System-on-Chip for 2.4 GHz ZigBee®/ IEEE 802.15.4 with Location Engine

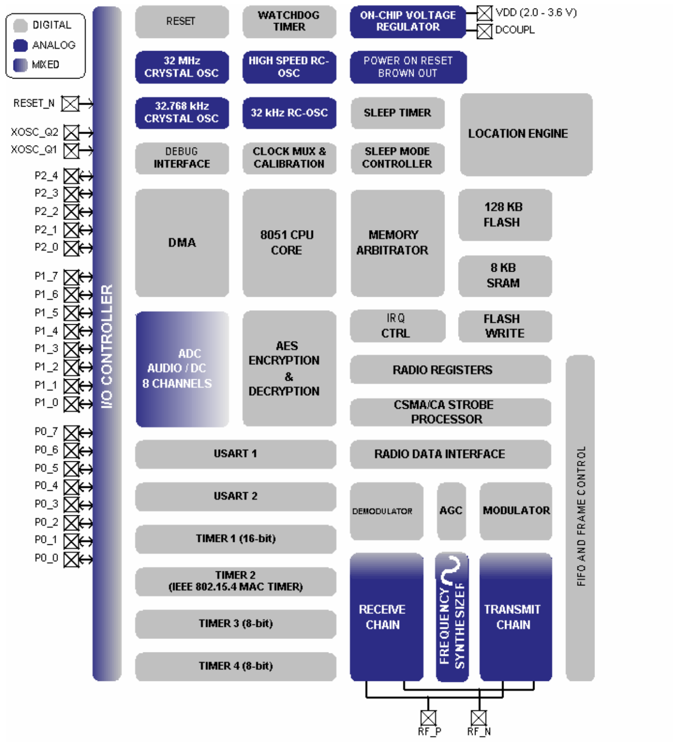
Applications

- *ZigBee® systems*
- *2.4 GHz IEEE 802.15.4 systems*
- *Home/building automation*
- *Industrial Control and Monitoring*
- *Low power wireless sensor networks*
- *Access Control*
- *PC peripherals*
- *Set-top boxes and remote controls*
- *Consumer Electronics*
- *Container/Vehicle Tracking*
- *Active RFID*
- *Inventory Control*

Product Description

The ***CC2431*** is a true System-On-Chip (SOC) for wireless sensor networking ZigBee®/IEEE 802.15.4 solutions. The chip includes a location detection hardware module that can be used in so-called blind nodes (i.e. nodes with unknown location) to receive signals from nodes with known location's. Based on this the location engine calculates an estimate of a blind node's position. The ***CC2431*** enables ZigBee® nodes to be built with very low total bill-of-material costs. The ***CC2431*** combines the excellent performance of the leading ***CC2420*** RF transceiver with an industry-standard enhanced 8051 MCU, 128 KB flash memory, 8 KB RAM and many other powerful features. Combined with the industry leading ZigBee® protocol stack (Z-Stack™) from Texas Instruments, the ***CC2431*** provides the market's most competitive ZigBee® solution.

The ***CC2431*** is highly suited for systems where ultra low power consumption is required. This is achieved by various operating modes. Short transition times between these modes further ensure low power consumption.



Key Features

- Location Engine calculates the location of a node in a network
- High performance and low power 8051 microcontroller core.
- 2.4 GHz IEEE 802.15.4 compliant RF transceiver (industry leading ***CC2420*** radio core).
- ZigBee® protocol stack (Z-Stack™) from Texas Instruments includes support for ***CC2431*** 's location engine.
- Excellent receiver sensitivity and robustness to interferers
- 128 KB in-system programmable flash
- 8 KB RAM, 4 KB with data retention in all power modes
- Powerful DMA functionality
- Very few external components
- Only a single crystal needed for mesh network systems
- Low current consumption (RX: 27 mA, TX: 27 mA, microcontroller running at 32 MHz)
- Only 0.5µA current consumption in power-down mode, where external interrupts or the RTC can wake up the system
- 0.3 µA current consumption in power-down mode, where external interrupts can wake up the system
- Very fast transition times from low-power modes to active mode enables ultra low average power consumption in low duty-cycle systems
- CSMA/CA hardware support
- Wide supply voltage range (2.0 V – 3.6 V)
- Digital RSSI/ LQI support
- Battery monitor and temperature sensor
- ADC with up to eight inputs and configurable resolution
- 128-bit AES security coprocessor

Key Features (continued)

- Two powerful USARTs with support for several serial protocols.
- Hardware debug support
- Watchdog timer
- One IEEE 802.15.4 MAC Timer, one general 16-bit timer and two 8-bit timers
- RoHS compliant 7x7 mm QLP48 package
- 21 general I/O pins, two with 20 mA sink/source capability
- Powerful and flexible development tools available

Note:

The CC2431 and the CC2430 are pin compatible, and the MCU and RF parts of the CC2430-F128 are identical to the CC2431 except the Location Engine. This data sheet complements the CC2430 data sheet with a description of the Location Engine. For complete information about the CC2431, please refer to the CC2430 data sheet in addition to this data sheet. The CC2430 data sheet can be found here:

http://focus.ti.com/lit/ds/symlink/cc2430.pdf

Table Of Contents

1 Register conventions

Each RF register is described in a separate table. The table heading is given in the following format:

REGISTER NAME (XDATA Address)

In the register descriptions, each register bit is shown with a symbol indicating the access mode of the register bit. The register values are always given in binary notation unless prefixed by '0x' which indicates hexadecimal notation.

Table 1: Register bit conventions

Symbol	Access Mode
R/W	Read/write
R	Read only
R0	Read as 0
R1	Read as 1
W	Write only
W0	Write as 0
W1	Write as 1
H0	Hardware clear
H1	Hardware set

2 Location Engine

The Location Engine is used to estimate the position of nodes in an ad-hoc wireless network. Reference nodes exist with known coordinates, typically because they are part of an installed infrastructure. Other nodes are *blind nodes*, whose coordinates need to be estimated. These blind nodes are often mobile and attached to assets that need to be tracked.

The Location Engine implements a distributed computation algorithm that uses received signal strength indicator (RSSI) values from known reference nodes. Performing location calculations at the node level reduces network traffic and communication delays otherwise present in a centralized computation approach.

The Location Engine has the following main features:

- 3 to 16 reference nodes can be used for the location estimation algorithm
- Location estimate with readout resolution of 0.25 meters (note: The accuracy of the location estimate will depend on several factors described below).
- Time to estimate node location is 50 µs to 13 ms
- Location range 64 x 64 meters
- Runs location estimation with minimum CPU usage

To achieve the best possible accuracy one should use antennas that have near-isotropic radiation characteristics. The location error depends on signal environment, deployment pattern of reference nodes and the density of reference nodes in a given area. In general, having more reference nodes available improves the accuracy of the location estimation.

2.1 Location Engine Operation

This section describes the basic steps required to obtain location estimates from the Location Engine.

The Location Engine requires a set of three to 16 reference coordinates to be input together with a set of measured parameters. The output from the Location Engine consists of a pair of estimated location coordinates.

Before any input data is written, the Location Engine must be enabled by writing a 1 to the enable bit, `LOCENG.EN`. When the Location Engine is not in use, writing a 0 to `LOCENG.EN` will reduce the power consumption of the CC2431 by gating off the Engine's clock signal.

Figure 1 shows the basic operation of the Location Engine.

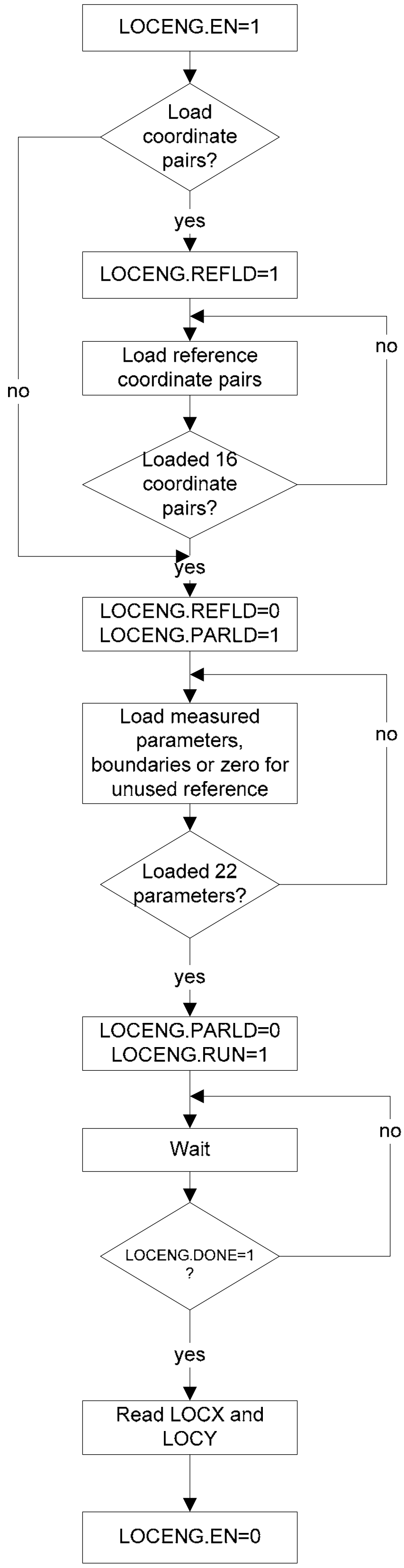


Figure 1: Location Engine Operation

2.1.1 Reference Coordinates

The Location Engine requires a set of between three and 16 reference coordinates [x0, y0, x1, y1, …, x15, y15] to be input. The reference coordinates express each reference nodes position in meters, as unsigned values in the interval [0, 63.75] meters. The finest possible readout resolution is 0.25 meter. The format used is fixed-point data with the two LSBs representing the fractional part and the remaining six bits representing the integer part, thus e.g. 63.75 is represented as 0xFF.

Reference coordinates are loaded into the RF register `REFCOORD`. Before writing to `REFCOORD`, a 1 must be written to the register bit `LOCENG.REFLD` to indicate that a set of reference coordinates are being written. Once the coordinate load process commences (`LOCENG.REFLD` =1), 16 coordinate pairs must always be written. However, it is possible for the Location Engine to use less than 16 reference coordinates, by marking certain reference coordinates as unused. Zeros shall be used to fill the unused reference coordinate slots, and they will be interpreted as unused when 0.0 is loaded as the RSSI value for those reference coordinates.

The reference coordinates are written in the order [x0, y0, x1, y1, …, x15, y15] to the register `REFCOORD`. After all coordinates have been written, a 0 is written to the register bit `LOCENG.REFLD`.

2.1.2 Measured Parameters

After the reference coordinates have been written, a set of measured parameters must be input to the Location Engine. These parameters consist of two radio parameters: Four search boundary coordinates and 16 RSSI values. The radio parameters are the values *A* and *n*. These radio parameters are used in the Engine's algorithm used to find the estimated location. The parameters *A* and *n* can be adjusted to describe the propagation environment in which a network of devices will operate.

2.1.2.1 Parameter Definitions

The measured parameters are described in this section together with how these should be estimated.

2.1.2.1.1 Parameter A

The radio parameter *A* is defined as the absolute value of the average power in dBm received at a close-in reference distance of one meter from the transmitter, assuming an omni-directional radiation pattern. For example, if the mean received power at one meter is -40 dBm, the parameter *A* is specified as 40.

The Engine expects the parameter *A* to be in the range [30.0, 50.0] with precision 0.5. The parameter A is given as an unsigned fixed-point value where the LSB bit is the fractional bit and the remaining bits are the integer part. A typical value for *A* is 40.0.

2.1.2.1.2 Parameter n

The radio parameter *n* is defined as the path loss exponent that describes the rate at which the signal power decays with increasing distance from the transmitter. This decay is proportional to d^{-n} where *d* is the distance between transmitter and receiver.

The actual parameter *n* value written to the Location Engine is an integer index value selected from a lookup table shown in Table 2.

As an example, in the case when the value *n*=2.98 is found from measurements, the closest available value of *n* in the lookup table is 3.00, corresponding to index 13. Therefore, the integer value 13 is used for the parameter *n* written to the Location Engine.

Refer to section 2.1.2.1.3 in order to find the value for *n* to be used.

Table 2: n parameter lookup table

n index	*n*	*n index*	*n*
0	1.000	16	3.375
1	1.250	17	3.500
2	1.500	18	3.625
3	1.750	19	3.750
4	1.875	20	3.875
5	2.000	21	4.000
6	2.125	22	4.125
7	2.250	23	4.250
8	2.375	24	4.375
9	2.500	25	4.500
10	2.625	26	4.625
11	2.750	27	5.000
12	2.875	28	5.500
13	3.000	29	6.000
14	3.125	30	7.000
15	3.250	31	8.000

The parameter *n* is written to the Location Engine as an integer index in the range [0, 31] as the index is given as an integer value with no fractional bits, e.g. the value *n* = 7 is loaded as 00000111. The typical value for *n* depends on the environment.

2.1.2.1.3 Parameter Estimation

The parameters *A* and *n* can be estimated empirically by collecting RSSI data (and therefore path loss data) for which the distances between the transmitting and receiving devices are known. Figure 2 is a scatter plot of abs(RSSI) data versus log distance in meters. A least-squares best-fit line is used to glean the specific values of *A* and *n* for the environment in which the data were measured:

- *A* is the y-intercept of the line, and
- *n* is the slope of the line

The data in Figure 2 give *A*=42.4 and *n*=2.98 for that environment. Note that the plot in this example does not show the actual y-intercept i.e. the point on the line where x=0.

The value of *A* loaded into the engine in this case would by 42.5. The value of *n* loaded into the engine, is seen to be 13 from Table 2.

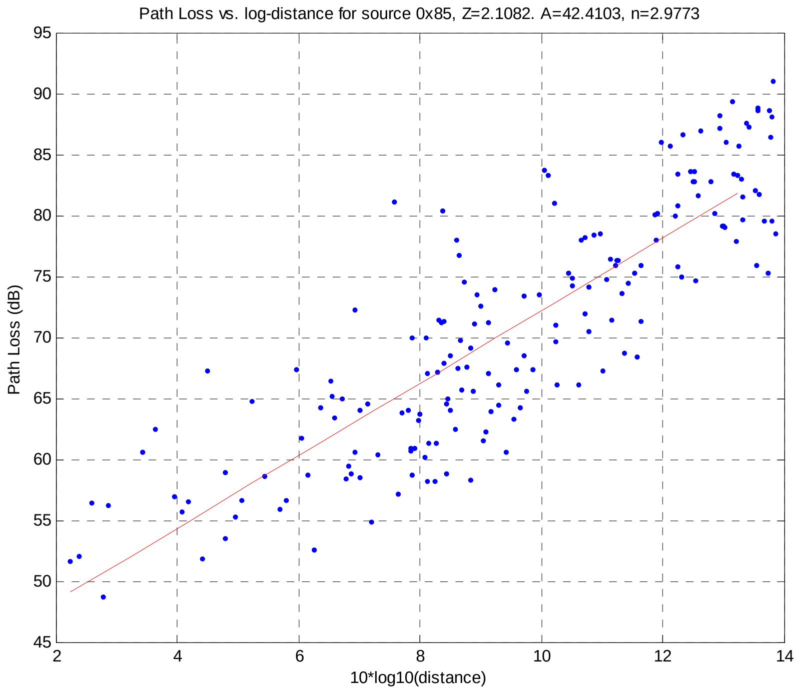


Figure 2: Path loss vs. log distance

2.1.2.1.4 Search Boundary Coordinates

It is possible to reduce error and estimation time by setting search boundaries for the estimated location X and Y coordinates. The maximum area that can be considered is with X and Y in the interval [0.0, 63.75] meters.

Assume that the Location Engine search is to be limited to include only the rectangular area bounded by the coordinates [x_{min}, y_{min}] and [x_{max}, y_{max}].

Four search boundary parameters are entered in the following order:

x_{min}, x_{delta} , y_{min}, y_{delta}

where:

$x_{delta} = x_{max} - x_{min}$

$y_{delta} = y_{max} - y_{min}$

Note that even when it is chosen to search in the whole possible search space, these coordinates must be entered as the coordinates for the whole space, i.e. the following values: 0.0, 63.75, 0.0, 63.75.

If some input parameters are omitted the Location Engine will not estimate correctly.

2.1.2.1.5 RSSI Values

The RSSI values are the RSSI measurements corresponding to the set of reference coordinates. The RSSI values are within the interval [-40 dBm, -95 dBm] with precision 0.5 dBm. The negative sign is removed in the value written. As an example, in the case where the value RSSI = -50.35 dB, this would be written into the location engine as 50.5.

Note that a value of 0.0 must be written as RSSI value for unused reference coordinates, if less than 16 reference nodes are used. The engine will not function correctly if only some of the parameters are loaded.

2.1.2.2 Loading Parameters

All measured parameters described in the previous sections are loaded into the RF register `MEASPARM`. Before writing to `MEASPARM`, a 1 must be written to the register bit `LOCENG.PARLD` to indicate that a set of measured parameters are being written. Once the parameter load process commences

(LOCENG.PARLD =1), all 22 parameters must be written.

The measured parameters must be written in the order [A, n, x_{min}, x_{delta}, y_{min}, y_{delta}, $rssi_0$, $rssi_1$, …, $rssi_{15}$] to the MEASPARM register. Once the parameter load process commences (LOCENG.PARLD =1) it must be completed with all 22 parameters. Included in these are the 16 RSSI values which must be all written, so any unused slots must be written as zeros. After all 22 parameters have been written, a 0 must be written to the register bit LOCENG.PARLD.

2.1.3 Location Estimation

The estimated location coordinates are given in meters in the interval [0.0, 63.75] with resolution 0.25 m. The data format uses the LSB bit as the fractional part.

When reference coordinates and measured parameters have been loaded, the location estimate is calculated by writing 1 to the LOCENG.RUN register bit. The estimated coordinates can be read from the LOCX and LOCY registers when LOCENG.DONE is set to 1. The time until estimated coordinates can be read varies with the search boundary parameters, from 50 µs to 13 ms (with 32 MHz system clock) after LOCENG.RUN was set to 1. The Location Engine does not produce any interrupt requests.

The value of the X coordinate estimate given by LOCX includes an offset value which must be removed to obtain the actual X coordinate. The offset removal must be performed after reading the LOCX register, to obtain the actual X value as follows:

$$X = (X_{LOCX} - x_{min} + 1) \% (x_{delta} + 1) + x_{min}$$

Where X_{LOCX} is the value read from register LOCX, and x_{min} and x_{delta} are the boundary parameters used as inputs to limit the search as described in section 2.1.2.1.4. Notice that the Y coordinate read LOCY from can be used directly.

The estimated coordinates remain valid in the LOCX and LOCY registers until new results have been calculated or until a reset.

Note that LOCENG.EN must be 1 during operation of the Location Engine.

2.2 Location Engine Register

This section describes the RF registers associated with the Location Engine. These registers are:

- LOCENG - Location Engine control and status
- REFCOORD - Reference coordinates input
- MEASPARM - Measured parameters input
- LOCX - Location estimate X coordinate
- LOCY - Location estimate Y coordinate

The RF registers reside in XDATA memory space. Table 3 gives an overview of register addresses while the remaining tables in this section describe each register in detail. Refer also to section 1 for Register conventions.

For the remaining RF registers refer to the CC2430 Data Sheet.

Table 3 : Overview of Location Engine RF registers

XDATA Address	Register name	Description
0xDF55	REFCOORD	Reference coordinates input
0xDF56	MEASPARM	Measured parameters input
0xDF57	LOCENG	Location Engine control and status
0xDF58	LOCX	Location estimate X coordinate
0xDF59	LOCY	Location estimate Y coordinate
0xDF60	CHVER	Chip Version
0xDF61	CHIPID	Chip Identification

REFCOORD (0xDF55)

Bit	Name	Reset	R/W	Description
7:0	REFCOORD	0	R/W	Location Engine reference coordinate [x0, y0, x1, y1, … x15, y15]

MEASPARM (0xDF56)

Bit	Name	Reset	R/W	Description
7:0	MEASPARM	0	R/W	Location Engine measured parameters of channel and reference nodes [A, n, x_{min}, x_{delta}, y_{min}, y_{delta}, $rssi_0$, $rssi_1$, …, $rssi_{15}$]

LOCENG (0xDF57)

Bit	Name	Reset	R/W	Description
7:5	-	00	R0	Reserved, read as 0.
4	EN	0	R/W	Enable location engine 0 Disable location engine 1 Enable location engine
3	DONE	0	R	Estimation completed. After 1 has been written to RUN, this bit is cleared and then set to 1 when the estimated data is ready.
2	PARLD	0	R/W	Load parameters. This bit shall be written as 1 before the set of parameters are written to MEASPARM. Write 0 to this bit after the last parameter has been written.
1	REFLD	0	R/W	Load reference coordinates. This bit shall be written as 1 before the set of coordinates are written to REFCOORD. Write 0 to this bit after the last coordinate has been written.
0	RUN	0	R0W1	Location estimate start. This bit shall be written as 1 when desired coordinates and parameters have been written to REFCOORD and MEASPARM registers. Estimation process starts when 1 is written to this bit. Always read as 0.

LOCX (0xDF58)

Bit	Name	Reset	R/W	Description
7:0	LOCX	00h	R	Location estimate X coordinate with offset.

LOCY (0xDF59)

Bit	Name	Reset	R/W	Description
7:0	LOCY	00h	R	Location estimate Y coordinate.

CHVER (0xDF60)

Bit	Name	Reset	R/W	Description
7:0	VERSION[7:0]	0x03	R	Chip revision number. The current die revision is as follows: 0x04 : Die revision E The current number in VERSION[7:0] may not be consistent with past or future die revisions of this product

CHIPID (0xDF61)

Bit	Name	Reset	R/W	Description
7:0	CHIPID[7:0]	0x89	R	Chip identification number. Always read as 0x89.

3 Ordering Information

Table 4: Ordering Information

Ordering part number	Description	MOQ
CC2431RTC	CC2431, QLP48 package, RoHS compliant Pb-free assembly, trays with 260 pcs per tray, 128 Kbytes in-system programmable flash memory, System-on-chip RF transceiver.	260
CC2431RTCR	CC2431, QLP48 package, RoHS compliant Pb-free assembly, T&R with 2500 pcs per reel, 128 Kbytes in-system programmable flash memory, System-on-chip RF transceiver.	2500
CC2431ZRTC	CC2431, QLP48 package, RoHS compliant Pb-free assembly, trays with 260 pcs per tray, 128 Kbytes in-system programmable flash memory, System-on-chip RF transceiver, including royalty for using TI's ZigBee® Software Stack, Z-Stack™, in an end product	260
CC2431ZRTCR	CC2431, QLP48 package, RoHS compliant Pb-free assembly, T&R with 2500 pcs per reel, 128 Kbytes in-system programmable flash memory, System-on-chip RF transceiver, including royalty for using TI's ZigBee® Software Stack, Z-Stack™, in an end product	2500
CC2431DK	CC2431 Development Kit	1
CC2431ZDK	CC2431 ZigBee® Development Kit	1
CC2431EMK	CC2431 Evaluation Module Kit	1

MOQ = Minimum Order Quantity T&R = tape and reel

4 General Information

4.1 Document History

Table 5: Document History

Revision	Date	Description/Changes
2.01	2007-05-30	First data sheet for released product. Preliminary data sheets exist for engineering samples and pre-production prototype devices, but these data sheets are not complete and may be incorrect in some aspects compared with the released product.

5 Address Information

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	Korea	080-551-2804
	Malaysia	1-800-80-3973
	New Zealand	0800-446-934
	Philippines	1-800-765-7404
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