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

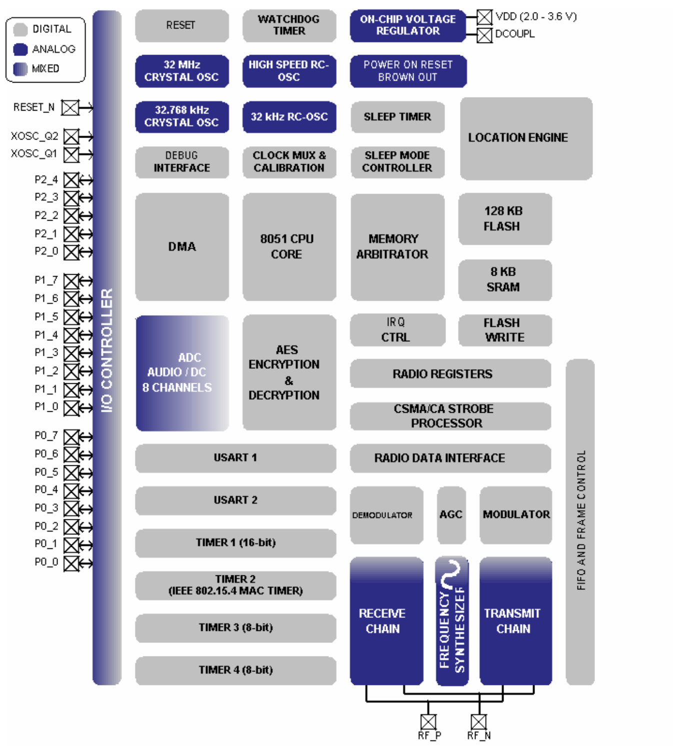
Applications

- *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™ / 802.15.4 solutions with location detection engine hardware onboard allowing location accuracy of around 3 meters or less. It 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 Figure 8 Wireless / Chipcon, 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 accurately 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).
- 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: 27mA, TX: 25mA, microcontroller running at 32 MHz)
- Only 0.9µA current consumption in power-down mode, where external interrupts or the RTC can wake up the system
- Less than 0.6µA current consumption in stand-by 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 (2.0V – 3.6V)
- Digital RSSI / LQI support
- Battery monitor and temperature sensor

Key Features (continued)

- 8-14 bits ADC with up to eight inputs
- 128-bit AES security coprocessor
- 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 7x7mm QLP48 package
- 21 general I/O pins, two with 20mA 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.

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.

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

Table 1: Register bit conventions

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, such as mobile neighbor nodes with the same Location Engine, or fixed infrastructure 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:

- Three to eight reference nodes can be used for the location estimation algorithm
- Location estimate with resolution of 0.5 meters
- Time to estimate node location less than 40 μs
- Location range 64 x 64 meters
- Location error can be less than 3 meters, depending on factors described below
- 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 eight 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.

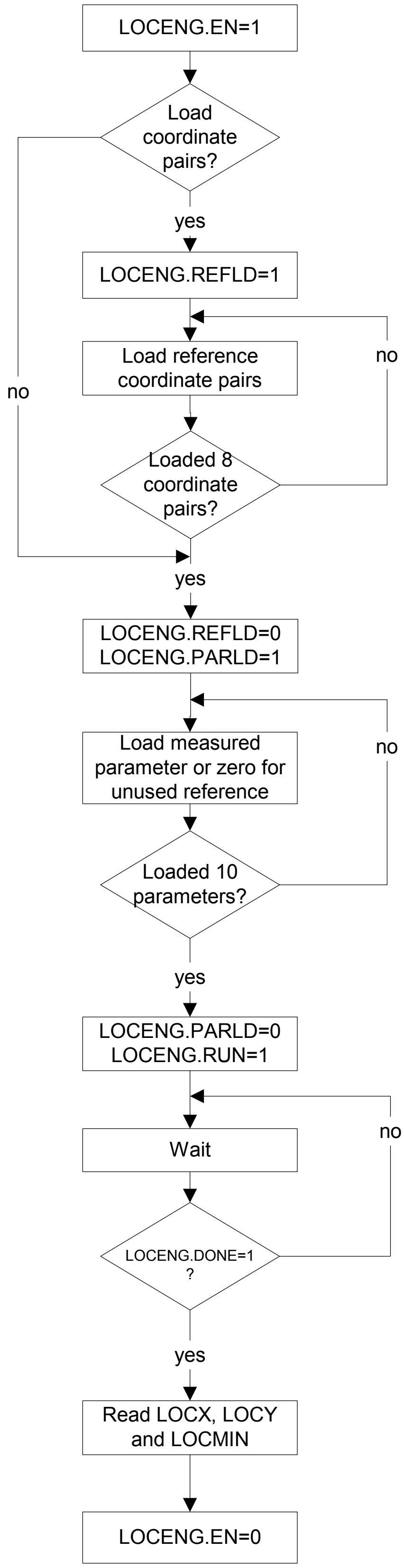


Figure 1: Location Engine Operation

2.1.1 Reference Coordinates

The Location Engine requires a set of between three and eight reference coordinates [x0, y0, x1, y1, … x7, y7] 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 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.

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), eight coordinate pairs must always be written. However, it is possible for the Location Engine to use less than eight reference coordinates, by marking certain reference coordinates as unused. Zeros can 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, …, x7, y7] 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 and eight 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.

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

Table 2: *n* parameter lookup table

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. A typical value for *n* is 13.

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.

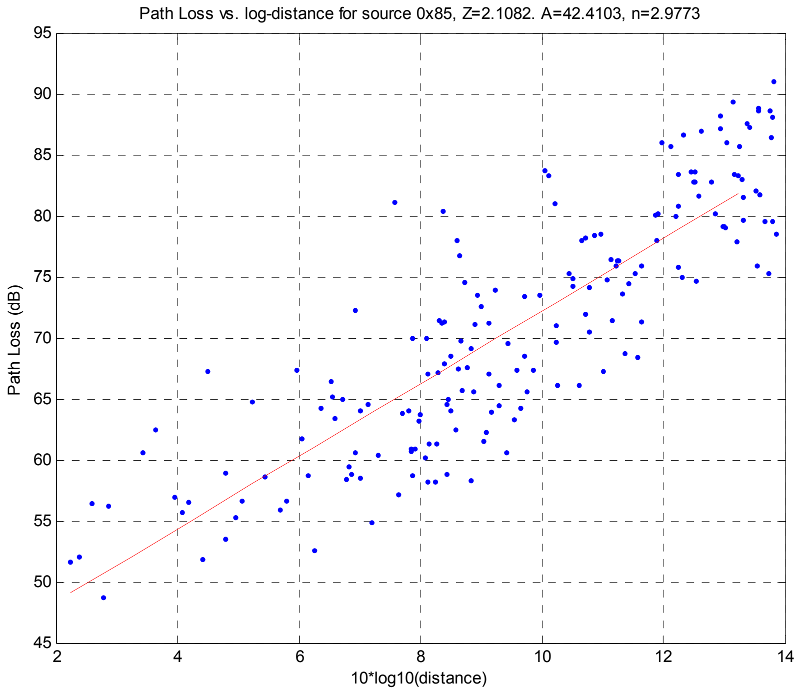


Figure 2: Path loss vs. log distance

2.1.2.1.4 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. The engine will not function correctly if only some of the parameters are loaded.

2.1.2.2 Loading Parameters

All measured parameters 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 ten parameters must be written.

The measured parameters must be written in the order [A, n, rssi0, rssi1, … rssi7] to the `MEASPARM` register. Once the parameter load process commences (`LOCENG.PARLD` =1) it must be completed. Eight RSSI values must be written, so any unused slots must be written as zeros. After all ten 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, 63.5] with precision 0.5 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. This occurs 1200 system clock cycles (16/32 MHz) after `LOCENG.RUN` was set to 1. The Location Engine does not produce any interrupt requests.

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 Registers

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
- `LOCMIN` Minimum function estimate

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
0xDF5A	LOCMIN	Minimum function estimate
0xDF60	CHVER	Chip Version
0xDF61	CHIPID	Chip Identification

Bit	Name	Reset	R/W	Description
7:0	REFCOORD	0	R/W	Location Engine reference coordinate [x0, y0, x1, y1, … x7, y7]

Table 4: Register REFCOORD (0xDF55)

Bit	Name	Reset	R/W	Description
7:0	MEASPARM	0	R/W	Location Engine measured parameters of channel and reference nodes [A, n, rssi0, rssi1, …, rssi7]

Table 5: Register MEASPARM (0xDF56)

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.

Table 6: Register LOCENG (0xDF57)

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

Table 7: Register LOCX (0xDF58)

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

Table 8: Register LOCY (0xDF59)

Bit	Name	Reset	R/W	Description
7:0	LOCMIN	00h	R	Location estimate minimum value

Table 9: Register LOCMIN (0xDF5A)

Bit	Name	Reset	R/W	Description
7:0	VERSION[7:0]	0x01	R	Chip revision number

Table 10: Register CHVER (0xDF60)

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

Table 11: Register CHIPID (0xDF61)

3 Ordering Information

Ordering part number		Description	Minimum Order Quantity (MOQ)
1371	CC2431-RTB1	CC2431, QLP48 package, RoHS compliant Pb-free assembly in tubes with 43 pcs per tube, Single Chip RF Transceiver	43
1372	CC2431-RTR1	CC2431, QLP48 package, RoHS compliant Pb-free assembly, tape and reel with 2500 pcs per reel, Single Chip RF Transceiver	2500
1367	CC2431DK	CC2431 ZigBee Development Kit	1
1368	CC2431ZDK Pro	CC2431 ZigBee Development Kit including support and training	1

Table 12: Ordering Information

4 General Information

4.1 Document History

Revision	Date	Description/Changes
1.0	2005-11-30	First release

Table 13: Document History

4.2 Product Status Definitions

Data Sheet Identification	Product Status	Definition
Advance Information	Planned or Under Development	This data sheet contains the design specifications for product development. Specifications may change in any manner without notice.
Preliminary	Engineering Samples and First Production	This data sheet contains preliminary data, and supplementary data will be published at a later date. Chipcon reserves the right to make changes at any time without notice in order to improve design and supply the best possible product.
No Identification Noted	Full Production	This data sheet contains the final specifications. Chipcon reserves the right to make changes at any time without notice in order to improve design and supply the best possible product.
Obsolete	Not In Production	This data sheet contains specifications on a product that has been discontinued by Chipcon. The data sheet is printed for reference information only.

Table 14: Product Status Definitions

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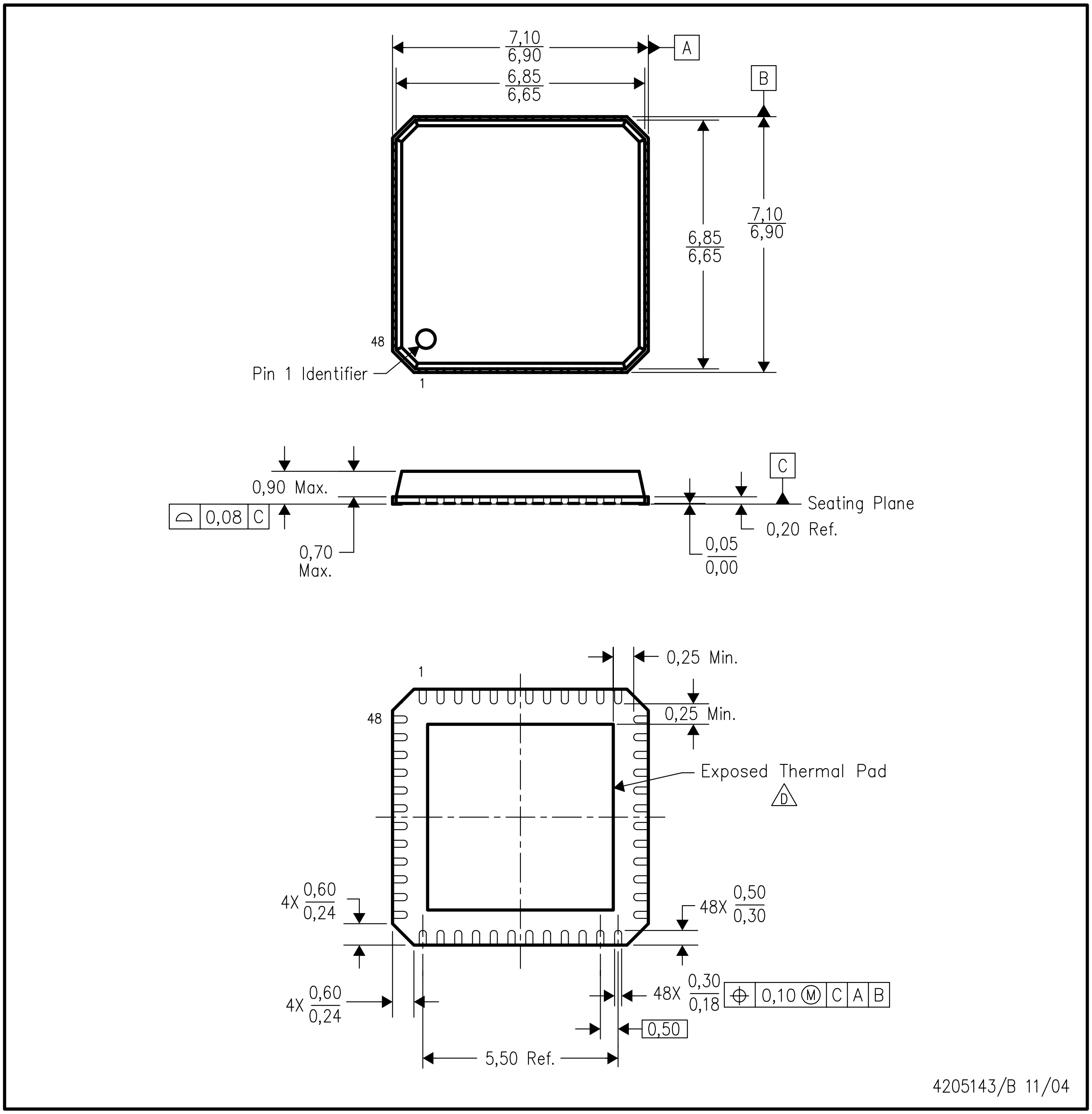
RTC (S–PQFP–N48) PLASTIC QUAD FLATPACK



NOTES:
A. All linear dimensions are in millimeters. Dimensioning and tolerancing per ASME Y14.5M–1994.
B. This drawing is subject to change without notice.
C. QFN (Quad Flatpack No–Lead) Package configuration.
D. The package thermal pad must be soldered to the board for thermal and mechanical performance. See the Product Data Sheet for details regarding the exposed thermal pad dimensions.

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