CC1100/CC2500 - Wake-On-Radio

By Siri Namtvedt

1 Introduction

The CC1100, CC1101, CC1100E, and CC2500 all have Wake on Radio (WOR) functionality, which enables the radio to periodically wake up from SLEEP mode and listen for incoming packets without MCU interaction. After a programmable time in RX, the chip goes back to the SLEEP unless a packet has been received. The purpose of this application note is to explain the theory of operation and the different registers involved when using Wake on Radio, as well as highlighting important aspects when using WOR mode. Figure 1 shows the relationship between the WOR events and the different radio states.

Figure 1. WOR Events and Radio States
Table of Contents

KEYWORDS.............................................................................................................................. 1
1  INTRODUCTION............................................................................................................. 1
2  ABBREVIATIONS........................................................................................................... 2
3  REGISTERS.................................................................................................................... 3
   3.1  WOREVT1 AND WOREVT0 ................................................................. 3
   3.2  WORCTRL......................................................................................................... 7
       3.2.1  RC_PD................................................................................................. 7
       3.2.2  EVENT1[2:0] ..................................................................................... 7
       3.2.3  RC_CAL............................................................................................. 8
       3.2.4  WOR_RES[1:0] ............................................................................... 10
   3.3  MCSM2........................................................................................................ 11
       3.3.1  RX_TIME_RSSI.............................................................................. 11
       3.3.2  RX_TIME_QUAL............................................................................ 12
       3.3.3  RX_TIME[2:0] ............................................................................... 12
4   STROBE COMMANDS................................................................................................. 14
4.1   SWOR.............................................................................................................. 14
4.2   SWOR_RST................................................................................................. 14
5   WAKING THE RADIO FROM WOR MODE................................................................. 14
6   REFERENCES.......................................................................................................... 15
7   GENERAL INFORMATION.......................................................................................... 16
   7.1   DOCUMENT HISTORY........................................................................... 16

2  Abbreviations

CS      Carrier Sense
MCU     Micro Controller Unit
NA      Not Applicable
PQT     Preamble Quality Threshold
RSSI    Received Signal Strength Indicator
WOR     Wake on Radio
XOSC    Crystal Oscillator
3 Registers

This section covers the theory of operation, the equations governing WOR operation, as well as configuration of the different registers relevant for WOR mode. For more details on the registers described in this section, please see [1], [2], [3], and [4].

3.1 WOREVT1 and WOREVT0

In SLEEP mode with WOR enabled, reaching Event 0 will turn on the digital regulator and start the crystal oscillator. The time between two consecutive Event 0s is programmed with a mantissa value given by WOREVT1.EVENT0 and WOREVT0.EVENT0, and an exponent value set by WORCTRL.WOR_RES. See Equation 1.

\[
T_{Event0} = \frac{750 \cdot EVENT0 \cdot 2^{WOR\_RES}}{f_{XOSC}}
\]

Equation 1. \(T_{Event0}\)

Event 0 can be monitored on one of the GDOx pins by setting IOCFGx.GDOx_CFG = 0x24. See Figure 2.

![Figure 2. Event 0](image)

Due to a design error related to the WOR timer module, see [5], [6], [7], and [8], the time from the radio enters SLEEP mode until the next Event 0 is programmed to appear (\(T_{SLEEP}\)) should not be less than 11.08 ms when using a 26 MHz crystal and 10.67 ms when a 27 MHz crystal is used. If \(T_{SLEEP} < T_{SLEEP_{min}}\), there is a chance that the consecutive Event 0 will occur (750 · 128) / \(f_{XOSC}\) too early.

\(T_{SLEEP_{min}}\) can be calculated as showed in Equation 2:

\[
T_{SLEEP_{min}} = \frac{750}{f_{XOSC}} \cdot 384
\]

Equation 2. \(T_{SLEEP_{min}}\)

The minimum time between two Event 0s (\(T_{Event0_{min}}\)) depends on \(T_{Event1}\) (see 3.2.2), if the PLL is being calibrated or not, and the RX timeout. Example 1 will illustrate these dependencies. By looking at a plot of current consumption vs. time when the radio is configured for WOR mode (see Figure 3), an equation for \(T_{Event0_{min}}\) can be found (see Equation 3).
Figure 3. Current Consumption vs. Time

\[
\tau_{\text{Event}0_{\text{min}}} = \tau_{\text{Event1}} + \tau_{\text{IDLE to RX}} + \tau_{\text{Calibrate}} + \tau_{\text{RX timeout}} + \tau_{\text{IDLE}} + \tau_{\text{SLEEP} \to \text{IDLE}}
\]

Equation 3. \( \tau_{\text{Event}0_{\text{min}}} \)

\[
\tau_{\text{Event1}} = x \cdot \frac{750}{f_{\text{XOSC}}}, \text{ where } x \text{ is given by Table 1}
\]

Equation 4. \( \tau_{\text{Event1}} \)

<table>
<thead>
<tr>
<th>( x )</th>
<th>WORCTRL.EVENT1</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>2</td>
</tr>
<tr>
<td>12</td>
<td>3</td>
</tr>
<tr>
<td>16</td>
<td>4</td>
</tr>
<tr>
<td>24</td>
<td>5</td>
</tr>
<tr>
<td>32</td>
<td>6</td>
</tr>
<tr>
<td>48</td>
<td>7</td>
</tr>
</tbody>
</table>

Table 1. \( x \) Values to use in Equation 4

See section 3.2.2 for considerations that need to be taken into account when programming \( \tau_{\text{Event1}} \).

Example 1:

Assume using the register settings listed in Table 2 \((f_{\text{XOSC}} = 26 \text{ MHz})\).

<table>
<thead>
<tr>
<th>Register</th>
<th>Value</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>MCSM0</td>
<td>0x18</td>
<td>Calibrate when going from IDLE to RX</td>
</tr>
<tr>
<td>WORCTRL</td>
<td>0x78</td>
<td>EVENT1 = 7 and WOR_RES = 0</td>
</tr>
<tr>
<td>MCSM2</td>
<td>0x01</td>
<td>RX_TIME = 1</td>
</tr>
</tbody>
</table>

Table 2. Register Settings for Example 1

\[
\tau_{\text{Event1}} = 48 \cdot \frac{750}{26 \cdot 10^5} = 1.385 \cdot 10^{-3} = 1.385 \text{[ms]}
\]

(Equation 4 and Table 1)
It takes 798.8 us to go from IDLE to RX mode with calibration when using a 26 MHz crystal (see [1], [2], [3], and [4]).

\[ t_{IDLE \rightarrow RX}^{Calibration} = 798.8 \, \text{us} \]

MSCM2.RX_TIME = 1 and WORCTRL.WOR_RES = 0 \Rightarrow \text{Duty cycle} = 6.25 \% (see [1], [2], [3], and [4]). The duty cycle is used to calculate \( t_{RX \, \text{timeout}} \) (Equation 7).

\[ t_{IDLE} = 150\,\text{us} \quad (\text{see } 3.2.3) \]

\[ t_{SLEEP} = \frac{750}{26 \cdot 10^6} \cdot 384 = 11.08 \cdot 10^{-3} = 11.08 \, \text{ms} \]  \hspace{1cm} \text{(Equation 2)}

\[ t_{Event0_{\text{min}}} = 1.385 \cdot 10^{-3} + 798.8 \cdot 10^{-6} + (t_{Event0_{\text{min}}} \cdot 6.25\%) + 150 \cdot 10^{-6} + 11.08 \cdot 10^{-3} \]

\[ \Rightarrow t_{Event0_{\text{min}}} = 14.31 \cdot 10^{-3} = 14.31 \, \text{ms} \]  \hspace{1cm} \text{(Equation 3)}

\[ t_{Event0} = \frac{750}{26 \cdot 10^6} \cdot EVENT0 \cdot 2^{50} \geq 14.31 \cdot 10^{-3} \Rightarrow EVENT0 \geq 497 \]  \hspace{1cm} \text{(Equation 1)}

\[ EVENT0 = 497 \Rightarrow \text{WOREVT1.EVENT0 = 0x01 and WOREVT0.EVENT0 = 0xF1.} \]

\[ t_{Event0_{\text{min}}} = 14.34 \cdot 10^{-3} = 14.34 \, \text{ms} \]  \hspace{1cm} \text{(Equation 1)}

![Figure 4. Current Consumption vs. Time (No Packets Received)](image)

Figure 4 shows how the radio will wake up every 14.34 ms when no packets are being received. If a packet is received, the packet will typically be processed by the MCU before the radio is being put back into WOR mode by issuing an SWOR strobe command (see Figure 5).

![Figure 5. Current Consumption vs. Time (One Packet Received)](image)

When a packet has been received and an SWOR strobe has been issued, \( t_{SLEEP} \) becomes less than \( t_{SLEEP_{\text{min}}} \) and there is a chance that the consecutive Event 0 will occur \((750\cdot128) / f_{\text{OSC}} = 3.69\cdot10^{-3} = 3.69 \, \text{ms} \) too early (see Figure 6). \( t_{Event0} \) will in this case be \( 14.34 \, \text{ms} - 3.69 \, \text{ms} = 10.65 \, \text{ms} \).

![Figure 6. Current Consumption vs. Time (\( t_{Event0} = 10.65 \, \text{ms} \))] (image)

After this, \( t_{Event0} = 14.34 \, \text{ms} \), as it is supposed to, but there will be a permanent time shift of -3.69 ms compared to the case where no packets were received (Figure 4).
If it is important for the application that there are no time shifts, a solution is to stay in IDLE until the next Event 0 occurs (can be monitored on a GDOx pin) and then strobe SWOR to make sure that the time from strobing SWOR until the next Event 0 is greater than \( t_{\text{SLEEPmin}} \). The application will then miss one RX period, but the next Event0 will occur when it is supposed to (see Figure 7).

**Figure 7. Current Consumption vs. Time (Avoiding Time Shift)**

**Example 2:**

Assume another scenario using the registers settings listed in Table 3 \((f_{\text{osc}} = 26 \text{ MHz})\).

<table>
<thead>
<tr>
<th>Register</th>
<th>Value</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>MCSM0</td>
<td>0x18</td>
<td>Calibrate when going from IDLE to RX</td>
</tr>
<tr>
<td>WORCTRL</td>
<td>0x38</td>
<td>EVENT1 = 3 and WOR_RES = 0</td>
</tr>
<tr>
<td>MCSM2</td>
<td>0x00</td>
<td>RX_TIME = 0</td>
</tr>
<tr>
<td>WOREVT1</td>
<td>0x28</td>
<td>EVENT0 = 10400</td>
</tr>
<tr>
<td>WOREVT0</td>
<td>0xA0</td>
<td></td>
</tr>
</tbody>
</table>

**Table 3. Register Settings for Example 2**

\[
I_{\text{Event0}} = \frac{750}{26 \cdot 10^6} \cdot 10400 \cdot 2^{50} = 300 \cdot 10^{-3} = 300 [\text{ms}] \\
\text{(Equation 1)}
\]

\[
I_{\text{Event1}} = 12 \cdot \frac{750}{26 \cdot 10^6} = 346.15 \cdot 10^{-6} = 346.15 [\mu\text{s}] \\
\text{(Equation 4 and Table 1)}
\]

MSCM2.RX_TIME = 0 and WOR_RES = 0 \Rightarrow \text{Duty cycle} = 12.5\%

\[
I_{\text{RX timeout}} = 0.3 \cdot 12.5\% = 37.5 \cdot 10^{-3} = 37.5 [\text{ms}] \\
\text{(Equation 7)}
\]

From Equation 3 we have that:

\[
I_{\text{SLEEP}} = I_{\text{Event0}} - I_{\text{Event1}} - I_{\text{IDLE to RX Calibration}} - I_{\text{RX timeout}} - I_{\text{IDLE}}
\]

\[
I_{\text{SLEEP}} = 0.3 - 346.15 \cdot 10^{-6} - 798.8 \cdot 10^{-6} - 37.5 \cdot 10^{-3} - 150 \cdot 10^{-6} = 261.21 \cdot 10^{-3} = 261.21 [\mu\text{s}]
\]

Even if \( I_{\text{SLEEP}} > I_{\text{SLEEPmin}} \) when no packets are being received, one has to make sure that an SWOR strobe is not issued too close to the following Event 0. This can be done by reading the WOR timer value from the WORTIME1 and WORTIME0 registers.

WORCTRL.WOR_RES = 0 means that the Event 0 resolution is given by \( 1 \cdot (750/f_{\text{osc}}) \) (see [1], [2], and [4]).

\[
x \cdot \left[ \frac{750}{26 \cdot 10^6} \right] = I_{\text{Event0}} - I_{\text{Sleep}} = 300 \cdot 10^{-3} - 11.08 \cdot 10^{-3} \implies x = 10016
\]

To make sure that there is more than 11.08 ms until the next Event 0 occurs, WORTIME1:WORTIME0 must be less than 10016.
Assume the same $t_{\text{Event0}}$, but using $\text{WORCTRL.WOR\_RES} = 1$ instead.

$\text{WORCTRL.WOR\_RES} = 1$ means that the Event 0 resolution is given by $2^5 \cdot \left( \frac{750}{f_{\text{osc}}} \right)$ (see [1], [2], [3], and [4]).

$$x \cdot 2^5 \cdot \frac{750}{26 \cdot 10^6} = t_{\text{Event0}} - t_{\text{SLEEPn}} = 300 \cdot 10^{-3} - 11.08 \cdot 10^{-3} \Rightarrow x = 313$$

This means that to make sure that there is more than 11.08 ms to the next Event 0, the timer value read from $\text{WORTIME1}$ and $\text{WORTIME0}$ must be less than 313 if it should be safe to issue an SWOR command.

Due to a design error affecting the synchronization mechanism between the SPI clock domain and the internal clock domain special care must be taken when reading the $\text{WORTIME1}$ and $\text{WORTIME0}$ registers. Please see [5], [6], [7], and [8] for more details. In addition to the workaround described in [5], [6], [7], and [8] (reading the registers several times) another workaround can be used since these registers are updated on the falling edge of the RC oscillator output. This workaround is to make sure that the registers are read on the rising edge of the RC oscillator output and that the reading is completed before the consecutive falling edge. The RC oscillator output can be monitored on a GDOx pin by settings $\text{IOCFGx.GDOx\_CFG} = 0x27$.

### 3.2 WORCTRL

#### 3.2.1 RC\_PD

The RC\_PD bit is the power down signal for the RC oscillator. This bit must be cleared for the RC oscillator to run.

#### 3.2.2 EVENT1[2:0]

Event 1 follows Event 0 after a programmed timeout (see Equation 4). The radio will wake up on Event 0 and issue an RX strobe on Event 1. If calibration of the PLL is to be performed when going from IDLE to RX ($\text{MCSM0.FS\_AUTOCAL} = 1$) the radio will enter RX mode 798.8 us after Event 1 occurred given that a 26 MHz crystal is being used. If calibration is disabled ($\text{MCSM0.FS\_AUTOCAL} = 0$), RX mode is entered 75.1 us after Event 1 (26 MHz crystal). Event1 can be monitored on one of the GDOx pins by setting $\text{IOCFGx.GDOx\_CFG} = 0x25$. $t_{\text{Event1}}$ must be long enough for the $\text{CHP\_RDYn}$ signal to be asserted before reaching Event 1.
It is possible to keep the crystal on during SLEEP mode (MCSM0.XOSC_FORCE_ON = 1) to be able to reduce \( t_{\text{Event1}} \), but this will cause the current consumption in SLEEP mode to increase significantly (see [1], [2], [3], and [4]). Figure 9 shows the current consumption when the crystal is turned off in SLEEP mode (A) and when the crystal is kept on (B). It is not possible to observe the difference in SLEEP current due to the resolution of the y-axis, but in the case where the crystal is running, one can see that the chip is ready and in IDLE mode about 110 \( \mu \)s earlier than what is the case if the crystal oscillator has been turned off. In the case where the crystal oscillator is running in SLEEP mode, it can be seen that the radio returns to SLEEP earlier than what is the case when XOSC is turned off. This is due to the fact that the calibration of the RC oscillator (see 3.2.3) starts earlier and thus finishes of sooner.

![Figure 8. Event 1](image)

**Figure 8. Event 1**

The RC_CAL bit enables calibration of the RC oscillator when set to one. The frequency of the low-power RC oscillator varies with temperature and supply voltage, and in order to keep the frequency as accurate as possible, the RC oscillator will be calibrated continuously whenever the XOSC is running and the radio is not in the SLEEP mode. When the radio enters SLEEP mode, the RC oscillator will use the last valid calibration result. It typically takes 2 ms to calibrate the RC oscillator. If the crystal is stable for \(~7\) ms every time the radio wakes up from SLEEP, the RC oscillator will have time to complete 3 calibrations and be in the middle of calibration number 4 when the radio goes back to SLEEP mode via IDLE (see Figure 10). It will in this case use calibration result number 3, which is the last valid calibration. However, if the crystal is running for less than 2 ms, the radio will enter IDLE mode after the RX timeout, and then stay in IDLE until one calibration of the RC oscillator is performed, before returning to SLEEP mode (see Figure 11). This is important to have in mind when calculating current consumption in WOR mode. Table 4 shows register setting for WOR mode where the crystal will be on and stable for about 7 ms.

![Figure 9. MCSM0.XOSC_FORCE_ON = 1](image)

**Figure 9. MCSM0.XOSC_FORCE_ON = 1**

### 3.2.3 RC_CAL

The RC_CAL bit enables calibration of the RC oscillator when set to one. The frequency of the low-power RC oscillator varies with temperature and supply voltage, and in order to keep the frequency as accurate as possible, the RC oscillator will be calibrated continuously whenever the XOSC is running and the radio is not in the SLEEP mode. When the radio enters SLEEP mode, the RC oscillator will use the last valid calibration result. It typically takes 2 ms to calibrate the RC oscillator. If the crystal is stable for \(~7\) ms every time the radio wakes up from SLEEP, the RC oscillator will have time to complete 3 calibrations and be in the middle of calibration number 4 when the radio goes back to SLEEP mode via IDLE (see Figure 10). It will in this case use calibration result number 3, which is the last valid calibration. However, if the crystal is running for less than 2 ms, the radio will enter IDLE mode after the RX timeout, and then stay in IDLE until one calibration of the RC oscillator is performed, before returning to SLEEP mode (see Figure 11). This is important to have in mind when calculating current consumption in WOR mode. Table 4 shows register setting for WOR mode where the crystal will be on and stable for about 7 ms.
## Table 4. Register Values for RX Timeout > RC Oscillator Calibration Time

Using the settings in Table 4 gives the following values for $t_{\text{Event0}}$ and the RX timeout:

$$t_{\text{Event0}} = \frac{750}{26 \cdot 10^6} \cdot 1733 \cdot 2^{40} = 49.99 \cdot 10^{-3} = 49.99 \text{ ms}$$

(Equation 1)

$$t_{\text{RX timeout}} = 49.99 \cdot 10^{-3} \cdot 12.5\% = 6.25 \cdot 10^{-3} = 6.25 \text{ ms}$$

(Equation 7)

### Figure 10. Current Consumption (EVENT1 = 3 and RX Timeout = 6.25 ms)

In this case, the RC oscillator has sufficient time to calibrate when the crystal is running. When the RX timeout is reached, the radio will go back to SLEEP mode, via IDLE, even if it is in the middle of a calibration. In IDLE mode the RCOSC will be set to use the last valid result and after a few 34.667 kHz periods (assuming a 26 MHz crystal), the radio will go back to SLEEP. For calculations one can use 150 us (~5 periods).

Changing $\text{MCSM2}$ to 0x05 ($\text{MCSM2.RX_TIME} = 5$) will reduce the duty cycle to 0.391%.

$$t_{\text{RX timeout}} = 49.99 \cdot 10^{-3} \cdot 0.391\% = 195.46 \cdot 10^{-6} = 195.46 \text{ us}$$

(Equation 7)

### Figure 11. Current Consumption (EVENT1 = 3 and RX Timeout = 195.49 us)
The calibration of the RC oscillator will not have completed when the RX timeout is reached and the radio will stay in IDLE mode until the calibration is finished.

In applications where the radio wakes up very often, typically several times every second, it is possible to turn off the calibration of the RC oscillator to reduce the current consumption. How this should be done is shown in the following code example:

```c
//----------------------------------------------
halSpiWriteReg(CCxxx0_MCSM2, 0x03); // RX_TIME = 3
    // (duty cycle = 1.563% when WOR_RES = 0)
halSpiWriteReg(CCxxx0_WOREVT1, 0x03); // EVENT0 = 800
halSpiWriteReg(CCxxx0_WOREVT0, 0x20); // EVENT1 = 3
    // RC_CAL = 1
    // WOR_RES = 0
//----------------------------------------------
halWait(3000); // Wait for RCOSC calibration
halSpiWriteReg(CCxxx0_WORCTRL, 0x30); // EVENT1 = 3
    // RC_CAL = 0
    // WOR_RES = 0
halSpiWriteReg(CCxxx0_WORCTRL, 0x20); // EVENT1 = 3
    // RC_CAL = 0
    // WOR_RES = 0

calib1 = halSpiReadStatus(CCxxx0_RCCTRL1_STATUS);
calib0 = halSpiReadStatus(CCxxx0_RCCTRL0_STATUS);
halSpiWriteReg(CCxxx0_RCCTRL1, calib1);
halSpiWriteReg(CCxxx0_RCCTRL0, calib0);
halSpiStrobe(CCxxx0_SWORRST);
halSpiStrobe(CCxxx0_SWOR);
while (TRUE);
//----------------------------------------------
```

If the calibration of the RC oscillator is turned off it will have to manually be turned on again at regular intervals. How often this must be done depends on the environment in which the application operates (voltage and temperature changes).

### 3.2.4 WOR_RES[1:0]

The WOR_RES bits control the resolution of \( t_{\text{event}} \), and hence the maximum timeout of the WOR module. For WOR applications, WORCTRL.WOR_RES should be set to either 0 or 1. WORCTRL.WOR_RES = 0 gives a resolution equal to \( 750/f_{\text{osc}} \) while WORCTRL.WOR_RES = 1 gives a resolution equal to \( 25\cdot750/f_{\text{osc}} \). For WORCTRL.WOR_RES equal to 2 or 3, the RX window will be so small compared to the accuracy of Event 0, that it will not make sense to use it. In applications where WOR is not used, other values of WORCTRL.WOR_RES can be used to achieve a certain RX timeout. For an example, see 3.3.3. It is also possible to use the WOR timer as a SLEEP timer and wake up the radio on external interrupts on every Event 0. In this case, it can be useful to use WORCTRL.WOR_RES = 2 or WORCTRL.WOR_RES = 3.
3.3 MCSM2

3.3.1 RX_Time_RSSI

When the RX_Time_RSSI bit is set to one, the RSSI level is compared to a programmable threshold a given time after RX mode has been entered. If the RSSI level is below the programmed threshold at this time, the radio will exit RX mode regardless of the RX timeout. If it is above the same threshold (carrier sense is asserted), it will stay in RX until a packet has been received or until it returns to SLEEP due to an RX timeout. The time it takes from entering RX mode until the RSSI level is valid is estimated using Equation 5.

\[
\text{RSSI response time} = \frac{8}{BW_{channel}} \left( \frac{\text{WAIT\_TIME}}{2} + 1 + 2^{\text{FILTER\_LENGTH}} \right) + \max \left[ \frac{20}{BW_{channel}}, \frac{10}{(8 \cdot \text{DataRate})} \right]
\]

Equation 5. RSSI Response Time

Where

\[
BW_{channel} = \frac{f_{\text{osc}}}{8 \cdot (4 + CHANBW_M) \cdot 2^{\text{CHANBW}_E}}
\]

Equation 6. BW\_Channel

For further details regarding the RSSI response time, please see [9].

Example 3:

This example uses the register settings from Table 4 but MCSM2 is changed from 0x00 to 0x10 (MCSM2.RX_Time_RSSI = 1). For all the other registers, the register settings recommended by SmartRF® Studio for 10 kbps (CC2500) is to be used. This means that AGCCTRL0 = 0x91 and MDMCFG4 = 0x78.

AGCCTRL0 = 0x91 ⇒ AGCCTRL0.WAIT\_TIME = 1 and
AGCCTRL0.FILTER\_LENGTH = 1

MDMCFG4 = 0x78 ⇒ MDMCFG4.CHANBW_E = 1 and
MDMCFG4.CHANBW_M = 3

\[
BW_{channel} = \frac{26 \cdot 10^6}{8 \cdot (4 + 3) \cdot 2^2} = 232.143 \cdot 10^3 = 232.143 \text{ [kHz]}
\]

(Equation 6)

\[
\text{RSSI response time} = \frac{8}{232143} \left( \frac{1}{2} + 1 + 2^1 \right) + \max \left[ \frac{20}{232143}, \frac{10}{(8 \cdot 10000)} \right]
\]

(Equation 5)

\[
= 245.6 \cdot 10^{-6} = 245.6 \text{ [us]}
\]

Figure 12 shows how the radio exits RX mode after only 245 us due to the lack of CS when MCSM2.RX_Time_RSSI = 1. In the case where MCSM2.RX_Time_RSSI = 0 or MCSM2.RX_Time_RSSI = 1 and RSSI is above the programmed threshold, the radio will stay in RX searching for a sync word for 6.25 ms.
3.3.2 RX_TIME_QUAL

When RX_TIME_QUAL = 0, the radio will stay in RX when the RX_TIME timer expires if a sync word is found. When RX_TIME_QUAL = 1, the radio stays in RX mode if a sync word is found or the preamble quality threshold is reached (PKTSTATUS.PQT_REACHED = 1). This threshold can be programmed using PKTCTRL1.PQT[2:0] and the higher the threshold, the smaller is the chance of receiving a false packet. An internal counter is being increased by one each time a bit is received that is different from the previous bit and decreased by 8 each time a bit is received that is the same as the last bit. A threshold of 4·PQT is used to gate sync word detection. PKTSTATUS.PQT_REACHED will be held high as long as the preamble quality exceeds the threshold and one sync word length (2 or 4 bytes depending on the MDMCFG2.SYNC_MODE setting) after it goes below. When PKTSTATUS.PQT_REACHED goes low, the radio goes back to SLEEP given that a sync word has not been detected. Be aware that using this feature might increase the time the radio is in RX mode even if no packets are being received. Due to this, it is possible that tSLEEP becomes less than tSLEEPmin (see 3.1)

3.3.3 RX_TIME[2:0]

The RX_TIME bits set the timeout for sync word search in RX for both WOR mode and ordinary RX operation. When using WOR mode, RX_TIME can have a value between 0 and 6 when WORCTRL.WOR_RES = 0, and between 0 and 3 when WORCTRL.WOR_RES = 1. RX_TIME = 7 means that the radio will stay in RX mode until a packet is received, regardless of the WORCTRL.WOR_RES setting. The timeout is relative to tEvent0.

\[ t_{RX \text{timeout}} = t_{Event0} \cdot \text{DutyCycle} \]

Equation 7. tRX Timeout
<table>
<thead>
<tr>
<th>RX_TIME[2:0]</th>
<th>WOR_RES = 0</th>
<th>WOR_RES = 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 (000)</td>
<td>12.5 %</td>
<td>1.95 %</td>
</tr>
<tr>
<td>1 (001)</td>
<td>6.250 %</td>
<td>9765 ppm</td>
</tr>
<tr>
<td>2 (010)</td>
<td>3.125 %</td>
<td>4883 ppm</td>
</tr>
<tr>
<td>3 (011)</td>
<td>1.563 %</td>
<td>2441 ppm</td>
</tr>
<tr>
<td>4 (100)</td>
<td>0.781 %</td>
<td>NA</td>
</tr>
<tr>
<td>5 (101)</td>
<td>0.391 %</td>
<td>NA</td>
</tr>
<tr>
<td>6 (110)</td>
<td>0.195 %</td>
<td>NA</td>
</tr>
<tr>
<td>7 (111)</td>
<td>Until end of packet</td>
<td></td>
</tr>
</tbody>
</table>

Table 5. Duty Cycle Approximation

The longest RX timeout possible when using WOR is 1.18 s. This is achieved by settings WORCTRL.WOR_RES[1:0] = 1 and MSCM2.RX_TIME[2:0] = 0.

\[ t_{\text{Event0}} = \frac{750 \cdot 65536 \cdot 2^{5i}}{26 \cdot 10^6} = 60.495 \text{s} \]  

(Equation 1)

\[ t_{\text{RX timeout}} = 60.495 \cdot 1.95\% = 1.18 \text{s} \]  

(Equation 7)

When running ordinary RX mode, longer timeouts can be achieved by selecting WORCTRL.WOR_RES = 2 and MSCM2.RX_TIME = 0, or by settings WORCTRL.WOR_RES = 3 and MSCM2.RX_TIME = 0 or 1. RX timeout (in us) is given by EVENT0 \cdot C \cdot 26/f_{\text{osc}} (in MHz), where C is given by Table 6.
<table>
<thead>
<tr>
<th>RX_TIME[2:0]</th>
<th>WOR_RES = 0</th>
<th>WOR_RES = 1</th>
<th>WOR_RES = 2</th>
<th>WOR_RES = 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 (000)</td>
<td>3.6058</td>
<td>18.0288</td>
<td>32.4519</td>
<td>46.8750</td>
</tr>
<tr>
<td>1 (001)</td>
<td>1.8029</td>
<td>9.0144</td>
<td>16.2260</td>
<td>23.4375</td>
</tr>
<tr>
<td>2 (010)</td>
<td>0.9014</td>
<td>4.5072</td>
<td>8.1130</td>
<td>11.7188</td>
</tr>
<tr>
<td>3 (011)</td>
<td>0.4507</td>
<td>2.2536</td>
<td>4.0565</td>
<td>5.8594</td>
</tr>
<tr>
<td>4 (100)</td>
<td>0.2254</td>
<td>1.1268</td>
<td>2.0282</td>
<td>2.9297</td>
</tr>
<tr>
<td>5 (101)</td>
<td>0.1127</td>
<td>0.5634</td>
<td>1.0141</td>
<td>1.4648</td>
</tr>
<tr>
<td>6 (110)</td>
<td>0.0563</td>
<td>0.2817</td>
<td>0.5071</td>
<td>0.7324</td>
</tr>
<tr>
<td>7 (111)</td>
<td>Until end of packet</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 6. Constants Used to Calculate RX Timeout

Max achievable RX timeout = \( \text{EVENT0}_{\text{Max}} \cdot C_{\text{Max}} = 2^{16} \cdot 46.8750 = 3072000 \text{ [us]} = 3.07 \text{ s} \)

4 Strobe Commands

4.1 SWOR

Issuing a SWOR strobe command will put the radio in WOR mode when CSn is released given that the radio is in IDLE mode when the strobe command is being issued and the RC oscillator has been enabled by setting WORCTRL.RC_PD = 0.

4.2 SWOR_RST

Issuing this strobe command will reset the WOR timer to the programmed Event 1. Assume that \( t_{\text{Event0}} = 14.34 \text{ ms} \) and \( t_{\text{Event1}} = 1.385 \text{ ms} \). The time from an SWOR_RST command strobe has been issued until the next Event 0 occurs is \( 14.34 \text{ ms} – 1.385 \text{ ms} = 12.96 \text{ ms} \).

5 Waking the Radio from WOR Mode

To exit WOR mode, an SIDLE strobe must be issued.
6 References

[1] CC1100 Low-Cost Low-Power Sub- 1 GHz RF Transceiver (cc1100.pdf)

[2] CC1101 Low-Cost Low-Power Sub-1GHz RF Transceiver (Enhanced CC1100 ) (cc1101.pdf)

[3] CC1100E Data Sheet (cc1100E.pdf)


[5] CC1100 Errata Notes (swrz012.pdf)


[7] CC1100E Errata Notes (swrz028.pdf)

[8] CC2500 Errata Notes (swrz002.pdf)

[9] DN505 RSSI Interpretation and Timing (swra114.pdf)
7 General Information

7.1 Document History

<table>
<thead>
<tr>
<th>Revision</th>
<th>Date</th>
<th>Description/Changes</th>
</tr>
</thead>
<tbody>
<tr>
<td>SWRA126B</td>
<td>2009.03.15</td>
<td>Added references to CC1100E. The time it takes to go from IDLE to RX mode with calibration when using a 26 MHz crystal is changed from 809 us to 798.8 us. The time it takes to go from IDLE to RX mode without calibration when using a 26 MHz crystal is changed from 88.4 us to 75.1 us. In Section 3.3.2, the description of the PQT threshold is changed in accordance with the data sheets [1], [2], [3], and [4].</td>
</tr>
<tr>
<td>SWRA126A</td>
<td>2008.13.03</td>
<td>Added CC1101, removed logo from header. Removed references to PKTCTRL1.AUTO_SYNC.</td>
</tr>
<tr>
<td>SWRA126</td>
<td>2007.01.12</td>
<td>Initial release.</td>
</tr>
</tbody>
</table>
IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, modifications, enhancements, improvements, and other changes to its products and services at any time and to discontinue any product or service without notice. Customers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All products are sold subject to TI’s terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its hardware products to the specifications applicable at the time of sale in accordance with TI's standard warranty. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by government requirements, testing of all parameters of each product is not necessarily performed.

TI assumes no liability for applications assistance or customer product design. Customers are responsible for their products and applications using TI components. To minimize the risks associated with customer products and applications, customers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any TI patent right, copyright, mask work right, or other TI intellectual property right relating to any combination, machine, or process in which TI products or services are used. Information published by TI regarding third-party products or services does not constitute a license from TI to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of TI information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. Reproduction of this information with alteration is an unfair and deceptive business practice. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

Resale of TI products or services with statements different from or beyond the parameters stated by TI for that product or service voids all express and any implied warranties for the associated TI product or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

TI products are not authorized for use in safety-critical applications (such as life support) where a failure of the TI product would reasonably be expected to cause severe personal injury or death, unless officers of the parties have executed an agreement specifically governing such use. Buyers represent that they have all necessary expertise in the safety and regulatory ramifications of their applications, and acknowledge and agree that they are solely responsible for all legal, regulatory and safety-related requirements concerning their products and any use of TI products in such safety-critical applications.

TI products are neither designed nor intended for use in military/aerospace applications or environments unless the TI products are specifically designated by TI as military-grade or "enhanced plastic." Only products designated by TI as military-grade meet military specifications. Buyers acknowledge and agree that any such use of TI products which TI has not designated as military-grade is solely at the Buyer's risk, and that they are solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI products are neither designed nor intended for use in automotive applications or environments unless the specific TI products are designated by TI as compliant with ISO/TS 16949 requirements. Buyers acknowledge and agree that, if they use any non-designated products in automotive applications, TI will not be responsible for any failure to meet such requirements.

Following are URLs where you can obtain information on other Texas Instruments products and application solutions:

<table>
<thead>
<tr>
<th>Products</th>
<th>Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amplifiers</td>
<td>Audio</td>
</tr>
<tr>
<td>Data Converters</td>
<td>Automotive</td>
</tr>
<tr>
<td>DLP® Products</td>
<td>Broadband</td>
</tr>
<tr>
<td>DSP</td>
<td>Digital Control</td>
</tr>
<tr>
<td>Clocks and Timers</td>
<td>Medical</td>
</tr>
<tr>
<td>Interface</td>
<td>Military</td>
</tr>
<tr>
<td>Logic</td>
<td>Optical Networking</td>
</tr>
<tr>
<td>Power Mgmt</td>
<td>Security</td>
</tr>
<tr>
<td>Microcontrollers</td>
<td>Telephony</td>
</tr>
<tr>
<td>RFID</td>
<td>Video &amp; Imaging</td>
</tr>
<tr>
<td>RF/IF and ZigBee® Solutions</td>
<td>Wireless</td>
</tr>
</tbody>
</table>

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2009, Texas Instruments Incorporated