode, a control loop measures the 32 kHz clock frequency and updates the trim value register to lower the error, until it falls below the target value. When the target accuracy is reached, the SFC module switches to Monitoring mode.

The convergence mode prevents the NBU from going into Low-Power mode, so it has a negative impact on the power consumption. Its duration depends on the initial frequency error of the FRO32K. Each frequency measurement takes 0.5 ms so 20 measurements (given as an example only) require less than 10 ms to converge.

2.1.2 Monitoring mode

When the clock accuracy is within the target value, the SFC remains in the Monitoring mode. In this mode, the measurement is triggered by an internal hardware signal on wake-up of the NBU domain from Low-Power mode. If the estimated frequency error exceeds the threshold, the SFC switches back to Convergence mode. The trim register is updated by one increment (positive or negative) and because the frequency has been adjusted and changed, the estimated filtered frequency is reset to discard all previous measurements.

The FRO32K frequency measurement values are noisy because of thermal noise on the FRO32K itself. Also, the frequency measurement can introduce some error. In Monitoring mode, it is required to filter the measurements by applying an exponential filter.

```
new_estimation = (new_measurement + ((1 << n) -1) * last_estimation) >> n
```

The default value for `n` is 7 (meaning 128 samples in the averaging window). If the frequency estimation value is still within the target range, the NBU power domain is allowed to go to low power.

In Monitoring mode, the frequency measurement duration is 2 ms. This value remains less than the minimal radio activity duration, ensuring it does not impact the low-power consumption.

2.2 Usage with low power

In Monitoring mode, the FRO32K frequency measurements are performed during the radio activity so it does not increase the active current as the source clocks are already active. Also, it does not increase the active time as the measurement takes some time.

In convergence mode, measurements and calibrations are done in loop until the Monitoring mode is reached (frequency error falls below target value). When the FRO32K frequency must be adjusted, the NBU core wakes up the main power domain and updates the FRO32K trimming register, therefore, consuming extra power. However, this typically only occurs during temperature variation due to the thermal noise of the FRO32K. During most of the time, the SFC stays in Monitoring mode.

Since the FRO32K consumes more power compared to the XTAL32K, the power consumption in low-power mode increases slightly. An additional 350 nA of current is expected when the FRO32K is used instead of the XTAL32K. The usage of the FRO32K instead of the XTAL32K brings impact on the power consumption and the behavior of the NBU. The NBU wakes up earlier if FRO32K is used.

Note: *The SFC cannot work while the CM33 core is in Power-down mode.*

2.3 How to enable the 32 kHz crystal-less mode in software

The 32 kHz crystal-less mode can be enabled in the software by simply defining the compilation flag `gBoardUseFro32k_d` to 1 in `board_platform.h` or in `app_preinclude.h`. By setting this flag to 1, the function `PLATFORM_InitFro32K()` is called during the application initialization to initialize the FRO32K. Otherwise, `PLATFORM_InitOsc32K()` function is called to initialize the XTAL32K instead.

2.4 FRO debugging

A debugging possibility is provided in the software with the function `void PLATFORM_RegisterFroNotificationCallback(PLATFORM_FroDebugCallback_t cb)`.

The registered callback function is triggered at each FRO measurement, and it could return useful information of the FRO32K to the arguments of the callback function. The arguments are `measured frequency`, `instant ppm value`, and `averaged ppm value`. An example of the prototype of the callback function is `static void FroNotificationCallback(uint16_t freq, int16_t ppm_mean, int16_t ppm)`.

3 System validation

This section describes the test results performed at both room temperature and various temperatures for the frequency and throughput measurements. These measurements are done using FRO32K and XTAL32K as clock sources.

Note:

The 32 kHz crystal-less mode with FRO32K as source clock is an experimental feature and has been validated with NXP demo examples only. It is recommended that you must validate this design at the application level on your side.

3.1 Clock accuracy at room temperature

The frequency is measured on the KW45B41Z-EVK board by outputting the RTC signal on the pin PTC7. Figure 1 illustrates the setup for clock frequency measurement.

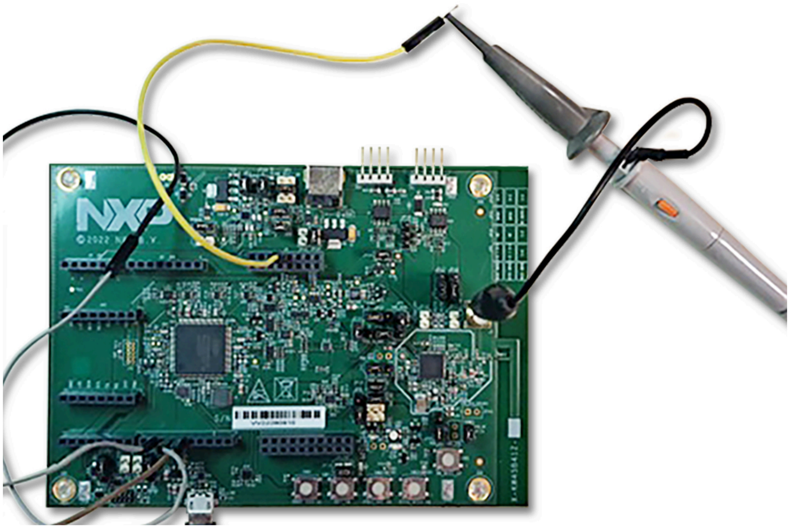

Figure 1. Clock frequency measurement setup

Two different software using either XTAL32K or FRO32K as clock source are programmed to the same board one after the other for the following measurements. The tests are conducted at 25 °C temperature.

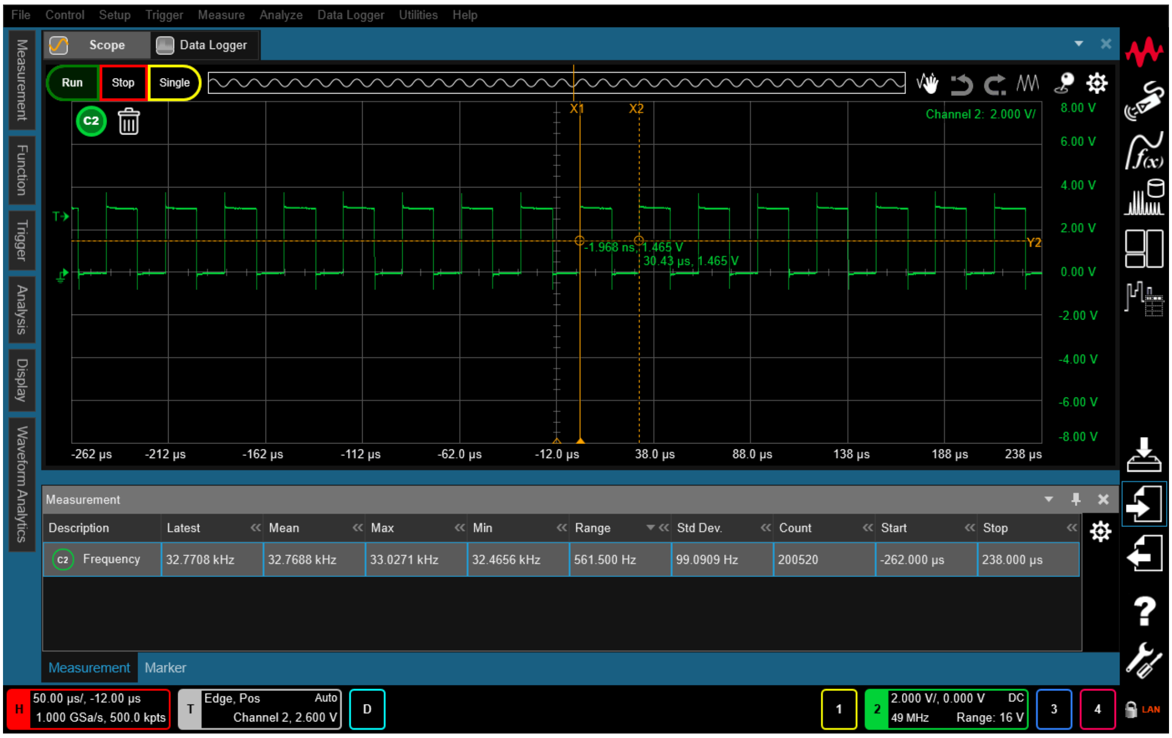

Figure 2. Frequency measurement with XTAL32K as clock source

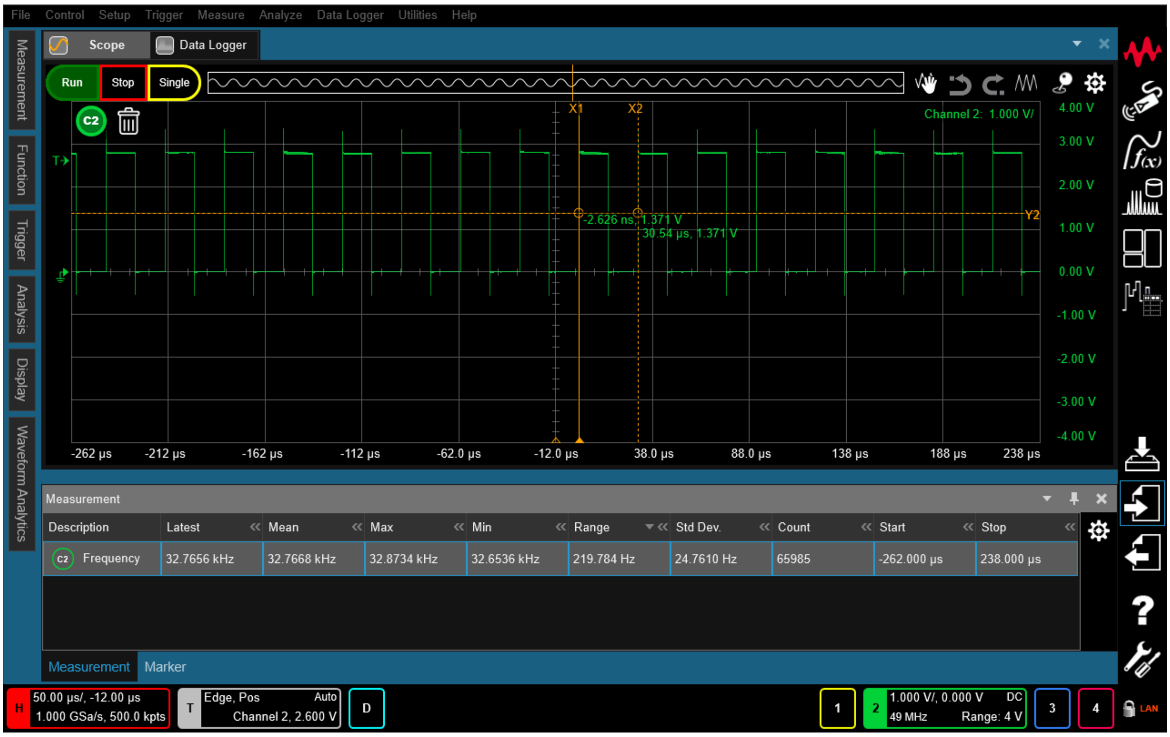

Figure 3. Frequency measurement with FRO32K as clock source

Table 1 describes the average measured frequency, calculated frequency accuracy, and standard deviation of the two configurations.

Table 1. Test results

Test name	XTAL32K	FRO32K
Measured Frequency (Hz)	32768.8	32766.8
Calculated frequency accuracy (ppm)	+24	-36
Measure standard deviation (Hz)	99.09	24.71

In steady state, the output frequency of the FRO32K is even more stable than that of the XTAL32K, which is due to the SFC module. The clock frequency accuracy of the XTAL32K is a bit better than the FRO32K, however, both are within the permitted accuracy range and are compliant with the Bluetooth Low Energy specification.

3.2 Clock accuracy during a temperature variation

The FRO32K has a greater thermal noise than a classical crystal, therefore, it is essential to ensure that the clock remains stable within the allowed range during a temperature variation.

The following test is conducted with a Device Under Test (DUT) under a ThermoStream, which controls its temperature. The DUT uses the FRO32K as the source clock, and the temperature varies from 25 °C to 85 °C. A logical analyzer is used to measure the RTC output with a sampling rate at 500 MS/s.

Figure 4. Frequency measurement with varying temperature and FRO32K as source clock

Figure 4 shows the two measurements highlighted in pink, both last 5 s for averaging. The first measurement area is when the temperature is at 25 °C stable, and the second one is during the temperature variation.

Table 2. Test results

Test name	25 °C	Varied temperature
Measured frequency (Hz)	32765	32762
Calculated frequency accuracy (ppm)	-92	-183

This test proved that the FRO32K provided a source clock that is within the target accuracy range even during a temperature variation.

3.3 Throughput test

Throughput measurements are performed using two different clock sources to verify if any connection is lost due to potential clock drift entailed when using the FRO32K as a clock source.

The `BLE_Shell` demo application is used for the throughput measurement. For details on the application and instructions on how to use it for throughput measurement, refer to KW45B41Z-EVK Software Development Kit (SDK).

The DUT is programmed with software using either the XTAL32K or the FRO32K as the source clock. After the communication establishment, the bit rate measurement is triggered manually, and the result is displayed on the prompt window.

Two clock configurations show identical performance, which proves that the 32 kHz crystal-less mode presents no disconnection and no performance degradation.

Figure 5. Throughput test with XTAL32K as clock source

Figure 6. Throughput test with FRO32K as clock source

3.4 Throughput test at temperature variation

Another test using the same setup is done with one DUT under ThermoStream, which varies the temperature from 25 °C to 85 °C. The DUT uses the FRO32K as a clock source. The results are identical to the previous ones, with no disconnection or performance degradation detected.

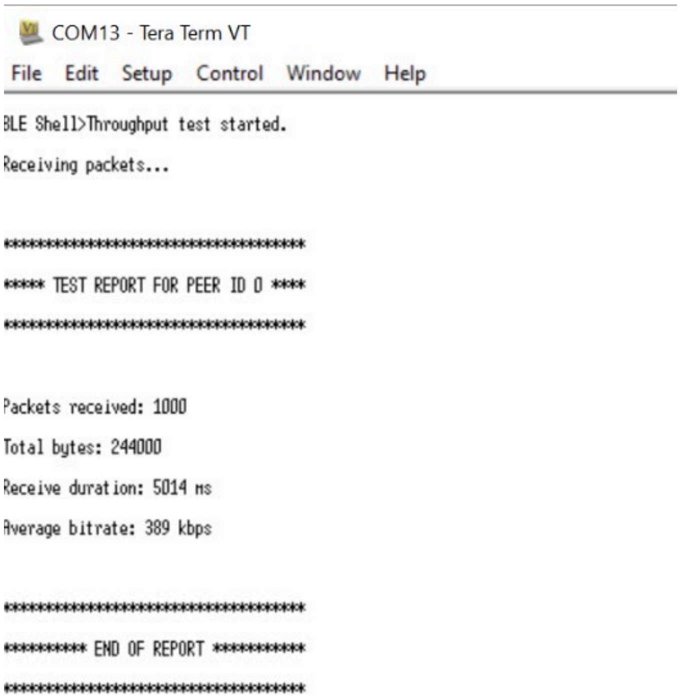

Figure 7. Throughput test with FRO32K as clock source at varying temperature

4 Conclusion

Various tests and measurements proved that the FRO32K can be used as the 32 kHz clock source instead of the XTAL32K, with the help of the SFC module. It can provide an accurate and stable 32 kHz clock source that satisfies the requirements of connectivity standards.

5 Note about the source code in the document

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6 Revision history

Table 3 summarizes revisions to this document.

Table 3. Revision history

Document ID	Release date	Description
AN14298 v.1.0	7 November 2025	Initial public release

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