AN017
Low Power Systems Using the CC1010

By K. H. Torvmark

Keywords

- *CC1010*
- *Low-power*
- *Remote Keyless Entry (RKE)*
- *Polling receiver*
- *Clock modes*
- *Power modes*

Introduction

This application note considers the development of low-power RF systems. It focuses on the CC1010 integrated RF transceiver and microcontroller, and describes several ways of minimizing the current consumption in designs using the CC1010.

The various power modes and clock modes of the CC1010 are also described in more detail.

Several examples are presented; these include wake-up on button press, wake-up at intervals as well as an RKE (Remote Keyless Entry) application.

An Excel spreadsheet for performing battery lifetime calculations is described, and can be downloaded from Chipcon's web site.

Low-power basics

Low power consumption is a very important requirement for battery-operated systems. Having a low current consumption translates directly into long battery lifetime.

Several approaches can be used to lower power consumption. Operation frequency is an important parameter. In CMOS circuits, power consumption generally scales linearly with the operating frequency. Therefore, it is important not to use a higher operation frequency than necessary for the application.

Perhaps the most important concept is duty-cycle. ICs implementing power-saving modes can be switched between active and power-saving modes to save power. The average current consumption will depend on the ratio between the time spent in active mode and the time spent in the power-saving mode.

Above all, when designing for low power consumption, a designer should take a system approach. Low power consumption should be considered in all phases of design. Early on, it is useful to do quick power calculations to see what approaches are feasible. Battery selection is often a very important factor in a design, and will decide the power consumption requirements.

Low-power features of the CC1010

By using the CC1010, you already have a head start to get low current consumption because of the integrated very-low-power RF transceiver. The CC1010 MCU core also includes numerous power-saving features.

Because of the many combinations possible, we will consider the MCU core and the RF transceiver power consumption separately. The only exception is for power-down mode, where both the RF transceiver and the MCU are shut off. Active, Idle and Power-down modes refer to the MCU. The RF transceiver part is either in RX mode, TX mode or it is turned off.

Clock modes

The CC1010 is equipped with two crystal oscillators; a high-frequency oscillator that can be used with crystals with frequencies between 3 and 24 MHz, and a low-frequency oscillator designed for use with a 32 kHz watch crystal. The CC1010 can be switched between these two clock sources by writing to the CMODE bit in the X32CON register. Running on the 32 kHz oscillator is called clock mode 1, running on the high-speed oscillator is called clock mode 0. Both oscillators must be powered up and have stabilised before switching between them. When reset, the CC1010 will default to running on the high-frequency oscillator. The clock to the entire CC1010 is switched when this function is used, it is not possible to run some parts of the CC1010 on one clock and other parts on the other clock. The single exception is the RTC, which always runs off the 32 kHz oscillator. The RTC cannot wake up the CC1010 from power-down mode, however.

Several factors come into play when deciding what operating frequency to use on the CC1010. In active mode, current consumption varies linearly with the operating frequency, as shown in Figure 1. In addition to the operating frequency/power consumption trade-off, there are also some considerations to make in respect to the RF transceiver part of the CC1010.

The RF data rates (600, 1200, 2400 … 76800 Baud) given in the datasheet assume a crystal frequency of 3.6864, 7.3728, 11.0592, 14.7456, 18.4320 or 22.1184 MHz. Other crystal frequencies can be used, but the RF data rates will then differ from those given in the data sheet. For example, using a 16 MHz instead of a 14.7456 MHz crystal, the data rates will be multiplied by 16/14.7456, so they will be 651, 1302 … 83333 Baud. The maximum data rate of 76.8 kBaud is only attainable using a 14.7456 MHz crystal.

Another consideration is for optimal frequencies in RX mode. The higher the crystal frequency, the closer the spacing between optimal frequencies. This is especially noticeable when using a low RF frequency such as 315 MHz. Please see AN011 [1] for more information.

All of these parameters can be evaluated using SmartRF® Studio. An approximate current consumption will be displayed in the status bar.

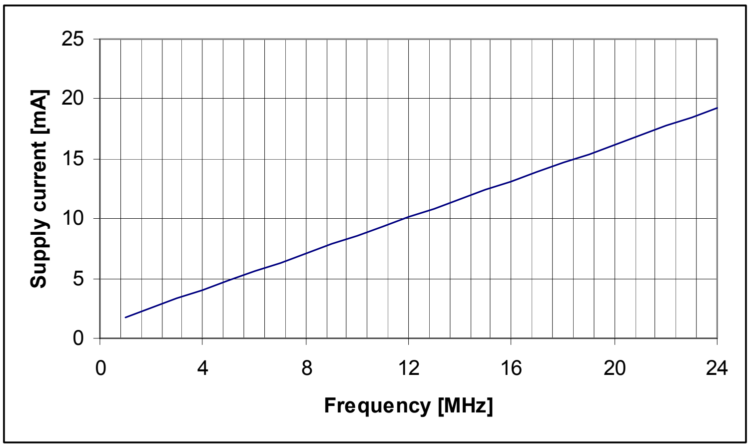

Figure 1: CC1010 current consumption as a function of operating frequency

Power modes

The CC1010 MCU has three different operating modes: Power-Down, Idle and Active. You need to have a good understanding of these operating modes to design a low-power system.

In Active mode, the MCU core and all peripherals are running. In this mode, nothing is shut off. The program can enter one of the other power modes by writing to the PCON register.

In Idle mode, the MCU core is stopped, but all peripherals are running. All internal registers keep their value. There are three ways of exiting this mode: either by an interrupt, reset or by turning power on and off. If an enabled interrupt is activated, the MCU will execute the corresponding ISR (Interrupt Service Handler), and resume operation with the instruction after the one that activated Idle mode.

In Power-down mode, both the MCU core and the peripherals are shut off. Only the ADC clock tree is enabled. The MCU can enter Active mode either by being reset or by turning the power on and off. If enabled, the ADC will cause a reset when the selected input exceeds a programmed threshold, and make the MCU exit Power-down mode. This requires that the 32 kHz oscillator be left on.

In addition to these power modes, the FLASH_LP Flash power control bits in the FLCON register set the power mode of the Flash program memory. For minimum power consumption, these bits should be set to 10, disabling the Flash program memory between instruction fetches and when the CC1010 is in Idle or Power-down mode.

Mode	Core	Peripherals	Typical current consumption	Exit condition
Active	Main osc.	Main osc.	10 mA at 11 MHz	Writing SFR
	32 kHz	32 kHz	1.1 mA	Writing SFR
Idle	Stopped	Main osc.	8.5 mA at 11 MHz	Interrupt Reset Power off/on
	Stopped	32 kHz	26 uA	
Power-Down	Stopped	Stopped	0.2 uA	Reset Power off/on

Table 1: CC1010 MCU Power modes

Waking up from power-down

Waking up from power-down mode requires that the CC1010 be reset. This can be done in several ways: turning power off and then on, programming the ADC to perform a reset when the input voltage exceeds a threshold, or by pulling the Reset pin low. The CC1010 will also be reset if the operating voltage is too low and the Power-on Reset circuit is turned on, or if the watchdog is active and the watchdog timer has expired.

When the CC1010 is reset, almost all registers (see the data sheet for exceptions) are reset to their default values. All pins are set as inputs, and all peripheral circuits assume their default states. RAM is not affected. The CPU resumes execution of code at address 0.

Software should use variables located in RAM or in Flash memory to keep track of their state in an application where reset is expected to occur.

Saving power

To get low power consumption, we have to use the features explained earlier. What approach is most effective will depend on the application.

Battery issues

Battery selection can be a science in itself. A number of factors have to be considered.

- Battery type: Primary (non-rechargeable) or Secondary (rechargeable)? The type of chemistry (Zinc-Carbon, Alkaline, Lithium, NiMH etc.) The various chemistries have different properties, the most important ones to look out for include maximum current output, capacity, shelf life, behavior versus temperature, cell voltage and discharge curve.
- Battery size – this is usually a trade-off between physical size/weight and capacity. Some types of batteries have significantly higher power densities than others, and are worth considering if space is tight.
- Cost is of course always an issue. Some of the more advanced battery types can be expensive. However, the focus must be on system cost. In some applications it may be worthwhile to use an expensive battery, as this can allow the designer to extend the lifetime so that battery changing by the end customer may not be necessary. This may save significant costs in plastics molding and cost of other components.

Battery manufacturers provide literature that describes their products in detail; we highly recommend getting hold of this information (much of it is available on the Internet) when deciding what battery to use.

The CC1010 operating voltage range is between 2.7 V and 3.6 V. Most primary battery types, such as Zinc-Carbon and Alkaline, have cell voltages of around 1.5 V and a sloping discharge profile. Using some form of voltage regulation may be preferable. Switching regulators have high efficiency and can even provide a higher voltage at the output than at the input, allowing a 3.3 V system to run on a single 1.5 V cell. Make sure to provide proper filtering and shielding when using switching regulators, as they are electrically noisy and can seriously degrade the performance of analog circuitry such as a radio receiver if not filtered properly. Linear regulators are quiet, but can only provide voltages lower than the input voltage.

Lithium cells are more expensive than the more common 1.5 V cells, but provide high capacities and have a very long shelf life. They are available with cell voltages of 3 V and 3.6 V. There are a couple of things to look out for: Make sure the battery can source the maximum current required by your application, and be aware of the passivation effect exhibited by some lithium cells. The passivation effect causes a thin passivation layer to cover the anode of the battery. This helps ensure the long shelf life of the battery, but may be a problem for a system drawing small currents (microampere range). Drawing pulses of higher current “punches” through the passivation layer and restores performance. Be aware, however, that the cell voltage may drop during the application of these pulses.

Remember to store batteries in a cool place; storing them in hot conditions can significantly reduce their shelf life.

Operation

Low-power applications can usually be classified according to their mode of operation. In some applications, all operation is initiated by the user (or external circuitry). In these types of applications, it is desirable to use the Power-down mode of the CC1010 if possible, as this keeps power consumption to an absolute minimum.

In other applications, the system must wake up periodically by itself. Typical examples of this is in order to record sensor data in a data logging application, or to check for incoming RF messages in a polling RF receiver. In this case, the CC1010 should be put in Idle mode and run on the 32 kHz oscillator to minimize power consumption.

The following section provides some more detailed examples for both of these types of applications.

Examples

Case 1: Wake-up on button press

In this case, the CC1010 can be awakened by an external event. This means that the Power-down mode can be used. We have two useful options for waking the CC1010 up from power-down mode; either we can use the Reset pin or the ADC reset functionality.

When relying on the Reset pin for wake-up, the CC1010 will typically draw 0.2 µA while in Power-down mode, this is the lowest power-down current possible with the CC1010.

The circuit shown below is ideal for waking up the CC1010 from a button press. By setting the general I/O pin high, the pushbutton cannot generate reset, this prevents the CC1010 from being reset when it is already active. The I/O pin should be set high when the CC1010 is active, and it should be set low just before the CC1010 enters Power-down mode. The RC low-pass filter takes care of switch debouncing and also ensures that the reset pin is held low until the high-speed crystal oscillator has stabilized. Because all I/O pins are set to inputs during reset, the general I/O pin will stop driving as soon as the Reset signal is detected. The RC filter should be dimensioned so that it keeps the voltage under 0.3·VDD for as long as the high-speed crystal oscillator needs to stabilize (see the datasheet for values for different crystals).

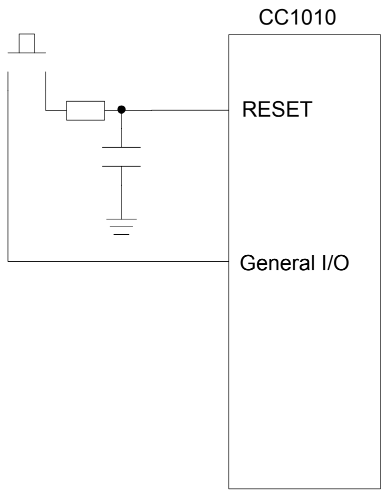

Figure 2: Using a button to wake up CC1010

If the system uses a key matrix, and you want the CC1010 to wake up when any of the buttons are pressed, this can be done with the following circuit:

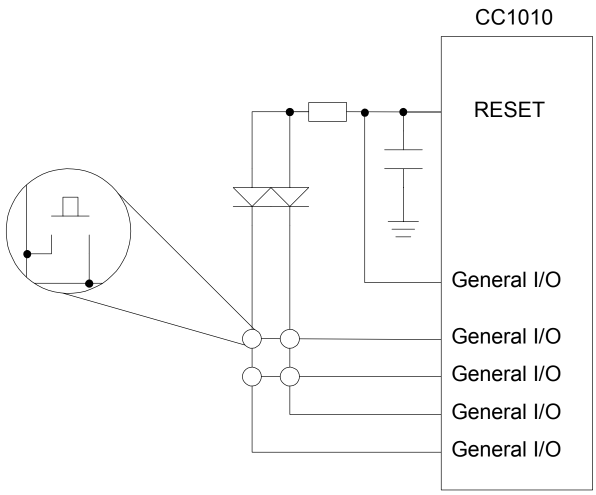

Figure 3: Keypad matrix wakeup

The lower four general I/O pins operate as in a standard keypad matrix, while the topmost general I/O pin ensures that Reset is not pulled low when the CC1010 is operating. It should be set to be a high-level output whenever the CC1010 should be prevented from being reset.

Case 2: Wake-up at intervals

In many cases, awaking the CC1010 at certain intervals in needed. The CC1010 can then poll any connected sensors, check for incoming RF packets and so on. There are several ways of doing this, and each has its pros and cons:

- Using the CC1010's Real Time Clock (RTC). The RTC can wake up the CC1010 from Idle mode at intervals between 1 and 127 seconds. The 32 kHz oscillator must be active for the RTC to function. If the CC1010 is running off the 32 kHz oscillator and in Idle mode, it will typically draw around 30 µA. In this mode, all of the CC1010 interrupts can wake up the MCU, so external interrupts and all the other peripherals can be monitored.
- For applications that require waking up at regular intervals with lower power consumption than possible using the Idle mode of the CC1010, we recommend using an external real-time clock circuit. These devices are inexpensive and can be programmed to wake up the CC1010 at time intervals of up to a month. Current draw will typically be in the microampere range.

Case 3: Low-power RF systems

The key to making a low-power RF system is to keep the duty cycle as low as possible, and keep the inactive current as low as possible. Quite often, the system is asymmetric; not all units have equal requirements for being low power.

For example, in an RKE (Remote Keyless Entry) system for installation in a car, the unit in the car does not have any big need to be low power, since the car battery has a very large capacity. The key fob unit, however, runs on small batteries and must have the longest possible battery life.

If the key fob initiates all communication, the system can be designed as follows:

- Most of the time, the CC1010 in the key fob is in the Power-down mode. It is awakened when a button is pushed (using the methods in case 1). In power-down, the CC1010 uses less than 0.4 µA. No other circuitry is active.

- When a button is pushed, the CC1010 wakes up. The wake-up time depends on the type of high-frequency crystal used. For a 7.3728 MHz, 16 pF load crystal, a typical time is 1.5 ms. During this time, the CC1010 draws around 7 mA.
- Once the crystal has stabilized, the CC1010 can start the RF transmission. Using a data rate of 2.4 kbit/s, a 64-bit message (typical for an RKE application) will take 27 ms. If the system uses full output power at 433 MHz, the CC1010 will use a total of around 34 mA while transmitting.
- Once the message has been sent, the key fob waits for an acknowledge message from the car. If the acknowledge message is 64 bits as well, this takes 27 ms. The CC1010 uses a total of 16 mA while receiving the message.
- When the acknowledge message has been received or a timeout has expired, the key fob blinks a LED to indicate success or failure. If this takes 500 ms, and the LED is run at 8 mA with 50% duty cycle, the average power consumption in this period is $7\,\text{mA} + \frac{8\,\text{mA}}{2} = 11\,\text{mA}$
- After this, the CC1010 goes back to Power-down mode.

The average current for the active part of the cycle is 13mA.

If this system is run on an alkaline AAA battery (1300 mAh) using a switching power supply with an 80% efficiency, the available capacity is 1300mAh·(1.5 V/3.3 V)·0.80=470 mAh. If the key fob is to have a 5 year life (43000 hours), the average current draw must be lower than 11 μA.

The “background” current consumption will consist of the 0.4 μA current draw of the CC1010 in Power-down mode plus the battery self-discharge current. Alkaline batteries typically lose around 4% of their capacity each year at room temperature. If the application requires a battery lifetime of many years, you may have to use lithium batteries, which have a very long shelf life. Assuming a power background consumption of 2 μA, we have 470 mAh-(2 μA·43000h)=380 mAh of capacity left for active mode operation. Assuming 5 operations per day, the battery lifetime will be limited by the shelf life of the battery.

Case 4: Polling RF receiver

If the previous RKE example requires that communication can be initiated by the transceiver in the car as well (to provide a theft alarm system, for instance), the key fob unit should be implemented as a polling RF receiver.

This entails waking up the CC1010 at intervals to check if the transceiver in the car is transmitting. The interval should be as long as possible in order to save power, but will be limited by the required response time of the system.

A good way to implement this is to have the unit in the car send a message with a very long preamble. If the preamble is longer than the polling interval of the key fob, the key fob will notice any incoming message in the absence of RF interference.

When the key fob wakes up, it starts the high-frequency oscillator, and waits until it has stabilized. It then puts the RF transceiver into receive mode and listens for a valid preamble. If none is found, it goes back to sleep. If a preamble is detected, the key fob waits for the message.

User-initiated communication can be handled as before, but the CC1010 will be in Idle mode running on the 32 kHz oscillator instead of in Power-down mode.

For an active period of 30ms (sufficient for crystal start up and the reception of 32 bits at 1.2kbit/s) every 20 seconds, battery life time of an alkaline AAA battery with a switching power supply will be about 0.9 years. User-initiated operation has not been included in the calculations, as it will be infrequent compared to the polling that occurs every 20 seconds.

Low-power calculation spreadsheet

Chipcon has made an Excel spreadsheet to simplify battery lifetime and other related calculations.

Low-power calculation spreadsheet

Chipcon AS, Author: K.H. Torvmark, revision 1.0

Green	Input
Yellow	Output
Blue	Intermediate values

AAA=1375mAh, AA=3100mAh, Coin cell=230mAh

Battery/Power supply specs

Battery capacity	1375,00	mAh
Battery voltage	1,50	V
System voltage	3,30	V
Power supply efficiency	80,00	%
System capacity	500,00	mAh

Polling receiver

Active current consumption	24,00	mA
Inactive current consumption	29,40	uA
Active duration	30,00	ms
Interval	20,00	s
Average current	0,07	mA
Operating lifetime	0,90	years

User-operated command - acknowledge

TX current consumption	41,40	mA
TX duration	64,00	ms
RX current consumption	23,90	mA
RX duration	100,00	ms
Processing current consumption	24,80	mA
Processing duration	500,00	ms
Average operations per day	5,00	
Inactive current consumption	1,00	uA
Capacity used per day	0,05	mAh/day
Operating lifetime	28,41	years

Time vs. Data rate

Data rate	2,40	kbit/s
Bits to receive/transmit	32,00	bits
Time required	13,33	ms

Figure 4: Screenshot of low-power calculation spreadsheet

As shown in Figure 4, this spreadsheet is divided into four separate sections. In the first section, the user can input battery and power supply related information. The output is the available current capacity of the system. If no voltage conversion is used, the battery voltage and the system voltage should be equal. The output of this section is used for current capacity in the other sections.

The second section is labeled “Polling receiver”. This section is used to calculate average current and operating lifetime for a polled (wake-up at constant intervals) system. You can input inactive and active current, and the durations of both states. Operating lifetime is calculated from the “System capacity” output of the first section.

The third section is labeled “User-operated command – acknowledge”, and can be used to calculate an operating lifetime for a system triggered by external events (such as user input). It is based on the model from Example 3, with the user triggering transmission of a message followed by reception of an acknowledgement. Current consumption and duration of RX and TX can be input, as well as the number of events per day and the inactive current consumption. Based on these inputs as well as the “System capacity” output from the first section, an operating lifetime is calculated.

The last section is labeled “Time vs. Data rate”, and can be used to calculate the time taken to receive a given number of bits at a given data rate. This is useful to calculate the durations in the other sections.

Cells are color-coded, so that input values are green, intermediate results are blue and final results are yellow.

Power consumption spreadsheet

Chipcon have also made a spreadsheet for easily computing the total current consumption of the CC1010 chip. In the data sheet, all current consumption specifications (with the exception of the power-down specification) are listed separately for the MCU and the RF transceiver. Therefore, they must be added together to compute the total current consumption. Also, the MCU current consumption scales with the operating frequency, as noted earlier. The spreadsheet takes both these points into consideration.

CC1010 current consumption

VCC = 3.3V, Flash Duty-Cycle = 50%

Main crystal oscillator 14,7456 MHz   3-24 MHz, 3,6864 / 7,3728 / 11,0549 / 14,7456 / 18,4320 / 22,1184 are standard frequencies

		RF frequency 433 MHz						RF frequency 868 MHz				
	TRX in PD	RX	TX, -20dBm	TX, -5dBm	TX, 0dBm	TX, 4dBm	TX, 10dBm	RX	TX, -20dB	TX, -5dBm	TX, 0dBm	TX, 4dBm
Active mode, main oscillator	14,9	24,0	20,2	23,8	25,3	39,7	41,5	26,8	23,5	28,8	31,9	38,4
Active mode 32 kHz oscillator	1,3	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Idle mode, main oscillator	12,8	21,9	18,1	21,7	23,2	37,6	39,4	24,7	21,4	26,6	29,8	36,3
Idle mode, 32 kHz oscillator	0,0294	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Power Down mode	0,0004	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Note: 915 MHz will be very similar to 868 MHz

The table show total current consumtion in mA

Figure 5: Screenshot of the power consumption spreadsheet

Both these spreadsheets are available for download at Chipcon’s web site (http://www.chipcon.com).

Cited references

[1] Chipcon Application note AN011: Programming the CC1000 frequency for best sensitivity

General references

[2] Energizer web site (http://www.energizer.com/)

[3] Duracell web site (http://www.duracell.com/)

[4] Varta web site (http://www.varta.com)

This application note is written by the staff of Chipcon to the courtesy of our customers. Chipcon is a world-wide supplier of RFICs. For further information on the products from Chipcon please contact us or visit our web site. An updated list of distributors is also available at our web site.

Contact Information

Address:
Chipcon AS
Gaustadalléen 21
N-0349 Oslo,
NORWAY

Telephone	:	(+47) 22 95 85 44
Fax	:	(+47) 22 95 85 46
E-mail	:	support@chipcon.com
Web site	:	http://www.chipcon.com

Disclaimer