FM31T372/374/376/378

System Supervisor & Temperature Compensated RTC (TCXO) with Embedded Crystal

Features

High Integration Device Replaces Multiple Parts
- Real-time Clock (RTC)
  - Embedded 32.768kHz Crystal
  - Temperature Compensated
- 32.768 kHz Clock Output
- Low-V_{DD} Detection Drives Reset
- Watchdog Timer
- Early Power-Fail Warning/NMI
- Two 16-bit Event Counters with Event Driven Interrupt Output
- Serial Number with Write-lock for Security

Ferroelectric Nonvolatile RAM
- 4Kb, 16Kb, 64Kb, and 256Kb versions
- Unlimited Read/Write Endurance
- 10 year Data Retention
- NoDelay™ Writes

Real-time Clock/Calendar
- Temp-Compensated Using On-Chip Sensor
  - ± 5 ppm over -40°C to +85°C
  - Accuracy ± 2 ½ min. per year
- Backup Current 1.4 µA (max.) at +25C
- Seconds through Centuries in BCD format
- Tracks Leap Years through 2099
- No External Crystal Required
- Offset Register to Correct for Crystal Aging
- Supports Battery or Capacitor Backup

Processor Companion
- 32.768 kHz Clock Output
- Active-low Reset Output for V_{DD} and Watchdog
- Programmable V_{DD} Reset Trip Point
- Manual Reset Filtered and Debounced
- Programmable Watchdog Timer
- Dual Battery-backed Event Counter Tracks System Intrusions or other Events
- Event Counter Driven Interrupt Output
- Comparator for Early Power-Fail Interrupt
- 64-bit Programmable Serial Number with Lock

Fast Two-wire Serial Interface
- Up to 1 MHz Maximum Bus Frequency
- Supports Legacy Timing for 100 kHz & 400 kHz
- Device Select Pins for up to 4 Memory Devices
- RTC, Supervisor Controlled via 2-wire Interface

Easy to Use Configurations
- Operates from 2.7 to 5.5V
- Small Footprint 14-pin "Green" SOIC (-G)
- Low Operating Current
- -40°C to +85°C Operation

Description

The FM31T37x is a family of integrated devices that includes the most commonly needed functions for processor-based systems. Major features include nonvolatile F-RAM memory available in various sizes, temperature-compensated real-time clock with embedded crystal, 32.768kHz clock output, low-VDD reset, watchdog timer, battery backed event counter, event driven interrupt output, lockable 64-bit serial number area, general purpose comparator that can be used for an early power-fail (NMI) interrupt or other purpose, and 2-wire serial interface to a host microcontroller. The family operates from 2.7 to 5.5V.

The real-time clock (RTC) provides time and date information in BCD format. It can be permanently powered from external backup voltage source, either a battery or a capacitor. The timekeeper uses an internal 32.768 kHz crystal which is factory-calibrated for excellent timekeeping accuracy over the industrial temperature range.

The FM31T37x devices integrate 4Kb, 16Kb, 64Kb, and 256Kb of F-RAM memory. F-RAM offers superior write speed and unlimited endurance. This allows the memory to provide system data collection and as read/write RAM storage. This memory is truly nonvolatile rather than battery-backed.

The processor companion includes commonly needed CPU support functions. Supervisory functions include a reset output signal controlled by either a low VDD condition or a watchdog timeout. /RST goes active when VDD drops below a programmable threshold and remains active for 100 ms after VDD rises above the trip point. A programmable watchdog timer runs from 100 ms to 3 seconds. The watchdog timer is optional, but if enabled it will assert the reset signal for 100 ms if not restarted by the host before the timeout. A flag-bit indicates the source of the reset.

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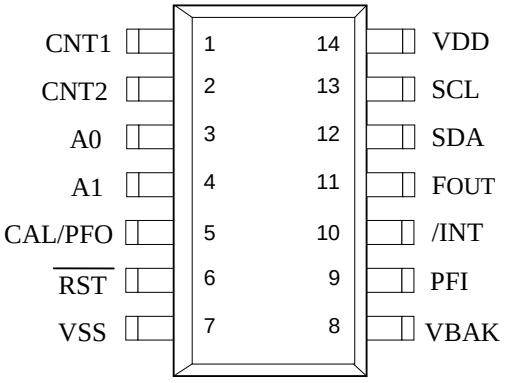
A general-purpose comparator compares an external input pin to the onboard 1.2V reference. This is useful for generating a power-fail interrupt (NMI) but can be used for any purpose. The family also includes a programmable 64-bit serial number that can be locked making it unalterable. Additionally it offers a dual battery-backed event counter that tracks the number of rising or falling edges detected on dedicated input pins.

Pin Configuration



Pin Name	Function
CNT1, CNT2	Event Counter Inputs
A0, A1	Device Select inputs
CAL/PFO	Clock Calibration and Early Power-Fail Output
/RST	Reset Input/Output
VSS	Ground
VBAK	Battery-Backup Supply
PFI	Early Power-fail Input
/INT	Event Counter Driven Interrupt Output
FOUT	32.768 kHz Clock Output
SDA	Serial Data
SCL	Serial Clock
VDD	Supply Voltage

Ordering Information

Base Configuration	Memory Size	Operating Voltage	Reset Threshold	Ordering Part Number
FM31T378	256Kb	2.7-5.5V	2.6V, 2.9, 3.9, 4.4V	FM31T378-G
FM31T376	64Kb	2.7-5.5V	2.6V, 2.9, 3.9, 4.4V	FM31T376-G
FM31T374	16Kb	2.7-5.5V	2.6V, 2.9, 3.9, 4.4V	FM31T374-G
FM31T372	4Kb	2.7-5.5V	2.6V, 2.9, 3.9, 4.4V	FM31T372-G

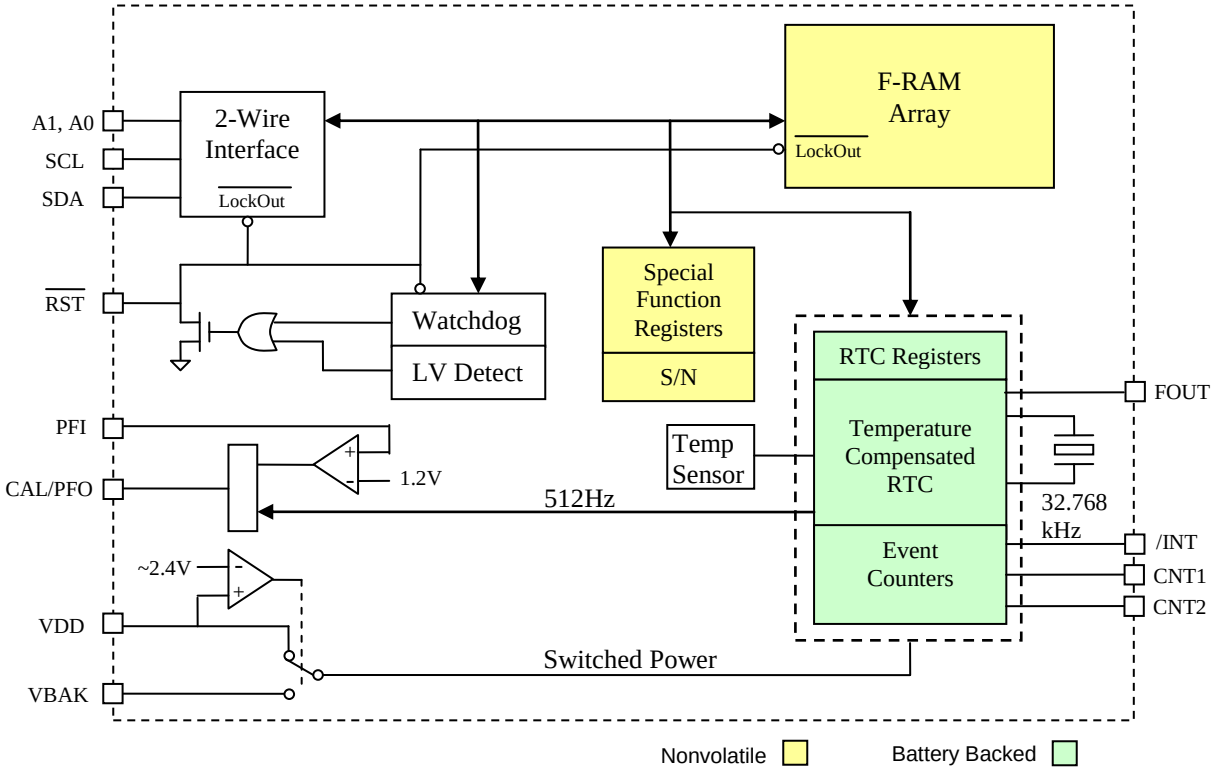


Figure 1. Block Diagram

Pin Descriptions

Pin Name	Type	Pin Description
A0, A1	Input	Device select inputs are used to address multiple memories on a serial bus. To select the device the address value on the two pins must match the corresponding bits contained in the device address. The device select pins are pulled down internally.
CNT1, CNT2	Input	Event Counter Inputs: These battery-backed inputs increment counters when an edge is detected on the corresponding CNT pin. The polarity is programmable. These pins should not be left floating. Tie to ground if pins are not used.
/INT	Output	Event Counter Driven Interrupt Output. This is a battery backed open-drain output. It goes low for at least 100 ms upon changes on either CNT1 or CNT2 pin. This pin can be left floating if not used.
CAL/PFO	Output	In normal operation, this is the early power-fail output. In CAL mode, it supplies a 512 Hz square-wave output for clock calibration.
FOUT	Output	32.768kHz Clock Output. This is a battery backed open-drain output. This pin can be disabled by setting the FOEN bit to "0". This pin can be left floating if not used.
/RST	I/O	Active low reset output with weak pull-up. Also input for manual reset.
SDA	I/O	Serial Data & Address: This is a bi-directional line for the two-wire interface. It is open-drain and is intended to be wire-OR'd with other devices on the two-wire bus. The input buffer incorporates a Schmitt trigger for noise immunity and the output driver includes slope control for falling edges. A pull-up resistor is required.
SCL	Input	Serial Clock: The serial clock line for the two-wire interface. Data is clocked out of the device on the falling edge, and into the device on the rising edge. The SCL input also incorporates a Schmitt trigger input for noise immunity.
PFI	Input	Early Power-fail Input: Typically connected to an unregulated power supply to detect an early power failure. This pin should not be left floating.
VBAK	Supply	Backup supply voltage: A 3V battery or a large value capacitor. If no backup supply is used, this pin should be tied to V_{DD}.
VDD	Supply	Supply Voltage

Overview

The FM31T37x family combines a serial nonvolatile F-RAM, a temperature compensated real-time clock with embedded crystal, and a processor companion. The companion is a highly integrated peripheral including a processor supervisor, a comparator used for early power-fail warning, nonvolatile event counters, and a 64-bit serial number. The FM31T37x integrates these complementary but distinct functions that share a common interface in a single package. Although monolithic, the product is organized as two logical devices, the F-RAM memory, and the RTC/companion. From the system perspective they appear to be two separate devices with unique IDs on the serial bus.

The memory is organized as a stand-alone 2-wire nonvolatile memory with a standard device ID value. The real-time clock and supervisor functions are accessed with a separate 2-wire device ID. This allows clock/calendar data to be read while maintaining the most recently used memory address. The clock and supervisor functions are controlled by 21 special function registers. The RTC and event counter circuits are maintained by the power source on the VBAK pin, allowing them to operate from battery or backup capacitor power when V_{DD} drops below an internally set threshold. Each functional block is described below.

Memory Operation

The FM31T37x is a family of products available in different memory sizes including 4Kb, 16Kb, 64Kb, and 256Kb. The family is software compatible, all versions use consistent two-byte addressing for the memory device. This makes the lowest density device different from its stand-alone memory counterparts but makes them compatible within the entire family.

Memory is organized in bytes, for example the 4Kb memory is 512 x 8 and the 256Kb memory is 32,768 x 8. The memory is based on F-RAM technology. Therefore it can be treated as RAM and is read or written at the speed of the two-wire bus with no delays for write operations. It also offers effectively unlimited write endurance unlike other nonvolatile memory technologies. The 2-wire interface protocol is described further on page 13.

The memory array can be write-protected by software. Two bits in the processor companion area (WP0, WP1 in register 0Bh) control the protection setting as shown in the following table. Based on the setting, the protected addresses cannot be written and the 2-wire interface will not acknowledge any data to protected addresses. The special function registers containing these bits are described in detail below.

Write protect addresses	WP1	WP0
None	0	0
Bottom ¼	0	1
Bottom ½	1	0
Full array	1	1

Processor Companion

In addition to nonvolatile RAM, the FM31T37x family incorporates a highly integrated processor companion. It includes a low voltage reset, a programmable watchdog timer, battery-backed event counters with interrupt output, a comparator for early power-fail detection or other purposes, and a 64-bit serial number.

Processor Supervisor

Supervisors provide a host processor two basic functions: detection of power supply fault conditions and a watchdog timer to escape a software lockup condition. All FM31T37x devices have a reset pin (/RST) to drive the processor reset input during power faults (and power-up) and software lockups. It is an open-drain output with a weak internal pull-up to V_{DD}. This allows other reset sources to be wire-OR'd to the /RST pin. When V_{DD} is above the programmed trip point, /RST output is pulled weakly to V_{DD}. If V_{DD} drops below the reset trip point voltage level (V_{TP}) the /RST pin will be driven low. It will remain low until V_{DD} falls too low for circuit operation which is the V_{RST} level. When V_{DD} rises again above V_{TP}, /RST will continue to drive low for at least 100 ms (t_{RPU}) to ensure a robust system reset at a reliable V_{DD} level. After t_{RPU} has been met, the /RST pin will return to the weak high state. While /RST is asserted, serial bus activity is locked out even if a transaction occurred as V_{DD} dropped below V_{TP}. A memory operation started while V_{DD} is above V_{TP} will be completed internally.

Figure 2 below illustrates the reset operation in response to the V_{DD} voltage.

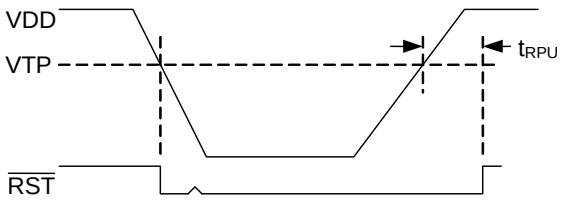


Figure 2. Low Voltage Reset

The bits VTP1 and VTP0 control the trip point of the low voltage detect circuit. They are located in register 0Bh, bits 1 and 0.

V_{TP}	VTP1	VTP0
2.6V	0	0
2.9V	0	1
3.9V	1	0
4.4V	1	1

The watchdog timer can also be used to assert the reset signal (/RST). The watchdog is a free running programmable timer. The period can be software programmed from 100 ms to 3 seconds in 100 ms increments via a 5-bit nonvolatile register. All programmed settings are minimum values and vary with temperature according to the operating specifications. The watchdog has two additional controls associated with its operation, a watchdog enable bit (WDE) and timer restart bits (WR). Both the enable bit must be set and the watchdog must timeout in order to drive /RST active. If a reset event occurs, the timer will automatically restart on the rising edge of the reset pulse. If WDE=0, the watchdog timer runs but a watchdog fault will not cause /RST to be asserted low. The WTR flag will be set, indicating a watchdog fault. This setting is useful during software development and the developer does not want /RST to drive. Note that setting the maximum timeout setting (11111b) disables the counter to save power. The second control is a nibble that restarts the timer preventing a reset. The timer should be restarted after changing the timeout value.

The watchdog timeout value is located in register 0Ah, bits 4-0, and the watchdog enable is bit 7. The watchdog is restarted by writing the pattern 1010b to the lower nibble of register 09h. Writing this pattern will also cause the timer to load new timeout values. Writing other patterns to this address will not affect its operation. Note the watchdog timer is free-running. Prior to enabling it, users should restart the timer as described above. This assures that the full timeout period will be set immediately after enabling. The watchdog is disabled when V_{DD} is below V_{TP}. The following table summarizes the watchdog bits. A block diagram follows.

Watchdog timeout	WDT4-0	0Ah, bits 4-0
Watchdog enable	WDE	0Ah, bit 7
Watchdog restart	WR3-0	09h, bits 3-0

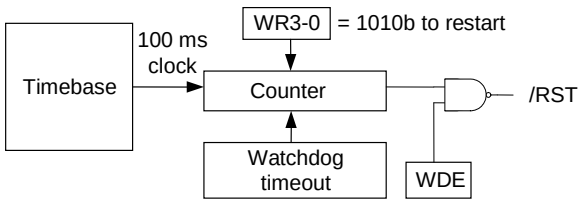


Figure 3. Watchdog Timer

Manual Reset

The /RST pin is bi-directional and allows the FM31T37x to filter and de-bounce a manual reset switch. The /RST input detects an external low condition and responds by driving the /RST signal low for 100 ms. A manual reset does not set any flags.

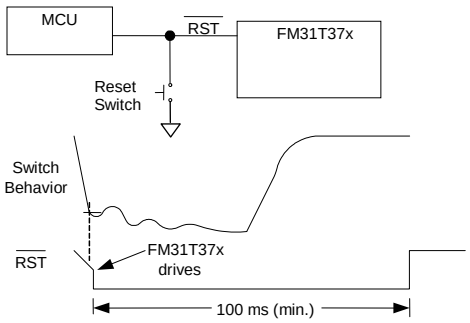


Figure 4. Manual Reset

Note that an internal weak pull-up on /RST eliminates the need for additional external components.

Reset Flags

In case of a reset condition, a flag will be set to indicate the source of the reset. A low V_{DD} reset is indicated by the POR flag, register 09h bit 6. A watchdog reset is indicated by the WTR flag, register 09h bit 7. Note that the flags are internally set in response to reset sources, but they must be cleared by the user. When the register is read, it is possible that both flags are set if both have occurred since the user last cleared them.

Early Power Fail Comparator

An early power fail warning can be provided to the processor well before V_{DD} drops out of spec. The comparator is used to create a power fail interrupt (NMI). This can be accomplished by connecting the PFI pin to the unregulated power supply via a resistor divider. An application circuit is shown below.

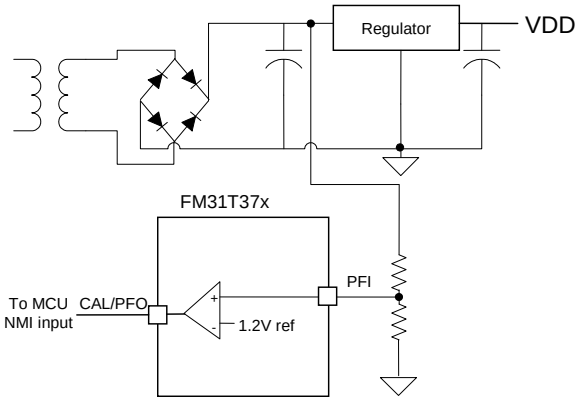


Figure 5. Comparator as Early Power-Fail Warning

The voltage on the PFI input pin is compared to an onboard 1.2V reference. When the PFI input voltage drops below this threshold, the comparator will drive the CAL/PFO pin to a low state. The comparator has 100 mV (max) of hysteresis to reduce noise sensitivity, only for a rising PFI signal. For a falling PFI edge, there is no hysteresis.

The comparator is a general purpose device and its application is not limited to the NMI function.

The comparator is not integrated into the special function registers except as it shares its output pin with the CAL output. When the CAL mode is invoked by setting the CAL bit (register 00h, bit 2), the CAL/PFO output pin is driven with a 512 Hz square wave and the comparator will be ignored. Since most users only invoke the CAL mode during production, this should have no impact on system operations using the comparator.

Event Counter

The FM31T37x offers the user two battery-backed event counters. Input pins CNT1 and CNT2 are programmable edge detectors. Each clocks a 16-bit counter. When an edge occurs, the counters will increment their respective registers. Counter 1 is located in registers 0Dh and 0Eh, Counter 2 is located in registers 0Fh and 10h. These register values can be read anytime VDD is above VTP, and they will be incremented as long as a valid VBAK power source is provided. To read, set the RC bit register 0Ch bit 3 to 1. This takes a snapshot of all four counter bytes allowing a stable value even if a count occurs during the read. The registers can be written by software allowing the counters to be cleared or initialized by the system. Counts are blocked during a write operation. The two counters can be cascaded to create a single 32-bit counter by setting the CC control bit (register 0Ch). When cascaded, the CNT1 input will cause the counter to increment. CNT2 is not used in this mode.

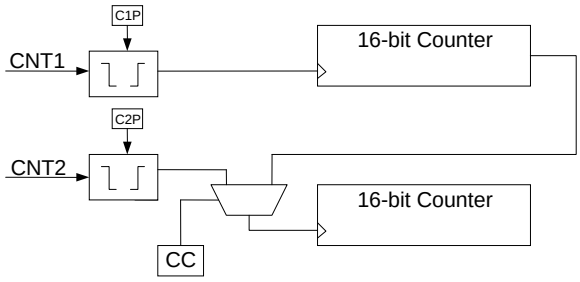


Figure 6. Event Counter

The control bits for event counting are located in register 0Ch. Counter 1 Polarity is bit C1P, bit 0; Counter 2 Polarity is C2P, bit 1; the Cascade Control is CC, bit 2; and the Read Counter bit is RC bit 3.

The polarity bits must be set prior to setting the counter value(s). If a polarity bit is changed, the counter may inadvertently increment. If the counter pins are not being used, tie them to ground.

Event Counter Driven Interrupt Output

The event counter driven interrupt is a battery backed open-drain output (/INT). A 100ms active low pulse generated for the host microcontroller upon changes on either CNT1 or CNT2 pins. The CNT2 pin will not generate an interrupt if the CC bit is set to '1' (counter set to cascaded 32-bit mode).

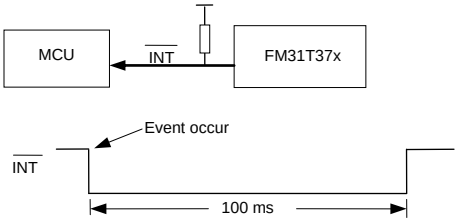


Figure 7. Event Counter Driven Interrupt Output

Serial Number

A memory location to write a 64-bit serial number is provided. It is a writeable nonvolatile memory block that can be locked by the user once the serial number is set. The 8 bytes of data and the lock bit are all accessed via the device ID for the processor companion. Therefore the serial number area is separate and distinct from the memory array. The serial number registers can be written an unlimited number of times, so these locations are general purpose memory. *However once the lock bit is set the values cannot be altered and the lock cannot be removed.* Once locked the serial number registers can still be read by the system.

The serial number is located in registers 11h to 18h. The lock bit is SNL, register 0Bh bit 7. Setting the SNL bit to '1' disables writes to the serial number registers, and *the SNL bit cannot be cleared*.

Real-Time Clock (TCXO) Operation

The real-time clock is a timekeeping function that can be battery or capacitor backed for continuous operation. The RTC is operated by a temperature compensated crystal oscillator (TCXO) based on an embedded 32.768 kHz crystal.

The RTC consists of an oscillator, clock divider, and a register system for user access. It divides down the 32.768 kHz time-base and provides a minimum resolution of seconds (1Hz). Static registers provide the user with read/write access to the time values. It includes registers for seconds, minutes, hours, day-of-the-week, date, months, and years. A block diagram (Figure 8) illustrates the RTC function.

The user registers are synchronized with the timekeeper core using R and W bits in register 00h described below. Changing the R bit from '0' to '1' transfers timekeeping information from the core into holding registers that can be read by the user. If a timekeeper update is pending when R is set, then the core will be updated prior to loading the user registers. The registers are frozen and will not be updated again until the R bit is cleared to '0'. R is used for reading the time.

Setting the W bit to '1' locks the user registers. Clearing it to '0' causes the values in the user registers to be loaded into the timekeeper core. W is used for writing new time values. Users should be certain not to load invalid values, such as FFh, to the timekeeping registers. Updates to the timekeeping core occur continuously except when locked.

Backup Power

The real-time clock/calendar is intended to be permanently powered. When the primary system power fails, the voltage on the V_{DD} pin will drop. When V_{DD} is less 2.4V the RTC (and event counters) will switch to the backup power supply on V_{BAK}. The clock operates at extremely low current in order to maximize battery or capacitor life. However, an advantage of combining a clock function with F-RAM memory is that data is not lost regardless of the backup power source.

The I_{BAK} current varies with temperature and voltage (see DC parametric table). The following graph shows I_{BAK} as a function of V_{BAK}. These curves are useful for calculating backup time when a capacitor is used as the V_{BAK} source.

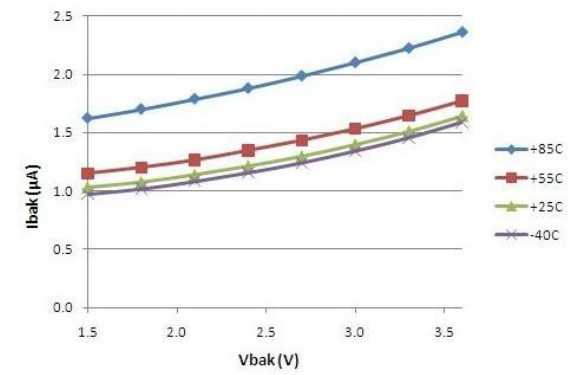


Figure 8. I_{BAK} vs. V_{BAK} Voltage

The minimum V_{BAK} voltage varies linearly with temperature. The user can expect the minimum V_{BAK} voltage to be 1.23V at +85°C and 1.90V at -40°C. The tested limit is 1.55V at +25°C. The minimum V_{BAK} voltage has been characterized at -40°C and +85°C but is not 100% tested.

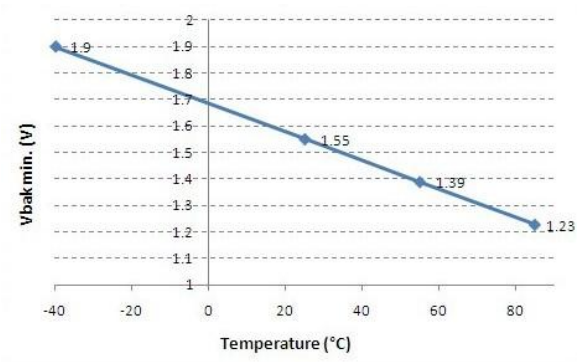


Figure 9. V_{BAK} (min.) vs. Temperature

Trickle Charger

To facilitate capacitor backup, the V_{BAK} pin can optionally provide a trickle charge current. When the VBC bit, register 0Bh bit 2, is set to '1' the V_{BAK} pin will source approximately 80µA until V_{BAK} reaches V_{DD} or 3.75V whichever is less. In 3V systems, this charges the capacitor to V_{DD} without an external diode and resistor charger. There is a Fast Charge mode which is enabled by the FC bit (register 0Bh, bit 5). In this mode the trickle charger current is set to approximately 1 mA, allowing a large backup capacitor to charge more quickly.

In the case where no battery is used, the V_{BAK} pin should be tied to V_{DD}.

Although V_{BAK} may be connected to V_{SS}, this is not recommended if the companion is used. None of the companion functions will operate below approximately 2.4V.

Note: Systems using lithium batteries should clear the VBC bit to '0' to prevent battery charging. The V_{BAK} circuitry includes an internal 1 KΩ series resistor as a safety element.

32.768 kHz Clock Output

The 32.768 kHz clock (with precision equal to that of the built-in crystal oscillator) can be output via the FOUT pin. This output is not temperature compensated. This clock can be disabled by clearing the FOEN bit to '0'.

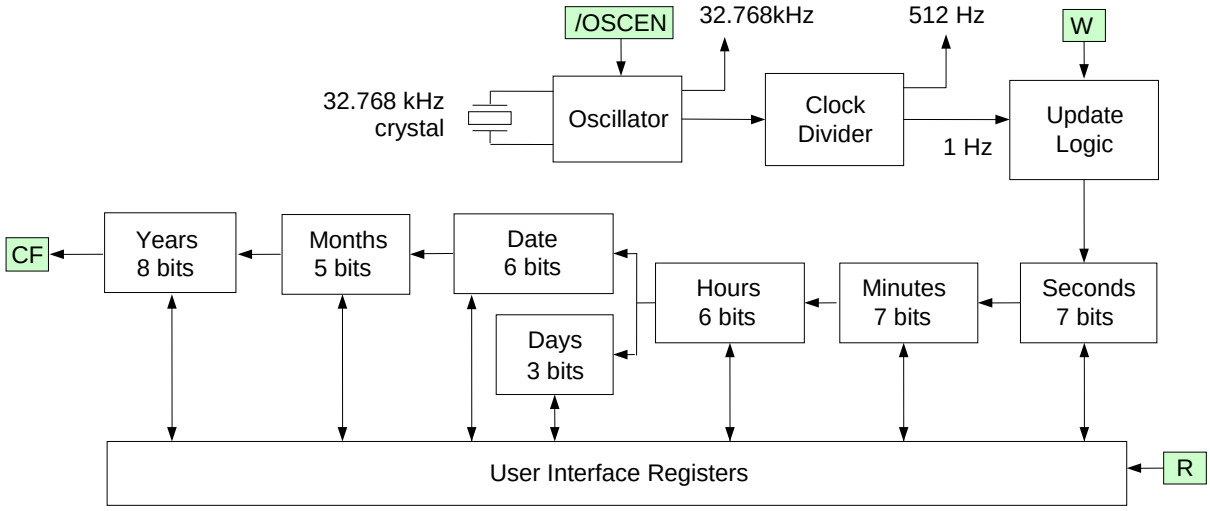


Figure 8. Real-Time Clock Core Block Diagram

Offset/Aging Compensation

The user can expect the RTC to be accurate from the factory. The RTC is calibrated at the factory at room temperature. The CAL bits setting in Register 01h will likely be a non-zero value. This is the initial calibration value assigned at the factory prior to shipment. The device may need re-calibrating after solder reflow or after some period of time due to crystal aging.

If the user needs to re-calibrate the RTC, the following describes the steps to change the calibration setting. Before making changes to the CAL bits, the user can read these bits to verify the current setting is an expected value. To enter calibration mode, the CAL bit in a register 00h must be set to '1'. When the RTC is in calibration mode, the CAL/PFO output pin is dedicated to the calibration function and the power fail output is temporarily unavailable. Calibration operates by applying a digital correction to the counter based on the frequency error. In this mode, the CAL/PFO pin is driven with a 512 Hz (nominal) square wave. Any measured deviation from 512 Hz translates into a timekeeping error. The 512Hz calibration output must be measured at +25°C. This output is not temperature compensated. The user converts the measured error in ppm and writes the appropriate correction value to the calibration register. The correction factors are listed in the following tables. Positive ppm errors require a negative adjustment that removes pulses. Negative ppm errors require a positive correction that adds pulses. Positive ppm adjustments have the CALS (sign) bit set to '1', whereas negative ppm adjustments have CALS = 0.

The calibration setting is stored in F-RAM so is not lost should the backup source fail. It is accessed with bits CAL.5-0 in register 01h. This value only can be written when the CAL bit is set to '1'. To exit the calibration mode, the user must clear the CAL bit to a 0. When the CAL bit is 0, the CAL/PFO pin will revert to the power fail output function.

Note: Temperature compensation is disabled when the CAL bit is set to '1'. The user should clear this bit to allow temperature compensation to activate.

Calibration Adjustments for Offset/Aging

Positive Calibration for Slow Measured Clocks					
	Measured Frequency Range at +25°C		Error Range (PPM)		
	Min	Max	Min	Max	Program Calibration Register to:
0	512.0000	511.9995	0.00	-1.02	1000000
1	511.9995	511.9984	-1.02	-3.05	1000001
2	511.9984	511.9974	-3.05	-5.09	1000010
3	511.9974	511.9964	-5.09	-7.12	1000011
4	511.9964	511.9953	-7.12	-9.16	1000100
5	511.9953	511.9943	-9.16	-11.19	1000101
6	511.9943	511.9932	-11.19	-13.22	1000110
7	511.9932	511.9922	-13.22	-15.26	1000111
8	511.9922	511.9911	-15.26	-17.29	1001000
9	511.9911	511.9901	-17.29	-19.33	1001001
10	511.9901	511.9891	-19.33	-21.36	1001010
11	511.9891	511.9880	-21.36	-23.40	1001011
12	511.9880	511.9870	-23.40	-25.43	1001100
13	511.9870	511.9859	-25.43	-27.47	1001101
14	511.9859	511.9849	-27.47	-29.50	1001110
15	511.9849	511.9839	-29.50	-31.53	1001111
16	511.9839	511.9828	-31.53	-33.57	1010000
17	511.9828	511.9818	-33.57	-35.60	1010001
18	511.9818	511.9807	-35.60	-37.64	1010010
19	511.9807	511.9797	-37.64	-39.67	1010011
20	511.9797	511.9786	-39.67	-41.71	1010100
21	511.9786	511.9776	-41.71	-43.74	1010101
22	511.9776	511.9766	-43.74	-45.78	1010110
23	511.9766	511.9755	-45.78	-47.81	1010111
24	511.9755	511.9745	-47.81	-49.85	1011000
25	511.9745	511.9734	-49.85	-51.88	1011001
26	511.9734	511.9724	-51.88	-53.91	1011010
27	511.9724	511.9714	-53.91	-55.95	1011011
28	511.9714	511.9703	-55.95	-57.98	1011100
29	511.9703	511.9693	-57.98	-60.02	1011101
30	511.9693	511.9682	-60.02	-62.05	1011110
31	511.9682	511.9672	-62.05	-64.09	1011111
32	511.9672	511.9661	-64.09	-66.12	1100000
33	511.9661	511.9651	-66.12	-68.16	1100001
34	511.9651	511.9641	-68.16	-70.19	1100010
35	511.9641	511.9630	-70.19	-72.22	1100011
36	511.9630	511.9620	-72.22	-74.26	1100100
37	511.9620	511.9609	-74.26	-76.29	1100101
38	511.9609	511.9599	-76.29	-78.33	1100110
39	511.9599	511.9589	-78.33	-80.36	1100111
40	511.9589	511.9578	-80.36	-82.40	1101000
41	511.9578	511.9568	-82.40	-84.43	1101001
42	511.9568	511.9557	-84.43	-86.47	1101010
43	511.9557	511.9547	-86.47	-88.50	1101011
44	511.9547	511.9536	-88.50	-90.54	1101100
45	511.9536	511.9526	-90.54	-92.57	1101101
46	511.9526	511.9516	-92.57	-94.60	1101110
47	511.9516	511.9505	-94.60	-96.64	1101111
48	511.9505	511.9495	-96.64	-98.67	1110000
49	511.9495	511.9484	-98.67	-100.71	1110001
50	511.9484	511.9474	-100.71	-102.74	1110010
51	511.9474	511.9464	-102.74	-104.78	1110011
52	511.9464	511.9453	-104.78	-106.81	1110100
53	511.9453	511.9443	-106.81	-108.85	1110101
54	511.9443	511.9432	-108.85	-110.88	1110110
55	511.9432	511.9422	-110.88	-112.92	1110111
56	511.9422	511.9411	-112.92	-114.95	1111000
57	511.9411	511.9401	-114.95	-116.98	1111001
58	511.9401	511.9391	-116.98	-119.02	1111010
59	511.9391	511.9380	-119.02	-121.05	1111011
60	511.9380	511.9370	-121.05	-123.09	1111100
61	511.9370	511.9359	-123.09	-125.12	1111101
62	511.9359	511.9349	-125.12	-127.16	1111110
63	511.9349	511.9339	-127.16	-129.19	1111111

Negative Calibration for Fast Measured Clocks					
	Measured Frequency Range at +25°C		Error Range (PPM)		
	Min	Max	Min	Max	Program Calibration Register to:
0	512.0000	512.0005	0.00	1.02	0000000
1	512.0005	512.0016	1.02	3.05	0000001
2	512.0016	512.0026	3.05	5.09	0000010
3	512.0026	512.0036	5.09	7.12	0000011
4	512.0036	512.0047	7.12	9.16	0000100
5	512.0047	512.0057	9.16	11.19	0000101
6	512.0057	512.0068	11.19	13.22	0000110
7	512.0068	512.0078	13.22	15.26	0000111
8	512.0078	512.0089	15.26	17.29	0001000
9	512.0089	512.0099	17.29	19.33	0001001
10	512.0099	512.0109	19.33	21.36	0001010
11	512.0109	512.0120	21.36	23.40	0001011
12	512.0120	512.0130	23.40	25.43	0001100
13	512.0130	512.0141	25.43	27.47	0001101
14	512.0141	512.0151	27.47	29.50	0001110
15	512.0151	512.0161	29.50	31.53	0001111
16	512.0161	512.0172	31.53	33.57	0010000
17	512.0172	512.0182	33.57	35.60	0010001
18	512.0182	512.0193	35.60	37.64	0010010
19	512.0193	512.0203	37.64	39.67	0010011
20	512.0203	512.0214	39.67	41.71	0010100
21	512.0214	512.0224	41.71	43.74	0010101
22	512.0224	512.0234	43.74	45.78	0010110
23	512.0234	512.0245	45.78	47.81	0010111
24	512.0245	512.0255	47.81	49.85	0011000
25	512.0255	512.0266	49.85	51.88	0011001
26	512.0266	512.0276	51.88	53.91	0011010
27	512.0276	512.0286	53.91	55.95	0011011
28	512.0286	512.0297	55.95	57.98	0011100
29	512.0297	512.0307	57.98	60.02	0011101
30	512.0307	512.0318	60.02	62.05	0011110
31	512.0318	512.0328	62.05	64.09	0011111
32	512.0328	512.0339	64.09	66.12	0100000
33	512.0339	512.0349	66.12	68.16	0100001
34	512.0349	512.0359	68.16	70.19	0100010
35	512.0359	512.0370	70.19	72.22	0100011
36	512.0370	512.0380	72.22	74.26	0100100
37	512.0380	512.0391	74.26	76.29	0100101
38	512.0391	512.0401	76.29	78.33	0100110
39	512.0401	512.0411	78.33	80.36	0100111
40	512.0411	512.0422	80.36	82.40	0101000
41	512.0422	512.0432	82.40	84.43	0101001
42	512.0432	512.0443	84.43	86.47	0101010
43	512.0443	512.0453	86.47	88.50	0101011
44	512.0453	512.0464	88.50	90.54	0101100
45	512.0464	512.0474	90.54	92.57	0101101
46	512.0474	512.0484	92.57	94.60	0101110
47	512.0484	512.0495	94.60	96.64	0101111
48	512.0495	512.0505	96.64	98.67	0110000
49	512.0505	512.0516	98.67	100.71	0110001
50	512.0516	512.0526	100.71	102.74	0110010
51	512.0526	512.0536	102.74	104.78	0110011
52	512.0536	512.0547	104.78	106.81	0110100
53	512.0547	512.0557	106.81	108.85	0110101
54	512.0557	512.0568	108.85	110.88	0110110
55	512.0568	512.0578	110.88	112.92	0110111
56	512.0578	512.0589	112.92	114.95	0111000
57	512.0589	512.0599	114.95	116.98	0111001
58	512.0599	512.0609	116.98	119.02	0111010
59	512.0609	512.0620	119.02	121.05	0111011
60	512.0620	512.0630	121.05	123.09	0111100
61	512.0630	512.0641	123.09	125.12	0111101
62	512.0641	512.0651	125.12	127.16	0111110
63	512.0651	512.0661	127.16	129.19	0111111

Register Map

The TCXO and processor companion functions are accessed via 25 special function registers mapped to a separate 2-wire device ID. The interface protocol is described below. The registers contain timekeeping data, control bits, or information flags. A description of each register follows the summary table below.

Register Map Summary Table

Nonvolatile = ☐ Battery-backed = ☐

Address	Data D7	D6	D5	D4	D3	D2	D1	D0	Function	Range
18h	Serial Number Byte 7								Serial Number 7	FFh
17h	Serial Number Byte 6								Serial Number 6	FFh
16h	Serial Number Byte 5								Serial Number 5	FFh
15h	Serial Number Byte 4								Serial Number 4	FFh
14h	Serial Number Byte 3								Serial Number 3	FFh
13h	Serial Number Byte 2								Serial Number 2	FFh
12h	Serial Number Byte 1								Serial Number 1	FFh
11h	Serial Number Byte 0								Serial Number 0	FFh
10h	Counter 2 MSB								Event Counter 2 MSB	FFh
0Fh	Counter 2 LSB								Event Counter 2 LSB	FFh
0Eh	Counter 1 MSB								Event Counter 1 MSB	FFh
0Dh	Counter 1 LSB								Event Counter 1 LSB	FFh
0Ch					RC	CC	C2P	C1P	Event Count Control	
0Bh	SNL	FOEN	FC	WP1	WP0	VBC	VTP1	VTP0	Companion Control	
0Ah	WDE	-	-	WDT4	WDT3	WDT2	WDT1	WDT0	Watchdog Control	
09h	WTR	POR	LB	-	WR3	WR2	WR1	WR0	Watchdog Restart/Flags	
08h	10 years				years				Years	00-99
07h	0	0	0	10 mo	months				Month	1-12
06h	0	0	10 date		date				Date	1-31
05h	0	0	0	0	0	day			Day	1-7
04h	0	0	10 hours		hours				Hours	0-23
03h	0	10 minutes			minutes				Minutes	0-59
02h	0	10 seconds			seconds				Seconds	0-59
01h	/OSCEN	CALS	CAL5	CAL4	CAL3	CAL2	CAL1	CAL0	OSC/CAL Control	
00h	reserved	CF	reserved	reserved	reserved	CAL	W	R	RTC Control	

Note: When the device is first powered up and programmed, all registers must be written because the battery-backed register values cannot be guaranteed. The table below shows the default values of the non-volatile registers. All other register values should be treated as unknown.

Default Register Values

Address	Hex Value
18h	0x00
17h	0x00
16h	0x00
15h	0x00
14h	0x00
13h	0x00
12h	0x00
11h	0x00
0Bh	0x40
0Ah	0x1F
01h	Factory programmed

Register Description

Address Description

18h	**Serial Number Byte 7**							
	D7	**D6**	**D5**	**D4**	**D3**	**D2**	**D1**	**D0**
	SN.63	SN.62	SN.61	SN.60	SN.59	SN.58	SN.57	SN.56
	Upper byte of the serial number. Read/write when SNL=0, read-only when SNL=1. Nonvolatile.							
17h	**Serial Number Byte 6**							
	D7	**D6**	**D5**	**D4**	**D3**	**D2**	**D1**	**D0**
	SN.55	SN.54	SN.53	SN.52	SN.51	SN.50	SN.49	SN.48
	Byte 6 of the serial number. Read/write when SNL=0, read-only when SNL=1. Nonvolatile.							
16h	**Serial Number Byte 5**							
	D7	**D6**	**D5**	**D4**	**D3**	**D2**	**D1**	**D0**
	SN.47	SN.46	SN.45	SN.44	SN.43	SN.42	SN.41	SN.40
	Byte 5 of the serial number. Read/write when SNL=0, read-only when SNL=1. Nonvolatile.							
15h	**Serial Number Byte 4**							
	D7	**D6**	**D5**	**D4**	**D3**	**D2**	**D1**	**D0**
	SN.39	SN.38	SN.37	SN.36	SN.35	SN.34	SN.33	SN.32
	Byte 4 of the serial number. Read/write when SNL=0, read-only when SNL=1. Nonvolatile.							
14h	**Serial Number Byte 3**							
	D7	**D6**	**D5**	**D4**	**D3**	**D2**	**D1**	**D0**
	SN.31	SN.30	SN.29	SN.28	SN.27	SN.26	SN.25	SN.24
	Byte 3 of the serial number. Read/write when SNL=0, read-only when SNL=1. Nonvolatile.							
13h	**Serial Number Byte 2**							
	D7	**D6**	**D5**	**D4**	**D3**	**D2**	**D1**	**D0**
	SN.23	SN.22	SN.21	SN.20	SN.19	SN.18	SN.17	SN.16
	Byte 2 of the serial number. Read/write when SNL=0, read-only when SNL=1. Nonvolatile.							
12h	**Serial Number Byte 1**							
	D7	**D6**	**D5**	**D4**	**D3**	**D2**	**D1**	**D0**
	SN.15	SN.14	SN.13	SN.12	SN.11	SN.10	SN.9	SN.8
	Byte 1 of the serial number. Read/write when SNL=0, read-only when SNL=1. Nonvolatile.							
11h	**Serial Number Byte 0**							
	D7	**D6**	**D5**	**D4**	**D3**	**D2**	**D1**	**D0**
	SN.7	SN.6	SN.5	SN.4	SN.3	SN.2	SN.1	SN.0
	LSB of the serial number. Read/write when SNL=0, read-only when SNL=1. Nonvolatile.							
10h	**Counter 2 MSB**							
	D7	**D6**	**D5**	**D4**	**D3**	**D2**	**D1**	**D0**
	C2.15	C2.14	C2.13	C2.12	C2.11	C2.10	C2.9	C2.8
	Event Counter 2 MSB. Increments on overflows from Counter 2 LSB. Battery-backed, read/write.							
0Fh	**Counter 2 LSB**							
	D7	**D6**	**D5**	**D4**	**D3**	**D2**	**D1**	**D0**
	C2.7	C2.6	C2.5	C2.4	C2.3	C2.2	C2.1	C2.0
	Event Counter 2 LSB. Increments on programmed edge event on CNT2 input or overflows from Counter 1 MSB when CC=1. Battery-backed, read/write .							
0Eh	**Counter 1 MSB**							
	D7	**D6**	**D5**	**D4**	**D3**	**D2**	**D1**	**D0**
	C1.15	C1.14	C1.13	C1.12	C1.11	C1.10	C1.9	C1.8
	Event Counter 1 MSB. Increments on overflows from Counter 1 LSB. Battery-backed, read/write.							
0Dh	**Counter 1 LSB**							
	D7	**D6**	**D5**	**D4**	**D3**	**D2**	**D1**	**D0**
	C1.7	C1.6	C1.5	C1.4	C1.3	C1.2	C1.1	C1.0
	Event Counter 1 LSB. Increments on programmed edge event on CNT1 input. Battery-backed, read/write.							

0Ch — Event Counter Control

D7	D6	D5	D4	D3	D2	D1	D0
-	-	-	-	RC	CC	C2P	C1P

RC: Read Counter. Setting this bit to 1 takes a snapshot of the four counters bytes allowing the system to read the values without missing count events. The RC bit will be automatically cleared.

CC: Counter Cascade. When CC=0, the event counters operate independently according to the edge programmed by C1P and C2P respectively. When CC=1, the counters are cascaded to create one 32-bit counter. The registers of Counter 2 represent the most significant 16-bits of the counter and CNT1 is the controlling input. Bit C2P is "don't care" when CC=1. Battery-backed, read/write.

C2P: CNT2 detects falling edges when C2P = 0, rising edges when C2P = 1. C2P is "don't care" when CC=1. The value of Event Counter 2 may inadvertently increment if C2P is changed. Battery-backed, read/write.

C1P: CNT1 detects falling edges when C1P = 0, rising edges when C1P = 1. The value of Event Counter 1 may inadvertently increment if C1P is changed. Battery-backed, read/write.

0Bh — Companion Control

D7	D6	D5	D4	D3	D2	D1	D0
SNL	FOEN	FC	WP1	WP0	VBC	VTP1	VTP0

SNL: Serial Number Lock. Setting to a 1 makes registers 11h to 18h and SNL permanently read-only. SNL cannot be cleared once set to 1. Nonvolatile, read/write.

FOEN: 32.768kHz Frequency Output Enable. Default is 1 = "On". Output FOUT turned off when FOEN = 0. Temperature compensation is not applied to the 32.768kHz frequency on the FOUT pin.

FC: Fast Charge: Setting FC to '1' (and VBC=1) causes a ~1 mA trickle charge current to be supplied on V_{BAK}. Clearing VBC to '0' disables the charge current. Nonvolatile, read/write.

WP1-0: Write Protect. These bits control the write protection of the memory array. Nonvolatile, read/write.

Write protect addresses	WP1	WP0
None	0	0
Bottom ¼	0	1
Bottom ½	1	0
Full array	1	1

VBC: VBAK Charger Control. Setting VBC to 1 causes ~80 µA (FC=0) trickle charge current to be supplied on VBAK. Clearing VBC to 0 disables the charge current. Nonvolatile, read/write.

VTP1-0: VTP select. These bits control the reset trip point for the low VDD reset function. Nonvolatile, read/write.

VTP	VTP1	VTP0
2.6V	0	0
2.9V	0	1
3.9V	1	0
4.4V	1	1

0Ah — Watchdog Control

D7	D6	D5	D4	D3	D2	D1	D0
WDE	-	-	WDT4	WDT3	WDT2	WDT1	WDT0

WDE: Watchdog Enable. When WDE=1, a watchdog timer fault will cause the /RST signal to go active. When WDE = 0 the timer runs but has no effect on /RST, however the WTR flag will be set when a fault occurs. Note as the timer is free-running, users should restart the timer using WR3-0 prior to setting WDE=1. This assures a full watchdog timeout interval occurs. Nonvolatile, read/write.

WDT4-0: Watchdog Timeout. Indicates the minimum watchdog timeout interval with 100 ms resolution. New watchdog timeouts are loaded when the timer is restarted by writing the 1010b pattern to WR3-0. Nonvolatile, read/write.

Watchdog timeout	WDT4	WDT3	WDT2	WDT1	WDT0
Invalid – default 100 ms	0	0	0	0	0
100 ms	0	0	0	0	1
200 ms	0	0	0	1	0
300 ms	0	0	0	1	1
:					
2000 ms	1	0	1	0	0
2100 ms	1	0	1	0	1
2200 ms	1	0	1	1	0
:					

	:							
	2900 ms			1	1	1	0	1
	3000 ms			1	1	1	1	0
	Disable counter			1	1	1	1	1

09h	**Watchdog Restart & Flags**							
	D7	**D6**	**D5**	**D4**	**D3**	**D2**	**D1**	**D0**
	WTR	POR	LB	-	WR3	WR2	WR1	WR0
WTR	Watchdog Timer Reset Flag: When a watchdog timer fault occurs, the WTR bit will be set to 1. It must be cleared by the user. Note that both WTR and POR could be set if both reset sources have occurred since the flags were cleared by the user. Battery-backed. Read/Write (internally set, user can clear bit).							
POR	Power-on Reset Flag: When the /RST pin is activated by a $V_{DD} < V_{TP}$ condition, the POR bit will be set to 1. It must be cleared by the user. Note that both WTR and POR could be set if the reset source has occurred since the flags were cleared by the user. Battery-backed. Read/Write (internally set, user can clear bit).							
LB	Low Backup Flag: On power up, if the VBAK source is below the minimum voltage to operate the RTC and event counters, this bit will be set to 1. The user should clear it to 0 when initializing the system. Battery-backed. Read/Write (internally set, user can clear bit).							
WR3-0	Watchdog Restart: Writing a pattern 1010b to WR3-0 restarts the watchdog timer. The upper nibble contents do not affect this operation. Writing any pattern other than 1010b to WR3-0 has no effect on the timer. This allows users to clear the WTR, POR, and LB flags without affecting the watchdog timer. Battery-backed, Write-only.							

08h	**Timekeeping – Years**							
	D7	**D6**	**D5**	**D4**	**D3**	**D2**	**D1**	**D0**
	10 year.3	10 year.2	10 year.1	10 year.0	Year.3	Year.2	Year.1	Year.0
	Contains the lower two BCD digits of the year. Lower nibble contains the value for years; upper nibble contains the value for 10s of years. Each nibble operates from 0 to 9. The range for the register is 0-99. Battery-backed, read/write.							
07h	**Timekeeping – Months**							
	D7	**D6**	**D5**	**D4**	**D3**	**D2**	**D1**	**D0**
	0	0	0	10 Month	Month.3	Month.2	Month.1	Month.0
	Contains the BCD digits for the month. Lower nibble contains the lower digit and operates from 0 to 9; upper nibble (one bit) contains the upper digit and operates from 0 to 1. The range for the register is 1-12. Battery-backed, read/write.							
06h	**Timekeeping – Date of the month**							
	D7	**D6**	**D5**	**D4**	**D3**	**D2**	**D1**	**D0**
	0	0	10 date.1	10 date.0	Date.3	Date.2	Date.1	Date.0
	Contains the BCD digits for the date of the month. Lower nibble contains the lower digit and operates from 0 to 9; upper nibble contains the upper digit and operates from 0 to 3. The range for the register is 1-31. Battery-backed, read/write.							
05h	**Timekeeping – Day of the week**							
	D7	**D6**	**D5**	**D4**	**D3**	**D2**	**D1**	**D0**
	0	0	0	0	0	Day.2	Day.1	Day.0
	Lower nibble contains a value that correlates to day of the week. Day of the week is a ring counter that counts from 1 to 7 then returns to 1. The user must assign meaning to the day value, as the day is not integrated with the date. Battery-backed, read/write.							
04h	**Timekeeping – Hours**							
	D7	**D6**	**D5**	**D4**	**D3**	**D2**	**D1**	**D0**
	0	0	10 hours.1	10 hours.0	Hours.3	Hours2	Hours.1	Hours.0
	Contains the BCD value of hours in 24-hour format. Lower nibble contains the lower digit and operates from 0 to 9; upper nibble (two bits) contains the upper digit and operates from 0 to 2. The range for the register is 0-23. Battery-backed, read/write.							
03h	**Timekeeping – Minutes**							
	D7	**D6**	**D5**	**D4**	**D3**	**D2**	**D1**	**D0**
	0	10 min.2	10 min.1	10 min.0	Min.3	Min.2	Min.1	Min.0
	Contains the BCD value of minutes. Lower nibble contains the lower digit and operates from 0 to 9; upper nibble contains the upper minutes digit and operates from 0 to 5. The range for the register is 0-59. Battery-backed, read/write.							

02h	Timekeeping – Seconds							
	D7	D6	D5	D4	D3	D2	D1	D0
	0	10 sec.2	10 sec.1	10 sec.0	Seconds.3	Seconds.2	Seconds.1	Seconds.0
	Contains the BCD value of seconds. Lower nibble contains the lower digit and operates from 0 to 9; upper nibble contains the upper digit and operates from 0 to 5. The range for the register is 0-59. Battery-backed, read/write.							

01h	OSC/Control							
	D7	D6	D5	D4	D3	D2	D1	D0
	$\overline{\text{OSCEN}}$	CALS	CAL5	CAL4	CAL3	CAL2	CAL1	CAL0
/OSCEN	/Oscillator Enable. When set to 1, the oscillator is halted. When set to 0, the oscillator runs. Disabling the oscillator can save battery power during storage. On a power-up without battery, this bit is set to 1. Battery-backed, read/write.							
CALS	Calibration sign. Determines if the calibration adjustment is applied as an addition to or as a subtraction from the time-base. Calibration is explained on page 8. This bit is factory programmed. Nonvolatile, read/write.							
CAL.5-0	These six bits control the calibration of the clock. These bits are factory programmed. Nonvolatile, read/write.							

00h	Flags/Control							
	D7	D6	D5	D4	D3	D2	D1	D0
	Reserved	CF	Reserved	Reserved	Reserved	CAL	W	R
Reserved	Reserved bits. Do not use. Should remain set to 0.							
CF	Century Overflow Flag. This bit is set to a 1 when the values in the years register overflows from 99 to 00. This indicates a new century, such as going from 1999 to 2000 or 2099 to 2100. The user should record the new century information as needed. This bit is cleared to 0 when the Flag register is read. It is read-only for the user. Battery-backed.							
CAL	When set to 1, the CAL/PFO pin gives a 512 Hz square-wave output for clock audit. When CAL bit set to 0, the clock operates normally, and the CAL/PFO pin is controlled by the power fail comparator. The CAL bit must be cleared to enable temperature compensation. Temperature compensation is not applied to the 512Hz frequency on the CAL/PFO pin. Battery-backed, read/write.							
W	Write Time. Setting the W bit to 1 freezes the clock. The user can then write the timekeeping registers with updated values. Resetting the W bit to 0 causes the contents of the time registers to be transferred to the timekeeping counters and restarts the clock. Battery-backed, read/write.							
R	Read Time. Setting the R bit to 1 copies a static image of the timekeeping core and place it into the user registers. The user can then read them without concerns over changing values causing system errors. The R bit going from 0 to 1 causes the timekeeping capture, so the bit must be returned to 0 prior to reading again. Battery-backed, read/write.							

Two-wire Interface

The FM31T37x employs an industry standard two-wire bus that is familiar to many users. This product is unique since it incorporates two logical devices in one chip. Each logical device can be accessed individually. Although monolithic, it appears to the system software to be two separate products. One is a memory device. It has a Slave Address (Slave ID = 1010b) that operates the same as a stand-alone memory device. The second device is a real-time clock and processor companion which have a unique Slave Address (Slave ID = 1101b).

By convention, any device that is sending data onto the bus is the transmitter while the target device for this data is the receiver. The device that is controlling the bus is the master. The master is responsible for generating the clock signal for all operations. Any device on the bus that is being controlled is a slave. The FM31T37x is always a slave device.

The bus protocol is controlled by transition states in the SDA and SCL signals. There are four conditions: Start, Stop, Data bit, and Acknowledge. The figure below illustrates the signal conditions that specify the four states. Detailed timing diagrams are shown in the Electrical Specifications section.

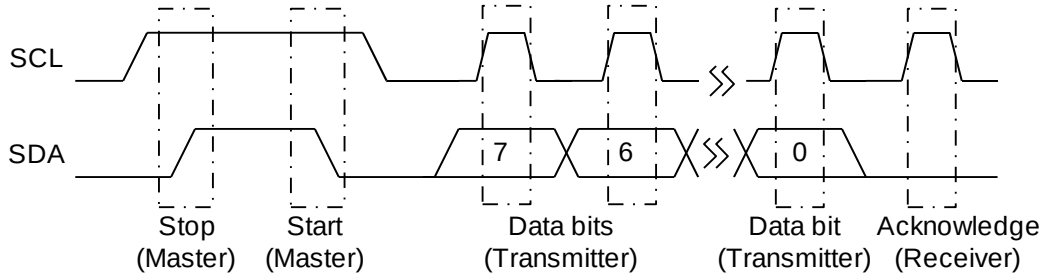


Figure 9. Data Transfer Protocol

Start Condition

A Start condition is indicated when the bus master drives SDA from high to low while the SCL signal is high. All read and write transactions begin with a Start condition. An operation in progress can be aborted by asserting a Start condition at any time. Aborting an operation using the Start condition will ready the FM31T37x for a new operation.

If the power supply drops below the specified VTP during operation, any 2-wire transaction in progress will be aborted and the system must issue a Start condition prior to performing another operation.

Stop Condition

A Stop condition is indicated when the bus master drives SDA from low to high while the SCL signal is high. All operations must end with a Stop condition. If an operation is pending when a stop is asserted, the operation will be aborted. The master must have control of SDA (not a memory read) in order to assert a Stop condition.

Data/Address Transfer

All data transfers (including addresses) take place while the SCL signal is high. Except under the two conditions described above, the SDA signal should not change while SCL is high.

Acknowledge

The Acknowledge (ACK) takes place after the 8th data bit has been transferred in any transaction. During this state the transmitter must release the SDA bus to allow the receiver to drive it. The receiver drives the SDA signal low to acknowledge receipt of the byte. If the receiver does not drive SDA low, the condition is a No-Acknowledge (NACK) and the operation is aborted.

The receiver might NACK for two distinct reasons. First is that a byte transfer fails. In this case, the NACK ends the current operation so that the part can be addressed again. This allows the last byte to be recovered in the event of a communication error.

Second and most common, the receiver does not send an ACK to deliberately terminate an operation. For example, during a read operation, the FM31T37x will continue to place data onto the bus as long as the receiver sends ACKs (and clocks). When a read operation is complete and no more data is needed, the receiver must NACK the last byte. If the receiver ACKs the last byte, this will cause the FM31T37x to

attempt to drive the bus on the next clock while the master is sending a new command such as a Stop.

Slave Address

The first byte that the FM31T37x expects after a Start condition is the slave address. As shown in figures below, the slave address contains the Slave ID, Device Select address, and a bit that specifies if the transaction is a read or a write.

The FM31T37x has two Slave Addresses (Slave IDs) associated with two logical devices. To access the memory device, bits 7-4 should be set to 1010b. The other logical device within the FM31T37x is the real-time clock and companion. To access this device, bits 7-4 of the slave address should be set to 1101b. A bus transaction with this slave address will not affect the memory in any way. The figures below illustrate the two Slave Addresses.

The Device Select bits allow multiple devices of the same type to reside on the 2-wire bus. The device select bits (bits 2-1) select one of four parts on a two-wire bus. They must match the corresponding value on the external address pins in order to select the device. Bit 0 is the read/write bit. A "1" indicates a read operation, and a "0" indicates a write operation.

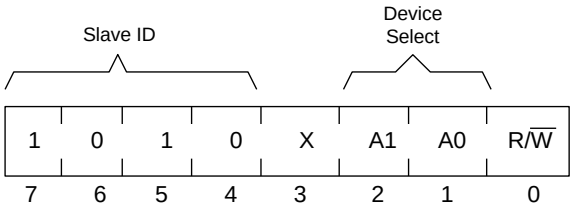


Figure 10. Slave Address - Memory

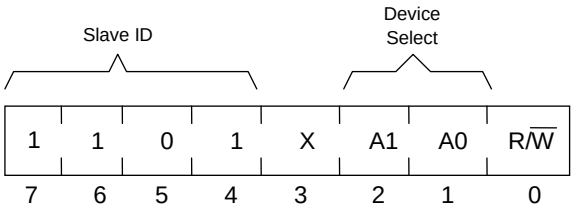


Figure 11. Slave Address – Companion

Addressing Overview – Memory

After the FM31T37x acknowledges the Slave Address, the master can place the memory address on the bus for a write operation. The address requires two bytes. This is true for all members of the family. Therefore the 4Kb and 16Kb configurations will be addressed differently from stand alone serial memories but the entire family will be upwardly compatible with no software changes.

The first is the MSB (upper byte). For a given density unused address bits are don't cares, but should be set to 0 to maintain upward compatibility. Following the MSB is the LSB (lower byte) which contains the remaining eight address bits. The address is latched internally. Each access causes the latched address to be incremented automatically. The current address is the value that is held in the latch, either a newly written value or the address following the last access. The current address will be held as long as VDD > VTP or until a new value is written. Accesses to the clock do not affect the current memory address. Reads always use the current address. A random read address can be loaded by beginning a write operation as explained below.

After transmission of each data byte, just prior to the Acknowledge, the FM31T37x increments the internal address. This allows the next sequential byte to be accessed with no additional addressing externally. After the last address is reached, the address latch will roll over to 0000h. There is no limit to the number of bytes that can be accessed with a single read or write operation.

Addressing Overview – RTC & Companion

The RTC and Processor Companion operate in a similar manner to the memory, except that it uses only one byte of address. Addresses 00h to 18h correspond to special function registers. Attempting to load addresses above 18h is an illegal condition; the FM31 xxT37x will return a NACK and abort the 2-wire transaction.

Data Transfer

After the address information has been transmitted, data transfer between the bus master and the FM31T37x begins. For a read, the FM31T37x will place 8 data bits on the bus then wait for an ACK from the master. If the ACK occurs, the FM31T37x will transfer the next byte. If the ACK is not sent, the FM31T37x will end the read operation. For a write operation, the FM31T37x will accept 8 data bits from the master then send an Acknowledge. All data transfer occurs MSB (most significant bit) first.

Memory Write Operation

All memory writes begin with a Slave Address, then a memory address. The bus master indicates a write operation by setting the slave address LSB to a 0. After addressing, the bus master sends each byte of data to the memory and the memory generates an Acknowledge condition. Any number of sequential bytes may be written. If the end of the address range

is reached internally, the address counter will wrap to 0000h. Internally, the actual memory write occurs after the 8th data bit is transferred. It will be complete before the Acknowledge is sent. Therefore, if the user desires to abort a write without altering the memory contents, this should be done using a Start or Stop condition prior to the 8th data bit. The figures below illustrate a single- and multiple-writes to memory.

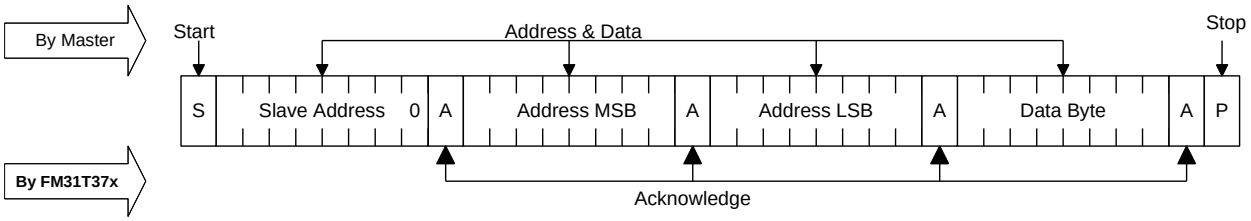


Figure 12. Single Byte Memory Write

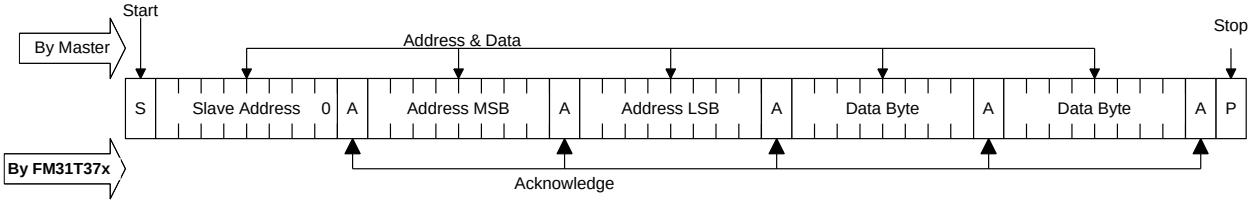


Figure 13. Multiple Byte Memory Write

Memory Read Operation

There are two types of memory read operations. They are current address read and selective address read. In a current address read, the FM31T37x uses the internal address latch to supply the address. In a selective read, the user performs a procedure to first set the address to a specific value.

Current Address & Sequential Read

As mentioned above the FM31T37x uses an internal latch to supply the address for a read operation. A current address read uses the existing value in the address latch as a starting place for the read operation. The system reads from the address immediately following that of the last operation.

To perform a current address read, the bus master supplies a slave address with the LSB set to 1. This indicates that a read operation is requested. After receiving the complete device address, the FM31T37x will begin shifting data out from the current address on the next clock. The current address is the value held in the internal address latch.

Beginning with the current address, the bus master can read any number of bytes. Thus, a sequential read is simply a current address read with multiple byte transfers. After each byte the internal address counter will be incremented.

Each time the bus master acknowledges a byte, this indicates that the FM31T37x should read out the next sequential byte.

There are four ways to terminate a read operation. Failing to properly terminate the read will most likely create a bus contention as the FM31T37x attempts to read out additional data onto the bus. The four valid methods follow.

1. The bus master issues a NACK in the 9th clock cycle and a Stop in the 10th clock cycle. This is illustrated in the diagrams below and is preferred.
2. The bus master issues a NACK in the 9th clock cycle and a Start in the 10th.
3. The bus master issues a Stop in the 9th clock cycle.
4. The bus master issues a Start in the 9th clock cycle.

If the internal address reaches the top of memory, it will wrap around to 0000h on the next read cycle. The figures below show the proper operation for current address reads.

Selective (Random) Read

There is a simple technique that allows a user to select a random address location as the starting point for a read operation. This involves using the first three bytes of a write operation to set the internal address followed by subsequent read operations.

To perform a selective read, the bus master sends out the slave address with the LSB set to 0. This specifies a write operation. According to the write protocol, the bus master then sends the address bytes that are loaded into the internal address latch. After the FM31T37x acknowledges the address, the bus master issues a Start condition. This simultaneously aborts the write operation and allows the read command to be issued with the slave address LSB set to a 1. The operation is now a read from the current address. Read operations are illustrated below.

RTC /Companion Write Operation

All RTC and Companion writes operate in a similar manner to memory writes. The distinction is that a different device ID is used and only one byte address is needed instead of two. Figure 16 illustrates a single byte write to this device.

RTC/Companion Read Operation

As with writes, a read operation begins with the Slave Address. To perform a register read, the bus master supplies a Slave Address with the LSB set to 1. This indicates that a read operation is requested. After receiving the complete Slave Address, the FM31T37x will begin shifting data out from the current register address on the next clock. Auto-increment operates for the special function registers as with the memory address. A current address read for the registers look exactly like the memory except that the device ID is different.

The FM31T37x contains two separate address registers, one for the memory address and the other for the register address. This allows the contents of one address register to be modified without affecting the current address of the other register. For example, this would allow an interrupted read to the memory while still providing fast access to an RTC register. A subsequent memory read will then continue from the memory address where it previously left off, without requiring the load of a new memory address. However, a write sequence always requires an address to be supplied.

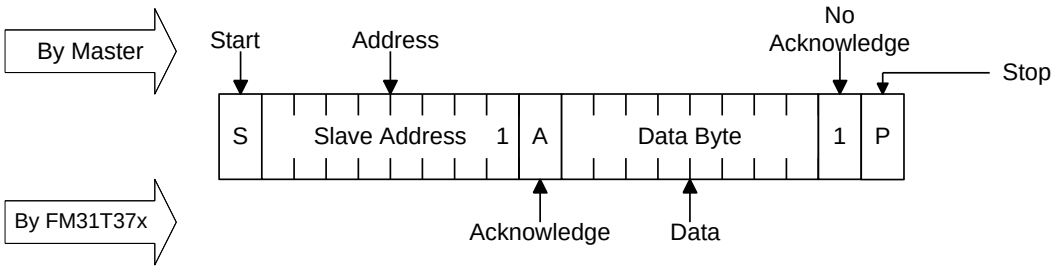


Figure 14. Current Address Memory Read

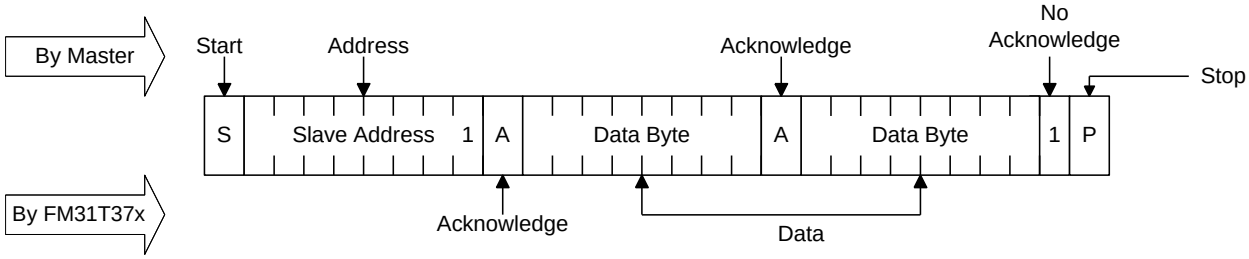


Figure 15. Sequential Memory Read

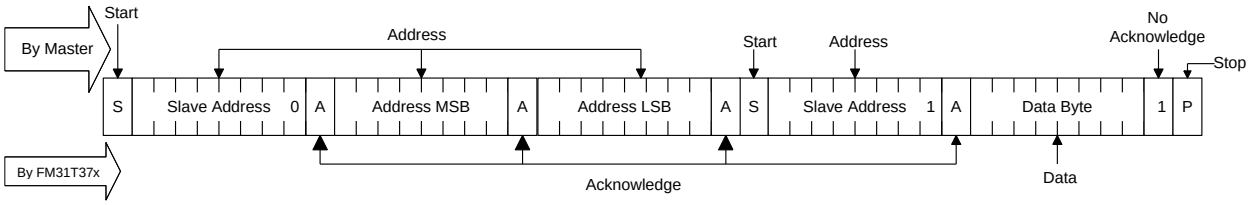


Figure 16. Selective (Random) Memory Read

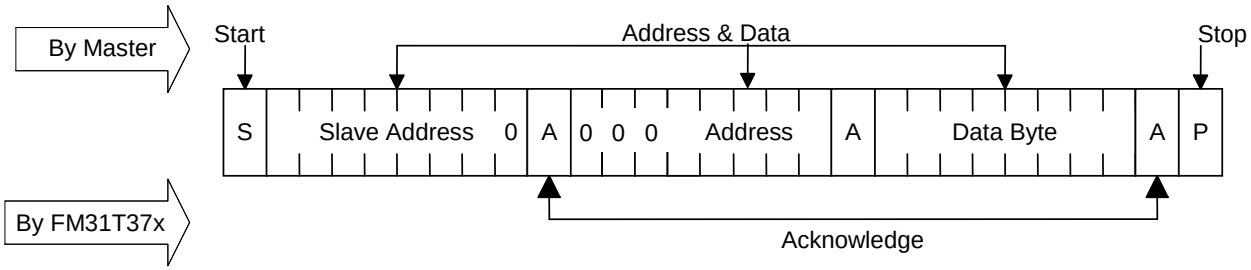


Figure 17. Byte Register Write

NOTE: It is required that Register Address bits A7-A5 are cleared (zeroes).

Addressing F-RAM Array in the FM31T37x Family

The FM31T37x family includes 256Kb, 64Kb, 16Kb, and 4Kb memory densities. The following 2-byte address field is shown for each density.

Table 4. Two-Byte Memory Address

Part #		1st Address Byte									2nd Address Byte							
FM31T378		x	A14	A13	A12	A11	A10	A9	A8		A7	A6	A5	A4	A3	A2	A1	A0
FM31T376		x	x	x	A12	A11	A10	A9	A8		A7	A6	A5	A4	A3	A2	A1	A0
FM31T374		x	x	x	x	x	A10	A9	A8		A7	A6	A5	A4	A3	A2	A1	A0
FM31T372		x	x	x	x	x	x	x	A8		A7	A6	A5	A4	A3	A2	A1	A0

Electrical Specifications

Absolute Maximum Ratings

Symbol	Description	Ratings
V_{DD}	Power Supply Voltage with respect to V_{SS}	-1.0V to +7.0V
V_{IN}	Voltage on any signal pin with respect to V_{SS}	-1.0V to +7.0V and $V_{IN} \le V_{DD}$+1.0V *
V_{BAK}	Backup Supply Voltage	-1.0V to +4.5V
T_{STG}	Storage Temperature	-55°C to + 125°C
T_{LEAD}	Lead Temperature (Soldering, 10 seconds)	260° C
V_{ESD}	Electrostatic Discharge Voltage - Human Body Model (AEC-Q100-002 Rev. E) - Charged Device Model (AEC-Q100-011 Rev. B) - Machine Model (AEC-Q100-003 Rev. E)	 2kV 1.25kV 100V
	Package Moisture Sensitivity Level	MSL-1

* The "$V_{IN} < V_{DD}$+1.0V" restriction does not apply to the SCL and SDA inputs which do not employ a diode to V_{DD}.
Stresses above those listed under Absolute Maximum Ratings may cause permanent damage to the device. This is a stress rating only, and the functional operation of the device at these or any other conditions above those listed in the operational section of this specification is not implied. Exposure to absolute maximum ratings conditions for extended periods may affect device reliability.

DC Operating Conditions (T_A = -40° C to + 85° C, V_{DD} = 2.7V to 5.5V unless otherwise specified)

Symbol	Parameter	Min	Typ	Max	Units	Notes
V_{DD}	Main Power Supply	2.7		5.5	V	7
I_{DD}	V_{DD} Supply Current @ SCL = 100 kHz @ SCL = 400 kHz @ SCL = 1 MHz			 500 900 1500	 µA µA µA	1
I_{SB}	Standby Current For V_{DD} < 5.5V For V_{DD} < 3.6V			 150 120	 µA µA	2
V_{BAK}	RTC Backup Supply Voltage @ T_A = +25ºC to +85ºC @ T_A = -40ºC to +25ºC	 1.55 1.9		 3.75 3.75	V V V	9
I_{BAK}	RTC Backup Supply Current @ T_A = +25ºC, V_{BAK} = 3.0V @ T_A = +85ºC, V_{BAK} = 3.0V @ T_A = +25ºC, V_{BAK} = 2.0V @ T_A = +85ºC, V_{BAK} = 2.0V			 1.4 2.1 1.15 1.75	 µA µA µA µA	4
I_{BAKTC}	Trickle Charge Current with V_{BAK}=0V Fast Charge Off (FC = 0) Fast Charge On (FC = 1)	 50 200		 120 2500	 µA µA	10
V_{TP0}	V_{DD} Trip Point Voltage, VTP(1:0) = 00b	2.55	2.6	2.70	V	5
V_{TP1}	V_{DD} Trip Point Voltage, VTP(1:0) = 01b	2.80	2.9	3.00	V	5
V_{TP2}	V_{DD} Trip Point Voltage, VTP(1:0) = 10b	3.80	3.9	4.00	V	5
V_{TP3}	V_{DD} Trip Point Voltage, VTP(1:0) = 11b	4.25	4.4	4.50	V	5
V_{RST}	V_{DD} for valid /RST @ I_{OL} = 80 µA at V_{OL} $V_{BAK} > V_{BAK}$ min $V_{BAK} < V_{BAK}$ min	 0 1.6			 V V	6
I_{LI}	Input Leakage Current			±1	µA	3
I_{LO}	Output Leakage Current			±1	µA	3
V_{IL}	Input Low Voltage All inputs except those listed below CNT1-2 battery backed (V_{DD} < 2.4V) CNT1-2 (V_{DD} > 2.4V)	 -0.3 -0.3 -0.3		 0.3 V_{DD} 0.5 0.8	 V V V	8

continued »

DC Operating Conditions, continued (T_A = -40° C to + 85° C, V_{DD} = 2.7V to 5.5V unless otherwise specified)

Symbol	Parameter	Min	Typ	Max	Units	Notes
V_{IH}	Input High Voltage					
	All inputs except those listed below	0.7 V_{DD}		V_{DD} + 0.3	V	
	PFI (comparator input)	-		3.75	V	
	CNT1-2 battery backed (V_{DD} < 2.4V)	V_{BAK} – 0.5		V_{BAK} + 0.3	V	
	CNT1-2 V_{DD} > 2.4V	0.7 V_{DD}		V_{DD} + 0.3	V	
V_{OL}	Output Low Voltage (I_{OL} = 3 mA), FOUT, /INT, /RST	-		0.4	V	
V_{OH}	Output High Voltage (I_{OH} = -2 mA)	2.4		-	V	
R_{RST}	Pull-up Resistance for /RST Inactive	50		400	KΩ	
R_{IN}	Input Resistance (pulldown)					
	A1-A0 for V_{IN} = V_{IL} max	20			KΩ	
	A1-A0 for V_{IN} = V_{IH} min	1			MΩ	
V_{PFI}	Power Fail Input Reference Voltage	1.175	1.20	1.225	V	
V_{HYS}	Power Fail Input (PFI) Hysteresis (Rising)		-	100	mV	

Notes
1. SCL toggling between V_{DD}-0.3V and V_{SS}, other inputs V_{SS} or V_{DD}-0.3V.
2. All inputs at V_{SS} or $V_{DD,}$ static. Stop command issued.
3. V_{IN} or V_{OUT} = V_{SS} to V_{DD}. Does not apply to A0, A1, PFI, or /RST pins.
4. V_{BAK} = 3.0V, V_{DD} < 2.4V, oscillator running, CNT1-2 at Vss or V_{BAK}.
5. /RST is asserted low when V_{DD} < V_{TP}.
6. The minimum V_{DD} to guarantee the level of /RST remains a valid V_{OL} level.
7. Full complete operation. Supervisory circuits, RTC, etc operate to lower voltages as specified.
8. Includes /RST input detection of external reset condition to trigger driving of /RST signal by FM31T37x.
9. The V_{BAK} trickle charger automatically regulates the maximum voltage on this pin for capacitor backup applications.
10. V_{BAK} will source current when trickle charge is enabled (VBC bit=1), V_{DD} > V_{BAK}, and V_{BAK} < V_{BAK} max.

AC Parameters (T_A = -40° C to + 85° C, V_{DD} = 2.7V to 5.5V, C_L = 100 pF unless otherwise specified)

Symbol	Parameter	Min	Max	Min	Max	Min	Max	Units	Notes
f_{SCL}	SCL Clock Frequency	0	100	0	400	0	1000	kHz	
t_{LOW}	Clock Low Period	4.7		1.3		0.6		µs	
t_{HIGH}	Clock High Period	4.0		0.6		0.4		µs	
t_{AA}	SCL Low to SDA Data Out Valid		3		0.9		0.55	µs	
t_{BUF}	Bus Free Before New Transmission	4.7		1.3		0.5		µs	
$t_{HD:STA}$	Start Condition Hold Time	4.0		0.6		0.25		µs	
$t_{SU:STA}$	Start Condition Setup for Repeated Start	4.7		0.6		0.25		µs	
$t_{HD:DAT}$	Data In Hold Time	0		0		0		ns	
$t_{SU:DAT}$	Data In Setup Time	250		100		100		ns	
t_R	Input Rise Time		1000		300		300	ns	1
t_F	Input Fall Time		300		300		100	ns	1
$t_{SU:STO}$	Stop Condition Setup Time	4.0		0.6		0.25		µs	
t_{DH}	Data Output Hold (from SCL @ VIL)	0		0		0		ns	
t_{SP}	Noise Suppression Time Constant on SCL, SDA		50		50		50	ns	

All SCL specifications as well as start and stop conditions apply to both read and write operations.

RTC Frequency Characteristics

Symbol	Parameter		Min	Typ	Max	Units
F_{OUT}	FOUT Clock Frequency		-	32.768	-	kHz
Δf/f	Frequency Stability vs. Temperature	0° C to +45° C			±3	ppm
		-40° C to +85° C			±5	ppm

Data Retention (T_A = -40° C to + 85° C, V_{DD} = 2.7V to 5.5V)

Symbol	Parameter	Min	Units	Notes
T_{DR}	Data Retention	10	Years	

Supervisor Timing (T_A = -40° C to + 85° C, V_{DD} = 2.7V to 5.5V)

Symbol	Parameter	Min	Max	Units	Notes
t_{RPU}	/RST Active (low) after V_{DD}>V_{TP}	100	200	ms	
t_{INTP}	Pulse Width of /INT Active	100	200	ms	
t_{RNR}	V_{DD} < V_{TP} noise immunity	10	25	µs	1
t_{VR}	V_{DD} Rise Time	50	-	µs/V	1,2
t_{VF}	V_{DD} Fall Time	100	-	µs/V	1,2
t_{WDP}	Pulse Width of /RST for Watchdog Reset	100	200	ms	
t_{WDOG}	Timeout of Watchdog	t_{DOG}	2*t_{DOG}	ms	3
f_{CNT}	Frequency of Event Counters	0	10	MHz	

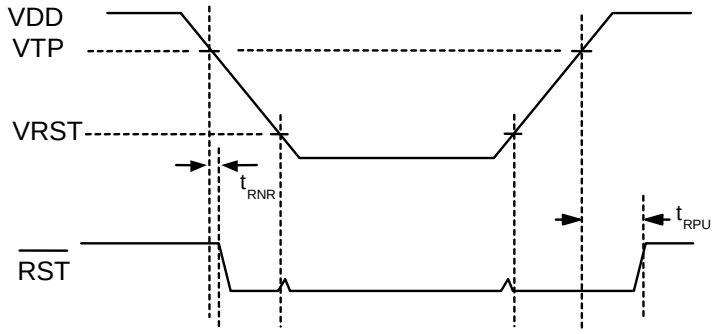
Notes

1 This parameter is characterized but not tested.

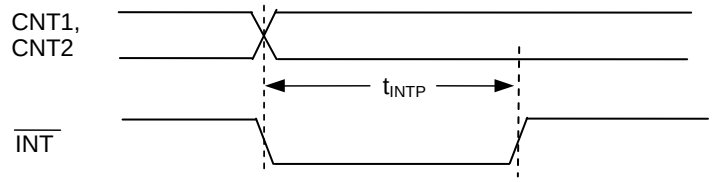
2 Slope measured at any point on V_{DD} waveform.

3 t_{DOG} is the programmed time in register 0Ah, V_{DD} > V_{TP} and t_{RPU} satisfied.

/RST Timing



/INT Pulse Width



AC Test Conditions

Input Pulse Levels	0.1 V_{DD} to 0.9 V_{DD}
Input rise and fall times	10 ns
Input and output timing levels	0.5 V_{DD}

Equivalent AC Load Circuit

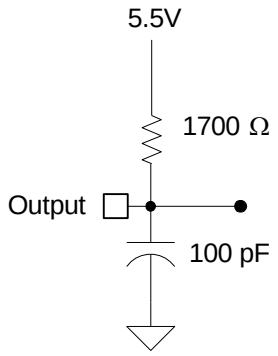
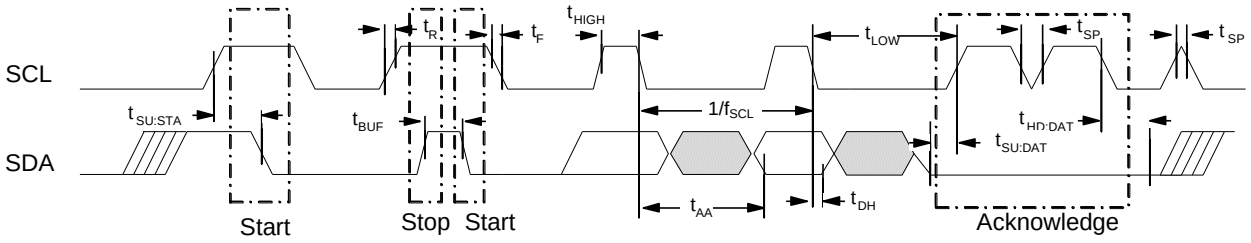


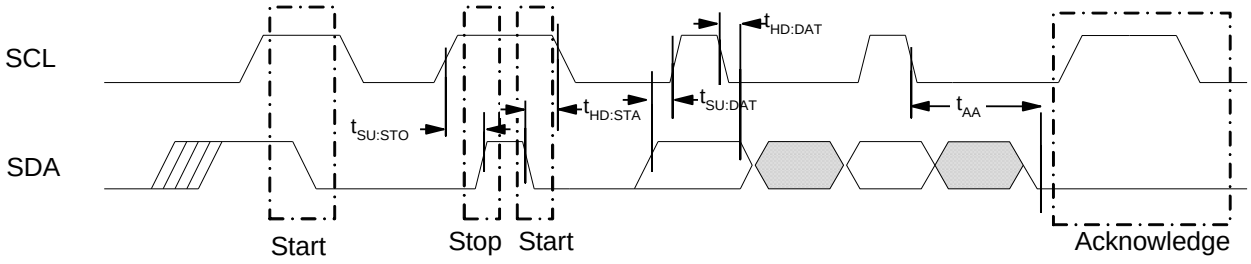
Diagram Notes

All start and stop timing parameters apply to both read and write cycles. Clock specifications are identical for read and write cycles. Write timing parameters apply to slave address, word address, and write data bits. Functional relationships are illustrated in the relevant data sheet sections. These diagrams illustrate the timing parameters only.

Read Bus Timing

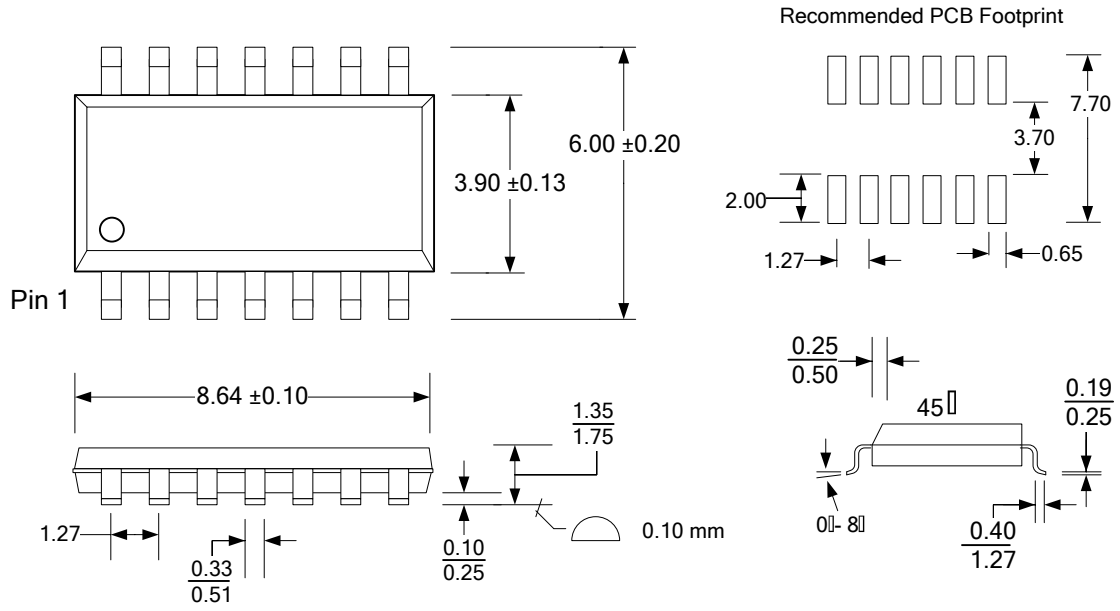


Write Bus Timing



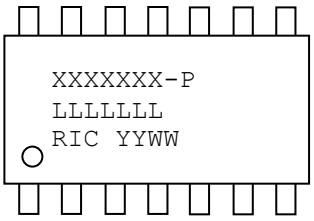
Mechanical Drawing

14-pin SOIC (JEDEC Standard)



Refer to JEDEC MS-012 for complete dimensions and notes.
All dimensions in millimeters.

SOIC Package Marking Scheme



Legend:
XXXXXX= part number, P= package type (-G)
LLLLLLL= lot code
RIC=Ramtron Int'l Corp, YY=year, WW=work week

Example: FM31T378, "Green" SOIC package, Year 2010, Work Week 20
FM31T378-G
A00003G
RIC 1020

Revision History

Revision	Date	Summary
1.0	6/14/2010	Preliminary status.
1.1	4/18/2011	Documentation updates and clarifications. Changed I_{BAK} limits.