RemoTI™ Power Consumption

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Keywords

- *RemoTI™*
- *CC2530*
- *Power Consumption*
- *Remote Controller*
- *Target*
- *CERC*
- *RF4CE*

1 Introduction

This application note describes the setup and power consumption measurements for the CC2530 based remote controller and target node.

It is assumed the reader of this application note has knowledge about RF4CE and CERC concepts.

The current consumption measurements are made using the *BasicRemote* sample application included with the RemoTI 1.0 release.

The current consumption measurements are presented, and battery life time is calculated for an example remote controller usage model. An accompanying Excel sheet is provided so that users can estimate their battery life based on their custom usage scenario.

Note that the results presented in this document are intended as a guideline only. A variety of factors will influence the battery life calculation and final measurements and calculations should be performed on customer hardware, in expected environment and under target application scenario.

Table of Contents

2 Abbreviations

ACK	Acknowledgement
CERC	Consumer Electronics Remote Controller
EM	Evaluation module
MAC	Medium Access Control
NWK	Network
PMx	Power Mode x
RC	Remote Controller
RF	Radio Frequency
RX	Receive
RF4CE	Radio Frequency for Consumer Electronics
STB	Set Top Box
TX	Transmit

3 Glossary

Active mode	The RF receiver is turned on continuously
Standby mode	The RF receiver is duty cycling

4 Important RF4CE and CERC Profile Parameters

This section describes important RF4CE and CERC profile parameters that will be referenced in subsequent sections.

4.1 RF4CE

The RF4CE specification [1] provides a means for a target node (TV, STB, etc) to enter standby mode when the equipment is turned off. A target node in standby mode must enable the RF receiver for a certain time at regular intervals to receive potential messages from a RC. The specification dictates the active period *nwkActivePeriod* > (*nwkcMinActivePeriod* = 16.8 ms) and the duty cycle *nwkDutyCycle* < (*nwkcMaxDutyCycle* = 1 s). This is illustrated in Figure 1.

Note that these two parameters can be configured by the application within the limitations stipulated by the specification. The target node sample application (RNP) included with the RemoTI 1.0 release is configuring *nwkDutyCycle* = 330 ms and *nwkActivePeriod* = 16 ms.

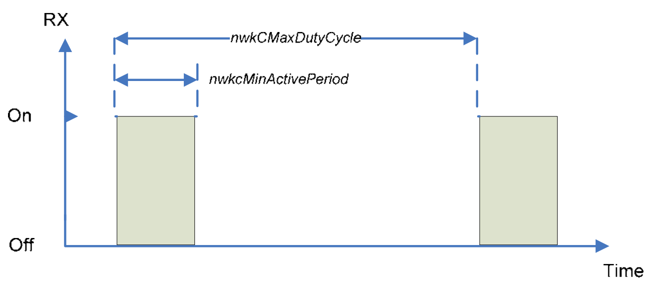

Figure 1. RF4CE Target Node Active Period and Duty Cycle

RF4CE provides a frequency agility mechanism by operating on three MAC channels as defined in [1]. The target node monitors the noise on the current operating channel and can decide to switch channel if the channel quality is compromised due to noise from other sources. This ensures the target node always operates on the channel with the least noise present.

The RF4CE specification provides multiple TX options when an RC sends a message to a target node. A message can be sent as a combination of

- Unicast or broadcast transmission
- Multi-channel or single channel operation
- With ACK or w/o ACK from receiving node

The TX options are controlled by the application and are passed to the RF4CE network layer together with the message data. The network layer will set specific MAC layer parameters based on the TX options before instructing the MAC layer to send the message over-the-air. The details of the TX options and the implications on the send procedure can be found in [1]. The RemoTI API document [2] describes the details of the RTI_SendDataReq() API and the various TX options parameters provided to the RemoTI application programmer.

The unicast, multi-channel, ACKed TX option deserves special attention. This TX option is designed to ensure a message is sent on each of the three channels within *nwkcMinActivePeriod*, and repeated for *nwkcMaxDutyCycle* or until an ACK is received. This TX option must be used to successfully wake up a target node from standby mode with one key press, i.e. the <power> key. It is prudent design to use this TX options when the target is in active mode as well to maximize the likelihood the message reached the recipient.

4.2 CERC Profile

The CERC profile specification [3] dictates the RC to send a '*user control pressed*' command when a key is pressed. If the key is not released within *aplcMaxKeyRepeatInterval* < 100 ms, the RC must send a '*user control repeat*' command. The 'user control repeat' command will be repeated every *aplKeyRepeatInterval* until the key is released. *aplKeyRepeatInterval* = 50 ms in RemoTI 1.0 which is the default value stipulated by the specification. It is optional to send a '*user control released command*' when the key is released only if no '*user control repeat*' command has been issued.

The implication of the 'user control repeated' command construct is that a single key press may result in multiple messages sent by the RC to the target node.

5 RC Current Measurements

This section describes the current measurement setup, and establishes the RC sleep and active current consumption. The active current consumption is established for three components;

1. Key de-bounce – An event triggered by every key press.
2. TX w/ACK – One message sent over-the-air with ACK received from the target node.
3. TX w/o ACK – One message sent over-the-air without an ACK received from the target node.

These components will be used in section 6 to establish the current consumption for a RC sending a message to a target node in active mode and in standby mode.

5.1 Active Current Measurement Setup

An Agilent Oscilloscope is used to capture the current waveform components. The voltage across a 10Ω resistor (±2%) is captured, and hence the current draw is 1/10 of the captured voltage. The setup in is shown in Figure 2.

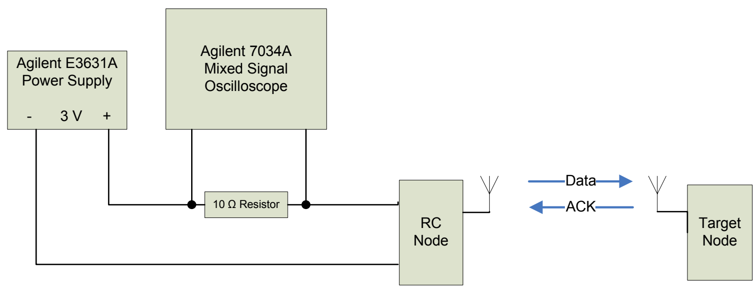

Figure 2. RC Active Current Measurement Setup

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5.1.1 Key De-Bounce Component Measurement

It is important that the RC consumes as little current as possible to enable long battery life. The RC is in deep sleep mode (PM3) as much as possible and wakes up on a key press to process the input and send the message over-the-air. In order to avoid input jitters when a key is pressed, the device wakes up on a key press and sets the sleep timer to expire in 25 ms and enters PM2. At this point we need to be in PM2 since the sleep timer is running. Figure 3 shows the current waveform for the key de-bounce component.

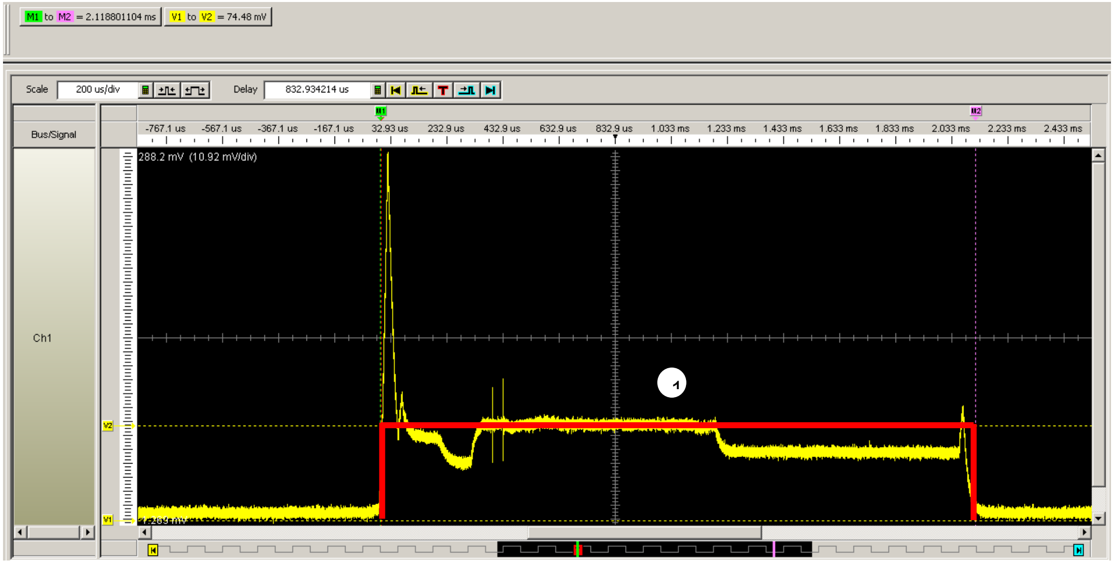

Figure 3. RC Key De-bounce Current Waveform

The current consumption for the key de-bounce component is summarized in Table 1.

Key De-bounce Component Average Current Consumption			
Events	Time	Current	Time*Current
1. Wake-up sequence, timer configuration, PM2	2.11 ms	7.45 mA	15.72 mAms
Total	2.11 ms		15.72 mAms

Table 1. RC Key De-Bounce Component Average Current Consumption

5.1.2 TX w/ACK Component Measurement

The device wakes up after the sleep timer expires following the key de-bounce component. The RC reads the key, prepares the message, performs CCA, sends the CERC 'user controlled pressed' command over-the-air and waits for an ACK from the target node.

After the ACK is received, the RC configures the sleep timer to expire in 50 ms and enters PM2. At timer expiration, the RC checks if the key is still pressed. It sends a CERC 'user control repeated' command if the key is still pressed, configures the sleep timer to expire in 50 ms and enter PM2 again. This will repeat until the key is release upon which the RC sends a CERC 'user control released' command and enters PM3.

A CERC 'user control pressed/repeated/released' command exhibit the same current waveform characteristics. Only the payload content of the messages will be different. The waveform in Figure 4 shows a successful TX w/ACK component based on either of the CERC commands.

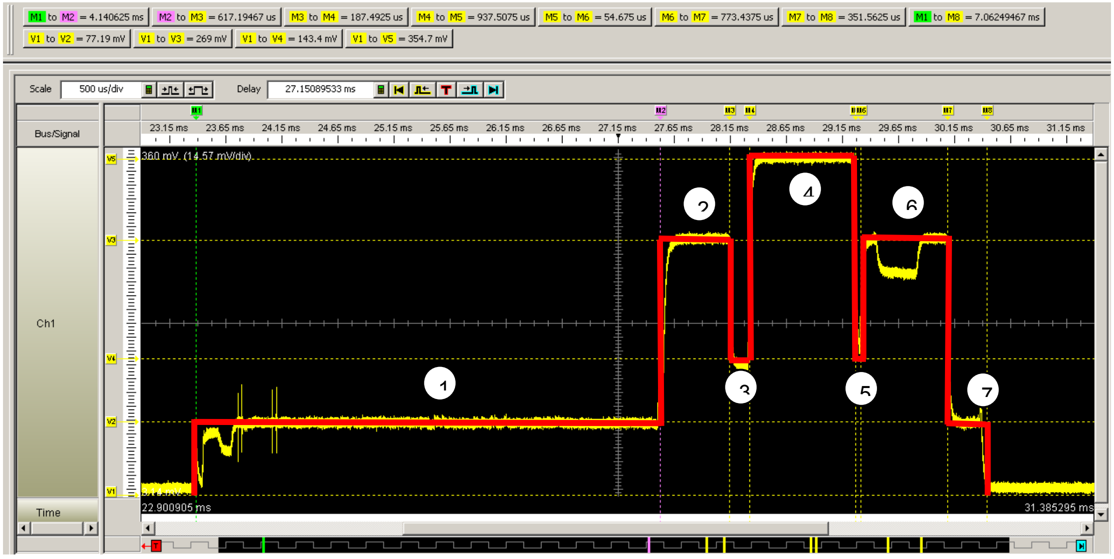

Figure 4. RC TX w/ACK Current Waveform

The current consumption for the TX w/ACK component is summarized in Table 2.

TX w/ACK Component Average Current Consumption			
Events	Time	Current	Time*Current
1. Wake-up sequence, key processing	4.14 ms	7.72 mA	31.96 mAms
2. CCA, radio in RX	0.62 ms	26.90 mA	16.60 mAms
3. RX/TX switch	0.19 ms	14.34 mA	2.68 mAms
4. TX	0.94 ms	35.47 mA	33.27 mAms
5. TX/RX switch	0.06 ms	14.34 mA	0.79 mAms
6. Wait for ACK, radio in RX	0.77 ms	26.90 mA	20.79 mAms
7. Processing and power down sequence to PM3	0.35 ms	7.72 mA	2.72 mAms
Total	7.06 ms		108.81 mAms

Table 2. RC TX w/ACK Component Average Current Consumption

Note that the TX power level can be configured by the application programmer. RemoTI 1.0 default configuration is set to max output power = +4.5 dBm.

5.1.3 TX w/o ACK Component Measurement

A RC sending a message to a target node in standby mode should use the unicast, multi-channel, ACKed TX option as explained in section 4.1. This ensures the RC continuously repeats the message for *nwkcMaxDutyCycle* or until the target node receives and ACKs the message.

Figure 5 shows the waveform when the RC is repeating the message without receiving the ACK.

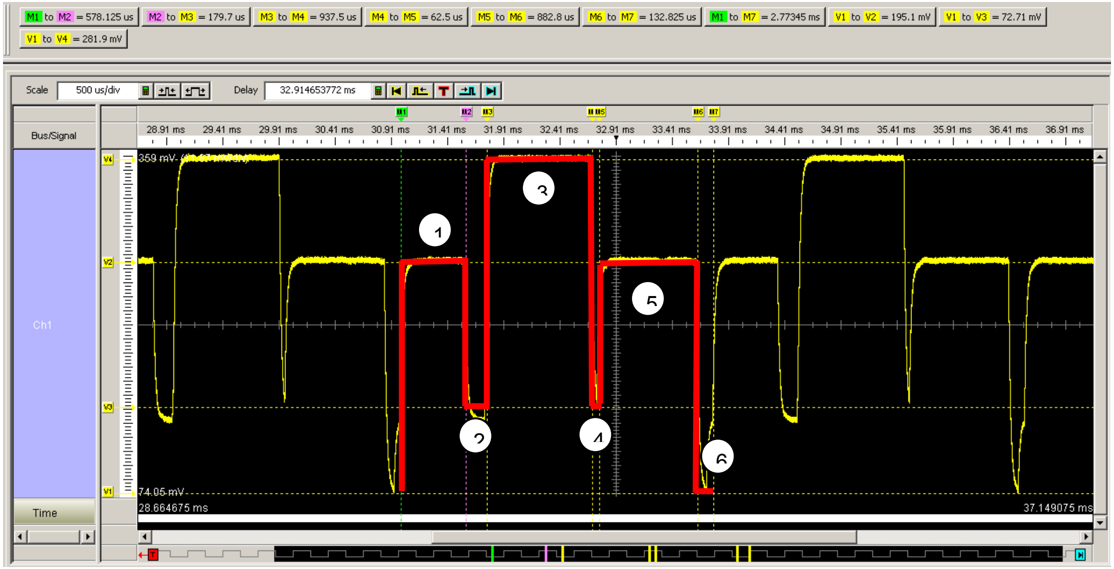

Figure 5. RC TX w/o ACK Current Waveform

The current consumption for the TX w/o ACK component is summarized in Table 3.

TX w/o ACK Component Average Current Consumption			
Events	Time	Current	Time*Current
1. CCA, radio in RX	0.58 ms	26.92 mA	15.56 mAms
2. RX/TX switch	0.18 ms	14.68 mA	2.64 mAms
3. TX	0.94 ms	35.60 mA	33.39 mAms
4. TX/RX switch	0.06 ms	14.68 mA	0.92 mAms
5. Wait for ACK, radio in RX	0.88 ms	26.92 mA	23.77 mAms
6. Processing	0.13 ms	14.68 mA	1.95 mAms
Total	2.78 ms		78.24 mAms

Table 3. RC TX w/o ACK Component Average Current Consumption

5.2 Sleep Current Measurement Setup

The RC spends majority of its time in deep sleep (PM3). The setup in Figure 6 is used to measure the sleep current of the RC. We are using an ampere-meter for this measurement since the current is very low.

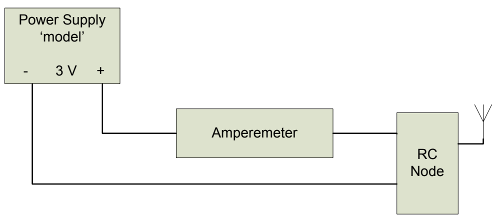

Figure 6. RC Sleep Current Measurement Setup

The sleep current is measured to 0.4 µA, which also corresponds to the typical value in the CC2530 datasheet [2].

6 RC Current Consumption Usage Model

This section uses the current consumption measurement in the previous section to establish the average RC current consumption when sending a message to a target in active mode and in standby mode.

The active mode and standby mode RC current consumption is used at the end of this section to calculate battery life time for the example usage model.

Note that interference triggering retransmissions at MAC and NWK layer is not accounted for in this model.

6.1 Active Mode

The target receiver is always turned on when in active mode. The assumption is therefore that a message sent by the RC is ACKed within a short time. No assumptions are made with respect to a compromised channel triggering message retries.

The RC active mode current consumption is comprised of the key de-bounce component and one TX w/ACK component as shown in Table 4.

Active Mode Current Consumption		
Components	Time*Current	Comments
1. Key-Debounce	15.72 mAms	From Table 1
2. TX w/ACK	108.81 mAms	From Table 2
Total	124.53 mAms	

Table 4. RC Active Mode Current Consumption

6.2 Standby Mode

The target receiver is duty cycling when in standby mode. The message sent by the RC is therefore likely to be repeated multiple times before an ACK is received. The assumption is the target will respond to the message within a short time after enabling its receiver.

The RemoTI 1.0 target node sample project (RNP) is configured with nwkDutyCycle= 300 ms. This means the receiver is turned off for *nwkDutyCycle – nwkcMinActivePeriod* = (330 – 16.8) ms

Elapsed time for each TX w/o ACK component is 2.78 ms as seen in Table 3. Statistically, it is reasonable to assume a uniform distribution such that the number of TX attempts to wake up the target node from standby mode on average is (330 -16.8) ms / 12.78 ms x 0.5 = 56.

The standby mode current consumption is comprised of the key de-bounce component, the statistically averaged number of TX w/o ACK components and the TX w/ACK component as shown in Table 5.

Standby Mode Current Consumption		
Components	Time*Current	Comments
1. Key-Debounce	15.72 mAms	From Table 1
2. TX w/o ACK	4 415.42 mAms	From Table 3 * 56 retries on average
2. TX w/ACK	108.81 mAms	From Table 2
Total	4 539.95 mAms	

Table 5. RC Standby Mode Current Consumption

6.3 Example Usage Model

A RC usage model is application specific in terms of how many target nodes it controls, number of messages sent when the target is in standby mode and in active mode. This application note assumes a usage model where the RC is controlling four target nodes with the following occurrences per day;

1. TV
   a. 2 RC key presses when in standby mode
   b. 50 RC key presses when in active mode
2. Receiver
   a. 2 RC key presses when in standby mode
   b. 100 RC key presses when in active mode
3. DVD/Blu-ray
   a. 1 RC key press when in standby mode
   b. 20 RC key presses when in active mode
4. STB
   a. 0 RC key presses when in standby mode (always powered on)
   b. 100 RC key presses when in active mode

In order to calculate the total average current consumption for the example RC usage model, we need to summarize the RC sleep, active mode and standby mode contributions for one day as seen in Table 6.

System	Number of units	Standby mode key presses	Active mode key presses	Standby mode current consumption [1]	Active mode current consumption [2]
TV	1	2	50	9 080 mAms	18 679 mAms
Receiver	1	2	100	9 080 mAms	37 359 mAms
DVD/Blu-ray	1	1	20	4 540 mAms	7 472 mAms
Cable/Satellite	1	0	100	0 mAms	37 359 mAms
Active Current	0	0	0	22 700 mAms	100 869 mAms
Active Total [3]					123 569 mAms
Sleep Total [4]					34 560 mAms
Total Power consumption					158 129 mAms

Table 6. RC Usage Model Total Average Current Consumption per Day

[1] Calculated by multiplying number of standby mode key presses with the RC standby mode current consumption (from Table 5)
[2] Calculated by multiplying number of active mode key presses with the RC active mode current consumption (from Table 4). In addition, it is assumed that a single key press will send a total of 3 messages to the target. This is to account for the repeat function of the CERC specification.
[3] This is the sum of standby and active mode current consumption
[4] Sleep current is assumed for the entire day, in other words, the time the radio is active is not subtracted from the total sleep time. This is a fair assumption since the sleep current "adder" to the active current is negligible. Total sleep current for a day: 24h * 3600 s/h * 1000 ms/s * 0.4µA = 34560 mAms

The average RC power consumption with the described usage model is therefore:

(Total power consumption mAms)/day / (1000 ms/s) / (3600 s/h) / (24 h/day) =
(180 373 mAms/day) / (1000 ms/s) / (3600 s/h) / (24 h/day) = 0.0018 mA

With a 3000mAh battery, this effectively translates to a battery life time of:

(Battery capacity mAh) / (Average current consumption mA) / (24h/day) / (365 days/year) =
(3000 mAh) / (0.0021 mA) / (24 h/day) / (365 days/year) = ~187 years

7 Target Node Current Consumption

7.1 Active Mode

The target node will keep the receiver on continuously when in active mode. The target will, however, enter TX mode and switch between RX/TX and TX/RX when ACKing a message received from the RC. The TX current is higher than the RX current, but since this event is very short and the contribution therefore is minimal it is reasonable to assume the target being in RX mode all the time for this calculation. As such, the average current consumption will be 26.90 mA as seen in Table 2, events 2 and 6.

7.2 Standby Mode

The target node standby current consumption depends on the active period and the duty cycle;

The most optimal power consumption is when *nwkDutyCycle = nwkcMaxDutyCycle*:
26.90 mA * *nwkcMinActivePeriod* / *nwkcMaxDutyCycle =*
26.90 mA * *16.8 ms* / *1000 ms = 0.45 mA*

The target node sample project (RNP) included with RemoTI 1.0 is setting *nwkDutyCycle =* 330 ms to enable low latency in addition to the power savings:
26.90 mA * *nwkcMinActivePeriod* / *nwkDutyCycle =*
26.90 mA * *16.8 ms* / *330 ms = 1.37 mA*

8 RC Current Consumption Usage Model Excel Sheet

An Excel sheet accompanies this application note to enable users to change the example RC usage model to match their application specifics.

The Excel sheet is comprised of the following tabs:

- RC Usage Model – This tab is used to configure the usage model specifics. The formulas uses data from the Power consumption Breakdown tab for the calculations.
- Power Consumption Breakdown – This tab is used to calculate the power consumption components based on the Key Debounce, TX with ACK and TX without ACK current profile measurements.
- Key Denounce – Current profile of the key de-bounce event.
- TX with ACK - Current profile of one message transmission with ACK received from the target node.

- TX without ACK - Current profile of repeated messages transmission without ACK received from the target node.

The yellow cells in the RC Usage Model tab can easily be changed by customers to modify the model to match their specific application scenario.

9 Conclusion

This application note has illustrated the power consumption for the RF part of a RC is very small. In fact, the self discharge of a typical alkaline battery is about 1 μA. The self discharge is therefore about 50% of the current consumption for the usage model described in this application note. Other system components e.g. LED, backlight, LCD etc. will likely be the major contributors to an RC total current consumption.

This application note has also illustrated the standby mode feature of a target node is instrumental for energy savings when the equipment is turned off.

References

[1] ZigBee RF4CE Specification (ZigBee Alliance document 094945r00ZB)

[2] http://focus.ti.com/docs/prod/folders/print/cc2530.html

[3] ZigBee RF4CE CERC Profile Specification (ZigBee Alliance document 094946r00ZB)

[4] RemoTI API, SWRA268

10 General Information

10.1 Document History

Revision	Date	Description/Changes
SWRA263	2009.04.29	Initial release.

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