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JN516x Power consumption

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Document information

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Abstract	Application note for JN516x platform design.

Revision history

Rev	Date	Description
0.x	2013	Previous release in Jennic templated. Updated for JN516x devices and removed JN5139/JN5148 information
1.6	June 2016	Update for JN5169 product and typo correction

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1. Introduction

This application note describes how to calculate the power required by an NXP JN516x wireless microcontroller running an IEEE 802.15.4-based application. The formulae necessary to calculate the time required to complete common 802.15.4 network operations are presented in conjunction with the electrical current consumed by the JN516x devices during these operations. Additionally, timings and current consumption information are provided for specific tasks. An example is included that describes how the information presented can be used to determine the battery capacity requirements of an application.

2. IEEE 802.15.4 network operations

The timings of all 802.15.4 operations are based on one fundamental piece of information, the symbol rate. When operating in the 2.4 GHz band, the symbol rate is defined as 62500 symbols per second. Each symbol comprises four bits of information and, therefore, the over-air data rate is 250 kbps. Below are the formulae required to calculate the time taken to perform common 802.15.4 network operations, based on this data rate.

2.1 Energy Detection (ED) scan

This is dependent on the number of channels to be scanned and the time for which each one is scanned, both of which are selected by the user.

NumberOfChannelsScanned = 1 to 16

ScanDuration = 0 to 14

ED Scan Period (ms) = $[960 \times (2^{ScanDuration} + 1) / 62.5] \times NumberOfChannelsScanned$

2.2 Data transmission

The maximum size of a data frame is 127 Bytes at Physical Layer, 9 to 25 Bytes form the MAC layer header. The size of the MAC layer header is dependent on the addressing mode used; see the table below for details.

Addressing mode*	MAC header size (Bytes)
No source or destination address (only PAN ID included)	9
16-bit source and destination addresses	13
64-bit source and destination addresses	25

* Further addressing mode combinations are available; see the IEEE 802.15.4 Standard for details.

The remaining 102 to 114 Bytes can be used for the transmission of data. The total time taken to transmit a single data frame can be calculated as follows:

PayloadSize (Bytes) = 1 to 114

MACHeaderSize (Bytes) = 9 to 25

PhyHeaderSize (Bytes) = 6

HeaderSize (Bytes) = MACHeaderSize + PhyHeaderSize = 15 to 31

Data Frame Transmission Period (ms) = (HeaderSize + PayloadSize) x 8 / 250

2.3 Beacon frame transmission

The maximum size of a beacon frame is 127 Bytes. This comprises a Physical layer header, a MAC layer header, beacon overhead and the beacon payload. The Physical layer header size is fixed at 6 Bytes. The size of the MAC layer header is dependent on the addressing mode used; see the table below for details.

Addressing mode	MAC header size (Bytes)
16-bit short address	11
64-bit address	17

The Beacon overhead depends on the number of GTSs used and the number of pending address fields. The beacon payload can take up the remaining Bytes and is available for the transmission of application-specific data.

PHYHeaderSize = 6 Bytes

MACHeaderSize = 11 or 17 Bytes

BeaconOverhead= 3 to 52 Bytes

BeaconPayload =

0 to (127 – PHYHeaderSize – MACHeaderSize – BeaconOverhead) Bytes

Beacon Frame Transmission Period (ms) =

(PHYHeaderSize + MACHeaderSize + BeaconOverhead + BeaconPayload) x 8 / 250

2.4 CSMA/CA channel access

Access to the radio channel is gained using the CSMA/CA algorithm. Before a data frame is transmitted, a Clear Channel Assessment (CCA) is performed to determine if the channel is currently in use. The CCA takes 8 symbol periods (0.128 ms) to complete. The time at which the CCA is performed and how frequently it is repeated (if the channel is found to be busy) are determined by the type of CSMA/CA algorithm used.

If regular beacons are not used then data is transmitted using unslotted CSMA/CA. This algorithm is based on back-off periods, where one back-off period is equal to 20 symbol periods. Two variables are used by the algorithm:

- *NB* is the number of times the algorithm has been required to back off while attempting the current transmission; this is initialised to zero.
- *BE* is the back-off exponent and is related to how many back-off periods a device will wait before attempting to assess the channel – the maximum number of back-off periods is given by (2^{BE} – 1). *BE* is initialised to *macMinBE* (in the range 0 to 3) and has a default value of 3.

The unslotted CSMA/CA algorithm works as follows:

1. *NB* is set to 0, *BE* is set to *macMinBE*
2. Delay implemented for a random period in the range 0 to (2^{BE} – 1) back-off periods
3. CCA is performed
4. If the channel is idle then data is transmitted, otherwise algorithm continues to Step 5
5. *NB* is set to *NB* + 1, *BE* is set to min(*BE* + 1, *aMaxBE*)
6. If *NB* is greater than *macMaxCSMABackoffs* then the transmission has failed, otherwise algorithm returns to Step 2

The time between requesting that a data frame is transmitted and it actually being transmitted is therefore dependent on the back-off period and the result of the CCA. The time taken to complete a single back-off period can be calculated as follows:

$$\text{BackoffPeriod (ms)} = (2^{BE} - 1) \times 20 / 62.5$$

(NB: with 62500 symbols per second, 1 symbol period equal to 1/62500s = 16 µs)

2.5 Data reception

The time taken to receive a data frame is exactly the same as the time taken to transmit it. However, it should be noted that the receiver must be switched on at some point before the data frame is expected to arrive. How long before depends on the type of network being used (beacon or non-beacon enabled) and how the application uses the network. An examination of this is beyond the scope of this document.

3. JN516x current consumption

Remark: Unless otherwise explicitly specified the supply and V_{DD} in the data sheet refers to inputs V_{DDA} and V_{DDD}, also by default the delays and power numbers are quoted with respect to the supply from V_{DDA} and V_{DDD}.

3.1 JN5161/JN5164/JN5168 DC current

This section contains information regarding the current consumption of the JN516x while performing various operations. All quoted currents are average values. Extraction done form JN516x datasheet.

Table 1. JN5161/64/68 current consumption and Sleep mode summary

Operation	Current (mA)	Notes
Active processing		
CPU active (Radio OFF)	1.7 + 0.205 MHz	CPU can run at 32, 16, 8, 4, 2 or 1 MHz GPIOs enabled. When in CPU Doze mode, the current related to CPU speed is not consumed.
Radio transmitting	15.3	CPU in Doze mode
Radio receiving	17.0	CPU in Doze mode
The following current figures should be added to those above if the feature is being used		
ADC	0.555	temperature sensor and battery measurements require ADC
Comparator	0.073/0.0008	Normal/Low power
UART	0.06	for each UART
Timer	0.021	for each timer
2-wire Serial Interface	0.046	
Sleep mode		
Sleep with IO wake-up	0.00012	waiting on IO event
Sleep with IO and 32 kHz RC oscillator timer wake-up	0.00064	
32 kHz crystal oscillator	0.0014	as an alternative sleep timer
The following current figures should be added to those above if the feature is being used		
RAM retention	0.0009	
Comparator (low-power mode)	0.0008	reduced response time
Deep-sleep mode		
Deep-sleep	0.00010	waiting on chip RESET or IO event

3.2 JN5169 DC current

Table 2. JN5169 current consumption summary

V_{DD} = 2 V to 3.6 V; T_{amb} = −40 °C to +125 °C; unless otherwise specified

Symbol	Parameter	Conditions		Min	Typ	Max	Unit
I_{DD}	supply current	CPU processing at:	[1]				
		32 MHz		-	7.8	-	mA
		16 MHz		-	5.1	-	mA
		8 MHz		-	3.8	-	mA
		4 MHz		-	3	-	mA
		2 MHz		-	2.6	-	mA
		1 MHz		-	2.5	-	mA
		CPU in software doze -					
		radio in receive mode; maximum input level at 10 dBm		-	15	-	mA
		radio in receive mode; maximum input level at 10 dBm; V_{DD} = 3 V; T_{amb} = 25 °C		-	14.7	-	mA
		radio in receive mode; maximum input level at 0 dBm		-	13	-	mA
		radio in transmit mode 10 dBm	[2]	-	23.3	-	mA
		radio in transmit mode 8.5 dBm	[2]	-	19.6	-	mA
		radio in transmit mode 3 dBm		-	14	-	mA
$I_{I(ADC)}$	ADC input current		[3] [4]	-	400	-	µA
$I_{DD(comp)}$	comparator supply current		[4]				
		operating mode		-	73	-	µA
		low-power mode		-	0.8	-	µA
$I_{DD(UART)}$	UART supply current	per UART	[4]	-	60	-	µA
$I_{DD(tmr)}$	timer supply current	per timer	[4]	-	60	-	µA
$I_{DD(sintf)}$	serial interface supply current		[4]	-	50	-	µA

[1] Digital consumption only. When in CPU doze, the current related to CPU speed is not consumed.
[2] To reach the maximum TX power, 2.8 V is the minimum.
[3] Temperature sensor and battery measurements require ADC.
[4] These numbers should be added to I_{DD} if the feature is being used.

Table 3. Sleep mode JN5169

V_{DD} = 2 V to 3.6 V; T_{amb} = −40 °C to +125 °C; unless otherwise specified.

Symbol	Parameter	Conditions		Min	Typ	Max	Unit
$I_{DDD(IO)}$	input/output digital supply current	in sleep mode; with I/O wake-up; T_{amb} = 25 °C	[1]	-	0.10	-	µA
		in sleep mode; with I/O and RC oscillator timer wake-up; T_{amb} = 25 °C		-	0.73	-	µA
$I_{DD(xtal)}$	crystal oscillator supply current	for 32 kHz crystal oscillator		-	0.6	-	µA
$I_{ret(RAM)}$	RAM retention current	T_{amb} = 25 °C	[2]	-	0.7	-	µA
$I_{DD(comp)}$	comparator supply current	low-power mode	[2] [3]	-	0.8	-	µA

[1] Waiting on I/O event.
[2] RAM and comparator supply currents should be added to $I_{DDD(IO)(sleep)}$ if the feature is being used.

[3] Reduced response time.

Table 4. Deep-sleep mode JN5169

V_{DD} = 2 V to 3.6 V; T_{amb} = −40 °C to +125 °C; unless otherwise specified.

Symbol	Parameter	Conditions		Min	Typ	Max	Unit
I_{DDD}	digital supply current	deep sleep mode; measured at 25 °C	[1]	-	50	-	nA

[1] Waiting on chip RESET or I/O event.

4. JN516x Wake-up timings

This section contains information about the time taken by the JN516x to perform operations that are not related to the 802.15.4 protocol.

Table 5. JN5161/JN5164/JN5168 wake up timing

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
	time for crystal to stabilise, ready to run CPU	reached oscillator amplitude threshold; default bias current	-	0.74	-	ms
	time for crystal to stabilise, ready for radio activity		-	1.0	-	ms
	wake-up from Deep-sleep or from Sleep modes	time to CPU release	-	170	-	µs
	start-up time from reset (RESETN pin, BOR or SVM)	time to CPU release	-	180	-	µs
	Wake-up from CPU Doze mode	reached oscillator amplitude threshold; default bias current	-	0.2	-	µs

Table 6. JN5169 wake-up timing

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
$t_{startup}$	start-up time	CPU start-up time; time for crystal to stabilize ready to run CPU; reached oscillator amplitude threshold. Default bias current	-	0.74	-	ms
		radio start-up time; time for crystal to stabilize ready for radio activity	-	1	-	ms
		from reset RESET_N pin, BOR or SVM	-	180	-	µs
t_{wake}	wake-up time	from deep sleep mode or from sleep mode	-	170	-	µs
t_{wake}	wake-up time	from CPU Doze mode	-	0.2	-	µs

5. Battery capacity calculation – example for JN5168

The following example illustrates how to calculate the battery capacity required by a device in a non-beacon enabled star network that continuously performs the following actions:

1. Wakes from sleep
2. Reads data from a sensor connected to the two-wire serial interface
3. Performs a Clear Channel Assessment (CCA)
4. Transmits a data frame containing a payload of 64 Bytes
5. Sleeps (without holding the memory contents) for 10 min before repeating Step 1

The durations and electrical currents corresponding to the above phases of device operation are determined below.

Waking from sleep

If the contents of RAM have not been held, the time taken to wake from sleep mode can be calculated by adding the oscillator start-time to the application bootloader time (the bootloader initialises the .bss and .data RAM segments). Note that the JN516x devices start up using a fast RC oscillator and begin executing bootloader code at 26 MHz. After a further (740-170) µs, the faster 32 MHz crystal has stabilized and a glitch-less switchover occurs. The application code should wait until the crystal is stable for radio transmission, which occurs a further 230 µs later
(i.e. 1 ms from reset/wake event)

Time to wake from sleep = (1 – 0.170) = **0.83 ms**

While the bootloader is initializing the C-runtime environment, the wireless transceiver will not be operating and therefore the current drawn is **4.98 mA** (CPU clock rate of 16 MHz – default value).

Reading data from sensors

It is assumed that it takes **1 ms** to read data from the sensor attached to the two-wire serial interface. During this time, the current drawn by the JN516x is **5.04 mA**. No account is taken of the current drawn by the sensor.

Performing CCA

Before a data frame can be transmitted, the CSMA/CA algorithm is used to check that the channel is not being used. The time taken to execute the CSMA/CA algorithm in a non-beacon enabled network (assuming that the channel is found to be clear after the CCA and that the random back-off period is 2) can be calculated as follows:

BackoffPeriod (ms) = $(2^2 - 1) \times 20 / 62.5$ = **0.96 ms**

CCA Period (ms) = **0.128 ms**

During the back-off period, the application is running and the transceiver is on although it is not transmitting and receiving. The current drawn during this period is **5.16 mA**. During a CCA, the radio receiver is on and therefore the current drawn is **20.28 mA**.

Transmitting data

Assuming that no source and destination data is included, the time taken to transmit a data frame can be calculated as follows:

Data Frame Transmission Period (ms) = (HeaderSize + PayloadSize) x 8 / 250

Data Frame Transmission Period (ms) = (15 + 64) x 8 / 250 = **2.528 ms**

The current drawn during this period is **15.3 mA**, the default transmitting current at 3 dBm.

While sleeping

The current drawn during the (approximately) 10-minute sleep period is 0.64 µA (Sleep mode with I/O and RC oscillator timer wake-up).

Using the above time and current data, it is possible to calculate that the average current required by the application is approximately 0.732 µA (see below for detailed calculation).

The device should therefore be capable of operating for over 35 years when powered by a CR2032 225-mAh button-cell.

The average current drawn by this application can be calculated by adding the electrical charge consumed during each phase and dividing by the total cycle time (10 minutes).

Phase	Current (mA) x Time (ms)	Charge (µC)
Wake from sleep	4.98 mA x 0.83 ms	4.13
Read sensors	5.04 mA x 1 ms	5.04
CCA back-off	5.16 mA x 0.96 ms	4.95
CCA	20.28 mA x 0.128 ms	2.6
Transmit data	15.3 mA x 2.528 ms	39.7
Sleep	0.00064 mA x 600000 ms	384
	Total	439.4

Therefore, 439 µC of charge is consumed over a total cycle time of 600 s (10 minutes):

Average Current = Total Charge Consumed / Time = 439 / 600 = **0.732 µA**

Note: This figure does not take into account the current drawn by the sensor or the self-discharge of the battery.

If the calculations are repeated for a range of sleep durations, the following graph of lifetime versus sleep duration is produced.

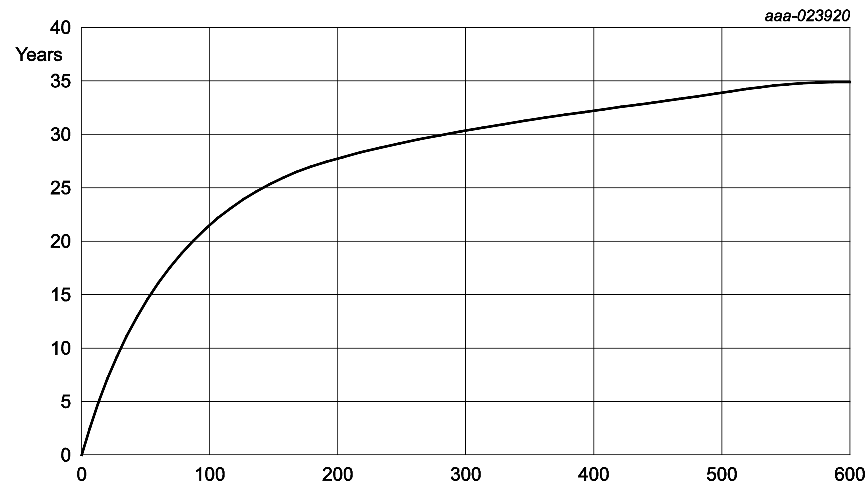

Fig 1. Lifetime versus sleep duration

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