MICRO CRYSTAL SWITZERLAND

Application Note

Multiple Interrupt Lines with RV-3028-C7 Real-Time Clock Module

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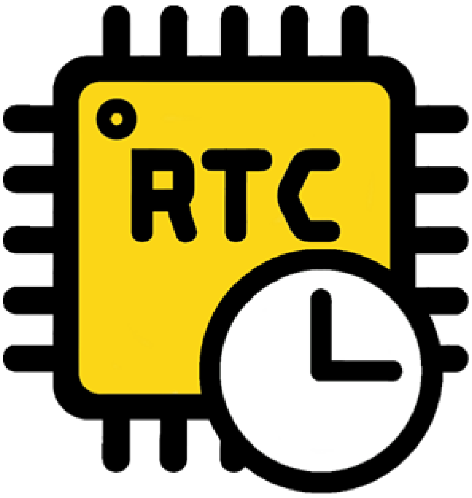
Wake-up Options For Lowest Power Operation in WSN



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Content

1. Introduction

For a wearable or portable battery operated sensor node, the extension of battery lifetime is a key factor to prevent costly frequent battery replacements and to support a hassle-free user experience.

Selecting the right sensor and MCU based on low-power feature is important but not sufficient. It is the energy profile (which MCU peripheral or external component needs to be active and for how long) of the full application that should drive the choice of specific components.

In many low-power sensor nodes, also called end device, there is no need to have permanent operation of the MCU, sensor or RF communication peripheral. They spend most of their time sleeping.

Depending on the application, it is possible to take advantage of the MCU's multiple reduced power modes like Idle, Sleep, Deep-sleep, Power-down, or Deep power-down when available, in order to optimize the device's power usage.

In what is commonly called "sub-sleep" mode, the major portions of the MCU are turned off (core, peripheral and memory are stopped) leaving only Timer, Interrupt handling and Real-Time Clock (RTC) functions active. Nonetheless, MCU power consumption with on-board RTC function active remains typically far above (> 500 nA) compared to an external RTC module.

Using an ultra-low-power external RTC module, as the only always-on component, allows accurate timekeeping while being able to wake-up MCU at defined intervals or on event detection with the lowest energy budget (typically 45 nA in timekeeping mode for the **RV-3028-C7**).

The rapid growth and large-scale deployment of the IoT-based wireless systems have caused dissipating a massive amount of energy. This leads to a significant need to develop and use mechanisms and techniques that can help save energy of battery-operated devices and extend their operating life.

This Application Note discusses some of the features available to extend battery life in battery-powered RF ecosystems by taking advantage of the unique features of the **RV-3028-C7** or **RV-5028-C7 Medical** ultra-low-power Real-Time Clock modules. It addresses specifically the multiple interrupt lines required in a wireless sensor node (WSN) application in order to minimize power consumption.

Careful evaluation is recommended before applying the RTC module register configurations described in this application note.

All considerations about **RV-3028-C7** presented in this document are directly applicable to **RV-5028-C7 Medical** as this latter part differs only in term of type of lid used in assembly (full ceramic package) and testing process (higher specifications related to its specific use in implantable medical devices).

2. Applications requiring multiple interrupt lines

2.1. Use case example – Wireless Sensor Node (WSN)

Many low-power sensor applications have to perform wireless communication to transmit periodically or on demand sensor measurement data. It is even possible to use opportunistic sensor data collection (OSDC) scenario, when a mobile entity (e.g., a pedestrian or a vehicle), equipped with a RF-enabled device, can collect the data obtained by the sensor node once both are within direct communication range.

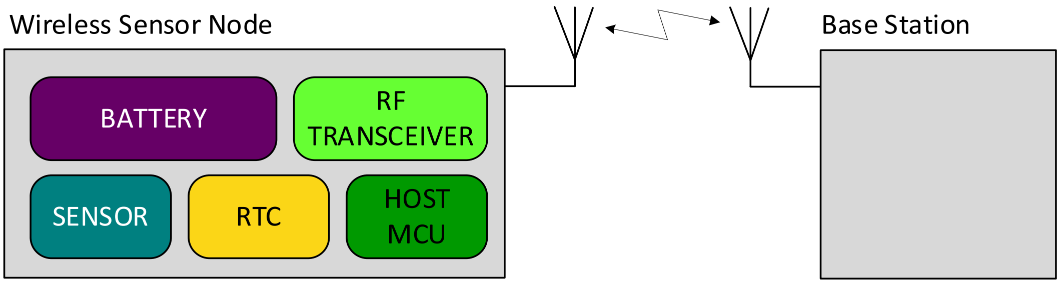


Figure 1: Application Example

In WSN domain, most applications use a RF link infrequently due to the overriding need to conserve battery power. In very low-power applications, the transceiver has to spend most of the time asleep in a very low-current state. Systems must first wait for the base station to initiate communications following a defined procedure.
Therefore, periodically, the sensor node transceiver should listen for a base station that wants to begin communication. This sniffing operation should be frequent enough to provide reasonable startup latency, but consume very low current since it occurs periodically. A major tradeoff exists between battery life and frequency of data collection for sensor nodes. If very frequent (1 to 10 seconds) data collection and transmission is required, the batteries must either have a very large capacity, be replaced or charged very frequently, or connected to an energy-harvesting source.

2.2. Key components

In such applications where true ultra-low-power devices need to be deployed, it is imperative to select key components able to fulfill the key functions with a minimal energy budget.

Table 1: WSN's key components

Host MCU	Provides key device function management – sensor reading, data treatment, data preparation and low power (sleep mode) capable.
Sensor	Provides physical quantification for point of interest (pressure, temperature, …) – signal conversion and transmission, sleep mode capable through I²C or through MCU GPIO controlling a MOSFET.
RF transceiver	Ensures wireless data transmission function with minimal power and that the radio can be kept in a sleep state for as much time as possible while maintaining responsiveness. Wake-up through sniffing capable.
Battery	Usually identified as the limiting factor in the application (frequent replacement or recharging is often not possible), it has to offer the longest lifetime at minimal size and cost.
RTC	Allows timekeeping, timestamping, timer, alarm **and most of all enables timing based or external event interrupts to wake-up other key components while operated in ultra-low power mode**.

2.3. Timing constraints of the application

The periodic activities have to be controlled through two independently scheduled periods; one for the RF sniffing (T_{SNIFF}) and one for the sensor readings (T_{SENSE}).

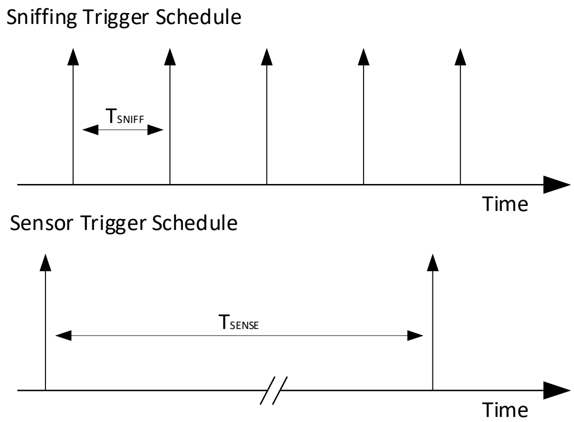


Figure 2: Application Schedule Example

According to typical low-power application needs, it can be considered that the sensor measurements are performed at a periodicity (T_{SENSE}) larger than one minute and can even be defined in hours or days. In contrast, the sniffing period (T_{SNIFF}) is expected to be in the range of seconds in order to detect the request for communication sent by the base station collecting measurement data.

Nowadays, state of the art transceiver incorporates a wake-up receiver that allows the IC to operate with an ultra-low power average consumption while sniffing periodically (typically 1 to 5 seconds) with an external strobe. If a specially coded wake-up message is detected while sniffing, the WSN is woken up autonomously, it wakes-up the Host MCU fully and starts a communication session, including any application related activities (data download, application parameters re-configuration ...).

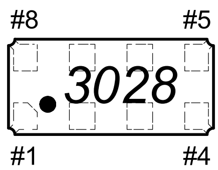
As explained, such applications require two independent interrupts, physical signals with two different periods. One signal has to frequently wake-up the RF transceiver to perform the sniffing, enabling communication with the base station. The other interrupt has to wake-up the MCU, typically less frequently, in order to perform sensor readings, data processing required for edge computing (calculation, filtering ...) and store the data into memory.

External RTC modules are generally designed with a single interrupt line with the aim to wake-up an MCU periodically or in the presence of an alarm. Due to its very compact sized package the RV-3028-C7 RTC module, offers a limited number of connections. With only 8 pins; where two are dedicated to I^2C communication (SDA, SCL), two to the power supply (V_{DD}, V_{SS}), one for a backup source (V_{BACKUP}), one for the detection of external events (EVI), and one for frequency output (CLKOUT), which leaves only one line fully dedicated to interrupts ($\overline{INT}$).

The lack of a second dedicated interrupt output pin can however be **solved by creatively using the CLKOUT signal**.

Table 2 : Pinout

#1	CLKOUT
#2	$\overline{INT}$
#3	SCL
#4	SDA
#5	V_{SS}
#6	V_{BACKUP}
#7	V_{DD}
#8	EVI



2.4. CLKOUT used as interrupt

When different periodic and programmable interrupt intervals are needed in the application, a single interrupt line is in that respect not sufficient to independently trigger the MCU and the RF wireless communication chip for wake-up/sniffing events, whilst ensuring best power efficiency.

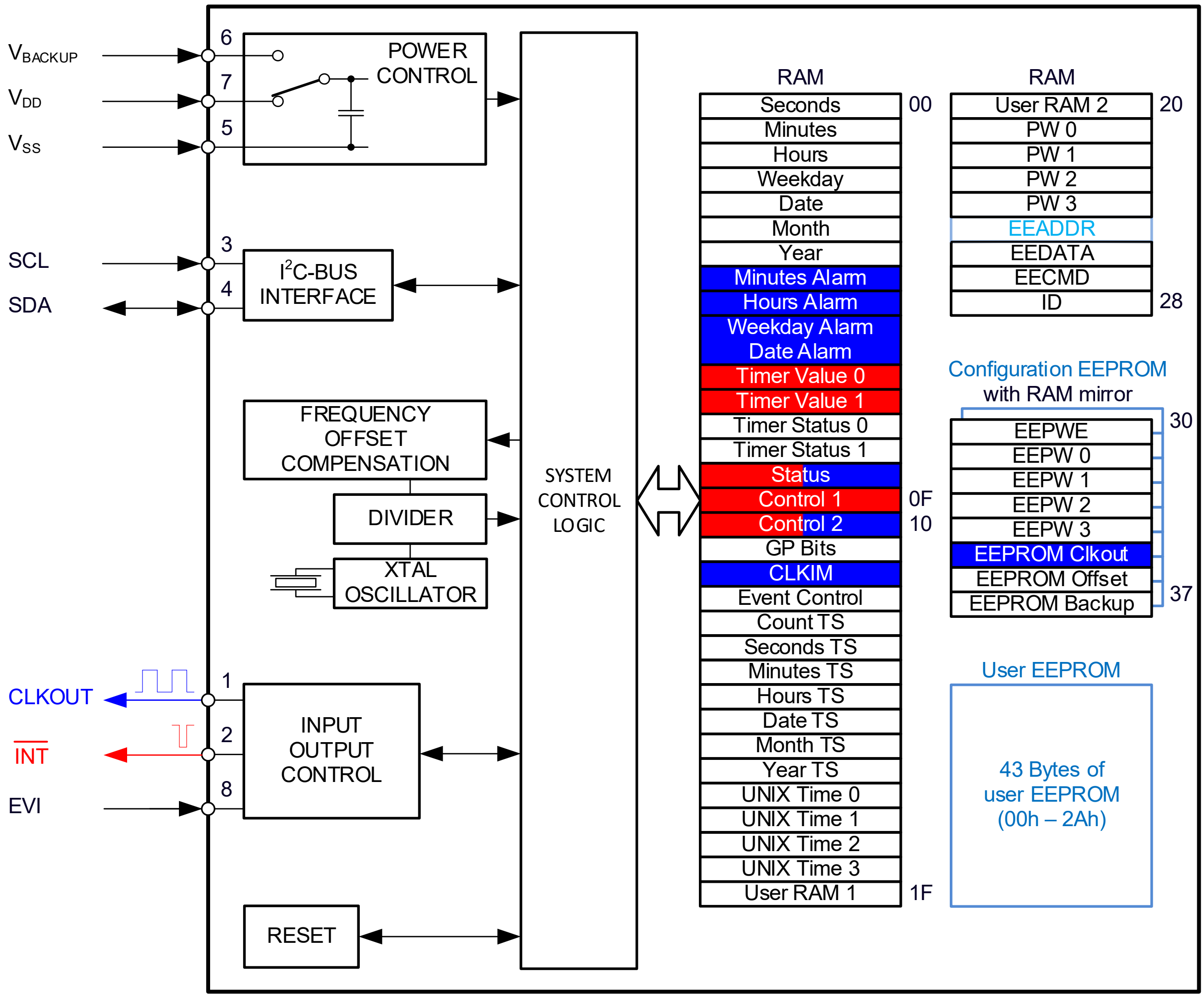


Figure 3: RV-3028-C7 Block Diagram

To address this limitation, a function is available within the **RV-3028-C7** RTC module to meet the requirements of a second physical interrupt output line. This extra feature is the controlled oscillator output-line CLKOUT pin.

As the role of this interrupt is to wake-up the MCU at a much longer time interval than the one used for the RF sniffing, $T_{SENSE} >> T_{SNIFF}$ (Figure 2), a practical approach to use:

- Periodic Countdown Timer Interrupt for the RF sniffing interrupt $\overline{\text{INT}}$ on pin 2
- Alarm Interrupt to trig a low to high signal on CLKOUT pin 1.

Following MCU wake-up performed through the square wave generated on CLKOUT pin, an I²C communication between the MCU and the RTC module is required to stop generating the clock output in order to limit power consumption, clear corresponding interrupt status flags and to prepare the next Alarm event.

According to sensor reading and data analysis requirements, the delay for the next wake-up (T_{SENSE}) can be adapted. The minimum period resolution for this alarm is one minute.

2.4.1.CLKOUT used as interrupt in the use case

Unlike the open-drain type $\overline{\text{INT}}$ output, which requires a pull-up (③ in Figure 4), CLKOUT is a push-pull output and can be connected directly to a GPIO.
CKLOUT push-pull output is constantly driven (HIGH or LOW) and is unidirectional; it does not allow connecting multiple devices together in a bus configuration, as it is the case for an open drain output.

The schematic below presents a typical WSN example with dual wake-up capabilities, including explanations:

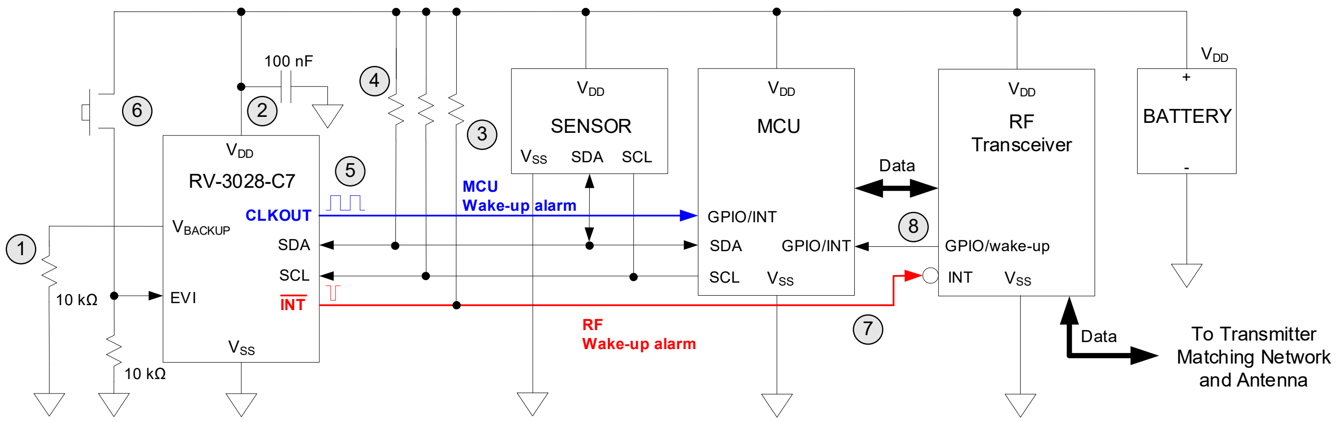


Figure 4: Example of Wireless Sensor Node (WSN) with wake-up managed by RV-3028-C7 RTC Module

① Backup Switchover functionality is disabled by default. It is recommended to not leave V_{BACKUP} power supply pin floating. No extra backup battery is usually present in battery operated WSN.
Connection to V_{SS} through a 10 kΩ resistor keeps functional test possible.

② Use a 100 nF decoupling capacitor close to the device.

③ $\overline{\text{INT}}$ pin is an open-drain output and requires a pull-up resistor (select the largest value in order to limit power consumption).

④ I²C lines SCL, SDA are open-drain and require pull-up resistors to V_{DD}. Select the largest value (typ. 10 kΩ for a 400 kHz communication) in order to limit current while guarantying communication. The communication sequence to perform sensor readings and new alarm settings will have to be minimized to limit power consumption.

⑤ CLKOUT used as INT signal for MCU wake-up; this is done by configuring CLKOUT management registers.
See 2.4.3 Interrupt CLKOUT configuration for details.

⑥ EVI input is set to detect rising edge or high-level of tamper detection signal; can be used as an Application specific interrupt signal. The EVI Input is never floating thanks to the 10 kΩ connected to V_{SS}.

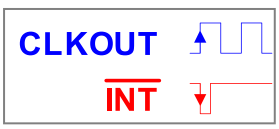
⑦ RF Transceiver wake-up done through $\overline{\text{INT}}$. Signal is active LOW, i.e. signal passing from HIGH to LOW for a predefined duration t_{RTN1}. (see Table 14 for details).

⑧ When RF Transceiver detects presence of base station, a wake-up signal is generated to activate MCU in order to start communication between WSN and base station.

An interrupt is generated in an MCU when a bit in the port interrupt flag and its corresponding port interrupt enable are both set. The pin interrupt feature is capable to wake up the CPU when it is in sleep/stop or wait mode.

In this use case, the principle is to use the signals from **RV-3028-C7** as standard hardware interrupt lines passing from one state to the other.

For this example the MCU interrupt flag mask has to be set with active high level selected for the CLKOUT interrupt signal, i.e. signal passing from LOW to HIGH and the opposite for the standard INT line (active LOW, i.e. signal passing from HIGH to LOW).



2.4.2. CLKOUT function

CLKOUT is a signal generated by the internal oscillator based on the RTC embedded 32.768 kHz crystal. This signal has a 50 ±10% duty cycle and can be configured to generate square signal of various frequencies:

- 32.768 kHz
- 8192 Hz
- 1024 Hz
- 64 Hz
- 32 Hz
- 1 Hz

The CLKOUT signal operation can be either controlled through a control register or linked to an interrupt function. This offers the option to use it as an extra physical hardware interrupt line to the standard wired $\overline{INT}$.

Table 3 shows the four interrupt functions that can be used to trigger CLKOUT signal.

Table 3: RTC interrupt functions able to trigger CLKOUT output

1	PERIODIC COUNTDOWN TIMER	When countdown, counting any period set from 244.14 µs to 4095 minutes, reaches 0.
2	PERIODIC TIME UPDATE	Periodically at the One-Second or the One-Minute update time, according to the selected timer source.
3	ALARM	For alarm settings such as weekday/date, hour and minute settings.
4	EXTERNAL EVENT	In presence of input events on EVI pin.

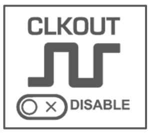
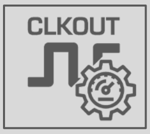
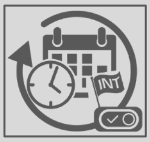
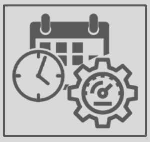
As explained, the Periodic Countdown Timer is used, in this specific example, for the automatic activation of the sniffing RF transceiver. The interrupt function triggering the CLKOUT is based on the Alarm settings.

A weekday/date, hour or minute Alarm Interrupt event occurs when all selected Alarm registers match to the respective counters.

2.4.3. Interrupt CLKOUT configuration

This interrupt is configured through 6 steps:

Table 4: Alarm Interrupt configuration principle

Step #	Description and register to be set	Synoptic
1	**CLKOUT set at LOW level** (CLKOE – Clock output signal is disabled, pin remains at LOW level state in absence of an alarm) EEPROM Clkout Register	
2	**CLKOUT frequency selection** (FD - offers the selectable frequencies that is generated at CLKOUT pin for application use. EEPROM Clkout Register	
3	**CLKOUT activation** (CLKIE – Clock output on Interrupt bit enabled, allowing to output the clock on CLKOUT pin) Control 2 Register	
4	**Interrupt signal activation when an Alarm occurs** (AIE – Alarm Interrupt Enable bit enabled) Control 2 Register	
5	**Clock Interrupt Mask definition** (CAIE – enable the interrupt based on Alarm settings) Control Interrupt Mask Register	
6	**Time alarm settings** (corresponding to the time between the Alarm Interrupt, T_{SENSE} in our case) Minutes Alarm Register	

Many configuration registers can be write-protected by password. For more details about password protection, please refer to: 4.18.USER PROGRAMMABLE PASSWORD in the Application Manual for details.

2.4.3.1. EEPROM Clkout Register

Register used to configure the CLKOUT signal present on CLKOUT pin.
Can be write-protected by password.

EEPROM Clkout Bit 6 (CLKSY) is disabled as no synchronization is required in this case.
EEPROM Clkout Bit 7 (CLKOE) Clock output signal is disabled, pin remains at LOW level state in absence of an alarm enable clock output on CLKOUT pin.

Table 5: EEPROM Clkout Register Configuration for CLKOUT signal

Address	Function	Conv.	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
35h	EEPROM Clkout	R/WP	CLKOE	CLKSY	-	-	PORIE	FD		
	Bit value		0	0	0	0	0	0	0	0

Bit	Symbol	Value	Description
7	CLKOE		CLKOUT Enable bit
		0	The CLKOUT pin is LOW (if CLKF flag is 0).
		1	The clock output signal on CLKOUT pin is enabled. – Default value on delivery
6	CLKSY		CLKOUT Synchronized enable/disable
		0	Disabled
		1	Enables the Synchronized enable/disable (by CLKOE bit or CLKF flag) of the CLKOUT frequency. – Default value on delivery
2:0	FD	000 to 111	CLKOUT Frequency Selection

EEPROM Clkout Bit 0:2 (FD) are defining the CLKOUT Frequency.
In below example a frequency of 64 Hz is defined with the three FD bits.

Table 6: CLKOUT Frequency Selection with FD value

FD value	CLKOUT Frequency Selection
000	32.768 kHz – Default value on delivery
001	8192 Hz
010	1024 Hz
011	64 Hz
100	32 Hz
101	1 Hz

A transition from LOW to HIGH is needed by the MCU GPIO interrupt detection pin to trigger the wake-up. To avoid any timing issue, it is safe to configure the CLKOUT of RV-3028-C7 at a frequency allowing a reliable wake-up of the MCU. With step duration configurable between 15 µs and 500 ms, the signal is long enough for level stabilization and to pass successfully the commonly used interrupt glitch filter. MCU has then sufficient time to detect level change.

With 64 Hz CLKOUT frequency settings, as selected in the example here above, the time allowed for MCU wake-up is of 7.8125 ms. The first transition from LOW to HIGH occurs after a half period of 64 Hz, i.e. 7.8125 ms.

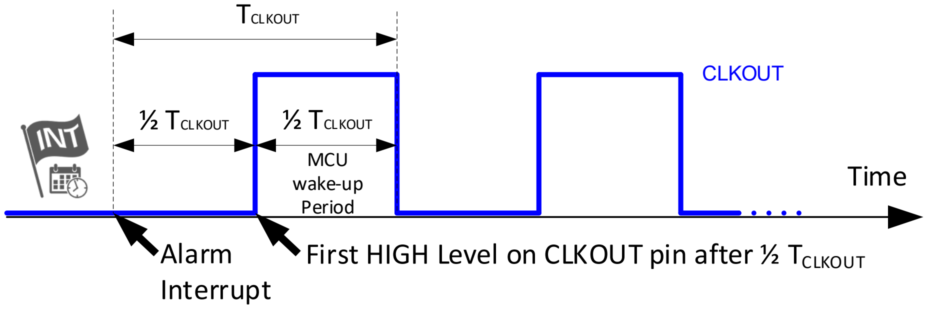


Figure 5: CLKOUT profile once Alarm Interrupt occurs

2.4.3.2. Control 2 Register

Register used to control the interrupt event based on the Alarm for the CLKOUT pin.
Can be write-protected by password.

Control 2 Bit 3 (AIE) is set to allow generation of a signal on $\overline{INT}$ pin when an Alarm event occurs.
Required for internal hardware Alarm interrupt management.
Control 2 Bit 6 (CLKIE) is set to enable clock output on CLKOUT pin.

Table 7: Control 2 Register Configuration for Alarm Interrupt

Address	Function	Conv.	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
10h	Control 2	R/WP	TSE	CLKIE	UIE	TIE	AIE	EIE	12_24	RESET
	Bit value		0	1	0	1	1	0	0	0

Bit	Symbol	Value	Description
6	CLKIE		Interrupt Controlled Clock Output Enable bit.
		0	Disabled – Default value
		1	When set to 1, the clock output on CLKOUT pin is automatically enabled when an interrupt occurs, based on the Clock Interrupt Mask Register (12h) and according to clock setting defined by the FD field.
3	AIE		Alarm Interrupt Enable bit
		0	No interrupt signal is generated on $\overline{INT}$ pin when an Alarm event occurs or the signal is cancelled on $\overline{INT}$ pin. – Default value
		1	An interrupt signal is generated on $\overline{INT}$ pin when an Alarm event occurs. This setting is retained until the AF flag is cleared to 0 (no automatic cancellation).

2.4.3.3. Clock Interrupt Mask Register

Allows selecting a defined interrupt for automatic clock output.
Can be write-protected by password.

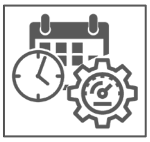
Clock Interrupt Mask Bit 2 enable the Clock output on CKLOUT pin when Alarm Interrupt occurs.

Table 8: Clock Interrupt Mask Configuration for Alarm Interrupt

Address	Function	Conv.	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
12h	Clock Interrupt Mask	R/WP	-	-	-	-	CEIE	CAIE	CTIE	CUIE
	Bit value		0	0	0	0	0	1	0	0

Bit	Symbol	Value	Description
2	CAIE		Clock output when Alarm Interrupt bit.
		0	Disabled – Default value
		1	Enabled. Internal signal AI is selected.

2.4.3.4. Minutes Alarm Register



Register used to enable the alarm based on minutes and to set the value for this minute alarm. Can be write-protected by password.

Minutes Alarm Bit 0:6 allow to set value in two binary coded decimal (BCD). Values will range from 00 to 59.
Minutes Alarm Bit 7 holds the Minutes Alarm Enable bit AE_M

Table 9: Minutes Alarm Register Configuration

Address	Function	Conv.	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
07h	Minutes Alarm	R/WP	AE_M	40	20	10	8	4	2	1
	Bit value		0	Coded Minute Alarm in BCD (see example below)						

Bit	Symbol	Value	Description
7	AE_M		Minutes Alarm Enable bit.
		0	Minutes Alarm is enabled.
		1	Minutes Alarm is disabled. – Default value
6:0	Minutes Alarm	00 to 59	Holds the alarm value for minutes, coded in BCD format.

Binary-coded decimals (BCD) are an easy way to represent decimal values, as each digit is represented by its own 4-bit binary sequence. For time purpose, 7 bits are sufficient to code from 00 to 59 minutes.

Example for Minutes Alarm set at 45 minutes in BCD:

4				5			
0	1	0	0	0	1	0	1

Remark:
In this specific example, the principle applied for the Alarm Interrupt to wake-up the MCU is that it should happen every hour at XX:45 with Minutes Alarm remaining set with this time after each MCU wake-up. The only register to set is then the one of the Minutes Alarm. When another schedule is needed to extend the period between sensor readings to several hours, days or even weeks it is necessary to enable other alarm bits and to set required values for Hours Alarm or Weekday/Date Alarm.

Here below are presented the various options to set alarm event. Refer to 3.5. ALARM REGISTERS in the Application Manual for details.

Table 10: Alarm Interrupt

Alarm enable bits			Alarm event
AE_WD	AE_H	AE_M	
0	0	0	When minutes, hours and weekday/date match (once per weekday/date)
0	0	1	When hours and weekday/date match (once per weekday/date)
0	1	0	When minutes and weekday/date match (once per hour per weekday/date)
0	1	1	When weekday/date match (once per weekday/date)
1	0	0	When hours and minutes match (once per day)
1	0	1	When hours match (once per day)
1	1	0	When minutes match (once per hour) – example used in this Application Note
1	1	1	All disabled – Default value
AE_x bits (where x is WD, H or M) AE_x = 0: Alarm is enabled AE_x = 1: Alarm is disabled – Default value			

2.5. Interrupt $\overline{INT}$ function

In **RV-3028-C7** RTC module, the interrupt $\overline{INT}$ pin can indicate six types of different interrupt functions:

Table 11: RTC interrupt functions

1	PERIODIC COUNTDOWN TIMER	When countdown, counting any period set from 244.14 µs to 4095 minutes, reaches 0.
2	PERIODIC TIME UPDATE	Periodically at the One-Second or the One-Minute update time, according to the selected timer source.
3	ALARM	For alarm settings such as weekday/date, hour and minute settings.
4	EXTERNAL EVENT	In presence of input events on EVI pin.
5	AUTOMATIC BACKUP SWITCHOVER	When switchover from VDD Power state to VBACKUP Power state occurs. Used in design with two power sources (main and backup).
6	POWER ON RESET	When voltage drop below VPOR is detected (VDD < VPOR)

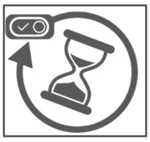
$\overline{INT}$ pin outputs the logic OR operation result of these interrupt outputs.

For the frequent sniffing wake-up, the Periodic Countdown Timer is the most suitable interrupt function to use.

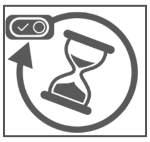
2.5.1.Periodic Countdown Timer Interrupt $\overline{INT}$ configuration

This interrupt is configured through four steps and the configuration of four registers:

Table 12: Periodic Countdown Timer Interrupt configuration principle

Step #	Description and register to be set	Synoptic
1	**Timer activation** (TE - Timer Enable bit enabled) Control 1 Register	
2	**Timer duration definition** (based on the Timer Clock Frequency and the number of periods to be counted) Control 1 Register & Timer Value Registers	
3	**Interrupt signal activation when a Periodic Countdown Timer occurs** (TIE – Timer Interrupt Enable bit enabled) Control 2 Register	
4	**Timer automatic repetition activation** (TRPT – Timer RePeaT bit enabled) Control 1 Register	

2.5.1.1. Control 1 Register



Allows selecting and setting operations for the Periodic Countdown Timer.
Can be write-protected by password.

Control 1 Bit 2 (TE) is set to activate the Periodic Countdown Timer.

Control 1 Bit 7 (TRPT) is set to enable the automatic repetition of the Periodic Countdown Timer.

Table 13: Control 1 Register Configuration

Address	Function	Conv.	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
0Fh	Control 1	R/WP	TRPT	-	WADA	USEL	EERD	TE	TD	
	Bit value		1	0	0	0	0	1	0	1

Bit	Symbol	Value	Description
7	TRPT		Timer Repeat bit. Specifies either Single or Repeat Mode for the Periodic Countdown Timer Interruption function
		0	Single Mode is selected. When the Countdown Timer is enabled (TE = 1) it will halt when it reaches zero and TE is automatically cleared. – Default value
		1	Repeat Mode is selected. When the Countdown Timer is enabled (TE = 1) it automatically reloads the value from the Timer Value registers upon reaching 0, and continues counting.
2	TE		Periodic Countdown Timer Enable bit. This bit controls the start/stop setting for the Periodic Countdown Timer Interruption function
		0	Stops the Periodic Countdown Timer Interrupt function. TE is also automatically cleared when Single Mode is selected (TRPT = 0) and when the Countdown Timer reaches zero. – Default value
		1	Starts the Periodic Countdown Timer Interrupt function (a countdown starts from the preset value set in Timer Value registers).
1:0	TD	00 to 11	Timer Clock Frequency selection. Sets the countdown source clock for the Periodic Countdown Timer Interrupt function. With this setting the Auto reset time t_{RTN1} is also defined.

The Control 1 Bits 1:0 (TD) are defining the Timer Clock Frequency. Depending on the sniffing period (T_{SNIFF}) required by the application, one of the four frequencies can be selected (in-between factor being 60, 64 and 64).

Table 14: Timer Clock Frequency Selection

TD value	Timer Clock Frequency	Countdown Period	t_{RTN1}
00	4096 Hz – Default value	244.14 µs	122 µs
01	64 Hz	15.625 ms	7.813 ms
10	1 Hz	1 s	
11	1/60 Hz	60 s	

As an example, the Timer Clock Frequency is set at 64Hz. The corresponding Countdown Period is then of 15.625 ms and the associated auto reset time t_{RTN1} (low-level state on $\overline{INT}$ pin) is 7.813 ms.

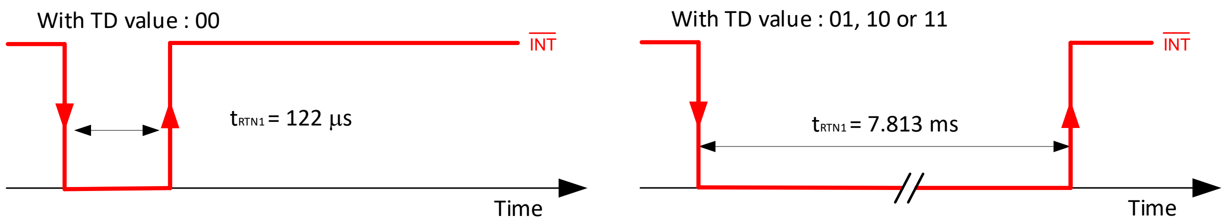


Figure 6: Auto reset time t_{RTN1} profiles according to TD values

2.5.1.2. Timer Value Registers

Set the lower 8 bits (Timer Value 0) and upper 4 bits (Timer Value 1) of the 12-bit Timer Value for the Periodic Countdown Timer.

As experienced by many designers, periods too long for SLEEP/SNIFF can lead to poor user perception related to responsiveness; indeed, while waiting for the connection the user is getting impatient. On the other hand triggering the RF transceiver too often will lead to excessive power drain.

A smart definition of the duty cycle according to the application and power budget is important.
A 1-second external strobe period is chosen as the typical example of Countdown Period target for Timer Value calculation.

Once Timer Clock Frequency and Countdown Period corresponding to T_{SNIFF} are defined, the Timer Value can be calculated with below formula:

Timer Value in decimal:

Timer Value = Timer Clock Frequency x Countdown Period
Timer Value = 64 (Hz) x 1 (sec) = 64d

Table 15: Countdown Period according to Timer Clock Frequency and Timer Value

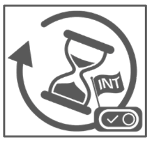
Timer Value (0Ah and 0Bh)	Countdown Period			
	TD = 00 (4096 Hz)	TD = 01 (64 Hz)	TD = 10 (1 Hz)	TD = 11 (1/60 Hz))
0	-	-	-	-
1	244.14 µs	15.625 ms	1 s	1 min
2	488.28 µs	31.25 ms	2 s	2 min
:	:	:	:	:
41	10.010 ms	640.63 ms	41 s	41 min
64 ←	15.625 ms	1 s	64 s	64 min
205	50.049 ms	3.203 s	205 s	205 min
410	100.10 ms	6.406 s	410 s	410 min
2048	500.00 ms	32.000 s	2048 s	2048 min
:	:	:	:	:
4095 (FFFh)	0.9998 s	63.984 s	4095 s	4095 min

The Timer Value obtained can then be set in the 12-bit Timer Value registers as shown here below.
Timer Value Bit 6 (64) is set to 1 and remaining bits are 0.

Table 16: Timer Value Registers allowing number of cycle selection

Address	Function	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
0Ah	Timer Value 0	128	64	32	16	8	4	2	1
0Bh	Timer Value 1	○	○	○	○	2048	1024	512	256

2.5.1.3. Control 2 Register



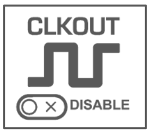
The last register to set is Control 2, where Control 2 Bit 4 (TIE) is enabled.
It enables the generation of the negative pulse on $\overline{INT}$ pin when the sniffing period (Periodic Countdown Timer corresponding to T_{SNIFF}) has elapsed.

Table 17: Control 2 Register Configuration for Periodic Countdown Timer Interrupt

Address	Function	Conv.	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
10h	Control 2	R/WP	TSE	CLKIE	UIE	TIE	AIE	EIE	12_24	RESET
	Bit value		0	0	0	1	0	0	0	0

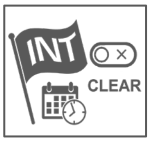
Bit	Symbol	Value	Description
4	TIE		Periodic Countdown Timer Interrupt Enable bit
		0	No interrupt signal is generated on $\overline{INT}$ pin when a Countdown Timer event occurs or the t_{RTN1} - signal on $\overline{INT}$ pin is cancelled. – Default value
		1	An interrupt signal is generated on $\overline{INT}$ pin when a Periodic Countdown Timer event occurs. The low-level output signal is automatically cleared after t_{RTN1} = 122 µs (TD = 00) or t_{RTN1} = 7.813 ms (TD = 01, 10, 11).

2.6. MCU flags clearing activity



Once MCU detects the CLKOUT signal transition from LOW to HIGH and after MCU core wakes up, one of the first action to be managed is to send an I²C command in order to stop the Clock output.

Status Bit 6: clearing the CLKF Flag will stop clock output on pin CLKOUT.



The Alarm Flag has to be cleared. The Alarm detection generates a low-level interrupt signal on the $\overline{INT}$ pin. This artifact on this line means that the RF transceiver will detect an asynchronous unexpected extra wake-up signal and that a sniffing will take place.

Status Bit 2: Once Alarm Interrupt occurs, $\overline{INT}$ pin is set to LOW. The Alarm Flag AF has to be cleared to set $\overline{INT}$ pin back to HIGH and to prepare the next cycle of alarm detection by the RTC (after next T_{SENSE}).

Table 18: Status Register Actions to clear Alarm Interrupt and stop CLKOUT output

Address	Function	Conv.	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
0Eh	Status	R/WP	EEbusy	CLKF	BSF	UF	TF	AF	EVF	PORF
	Bit value		0	1 → 0	0	1	0	1 → 0	0	1

Bit	Symbol	Value	Description
6	CLKF		Clock Output Interrupt Flag
		0	When cleared to 0 the frequency output will stop.
		1	If set to 0 beforehand, indicates the occurrence of an interrupt driven clock output on CLKOUT pin. The value 1 is retained until a 0 is written by the user.
2	AF		Alarm Flag
		0	No event detected.
		1	If set to 0 beforehand, indicates the occurrence of an Alarm Interrupt event. The value 1 is retained until a 0 is written by the user.

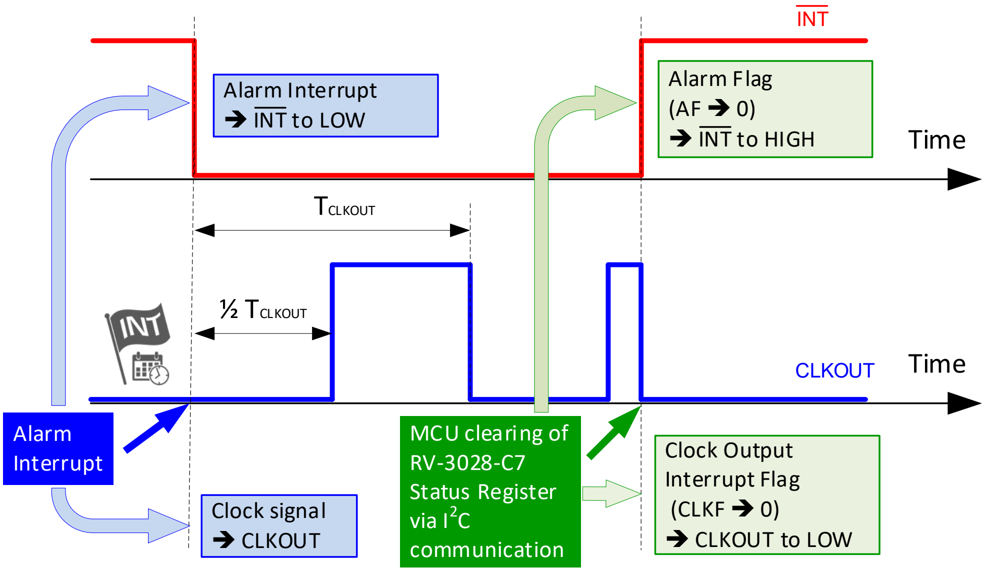


Figure 7: Alarm Interrupt active and clearing operation

Important remarks:
Once MCU is woken-up, disabling clock output on CLKOUT pin is necessary to limit the power consumption of the RTC and to benefit of the power savings provided by this mode of operation.

Following MCU wake-up performed through the square wave generated on CLKOUT pin, an I²C communication between the MCU and the RTC module is required to stop the clock output generation, to clear corresponding interrupt status flags and to prepare the next Alarm event.

The MCU will then be able to perform its tasks (sensor activation, readings, data treatment, new alarm settings when needed and back to sleep mode).
According to sensor readings and data analysis, the delay for the next wake-up (T_{SENSE}) can be adapted through the alarm settings. The minimum period resolution for this alarm is one minute.

Every CLKOUT based interrupt will generate as well an $\overline{INT}$ signal interrupt that will add an extra sniffing trigger to the application and therefore slightly increase current consumption. As the T_{SENSE} period is much longer than the T_{SNIFF} interval, such increase in RF-transceiver operation can be considered as not significant (<1%).

When not in use it is also advised to disable the I²C module of the MCU in order to reduce power consumption.

2.7. Main benefits

The automatic repetition of the Countdown Timer and the RTC controlled release of the LOW-level interrupt signal used to wake-up the RF transceiver (sniffing interrupt INT) allows maintaining the MCU in sleep mode as long as the alarm period is not elapsed.
This duty-cycle activity is ideal to limit power consumption as shown in the activity chart here below. Activity surfaces are indicative only; please refer to 2.9 Battery life considerations for more details on energy consumption.

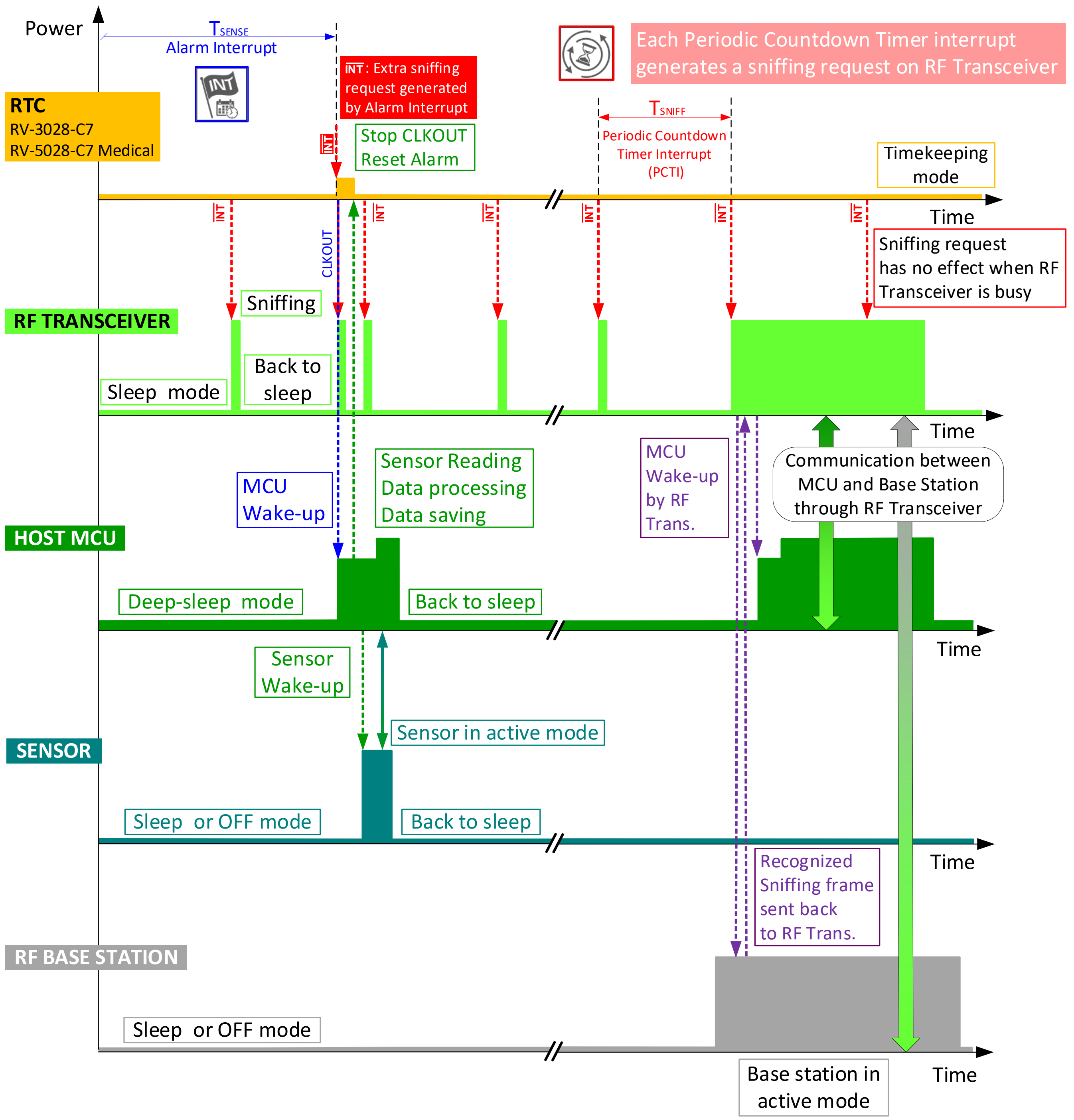


Figure 8: WSN activity chart when using an RTC

During duty-cycling, the node Host MCU is periodically put into sleep mode and is woken up only to perform measurement (Alarm interrupt) or to transmit/receive data through RF transceiver interrupt.
In classic designs, the so called duty-cycling ratio (the ratio of time the transceiver is in transmit or receive mode to time off) cannot go arbitrarily low, due to:

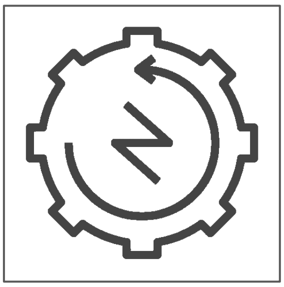
- **idle listening**: occurs when the node monitors the communication medium for ongoing transmissions, but there is no data to be received by the node. Since nodes must listen periodically to limit data latency, there is a listening power consumption that cannot be avoided, even in low data traffic scenarios.

- **overhearing**: occurs when a node receives packets from its neighbours that are not intended for that node, leading to energy waste, especially when the network density is high and the data traffic is heavy.

By using the smart approach described here, where ultra-low power modes are applied to Host MCU and RF transceiver while letting the RTC manage the wake-up operations, it is possible to minimize idle listening and overhearing power loss.

2.8. Application optimization

The optimization of node operation can be performed through the modification of trigger schedule and related sleep/sniffing/wake-up time periods adaptation. This is managed by the MCU and I^{2}C communication with the RTC through modification of interrupt related registers (see 4.7. INTERRUPT OUTPUT in the Application Manual for details).



If the sensor node finds that its power level is low or its computing load is too high, it can dynamically change some timing parameters and processing power (MCU running clock) to improve the situation and extend battery life.

This dynamic restructuring of the parameters in the application code will allow the node to still participate in the communication network without sacrificing its power. The additional burden that will result from adopting this method is that application code has to be written to suit parameterized increase/decrease of sleep/activity windows and intervals as well as MCU clock frequency (processing power).

2.9. Battery life considerations

The battery life for typical low-power sensor nodes depends upon a number of factors. For the battery life calculation and optimization of system operation, the designer will have to make assumption on the time needed for sensor measurement, frequency of readings, potential MCU edge computing, size of data transmitted and frequency of transmissions.

Each use case has to be analyzed according to the dependent parameters like application constraints (transmission distance), defined hardware (selected MCU, system clock frequency ...), software (poor coding can increase power consumption), peripheral and response time requirements.

Through measurement and/or calculation of OFF/ON state duration and current consumption of each component, it will be possible to figure out energy requirements (battery capacity) and manage trade-offs among lifetime, cost, size and user/application needs imperatives.

Knowing that battery self-discharge is usually a large contributor to power consumption (up to 10% capacity loss per year); it is advisable to select carefully the battery type for the application and to add energy harvesting devices when needed.

The smart approach of WSN power management as described in this application note is a typical use case where minimized sleep mode power consumption is optimized during the >99% of product life operation.

With the **RV-3028-C7 Real-Time Clock Module** requiring only 45 nA in timekeeping mode and typical high performance RF-transceiver and MCU having an average current consumption of 500 nA in deep sleep and sniffing mode; one can consider that during 99% of the time the WSN current consumption is below 1 µA.

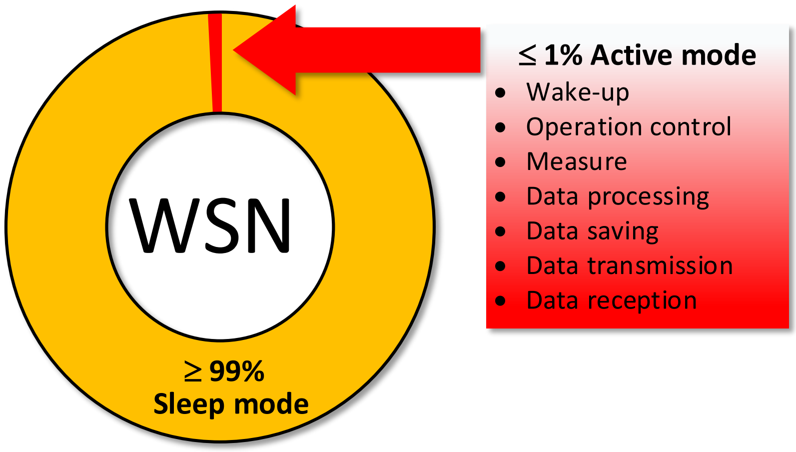


Figure 9: Typical WSN activity mode repartition over time

3. Conclusions

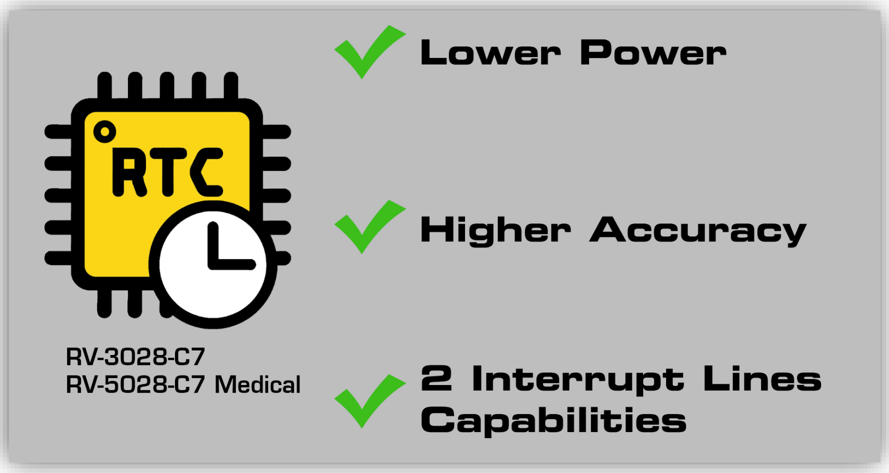
Energy efficient design does not depend only on one or two factors; instead, it requires a suitable combination of factors. From the selection of nodes components to the routing algorithm selection, the combination will have significant impact on energy consumption of a WSN network.

The features available in Micro Crystal's RTCs address and solve some of the design's challenges in power consumption that microcontroller-based WSN hardware are not able to fulfil alone.

The RTC module as the component with the lowest power consumption, is the ideal choice as the always-on device, when no other task is active and when time required for full MCU initialization at restart is not application critical (MCU placed in deep sleep mode or even fully disconnected from power supply).
With the features offered by the **RV-3028-C7** / **RV-5028-C7 Medical**, it is possible to bring designs a step closer towards extreme low power operation and extended battery life. This while lowering global power and providing higher time accuracy.

The option presented in this Application Note how to configure and use $\overline{\text{INT}}$ and CKLOUT as interrupt lines in a Wireless Sensor Node, offers the capability to periodically drive the wake-up functions of two independent components like an RF transceiver for sniffing and an MCU for sensor and data management.

RTCs were never considered as key components in systems, however the always on timekeeping function is a must-have and the choice of RTC is conditioning today's design of personal electronics, medical devices, or industrial products where power savings and backup timekeeping are at premium.



4. Questions/Feedback

Even if a system processor has an integrated RTC, there is often the need for extra alarms, timestamp linked to external event (damper detection), backup battery management, or more commonly a higher time accuracy through temperature compensation. Those are only a few additional functions available and provided by Micro Crystal RTC modules.

Please visit to discover how Micro Crystal products can benefit your application.

We believe that "Great Questions" lead to "Great Designs", so do not hesitate to contact us for any question you may have about your requirements and your RTC design.

Micro Crystal values feedback on its RTC modules and documentation.
Please send feedback to Micro Crystal via: marketing@microcrystal.com

5. Reference documents

Document	Name	Link
Application Manual	RV-3028-C7 Application Manual	Download
Parametric Table	RTC Modules Parametric Table	Download
Technical Note	RTC Selection and FAQ	Download

6. Document version

Date	Version #	Changes
January-21-2022	1.0	Initial version - NMO