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AN402

F-RAM™ RTC Oscillator Design Guide

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Associated Part Family: FM31278, FM31276, FM31L278, FM31L276, FM31256, FM3164, and FM33256B
Related Application Notes: click here

AN402 describes the real-time clock (RTC) oscillator and provides design considerations for using the RTC in the F-RAM™ processor companions.

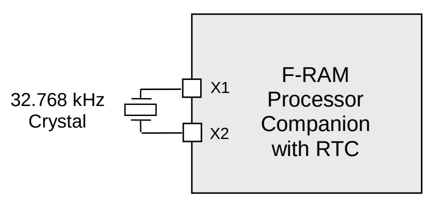
1 Overview

The FM31xxx and FM33xxx are integrated processor companion devices that feature a real-time clock or RTC. The RTC provides the date and time information for the system. The RTC operates on V_{DD} power and switches to a backup supply when the V_{DD} power is removed. Under backup power, the RTC draws very little current, which allows a long operating time. The accuracy of the RTC is dependent mainly on the accuracy of the crystal oscillator. The crystal frequency is affected by the capacitive rating of the crystal and the operating temperature. This application note focuses on the RTC oscillator and provides design considerations for a system designer using these devices.

2 Oscillator and Crystals

The heart of the RTC is the oscillator, which uses a 32.768-kHz crystal. It provides an accurate, low-power time base for the divide-by counters that generate seconds, minutes, hours, and more. The oscillator must work properly and be undisturbed for the clock/time to be accurate over long periods of time. An F-RAM processor companion with crystal is shown in Figure 1.

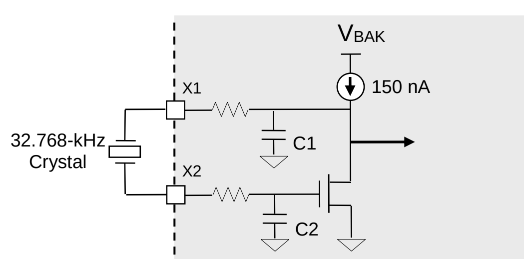
Figure 1. Crystal Hookup to F-RAM RTC



The RTC oscillator is designed to use a 32.768-kHz crystal (having 6 pF/12.5 pF load capacitance specification) without the need for any external components. If additional components, such as capacitors or resistors, are connected to the X1 or X2 pins, the oscillator will not operate properly because the DC operating point and the oscillator frequency will be shifted. It is possible that the oscillator will not even start at power up. Passive 10X oscilloscope probes with 10 pF and 10 MΩ impedance will also upset the oscillator.

The simplified schematic of the oscillator in Figure 2 shows a Pierce oscillator with C1 and C2 loading capacitors inside the chip.

Figure 2. Simplified Oscillator Circuit



The capacitors operate in series with the crystal, so the CLOAD is C1 * C2 / (C1 + C2). For all F-RAM parts, C1 and C2 are 12 pF; hence, CLOAD is 6 pF. The F-RAM RTC oscillator is optimized for using the 6-pF crystal to achieve the lowest operating current under backup power. A 12.5-pF crystal will also work equally well but draws almost twice as much current. When using a 12.5-pF crystal, consider the loading mismatch and take appropriate measure to offset the frequency shift.

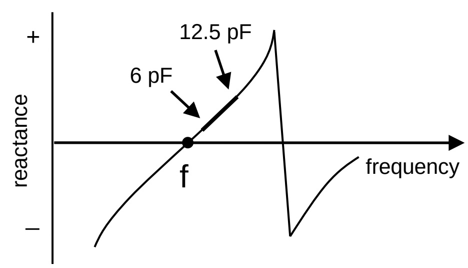
Note: All 32.768-kHz crystals have a load capacitance specification. There are two common crystals in the market: a “6 pF” type and a “12.5 pF” type. This is the recommended capacitive load that the crystal must see across the X1 and X2 pins while operating. That is, the X1/X2 pins must present a 6-pF load to a 6-pF crystal. The load capacitance specification is not the actual capacitance of the crystal. The actual capacitance of the crystal (shunt capacitance) is about 1 pF.

3 Oscillator Frequency Shift

Typically, RTC calibration is required primarily to compensate for the crystal tolerance, whether ±10 ppm, ±20 ppm, or ±50 ppm. The use of a 12.5-pF crystal introduces a loading mismatch factor when calibrating the RTC. A 12.5-pF crystal expects a capacitive load of 12.5 pF to ensure accurate frequency. However, because the F-RAM processor companions are designed for 6-pF crystals, the load presented to the crystal is roughly half the rated value. Therefore, this lighter load presented across the crystal shifts the oscillation frequency. The shift has been measured and is typically about +90 ppm or 2.9 Hz. The actual crystal frequency will be 32.7709 kHz. In calibration mode, this frequency shift can be measured directly on the CAL pin (ACS pin on FM33256B) as 512.046 Hz. Figure 3 shows the parallel resonance area as the bold line where the RTC oscillator operates. A 12.5-pF crystal (with 6-pF load) operates higher on the curve.

A +90 ppm error translates to nearly four minutes of clock deviation per month (the clock runs fast), so calibrating the RTC is highly desirable to achieve clock accuracy. You must note that the effect of the calibration setting to minimize the frequency error will not be observed on the CAL pin (ACS pin on FM33256B). The RTC applies a digital correction to the counter logic downstream of the 512-Hz output.

Figure 3. Higher Oscillator Frequency for 12.5 pF Crystal



If you use a 12.5-pF crystal, Cypress recommends that the specified tolerance be ±20 ppm (or better) to ensure that the total error (tolerance + mismatch) remains within the ±135 ppm calibration range. If you use a 6-pF crystal, the tolerance can be as high as ±100 ppm, because this is well within the calibration range.

Precautionary note: The oscillator’s 32.768-kHz frequency cannot be monitored directly by probing the X1 and X2 pins. Do not attach a scope probe or meter to the X1 and X2 pins. In calibration mode, the CAL pin is used to check the frequency. Moreover, the calibration code can be entered only in calibration mode.

4 Calibration Procedure

The following sequence shows how to measure the oscillator frequency and apply a calibration code. On two-wire devices, remember to use the slave ID 1101b to access the RTC registers.

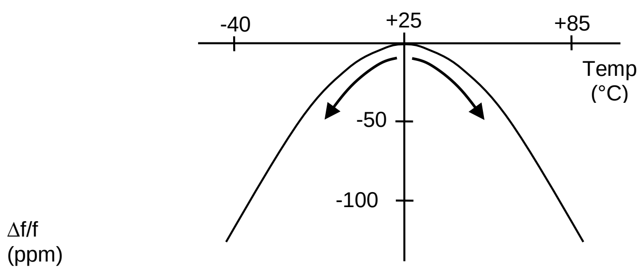
1. Apply V_{DD}.
2. Apply V_{BAK}.
3. Cycle V_{DD} off then on again.
4. Turn on the oscillator by setting $\overline{\text{OSCEN}}$ bit low. Write 00h to RTC Register 01h (For FM33256B, write 00h to RTC Register 00h).
5. Set CAL bit high. Write 04h to RTC Register 00h.

6. Measure the 512-Hz output on CAL pin (ACS pin on FM33256B) with a frequency counter.
7. Determine the calibration code setting from the table in Calibration Table (This table is also available in the device datasheet).
8. Apply the calibration code. For example, a 12.5-pF crystal makes the oscillator run fast and the CAL output is 512.046 Hz. Write 16h to RTC Register 01h.
9. Reset CAL bit. Write 00h to RTC Register 00h.

5 Temperature Effects

A key factor that contributes to timekeeping error is the crystal's temperature – even after the RTC is calibrated. A calibration code can compensate for timekeeping errors due to capacitive load mismatch and crystal tolerance, but not for temperature. Figure 4 shows a typical temperature curve for 32.768-kHz crystals. As temperature rises or drops from +25 °C, the oscillation frequency shifts lower and therefore the clock slows down.

Figure 4. Crystal Frequency Change vs. Temperature



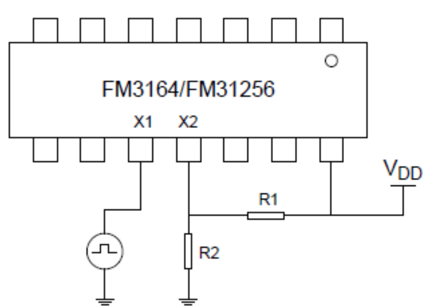
If your system is at room temperature most of the time and has few excursions above and below 25 °C, then you should calibrate to “zero out” any frequency error by complying with the table in Calibration Table. On the other hand, if the system frequently spends time above or below room temperature, you will achieve improved clock accuracy by intentionally creating a slightly positive frequency error.

For example, assume the system spends half the time at 25 °C and half at 50 °C, and the frequency error at 50 °C is -30 ppm. Applying a calibration code that will shift clock by +15 ppm will compensate for temperature changes. Consult the crystal manufacturer for a temperature dependence curve.

6 External Oscillator

If a 32.768-kHz crystal is not used, an external oscillator may be connected to the F-RAM RTC oscillator. Apply the oscillator to the X1 pin. Its high and low voltage levels can be driven rail-to-rail or to amplitudes as low as approximately 500 mV p-p. To ensure proper operation, a DC bias must be applied to the X2 pin. It should be centered between the high and low levels on the X1 pin. This can be accomplished with a voltage divider as shown in Figure 5.

Figure 5. External Oscillator



In the above example, R1 and R2 are chosen such that the X2 voltage is centered on the X1 oscillator drive levels. If you wish to avoid the DC current, you may choose to drive X1 with an external clock and X2 with an inverted clock using a CMOS inverter.

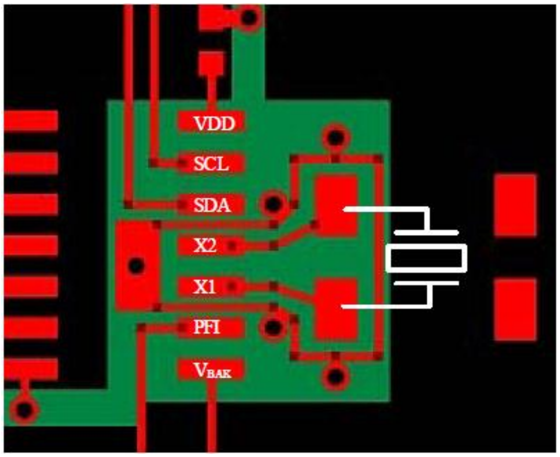
7 Layout Recommendations

The X1 and X2 crystal pins are high-impedance pins, which must be treated with care:

- Ensure that the crystal lead length to the X1 and X2 pins is short, less than 5 mm. Also the X1 and X2 trace lengths should be less than 5 mm.
- Ensure that the V_{DD} pin has good decoupling (0.1 uF with return to ground plane).
- Do not route other signals close to the X1/X2 pins, even if the signal is routed on an inner board layer.
- Use a guard ring (ground) around the crystal pins.
- Use a ground plane on the back or inner board layer.

An FM31xx device and SMD crystal are shown in the example layout shown in Figure 6. Note the plated-through holes that tie the guard ring down to the ground plane.

Figure 6. Layout for Surface Mount Crystal
(red = top layer, green = bottom layer)



8 Summary

This application note described the oscillator selection, frequency shift, calibration procedure, and layout design guidelines for F-RAM processor companion devices.

9 Related Application Notes

You can refer to the following application notes for better understanding of the F-RAM processor companion devices.

- AN407 - A Design Guide to I2C F-RAM Processor Companions – FM31278, FM31276, FM31L278, and FM31L276
- AN408 - A Design Guide to SPI F-RAM Processor Companion - FM33256B
- AN400 - Generating a Power-Fail Interrupt using the F-RAM Processor Companion
- AN401 - Charging Methods for the F-RAM RTC Backup Capacitor
- AN404 - F-RAM RTC Backup Supply (VBAK pin) and UL Compliance

A Calibration Table

Positive Calibration for Slow Clocks (Calibration will achieve ±2.17 PPM after calibration)					
	Measured Frequency Range		Error Range (PPM)		Program Calibration Register to:
	Min	Max	Min	Max	
0	512.0000	511.9989	0	2.17	000000
1	511.9989	511.9967	2.18	6.51	100001
2	511.9967	511.9944	6.52	10.85	100010
3	511.9944	511.9922	10.86	15.19	100011
4	511.9922	511.9900	15.20	19.53	100100
5	511.9900	511.9878	19.54	23.87	100101
6	511.9878	511.9856	23.88	28.21	100110
7	511.9856	511.9833	28.22	32.55	100111
8	511.9833	511.9811	32.56	36.89	101000
9	511.9811	511.9789	36.90	41.23	101001
10	511.9789	511.9767	41.24	45.57	101010
11	511.9767	511.9744	45.58	49.91	101011
12	511.9744	511.9722	49.92	54.25	101100
13	511.9722	511.9700	54.26	58.59	101101
14	511.9700	511.9678	58.60	62.93	101110
15	511.9678	511.9656	62.94	67.27	101111
16	511.9656	511.9633	67.28	71.61	110000
17	511.9633	511.9611	71.62	75.95	110001
18	511.9611	511.9589	75.96	80.29	110010
19	511.9589	511.9567	80.30	84.63	110011
20	511.9567	511.9544	84.64	88.97	110100
21	511.9544	511.9522	88.98	93.31	110101
22	511.9522	511.9500	93.32	97.65	110110
23	511.9500	511.9478	97.66	101.99	110111
24	511.9478	511.9456	102.00	106.33	111000
25	511.9456	511.9433	106.34	110.67	111001
26	511.9433	511.9411	110.68	115.01	111010
27	511.9411	511.9389	115.02	119.35	111011
28	511.9389	511.9367	119.36	123.69	111100
29	511.9367	511.9344	123.70	128.03	111101
30	511.9344	511.9322	128.04	132.37	111110
31	511.9322	511.9300	132.38	136.71	111111

Negative Calibration for Fast Clocks (Calibration will achieve ±2.17 PPM after calibration)					
	Measured Frequency Range		Error Range (PPM)		Program Calibration Register to:
	Min	Max	Min	Max	
0	512.0000	512.0011	0	2.17	000000
1	512.0011	512.0033	2.18	6.51	000001
2	512.0033	512.0056	6.52	10.85	000010
3	512.0056	512.0078	10.86	15.19	000011
4	512.0078	512.0100	15.20	19.53	000100
5	512.0100	512.0122	19.54	23.87	000101
6	512.0122	512.0144	23.88	28.21	000110
7	512.0144	512.0167	28.22	32.55	000111
8	512.0167	512.0189	32.56	36.89	001000
9	512.0189	512.0211	36.90	41.23	001001
10	512.0211	512.0233	41.24	45.57	001010
11	512.0233	512.0256	45.58	49.91	001011
12	512.0256	512.0278	49.92	54.25	001100
13	512.0278	512.0300	54.26	58.59	001101
14	512.0300	512.0322	58.60	62.93	001110
15	512.0322	512.0344	62.94	67.27	001111
16	512.0344	512.0367	67.28	71.61	010000
17	512.0367	512.0389	71.62	75.95	010001
18	512.0389	512.0411	75.96	80.29	010010
19	512.0411	512.0433	80.30	84.63	010011
20	512.0433	512.0456	84.64	88.97	010100
21	512.0456	512.0478	88.98	93.31	010101
22	512.0478	512.0500	93.32	97.65	010110
23	512.0500	512.0522	97.66	101.99	010111
24	512.0522	512.0544	102.00	106.33	011000
25	512.0544	512.0567	106.34	110.67	011001
26	512.0567	512.0589	110.68	115.01	011010
27	512.0589	512.0611	115.02	119.35	011011
28	512.0611	512.0633	119.36	123.69	011100
29	512.0633	512.0656	123.70	128.03	011101
30	512.0656	512.0678	128.04	132.37	011110
31	512.0678	512.0700	132.38	136.71	011111

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**	4018188	MEDU	06/07/2013	New Spec.
*A	4559478	MEDU	11/04/2014	Changed title from “F-RAM RTC Oscillator Guide” to “F-RAM RTC Oscillator Design Guide”. Included content from AN403, “F-RAM RTC Crystals – 6 pF vs. 12.5 pF”. Updated 6-pF RTC oscillator load for all F-RAMs. Added Related Application Notes. Added Appendix A (for the calibration table).
*B	5293268	MEDU	06/02/2016	Updated to new template.
*C	5847834	HARA	08/17/2017	Updated logo and copyright.

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